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Reshaping energy landscape: a regional approach to explore electricity infrastructure networks*

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ABSTRACT

Reconfiguring energy infrastructure networks to accommodate the expansion of renewable energy can have specific regional manifestations with regional advocacy being used to promote innovations and solutions on the ground. The paper introduces the analytical concept of *territorial responsiveness* to unpack these regional manifestations. The paper tests a number of constituent properties of *territorial responsiveness* in two Italian regions, Apulia and Sardinia. These regions show that while the regional level has had a modest influence in the regulation of network infrastructure, regional actors played a role in rendering their territory, directly or indirectly, available for infrastructural investment and mediated potential constraints, both material/infrastructural and constitutional. The paper argues that the concept of *territorial responsiveness* can add to energy landscape research as it contributes towards understanding the territorial restructuring of agency, unpacking the relations and participation in infrastructure renewals that are emerging around infrastructure change, often with varying spatial reach.

KEYWORDS

Energy landscape; regions; energy infrastructure; regional development; renewable energy

1. Introduction

Efforts towards achieving net-zero require emphasis on the need to increase the development of renewable energy (hereafter, RE) (IPCC, 2019). The move towards energy systems that rely on higher shares of RE has, however, amplified the need for transforming the electricity network - both at transmission and distribution levels (Funcke & Bauknecht, 2016).

The transition to a greener energy system poses significant challenges for electricity transmission and distribution infrastructure with an increasing geographical re-organisation of production and load. While energy networks infrastructure (the pipes, cables and wires that link energy production with consumers) is subject to some form of national economic regulation that secures wider social benefits, electricity networks also become an important mediating factor between physical resource endowments and institutional/governance structures. Most significant decisions aimed at steering energy systems are made at the national level (Cherp, Vinichenko, Jewell, Brutschin, & Sovacool, 2018). However, the challenges surrounding energy infrastructure networks provision and governance simultaneously involve other spatial levels, as energy

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infrastructure is embedded in specific territories, even as it organises flows for other, wider spaces (Goldthau, 2014).

While global, national and regional power and infrastructure networks become intimately connected through the materially embedded transmission and distribution networks within specific territories and the interconnections between them (Hiteva & Maltby, 2014), grid capacity and infrastructure upgrades become site-specific issues. These relate to: (i) how the pre-existing built infrastructure may enable or limit RE potential; (ii) the requirements for new infrastructure, including transportation or distribution network upgrades; and (iii) the power to shape them (De Laurentis & Pearson, 2018). Therefore, the pre-existing network infrastructure, the rules that regulate it, and the way in which renewal is governed and financed, by who and at what geographical scale, have an important role in influencing RE potential (IEA, 2020).

Fruitful contributions have investigated the assemblages of material and socio-technical relations that occur at the urban level (Rutherford & Coutard, 2014). These contributions stress how the spatial and material aspects of energy are considered important in influencing urban development processes and urban energy landscapes, becoming one of the prominent conceptual lenses to understand how energy provision and urban development co-evolve (Castán Broto, 2019).

This paper argues that a regional perspective can offer a complementary frame to examine questions around infrastructure and agency in spatial and political terms, adding to the national and urban focus that dominates much energy transition research. Adjusting the analytical lens to the regional level offers an opportunity to investigate the multitude of actors and interests involved in infrastructure financing, production, and advocacy, highlighting particular energy transition problems and possible solutions. These include the challenge of reconfiguring networks to accommodate the expansion of RE, much of which is occurring in rural areas with limited inherited grid capacity. While this is a problem in many countries (IEA, 2020), such problems may have specific regional manifestations with regional advocacy being used to promote innovations to solve concrete problems on the ground. It further recognises how the structures and histories of regions themselves shape decisions about infrastructure development, including the disruption or perpetuation of socio-economic patterns (Addie, Glass, & Nelles, 2020).

A regional lens to view landscape change resonates well within landscape studies and, while this lens is adopted in studies of the management of water resources (Norman & Cook, 2015), it can also be adopted in the dialogue between landscapes and energy. Acknowledging competing conceptualisations of what a 'region' is (Paasi & Metzger, 2017), the region is understood here primarily as a sub-national level of government, with significant supra-local governance capacity and cohesiveness.[1] The paper treats this conceptualisation critically, as a way of examining the often-difficult relations between territorially bounded government bodies, with limited formal powers, and the steering of spatially-extensive infrastructures. This illuminates wider issues regarding the distribution of agency to steer network change (Kuzemko & Britton, 2020). As new 'territorialities' are introduced as a part of a 'geopolitical infrastructural governance milieu' that sees regions as functional regional assemblages (e.g. city-regions, Jonas (2017); mega-regions, Schafran (2014)) regional landscapes can include regions of all sizes (sub-national as well as functional regions that span across national borders). Yet, the paper argues that energy infrastructure networks while serving wider governance goals (e.g. national security and energy transitions) are also spatially embedded, representing an important element that shape energy landscapes. The paper, therefore, questions how the contextual and socio-material elements of energy network infrastructure, or *territorial responsiveness*, can be useful in investigating the interactions between energy and regional energy landscapes?

