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SPECIAL FEATURE: ORIGINAL ARTICLE

Urban Sustainability and the Governance of Heterogeneous Energy Systems

Heterogeneous energy landscapes and the challenges for spatial planning: the Port of Ravenna and its hinterland

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Abstract
This article investigates how the changes in energy supply and the switch to renewable sources are transforming long-established industrial sites into novel energy landscapes. These are composed of heterogeneous spaces which pose challenges to the current governance of urban transformations, especially in terms of spatial planning. Such a trend is evident in sites with a high density of energy infrastructures, as well as a great degree of interdependence between these and the urban space, such as ports and their hinterlands. In Italy, Ravenna is an example of this. Once a major hub for gas extraction and processing in the Adriatic Sea, this Port has recently been the target of numerous projects to combine diverse energy facilities, turning it into the largest green energy hub in the Mediterranean. This transformation has however major implications for its surroundings: altering the environment, changing the maritime ecology, and complexifying the urban landscape with new functions and uses. With respect to this, the article advocates for an in-depth investigation of the heterogeneous spaces that form this landscape, and their interactions, to evidence the opportunities and risks of the ongoing energy-related transformations. This knowledge is useful to open up vistas on the many points of friction produced by current energy projects and to propose alternative spatial arrangements and design approaches to mitigate and govern existing tensions.

Keywords Infrastructure · Landscape · Port · Planning · Energy · Ravenna

Introduction

Over the last 3 years, rising global energy demand and changing geopolitical conditions have required a diversification of energy supply in Europe, with massive investment in renewable sources (Skjærseth 2021; Osička and Černoch 2022). This condition has stimulated grassroot interventions to increase energy efficiency at a local level (Soares da Silva and Horlings 2020; Lowitzsch et al. 2020; Campos and Marín-González 2020), as well as large-scale projects targeting energy-intensive sites for logistics and production (Doukas et al. 2022; Hassan et al. 2024). The latter have become testbeds for novel infrastructural configurations, with a radical transformation of long-established industrial sites into new spaces for energy-related uses.

The most radical (and controversial) features of these strategies can be seen in the second-tier logistics and energy centres of the Mediterranean, particularly those in the Adriatic–Ionian Region. After the financial crisis of 2008 and the ensuing austerity policies (Gambarotto et al. 2019), these hubs suffered drastic cutbacks in funding that slowed transformations and hindered infrastructure upgrades (Canesi 2019; Petrova and Prodromidou 2019). However, the last few years have seen a rapid turnaround of this situation. The EU has invested 256 million euros to upgrade the port infrastructures in the Adriatic Sea (Bodewig 2020), and national policies, such as the Italian National Recovery and Resilience Plan (NRRP), have injected additional resources to fuel their development (Twrdy and Zanne 2020; Catalano et al. 2022). In parallel, these ports have also caught the interest of international players such as China, which has targeted the Adriatic Sea as the European terminus for the maritime Silk Road (Governa et al. 2025; Spigarelli and Lepore 2023). These initiatives have triggered a boom in

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infrastructural projects, in turn, driving the transformation of inland and maritime spaces.

While most investment before 2022 was in logistics and commerce, the outbreak of the Russian–Ukrainian War and the subsequent import ban on Russian gas have shifted the focus to energy (Berisha 2023). Priority has been given to the upgrade of networks and facilities, as well as the diversification of production and supply systems, especially towards renewable sources (Falcone et al. 2021). These objectives have been pursued by combining various infrastructures into a new energy landscape to take full advantage of spatial features and natural resources. However, this reconfiguration, which implies the combination of many energy systems, has resulted in a spatial heterogeneity which current policies and planning activities find challenging to address and govern effectively. The Port of Ravenna, Italy, is an example of this. Once the centre of offshore gas extraction in the Adriatic Sea, this hub is now being radically reconfigured under the impetus of the current urgent demand for energy, and the drive towards green transitions. The ongoing transformations aim to build a new composite landscape where large-scale infrastructures integrate with the existing configuration. Not only is this process changing the energy network, but it is also impacting the entire territory, with ramifications for the environment and urban spaces.