This is addressed by first considering literature that attributes an increasing significance to the subnational level of the region as an important site for action to promote low-carbon energy systems. This is followed by an introduction to the analytical concept of *territorial responsiveness* and its properties. This framework is used to examine challenges and opportunities in the two

case study regions. The paper concludes by considering the lessons to be drawn from the cases and highlighting areas that require further research.

2. Regional development framing of renewable energy

While the geography of energy transitions is maturing (Binz, Coenen, Murphy, & Truffer, 2020) a number of contributions emphasise the role that regional institutional settings play in influencing sustainability transitions (Chlebna & Mattes, 2020; Hansen and Coenen, 2015). Researchers are devoting more attention to understand the growing significance of the regional scale as a form of energy space (Coenen, Hansen, Glasmeier, & Hassink, 2021) exploring the way in which regional actors engage with energy flows and infrastructures. A substantial body of regional studies literature has focussed on innovation and regional capabilities for developing new growth paths (Trippl, Baumgartinger-Seiringer, Frangenheim, Isaksen, & Rypestøl, 2020), where regions emerge as sites for innovation and experimentation (Njøs, Sjøtun, Jakobsen, & Fløysand, 2020). Regional scholars have begun to explore the relationship between decarbonisation and regional development (Gibbs, 2018; While & Eadson, 2021), offering an account of decarbonisation as a process of economic restructuring altering spatial distributions of economic activity (e.g. job creation) contributing to uneven energy development. Regional industrial specialisations, natural resource endowments and local/regional institutional set-ups become relevant and promote differences in approaches to energy transitions. Furthermore, reconfigured or new organisations have been emerging to promote RE, but also to enhance sub-national control over energy policy (Kuzemko & Britton, 2020; Moss, Becker, & Naumann, 2015).

While developing specific analytical and empirical preferences, these approaches emphasise how the varied combinations of assets (human, institutional, industrial, infrastructural and material) have shaped regional energy transitions. We can also see how similar regulatory settings (e.g. subsidies and incentives) can work differently at regional levels (De Laurentis, 2021) and how regional development governance, visions and policies have an important role to play in supporting energy regional transitions (Bradshaw & de Martino Jannuzzi, 2019).

Previous studies focussing on sub-national government have emphasised the fragmentary nature of democratic control over energy systems more broadly (Muinzer & Ellis, 2017), with research suggesting that as RE uptake increases regional RE objectives can be hindered by the current electricity infrastructure networks (Bryan, Evans, Jones, & Munday, 2017). Indeed, regional bodies seeking to base the economic development aspirations of their territory on exploiting RE often need to confront grid capacity issues (Cowell, Ellis, Sherry-Brennan, Strachan, & Toke, 2017). And while the electricity grid is very often flagged up as a constraint, and a constituent of the spatially uneven development of energy systems, few studies have seriously engaged in questions of energy network infrastructure governance and agency.

Clearly, RE innovation processes, including RE deployment, are not just pursued by national governments and incumbent actors (e.g. energy companies, utilities and regulators). They also involve a host of subnational actors and social and political interests that can mobilise different visions, instruments and responses in connection with mandates that meso-level government might hold in various policy spheres (e.g. land use, planning, transport and mobility, social welfare and economic development) (Roelich, Bale, Turner, & Neall, 2018; Rutherford & Jaglin, 2015). These can become a means through which regional actors can influence energy infrastructure change.

Important work has recognised the co-constructive relationship between the spatiality of infrastructures and urban governance, which is sensitive to the diverse effects of infrastructure materiality (Graham & Marvin, 2001; McFarlane & Rutherford, 2008). Studies that investigate the relationship between cities and infrastructure emphasise the specific configurations of agency in shaping such relations, suggesting that infrastructure systems need to be investigated not only

as individual objects but as parts of 'geographically spread socio-technological configurations', involving different technologies, relations, capacities and power relationships (Lawhon, Nilsson, Silver, Ernstson, & Lwasa, 2018, p. 720). How the spatial and material exert influence on urban energy landscapes has become one of the prominent conceptual lenses used to understand the co-evolution of energy provision and urban development (Castán Broto, 2019).

Building on these urban level insights, there are a growing number of studies of how spatial and material aspects of energy have influenced regional energy transitions (in Italy (De Laurentis & Pearson, 2018), in Germany (Gailing & Röhring, 2016), in France (Fontaine, 2020), and in the UK (Cowell et al., 2017)). While these contributions show that socio-material aspects of energy systems can have significant influences on the governance of energy systems, understanding the scope for transition requires us to disentangle the proximity and presence of energy network infrastructures in a given territory, from the steering of their operation and development.

The steering challenges for energy networks as RE increases relate not only to the balance between trans-spatial coverage and consistency but also on responsiveness to the socio-materialities of energy infrastructure networks- including current energy network configurations, the mechanism that enable the circulation of energy resources, the relations, capacities and power relations that encompass both the urban and the regional levels. If we understand landscapes in terms of the territorial expression of socio-material relations that emerge, and as suggested by Castán Broto (2019), energy landscapes in terms of the three interrelated elements of energy governance, flows and choreographies, one can see the merit of extending this approach and its sensitivity to include the contextual conditions, the multi-scalar nature and contingency that have emerged from the regional development framing of RE development processes discussed above.

Moreover, the regional level can be important in understanding processes of change in energy network infrastructure, as follows. Firstly, the promotion of RE entails significant spatial reconfiguration of energy systems, in terms of the distribution of potential resource *vis-à-vis* centres of demand. A regional view can help to take into account (i) the geographical shift in the location of major sources of electricity generation to utilise low-carbon sources, often in remote rural or coastal areas and (ii) the fact that large-sized wind and solar parks as well as electricity supply and heat infrastructure have implications that go beyond single municipal jurisdictions. Secondly, the regional scale can be seen as a middle ground between cities and the nation states, where infrastructure networks work effectively while also leveraging economies of scale. Thirdly, much infrastructure transcends both local and national administrative boundaries.

Energy infrastructure, and its regulation, functions across territorial units that seek to govern energy relationships and deliver energy-related collective goods (Hancock, Palestini, & Szulecki, 2021), emphasising an inherent tension between formal administrative arrangements and the networked governance of energy infrastructure systems. This also refers to how often a 'region' can be materially created by making close ties between places, regions and nations through geographical linkages enabled by large infrastructure systems (Högselius, 2021). While these links – from roads, railways, water and power lines – become visible in the physical landscape, they highlight the spatial imaginaries and political subjectivities that infrastructure can conjure (Bridge, Özkaynak, & Turhan, 2018), stressing how multiple interests are negotiated and situated within the unevenness of regional space.

To more explicitly draw out the mediating factors between energy network infrastructure and regional energy landscape, the paper proposes the analytical concept of *territorial responsiveness*.

3. Territorial responsiveness

The discussion above suggests that the spatial and material aspects of energy network infrastructure can have significant influences on governance as different contextual conditions and socio-material

characteristics in a specific territory can promote variety and shape energy transitions and their governance in manifold ways. These contextual conditions and socio-material characteristics are referred to here as *territorial responsiveness*. Constituting elements of territorial responsiveness are represented in Table 1.

Electricity network capacity is integral to the exploitation of RE resources and the pre-existing infrastructure, the rules that regulate them, and the way in which infrastructural renewal is governed and financed are important for benefitting from regional RE potential. Borrowing from new-institutionalist approaches (North, 1990), infrastructure networks will be influenced by varied *institutional arrangements,* including *formal regulations* (connection rights, transmission charges and location pricing, historical rules) and *informal societal norms* that regulate the behaviour of economic actors. Institutional arrangements shape energy-network infrastructure related decision making, overall energy and RE policies and can be associated with different governance choices (Ćetković & Buzogány, 2016; Kuzemko, Lockwood, Mitchell, & Hoggett, 2016). Institutional arrangements for energy network infrastructure, for instance, reflect a dominant model of national policy formulation in the regulation of network infrastructure supported by an overarching energy security and access agenda (Sataøen, Brekke, Batel, & Albrecht, 2015) that sees energy infrastructure network development as a national 'sustainable development priority' (Cotton & Devine-Wright, 2013, p. 1226).

Table 1. Territorial responsiveness in energy infrastructure network.