This paper intends to draw attention to this matter: building on empirical research on the Port of Ravenna and its hinterland, it offers a critical perspective on the heterogeneous landscapes brought about by the changes in energy infrastructures, and the issues they pose for spatial planning and urban governance. By following closely the remodelling of the existing spaces and infrastructures into a new energy hub, this article brings together research on infrastructure heterogeneity (Jaglin 2014; Monstadt and Schramm 2017; Lawhon et al. 2018) with discussion on energy-related landscape transformations (Swyngedouw 2015; Castán Broto 2019; Hein 2022; Frichot et al. 2022), analysing their implications for spatial planning and urban design. These two perspectives can be considered as complementary. The heterogeneity in infrastructure "enables a clearer analysis of infrastructural artefacts not as individual objects but as parts of geographically spread socio-technological configurations […] which involve many different technologies, relations, capacities and operations, entailing different risks and power relationships" (Lawhon et al. 2018). In parallel, the heterogeneity in landscape invites reflection on "the specificity of urban [as well as territorial] energy systems and the heterogeneous spatial arrangements that emerge within particular places" (Castán Broto 2019). Considering the changes both in the infrastructural configuration and in the land organisation, the combination of these perspectives is useful to open up vistas on the many points of friction produced by current energy projects and to propose alternative spatial arrangements and measures to mitigate and govern existing tensions.

This paper is structured as follows. The second section outlines the debate on heterogeneous infrastructure configurations and how they relate to current landscape studies on the spatial implications of energy systems. While this literature review transcends the specificity of the case study, a port city, research on energy transformations in ports is used to illustrate the relevance of investigating these sites. The third section presents the energy projects in the Port of Ravenna, the heterogeneous space brought about by their implementation, and the challenges these pose to planning. Finally, the concluding section reflects on the need for new approaches in spatial planning to govern the current landscape transformations.

The content of this paper is based on empirical research conducted in 2023 and 2024, which includes direct experience of the present developments in the Port, interactions with academics and practitioners participating in the design process, and semi-structured interviews with stakeholders involved in the infrastructural transformations, namely, three representatives of the Port Authority and one of the municipal administration, and six experts from companies operating within the Port. These interviews were fundamental to have a comprehensive picture of the current transformations within the Port and their implications, while gathering technical information on the ongoing projects. These first-hand data have been combined with secondary sources, such as planning and policy documents, consultancy reports, and official statistics. The findings of this investigation are here presented and discussed by means of cartography and photographs, in the tradition of landscape research on infrastructure (Waldheim and Berger 2008; Lyster 2013; Ramondetti 2024a, b; Belanger 2016). These materials enable the development of textured readings of the transformations produced by large-scale infrastructural programmes in specific contexts (Safina et al. 2023), highlighting two aspects: first, the spatial implications of energy-related infrastructure and the relationships it establishes with different built environments (in terms of morphologies, functions, and land uses); second, the multi-scalar impact of the energy-related projects, which are fusing land and sea both at a local and a regional scale. Furthermore, since there is no public map that shows the landscape resulting from the implementation of the ongoing initiatives, these original materials offer an important contribution for debating the spatialisation of current infrastructural and urban projects. Finally, with respect to the specific site of investigation, these visual materials also help to challenge consolidated iconography of port cities (Kowalewski 2018) and to develop alternative narratives.

Heterogeneous infrastructures and energy landscapes

Heterogeneous configurations[1] have been used to describe the provision of service deliveries that are materially and societally alternative to modern, large technical systems. Incremental networks, for example, have been described as heterogeneous: open-ended systems "always in-the-making" (Baptista 2019), which transform the urban into "a place of intermingling and improvisation" (Mbembé and Nuttall 2004). These configurations are usually the result of formal and informal practices, which organise infrastructures into unplanned arrangements of material objects imbued with a strong political stance by the actors involved in service delivery (Björkman and Harris 2018). Starting from the production of material assemblages, heterogeneous configurations serve "to test and prefigure new forms of infrastructure" (Silver 2014).