Properties	Details
Institutional arrangements (multi-level)	**Regulation and standards** Transmission charges (and location pricing) Connection rights/ rules Historical rules and institutions favouring centralised electricity infrastructures and utilities **Spatial planning and land-use** Land use preferences, Planning and land use law/rights
Opportunities and current spatial distributions of economic activities (multi-level)	**Economic development framing of opportunities** Attracting technology developers due to site availability for testing and experimental activities; potential sites for demonstration and experimental platforms (e.g. smart grid and storage) Existing local economic and technological structures, knowledges and competences are mobilised (e.g. local emergence of new paths)
Regional actors' participation	**Regional infrastructure development** Who participate in infrastructure development (e.g. transmission and distribution operators; local/ regional actors; level of public participation) Ability and willingness to provide funding for local infrastructure development (e.g. production, distribution and storage) Local and regional networks for the development of RE-based heat networks (e.g. housing and business networks) **Regional visions** Visions for RE might ignore the grid; treat existing grid capacity as 'firm', constraining RE location; or assume that extra grid capacity will materialise to follow new generation capacity to meet regional/ local targets and how they sit with energy security and access narratives ('national sustainable development priorities' and other infrastructure imaginaries)
Regional autonomy and distribution of power	**Autonomy to define RE objectives and infrastructure development** Degree to which objectives and measures are defined by different actors from within or outside the region Control of resources (financial and other resources) **Process of decision making in infrastructure development** Influence of state actors and local/ urban authorities Governing authority of energy infrastructure network
Infrastructure network obduracy and unevenness (multi-level)	**Infrastructure endowment and built environment** Physical landscape, land-use, settlement patterns and historical legacies Current infrastructure endowment and the built environment How network and congestion problems are felt differently across territories

A crucial aspect around infrastructure renewal is how to create space for the upgrading of energy network infrastructure, which is linked to the issues of spatial infrastructure planning. Institutional arrangements will therefore include the regulatory institutions that relate to land use policies and the role of spatial planning in helping to accelerate the growth of clean RE (Wolsink, 2018) and the associated transmission and distribution infrastructure. Planning constraints and resistance are often felt at the regional and the local levels (Balta-Ozkan, Watson, & Mocca, 2015).

Contextual and material characteristics can offer *opportunities for the economic development* of particular areas around RE and infrastructure network. The physical characteristics of an area that facilitate harnessing RE and the transfer of its flow (offshore wind and good port infrastructure) and the proximity to geographically fixed resources (geothermal energy and its relevance for promoting urban heat networks). Moreover, energy network infrastructure technologies might emerge and diffuse in places where natural conditions and specific physical characteristics require testing of, and learning about, technical specificities and where enhancements are required to address local problems.

Regional actors participation refers to the way in which the opportunities for regional infrastructure development are developed via networks and regional institutional arrangements of energy governance, as shaped by EU and national legislation (Gailing & Röhring, 2016). Such participation includes the actors involved (regional governments, regional actors and their networks) and the way in which they can exercise governance- via the establishment of visions, entrepreneurial agency and their active participation in economic development opportunities.

Often this participation can be directly influenced by *regional autonomy and the formal distribution of power*. Different countries and different governance systems give different roles to regional authorities, for example. The relationship between the local and the national also determines what the role of the regional is, dictating who has the right to participate and influence infrastructure change. Thus, infrastructure change and renewal- and the role of regional agency- can be seen in connection with some of the mandates that regions might hold in some policy areas and the opportunities these might offer to act in relation to energy infrastructure change.

A further property that characterises territorial responsiveness is *infrastructure network obduracy and unevenness*. The network infrastructure has traditionally played a crucial role in supplying energy to consumers: large scale electricity generation sources are connected to a high voltage transmission network (the 'grid'), which in turn is transported to supply-points of medium and low voltage distribution networks, and then delivered to the end-users. This current centralised model, while being adopted for RE, has not changed reflecting efficiency and market-driven principles that create inertia and path dependencies (Lockwood, Mitchell, Hoggett, & Kuzemko, 2017). The promotion of RE entails significant spatial reconfiguration of energy systems, in terms of the distribution of potential resource vis-à-vis centres of demand. The geographical shift in the location of major sources of electricity generation and renewable sources variability have given rise to congestion and load management problems. These can be experienced differently across different territories. Historical legacies, current infrastructure endowment, the built environment, unlikely sites re-casted for RE generation can increase socio-spatial differential in RE deployment, influencing energy network infrastructure agency.

Although separated in Table 1 for heuristic purposes, the constituting elements of *territorial responsiveness* will often appear in varying combinations, interacting with each other (for instance how regional actors can participate and influence spatial planning and land use). These interactions will also evolve and change over time as an inherent feature of energy transition is the immense fluidity of economic, environmental and technological knowledge, with institutions and institutional arrangements needing to adapt in response to this flux.

In what follows, *territorial responsiveness* is used as an analytical frame to unpack the distribution of regional agency to steer network change in two Italian regions, Apulia and Sardinia.