This conceptualisation of infrastructure heterogeneity has profound theoretical and empirical implications. Theoretically, it has contributed to cast doubt on the monolithic nature of globalised urban trends by demonstrating that there is neither a universal path to modernity, nor a sole notion of modernity (Graham and McFarlane 2014). Infrastructures are embedded in, and vary according to, specific political, environmental, and social contexts, and thus need to be considered as contextualised socio-technical systems. Furthermore, infrastructural heterogeneity has also contributed to the expansion of the term infrastructure to include dynamic and open-ended processes that involve a multiplicity of landscape (Castán Broto 2019) and agents (Simone 2021). Empirically, these studies promote an understanding of the myriads of service provision channels as a constitutive element of today's urban environment. This requires the adaptation of infrastructures to environmental specificities, local economies, and Indigenous cultures (Jaglin 2014). By eschewing a romanticisation of spontaneous systems of infrastructure provision, a propositional approach has been advocated to design novel, flexible configurations welcoming to different practices, and open to unpredictable uses (Jaglin 2015; Baptista and Cirolia 2022).

While heterogeneity has been widely adopted to problematise the making of infrastructures in the Global South (e.g. Faldi et al. 2019; Rateau and Jaglin 2022; Jambadu et al. 2023), this concept has been used in the Global North to describe splintered networks and tailor-made services resulting from the rise of neoliberal trends (Graham and Marvin 2001). According to Coutard and Rutherford (2015), in the post-networked city, "there is now greater value (environmental, economic etc.) in what is rendered mobile by/through infrastructure than in systems of pipes and wires simply as fixed assets". The importance given to resource metabolism, rather than to the networks per se, has led to the multiplication of technical devices and alternative deliveries. This trend results in heterogeneous configurations of energy and resources provision which, rather than arising from formal/informal hybridisation, derive from the integration, coexistence, and competition of diverse networks.

This kind of heterogeneity has been further increased by recent sustainability policies and green programmes. While the integration of environmentally friendly infrastructures within urban settings has been widely discussed—e.g. in terms of 'mediating technologies' (Furlong 2011), 'prosumerism' (Wahlund and Palm 2022), and 'dynamic status quo' (Deroubaix and Gobert 2024), it is important to address this topic also in sites with a high concentration of energy-intensive infrastructures, such as ports and their hinterlands. Following initiatives such as the 2018 World Ports Sustainability Programme and Climate Action, these hubs have become the testbed for new solutions aiming to minimise their environmental impacts and curb greenhouse gas emissions (Carpenter and Lozano 2020). In light of this, port authorities have promoted massive projects to integrate renewable energy facilities, as well as to develop microgrids and smart grids for efficient energy management (Misra et al. 2017). In parallel, port operators and private stakeholders have installed distributed energy systems to meet their own energy requirement, while maximising land exploitation and combining energy facilities with complementary functions (e.g. shadowing of goods and containers) (Iris and Lam 2019). Ultimately, the implementation of ecological transition policies has also changed the role of port authorities, turning them into "energy management promoters" (Acciaro et al. 2014), as well as leaders in establishing novel political frameworks and strategies to generate "territorial interdependency" between stakeholders (Carter and Drouaud 2024). Indeed, the implications of new energy projects transcend the confines of the port, linking sites for resources exploitation (e.g. offshore platforms) to those for energy consumption (e.g. cities and inland areas).

Consequently, the emerging heterogenous configurations—mainly driven by energy projects—are blurring the boundary between inland and maritime areas, producers and consumers, ports and urban spaces, and temporalities (Couling and Hein 2020; Elsner et al. 2019). Aside from the technical and political consequences, this shift towards more sustainable infrastructure also has strong spatial implications: "energy transition is a space-making process, but one also shaped by spatial context" (Bridge and Gailing 2020; see

[1] The notion of heterogeneous infrastructure is here used with a meaning different from that of hybrid infrastructure, which has been largely discussed in literature on Southern urbanism to overcome the dualism between formal and informal systems for energy provision (Cirolia and Pollio 2024; Jaglin et al. 2024).

also Coenen et al. 2012). To delve into this aspect, several studies have adopted the lenses of landscape to investigate the role of energy in reworking existing morphologies, modifying land uses, and changing ecosystems in relation to new economies and cultural practices (Ghosn 2010). The "petroleumscape" investigated by Hein (2022), is an example of "a layered physical and social landscape that reinforces itself over time through human action and connects urban and rural spaces, culture and nature, material and intangible practices". With a similar emphasis on the multifaceted implications of energy infrastructure, Castán Broto (2019) theorises energy landscapes as "connective tissue" to reflect on the relational aspects of material culture: "landscape as connective tissue can be apprehended through a process of enchantment with the different objects encountered in the landscape and the multiple forward and backward linkages that sustain them". In terms of spatial planning, landscape practices are of help "for urban designers wanting to link structures to specific flows, activities, construction materials and time" (Shane 2006).

With regard to the spatialisation of current sustainability programmes, a landscape approach "might help us to understand the role of heterogeneity in the energy transition and enrich the homogenising economic thinking which prevails to the analysis and the construction of renewable energy policies" (Nadaï and Horst 2010). Furthermore, since "socio-technical and spatial imaginaries are co-produced" (Chateau et al. 2021), a focus on landscape and its transformations might help us to better conceptualise the role of the energy-transition projects in shaping ecosystems, built environments, and architectures on a located reality. Ultimately, the acknowledgment of the landscapes resulting from the reconfiguration of energy systems is relevant for spatial planning "to position design's agency amid contemporary concerns for energy infrastructure, ecology, and globalization" (Ghosn 2010). Particularly, it helps to overcome the segmented, utility-centred view, and to draw attention to the heterogeneous spatial configurations that are integral parts of the energy production, transformation, and consumption systems, as well as of the environment and urban surfaces in which they are situated (for an applied example of this landscape approach on a port and its hinterland see James Corner Field Operations and FABRIC 2014). The following pages adopt this lens to explore the intertwining of sustainable energy projects and the on-land and offshore landscape of Ravenna and its port.

Building the Ravenna energy landscape

The spatial heterogeneity emerging from the integration of new energy systems into long-established industrial sites can be observed at Ravenna and its port. This infrastructure was founded by Enrico Mattei[2] to support the rapidly growing national industrial powerhouses in the 1950s. Major energy companies such as Eni, Sarom, and Siom built facilities along this 14-km waterway to benefit from the gas extracted offshore. Thus, the Port was mainly an industrial cluster, and it could rightly be called private as the quays were owned by the enterprises along the canal. Over the years, this hub underwent many transformations as a result of the changing fortunes of the industrial sector, management turnover, and the growth in logistics.

Today, about 15,000 people, i.e. 10% of Ravenna's population, work in the Port. It covers 2080 hectares, of which 150 hectares is for yards, and 85 hectares is for covered storage, with tanks for storing one million cubic metres of liquid bulks. Its 10.5 km docks host 26 private terminals, some of which belong to large industries such as Marcegaglia, Buzzi Unicem, Eni, and Saipem. Large industries and good connections make Ravenna the biggest Italian port for general cargo traffic with 27.3 million tonnes in 2022.[3] The Port also hosts two major Italian powerplants owned by Eni and Enel (producing 972 MWe and 750 MWe, respectively), as well as critical facilities for the Italian energy supply system. Both energy production and logistics activities are growing constantly (Assoporti and Autorità di Sistema Portuale 2022). This success is the result of the upgrade and expansion of energy and logistics infrastructures undertaken over the last 4 years, after a long period of financial restriction.

Between 2012 and 2020, only 500 million euros was allocated by the national government, mainly for the upkeep of the basic Port infrastructure (i.e. dredging the canal). However, because of financial constraints, even the maintenance activities proceeded slowly. Furthermore, since the Port Authority owns only the 10-m-wide quays along the canals, the local administration struggles to increase its income: leasing the docks to companies other than those located in the back area is almost impossible, and this makes it difficult to increase rental revenues for infrastructural interventions, or to negotiate the involvement of terminal operators.[4] As a

[2] Mattei was an Italian public sector manager. After WWII, he was entrusted to dismantle the Azienda Generale Italiana Petroli (Agip) established during the Fascist period. Instead, he reorganised it into Ente Nazionale Idrocarburi (Eni), and turned it into one of the leading industries in the energy sector, breaking the oligopoly of the Seven Sisters.