4. Methods

The paper draws from a research study (2014 - 2018) that examined the spatial unevenness of RE deployment in Italian regions. Documentary analysis, 20 extensive expert interviews with a broad range of actors (Supplementary Appendix), two study visits to Sardinia and Apulia and consultation of key secondary sources and policy documents allowed for data to be generated and analysed via thematic analysis. The use of case study design (Yin, 2014) highlighted different contextual conditions and institutional settings including: difference in RE deployment and opportunities, responses to pressures and identification of barriers to RE, infrastructure issues and policy strategies to address them.

Italy has experienced a steady growth in the RE sector with large increases in the period between 2009 and 2012. Italian regions have had little influence on the nationwide level of economic incentives applied to RE yet display great regional variations in the number of RE installations, their type and spatial distribution.

The promotion of RE entails significant spatial reconfiguration of energy systems, in terms of the distribution of potential resource vis-à-vis centres of demand. Both resource-rich regions, Apulia (the 'heel' of the country) and Sardinia (one of the two large Mediterranean islands) represent interesting cases for the paper as they have faced particular problems around infrastructure saturation that has hindered the scope and desire to shape the level of RE development within their territories. Differences and similarities utilising the analytical concept of territorial responsiveness and its properties are discussed next.

5. Apulia and Sardinia

5.1. Institutional arrangements and regional autonomy

Unbundling of the transmission and generation ownership resulted, in 2005, in the establishment of a national transmission system operator (TERNA), responsible for the transmission and dispatching of electricity. Whereas TERNA has sole responsibility for the transmission system, about 125 distribution operators manage the medium and low voltage lines, connecting final customers and producers, with e-Distribuzione serving around 85% of the Italian market. The Authority for Energy, Networks and the Environment also regulates, controls and monitors the electricity and gas markets and water services in Italy.

The expansion of RE sources has traditionally been seen as a way of increasing security in the national energy system, which lacks domestic hydrocarbon resources. EU's RE Directive (2009/28/EC) influenced the overall RE strategy, but reaching the Italian share of the 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. The national level has played a key role promoting RE deployment and regulating network infrastructure (e.g. in terms of price signals, capacity markets and the technical rules/codes for planning and operating connections to the grid), to increase the security of the Italian energy system. Changes both at transmission and distribution levels ranged from dispatch operations to the introduction of mechanisms to better measure and enhance the performance of frequency regulation and the construction of new lines (IEA, 2016). In terms of grid access and connections, the Italian government also established a principle of priority of access (in terms of priority of connection and grid access) to electricity from renewable sources subject to the security of the electricity systems. Significant grid investments to upgrade the transmission and distribution networks are also laid out over a 10-year period via a National Electricity Transmission Grid Development Plan.

Constitutional reform provided a new framework for sharing regulatory competences 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. Regions have policy authority for climate change and energy efficiency policies as well as infrastructure planning, development and consenting processes, including a high degree of autonomy in relation to the planning and development of their own innovation and industrial support programmes. Regions produce their own Regional Energy Plans that establish regional energy policy objectives offering opportunities to influence network infrastructure upgrade.

Regions co-ordinate all the agencies and authorities whose consent or opinion are required to bring the 'consenting process' for the development, construction and upgrade of transmission lines and substations. Permits are required and are mandated by state, regional and local legislations to ensure environmental protection and compatibility with existing infrastructure. In a number of instances the national level has sought to strengthen its role in planning of energy projects to enhance and streamline permitting procedures for infrastructure projects (the identification of national guidelines for the siting of energy projects and emphasis on urgency and public utility of RE installations, and associated infrastructures (MISE, 2010)). Network and congestion problems are now discussed.

5.2. Obduracy and unevenness

Italy's expanded RE capacity is often concentrated in regions that are distant from the main consumption centres and where grid development has not kept pace with the spread of production facilities. This has created local over-production problems and risks to the balance and security of the grid and the distribution network, to which a growing proportion of generation from renewables is connected. The most affected transmission lines are those located in Southern Italy (e.g. Apulia), with critical areas in the distribution networks concentrated in the major islands (e.g. Sardinia) and in the South, along transmission lines between Apulia and Campania (TERNA, 2017) (Figure 1).

Apulia is the second biggest electricity producer 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 among the regional primary substations, with Troia among the highest (62%). The very rapid development of electricity production from renewables in the region created significant congestion problems. Pending connection requests in Apulia by 2014 represented almost 50% of the entire national figure, nearly four times larger than those of other southern regions and significantly above the national average (BURP, 2014). Two upgrades to the grid network were necessary in the north and in the centre of Italy, but Apulia required 12, three of which were for new interregional interconnections, while the remaining nine related to the development of 380 kV stations.