[3] Incoming goods account for 85% of this traffic, in particular, metallurgical products for Marcegaglia factories (6.4 million tonnes), cereals and fertilisers for the agribusinesses in the lower Padania plain (5.7 million tonnes), and building materials for the ceramics cluster in Sassuolo (5.6 million tonnes).

[4] The Port Authority of Ravenna, later called the Port System Authority of the Central-Northern Adriatic Sea (AdSP MACS), was established in 1994. It operates as a public entity with significant managerial autonomy, but is accountable to the Italian Ministry of Infrastructure and Transport, which sets its strategic objectives and

result, the Port was subjected to infrastructural disruptions: quays became silted up and inoperable; frequent incidents on train lines produced delays in delivery; and inadequate safety systems contributed to maritime incidents.

This situation changed in 2020, when a massive development programme was undertaken under the European Green Deal, the Next Generation EU, and complementary national initiatives to improve sustainability and foster green energy transitions. Investment increased to 1.5 billion euros, and then doubled in 2023 in reaction to the energy crisis brought about by the Russian–Ukrainian War. To date, 4.1 billion euros has been invested by public authorities and local stakeholders: 2.3 billion euros for 11 green energy transition projects, while 1.8 billion euros for 38 intermodal and integrated logistics developments. As stated by a representative of the Port Authority: "the ambition of these initiatives is to construct the largest hub for producing and storing electricity in Northern Italy, in turn, encouraging the establishment of new businesses in the logistics and manufacturing sectors, and boosting urban development" (Interview 1 2023). What is clear is that the implementation of these projects has transcended energy infrastructures to generate new spaces, which pose challenges to the spatial planning and the governance of urban transformations.

The transformations in the energy infrastructure

From the earliest stages of its development, the Port of Ravenna was planned to be one of the largest energy clusters in Northern Italy. This long-established energy park is now home to Petrolifera Italo-Rumena (PIR) and Eni and Enel power stations, all supplied with gas from the many Adriatic offshore platforms and liquid petroleum Gas (LPG) conversion plants. At present, the public and private stakeholders are investing in the upgrade of the hub based on three actions: the increase in efficiency and energy storage, the step-up in renewable energy sources, and the reclamation of contaminated areas for energy-related usages.

The expansion of the energy storage facilities and the optimisation of the energy supply chain have become a national priority to replace the gas previously supplied by Russia. In October 2022, PIR, Edison, and Enagas inaugurated a 180-million-euro facility for the storage and distribution of 20,000 m^3 of LPG, enough to fuel about 12,000 trucks and 50 ferries each year, cutting CO_2 emissions by 6 million tonnes/year (Gruppo PIR 2018).[5] In addition, in early 2023, the national government allocated one billion euros for a new offshore LPG conversion plant. This is a floating platform where a regassification ship can receive LPG at a temperature of − 160 °C from LPG carriers, and then convert it to gas to be fed into the national grid. The plant, by Snam, is scheduled to start up in 2025, and will fill 8% of the national demand, i.e. five billion cubic metres of gas (Autorità di Sistema Portuale del Mar Adriatico Centro Settentrionale [AdSP MACS] 2024a). In parallel, outdated energy facilities are being modernised. Since the beginning of 2024, Enel has invested 90 million euros to upgrade the biggest power plant in the Port. Not only will the project increase capacity from 380 to 410 MWe and provide a 34-MWe storage system, but it will also reduce nitric oxide emission by 20% using a flue-gas denitrification process.

The expansion of the energy storage facilities, combined with other projects, will ramp up the production of electricity from renewable sources and increase the sustainability of the existing plants. The Port Authority has received 10.5 million euros to reclaim 50 hectares of the former Sarom refinery and to install a 20-MWe hydrogen solar farm there (AdSP MACS 2024b). Furthermore, work is progressing on increasing the efficiency of the Port logistics structures by installing a 16-MWe solar system. In parallel, the Agnes Company has plans for an offshore energy facility composed of two wind farms and a solar farm with a total capacity of 166 MWe, as well as a storage facility for 50 MWe (Agnes 2024). The project is a one-billion-euro investment and will be the largest green energy platform in the Mediterranean. The energy will be used to produce an estimated 4000 tonnes of hydrogen, both for industry and transportation, including the public transport network in Ravenna municipality.