Sardinia has a relatively confined electricity grid with limited interconnection to the Italian mainland, a limited thermoelectric park and a reduced energy demand due to the economic recession that started with the 2008 financial crisis. The region exports over 25% of net electricity production to Italy mainland. The network infrastructure presents distinctive bottlenecks, including a weakly meshed transmission and distribution with a single 380 KV interconnection that cuts across the region. The electricity network is connected to Italy mainland (via Tuscany) and to Corsica, with the current connection to Corsica reaching its end of life. There are also calls to phase out coal by 2025, adding to an already challenging situation as coal still represents the main source powering almost half of the thermoelectric plants in the region. Such peculiarities have reduced the opportunities for the connection and export of energy, making the energy

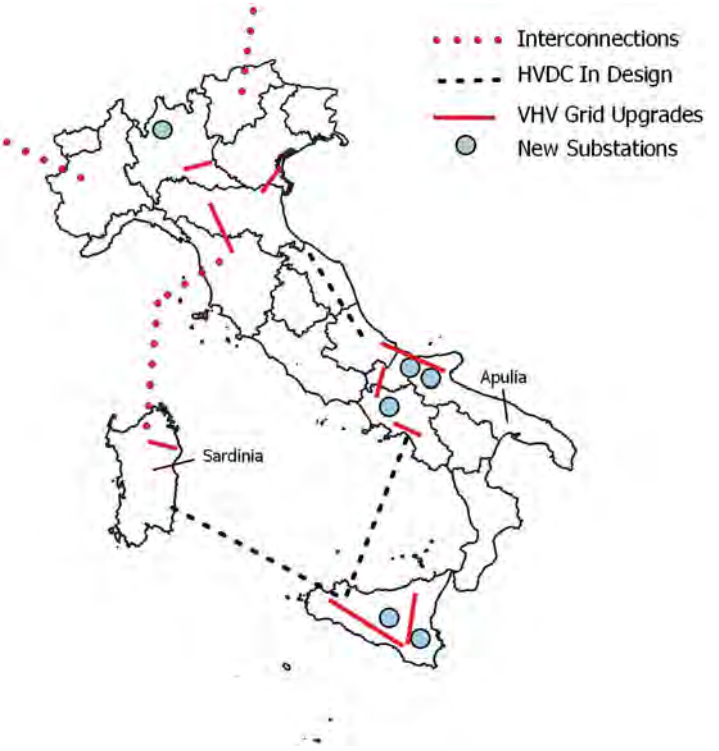

Figure 1. Priority projects for the National Transmission Grid in Italy (2021–2025). *Source*: Author's re-elaboration following TERNA (2021).

infrastructure subject to a more severe level of control from TERNA (via limiting dispatch orders). These physical constraints represent a limiting factor for RE deployment ('in Sardinia (.) the problem we have is that of the impact of renewables on the wider electricity network'INT13).

Some of these challenges in infrastructure provision have become opportunities for innovation and economic development to experiment with new socio-technical advancements. There have been differences, however, in the way in which the two regions have rendered their territory available for infrastructural investment and mediated potential constraints. How these have affected energy network infrastructure steering and participation is discussed next.

5.3. Opportunities and participation

As suggested, regions have had little influence in the regulation of network infrastructure, with a number of institutional arrangements being made at the national level. Nevertheless, regions have greater policy authority for energy planning and for their own innovation and industrial support programmes for the exploitation of indigenous renewable resources to contribute towards economic development goals. These have also provided opportunities to influence energy network infrastructure change.

In terms of energy planning for infrastructure development, it should be noted that while some of the network upgrades planned by both the distribution and transmission operators in both Apulia and Sardinia have been completed (or nearly completed), significant improvements are still awaiting the authorisation required. This is important as it shows that while the regional level, in Italy, can contribute to spatial infrastructure planning, these investments- and delays to their completion- highlight the importance of spatial infrastructure planning, the political decision making and steering of infrastructure renewal at different spatial levels. Nevertheless, under

uncertain distributions of planning competencies and fragmented regulatory frameworks (Corsatea, 2016), the relationships that network operators and regions have managed to establish with transmission and distribution operators have been useful to facilitate network improvement projects. Apulia's regional government participated in infrastructure governance round tables and signed a Memorandum of Understanding with TERNA to connect new RE power plants to the grid, to help mitigate the environmental impact of grid interventions. In Sardinia, the regional government is playing a role in facilitating dialogue across different parties involved in infrastructure renewal for the development of the Tyrennian Link between Sardinia and Sicily.

In Apulia, regional actors allocated resources and channelled European funding towards infrastructure renewal, while in Sardinia the regional energy plan identified a maximum capacity limit of 1500 MW of wind power as a limit that the current infrastructure in the region could accept (Regione Sardegna, 2012). This provided an opportunity for dissenting voices to raise concerns around the uptake of RE and infrastructure renewal.

Both regions have sought to negotiate regional energy resources, land-use values and interests, and constructed opportunities for, and barriers against, RE development via the establishment of discourses and visions for RE deployment. These also have had a role to play in influencing infrastructure renewals in different ways. In Apulia RE development was seen as a 'way of capitalising on favourable geographical conditions to alter patterns of economic growth and development' (INT15). On the contrary, the peculiarities of Sardinia's energy system, devoid of natural gas, with 94% energy dependence on mainland Italy, have had an important effect on RE deployment narratives. RE discourses in the region have been influenced by the opportunities to overcome a condition of *energy isolation* (Corsale & Sistu, 2016): via the interconnection between Sardinia and Italy mainland and a submarine pipeline to transport gas from Algeria. While the latter has been abandoned for both commercial and administrative reasons, the opportunities of infrastructure development around natural gas had the effect of dominating RE discourses in the region ('an investment argument that could provide the main solution to the national energy security problem' INT8).

The Apulian regional government in an attempt to assume a leadership role in RE (and to voice rejection to a possible return to nuclear power), acted as an 'entrepreneurial state' (cf Mazzucato, 2013), streamlining the bureaucratic procedures of licence concessions, promoting public sector deployment and financial support for the creation of energy parks. Activities also included the establishment of a New Energy Cluster initiative, led by the regional development agency ARTI, that attracted 392 organisations (including national and international research organisations and businesses). The Sardinian regional government and Sardinia Research, the public research organisation in the region, also sought to promote the emergence of a RE cluster- which included priority areas such as integration and management of RE sources and analysis and monitoring of micro-networks electrical mobility and integration. However, the cluster initiative only attracted 35 actors among regional businesses, universities, research bodies and local authorities.

These forms of collaborative governance between research organisations, businesses and regional, national and international bodies not only have been crucial for RE development (Gailing & Röhring, 2016) but have been relevant to provide solutions to the infrastructure bottleneck, allowing regional actors to participate in addressing these. In Apulia, while a number of infrastructure solutions to upgrade the transmission and distribution networks have been implemented by TERNA (including demand management solutions, the construction and modernisation of substations, the upgrade to 380 kV lines to address capacity requirements and inter-regional connectors), the regional government and regional intermediary organisations have actively participated providing resources, networks and socio-technical expertise. These include the INGRID Project, a 39 MWh pilot plant for hydrogen-based storage for grid balancing, based in Troia, to overcome 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 ARTI. Building from this experience, the region became again the location of a Horizon 2020 spin-off project, the Store and Go project, which explored how the renewable power used in the

existing electrolyser established within Ingrid to generate hydrogen can be integrated and operated within the existing gas network. The region also initiated 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. Associated with this funding was the Apulia Active Network project led by e-distribuzione, aimed at testing a smart grid development at the regional scale.

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. Sardinia's infrastructure challenges have provided the opportunity for the national transmission operator to experiment with storage applications and to test the use of Synchronous Compensators to enhance system stability and security, making Sardinia a 'high-tech hub' (INT20) for energy experimentation.

As shown, regional agency lies in discretionary regional economic development spending, and the two regions reveal interesting insights about the relation between regions, agency and energy network infrastructure. RE deployment has been affected by the established infrastructure networks and the materially embedded transmission and distribution networks in the two regions. As a result, both regions have had to participate in decision-making processes for infrastructure renewal to overcome the constraints and limits the infrastructure posed. Differences and similarities in territorial responsiveness in the two Italian regions are highlighted in Table 2.

Table 2. Territorial responsiveness in Italian regions- difference and similarities in Apulia and Sardinia.

Institutional arrangements	• Regulatory regime defined at national level. • Pressures from international and European regulatory frameworks in increasing RE deployment. • Regional role in energy planning governance: 'concurrent legislative powers', regional and local involvement in consenting and administrative matters.
Opportunities and current spatial distributions of economic activities	• Grid capacity issues and constraint in both regions have provided opportunities for experimentation. • Both regions as sites of experimentation to solve infrastructure bottlenecks. • EU programmes and European funding towards infrastructure renewal, especially smart grids in both Apulia and Sardinia.
Regional autonomy and distribution of power	• Sharing of regulatory competences between national, regional and local levels. • Regions high degree of autonomy for their own innovation and industrial support programmes. • Apulia and Sardinia both produced Regional Energy plans.
Regional actors' participation	Apulia: • Regional government, development agency and regional networks participated in innovative programmes. • Regional vision of RE expansion. Sardinia: • Lack of entrepreneurial capacity and limited regional participation. • Testing and experimenting mainly promoted by national transmission operator. • Sardinia opportunities to switch to gas and limit to RE growth due to infrastructure constraints. Both regions playing a role in facilitating dialogue across different parties involved in infrastructure renewal planning and consent.
Infrastructure network obduracy and unevenness	Both regions experiencing problems higher than Italian average levels Apulia: • Required three new interregional interconnections and nine upgrades related to the development of 380 kV high-voltage stations; • Higher number of pending requests; • High electricity reverse flow among the regional primary substations. Sardinia: • Weakly meshed transmission and distribution and a single 380 KV; interconnection that cuts across the region; • Connections to Italy mainland (via Tuscany) and to Corsica, with the current connection to Corsica reaching its end of life.

6. Conclusion

This paper suggested that a regional lens can be a useful frame to understand landscape change when investigating the challenge of reconfiguring networks to accommodate the expansion of RE.

The paper sought to investigate the role of the region in steering network infrastructure change and argued that some of the challenges affecting this have specific regional manifestations with advocacy being used to promote innovations and solutions on the ground. The paper highlighted how the contextual conditions and socio-material characteristics, referred to here as *territorial responsiveness*, has been useful to unpack the relations and participation in infrastructure change, with varying spatial reach. The framework helped identify the role for regional actors in facilitating the network accommodation of more RE capacity and in addressing obduracy and unevenness in energy network infrastructure. The physical and material bottlenecks have provided the opportunities to experiment with new socio-technical advancements (as highlighted in both regions in terms of storage and smart grid implementation). There are differences emerging across the two regions in the way in which they have mediated potential constraints. These differences refer to the way in which regional actors have participated in the governance, financing and decision making around infrastructure renewal. Apulia regional government and regional intermediary organisations (such as the regional development agency) have actively participated in the experimentation of technological solutions, by providing resources, networks and socio-technical expertise. Infrastructure challenges presented in Sardinia also allowed the testing of new technological solutions; yet the lack of a critical mass of energy actors hampered participation with innovative solutions been led primarily by TERNA.

Regional actors both in Apulia and Sardinia have also allocated resources and channelled European funding towards infrastructure renewal, especially smart grid. This highlights that EU projects are another important tool in modernising grids, with Italy among the highest performers within the European Programs, particularly Horizon 2020. While this highlights the role of EU-policy making strategies in influencing regional governance it also stresses how narratives of infrastructure renewal can form parts of the economic development strategies of regional governments. This confirms that regional agency lies in discretionary regional economic development spending. While a denser network of regional, national and international organisations can facilitate regional participation to innovative solutions, as the Apulian case shows, so does the spatial organisation of the network operators themselves (Sardinian experimentation occurred in TERNA's owned facilities).

While network infrastructure organisation, and the diverse institutions that underpin its operation, are often configured at 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. The nature and reach of regional-level agency helped channel resources and investment to solve constraints and inheritances by mediating between local sites of investments and wider geographies of energy. Hence, the case studies show that the regional level can be part of the multi-actor decision making systems that manage energy network infrastructure, encompassing the formal allocation of political and financial resources allocated by nation state.

Territorial responsiveness and its properties have helped to unpack some of the agency processes of infrastructure renewal and how these have been reconfigured by regional actors, further elucidating the distribution of agency. The fact that the paper only undertook two regional case studies suggests that the empirical significance remains limited. Further research is required to illuminate in greater detail the relationships between energy landscape and regions. As highlighted, the two Italian regions investigated are administrative regions with clear geographical boundaries and with some government functions and powers connected to them. An interesting area of research would be to investigate how well territorial responsiveness can help to capture

the relationship between regions and energy network infrastructure when functional boundaries are introduced (for instance by looking at functional regions- city regions or mega regions) in an attempt to investigate further how energy network infrastructure can blur geographical and administrative boundaries. Nevertheless, the paper raises important questions about the scale of change in infrastructure landscapes and stressed that contextual elements and the socio-material characteristics that the concept of territorial responsiveness brings into focus- are relevant and need to be brought back into energy landscapes. This is an area that could benefit from further conceptual and empirical enhancement.

Note

1. The paper contends that 'many regions are actually territories deployed within the processes of governance (….) characterised by multifaceted power relations' (Paasi & Metzger, 2017, p. 23).

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