In conjunction with these projects, abandoned industrial sites and brownfields are being reclaimed for energy facilities. Eni has built a solar farm, a soil reclamation processing site, and a multi-functional platform for waste treatment on 45 hectares of reclaimed land (Eni Rewind 2024). Furthermore, plans have been made for a one-billion-euro investment to install a carbon capture and storage (CCS) facility for the transportation of CO_2 to exhausted gas fields off the coast of Ravenna (The CCUS Hub 2021). This infrastructure will be realised in two construction phases: the first (2026–2030) aims to offset the emissions from the Casal Borsetti power station and the Versalis chemical cluster, i.e.

Footnote 4 (continued)

guidelines. The Port Authority is responsible for most aspects of port management, such as development, planning, and traffic regulation; and its main sources of revenue are leasing docks and industrial buildings, and taxes on maritime trade. For most port authorities, this status grants a great deal of political and financial independence; however, the case of Ravenna is an exception. Since the port was self-built by private companies, the nationalisation in 1994 regards only the 10-m-wide quays along the canal, with neither land nor buildings. This condition weakens the role of the Port Authority, which has few sources of revenue and is forced to negotiate development objectives and port projects with private stakeholders and local administrations.

[5] The reduction is calculated in relation to the CO_2 produced using traditional fuels.

4 tonnes/year of CO_2; the second (2030–2060) will absorb 16 tonnes/year for other local energy-intensive industries which will take advantage of this facility to reduce European carbon taxes.

The CCS hub is not the only project promoting cooperation between different industries to integrate energy facilities. Sharing energy is at the core of the Port Renewable Energy Community: an association of public and private actors involved in the production and management of energy from renewable sources. Within this framework, projects such as Ravenna Green Port entail the cold ironing of the terminals to be achieved by means of on-site renewable sources and technology upgrades.[6] In light of this, the port power plants have all installed cogeneration systems with combined heat power. Enel's station employs its most advanced technology, having fitted turbogas turbines exploiting the residual heat to achieve an efficiency of over 85%. Enel has also cooperated to provide analogous facilities for the PIR industry: an 800-kW system to produce both electricity and heat, decreasing energy costs by 20% while reducing CO_2 emission by 900 tonnes/year. Similarly, the Marcegaglia Steel Mill has just installed three cogeneration plants for a total of 36 MWe to supply 100% of heating and 70% of energy (Energard 2022). Collectively, these initiatives aim to promote an integrated energy hub with a combination of various infrastructures to increase electricity production, improve energy management, and reduce pollution.

The emergence of heterogeneous spaces

The many energy projects underway display the dynamic development of the Port of Ravenna, and the efforts of local and national administrations to promote an integrated energy hub. The result is a new cluster made up of different systems to promote sustainable energy provision. Not only does this reconfiguration imply a change in energy systems, but it also produces a plethora of spaces, directly or indirectly related to energy and industrial development.

First is the new extended landscape devoted to energy facilities (Fig. 1) and the novel ecology this produces. The Agnes project will install 75 offshore wind turbines on an area of 8500 hectares, creating an underwater forest of foundations and cables. This anthropic landscape will have a strong impact on the maritime flora and fauna, which is expected to be mitigated by releasing oxygen, a by-product of the hydrogen processing, into the sea to improve the maritime ecosystem.[7] Similar transformations are due to the LNG plant, which requires the construction of a 900-m-long offshore breakwater and excavations for a 40-km underground pipeline (Regione Emilia-Romagna 2024). To compensate local municipalities for this development, 25 million euros has been distributed. This funding has been allocated for public facilities, particularly the upgrade of 10,298 streetlamps to reduce consumption by 3199.25 MWh/year, and for the reforestation of 100 hectares south-east of the Port to be transformed into a nature reserve (Ravenna Municipality 2022). This new forest will be located near the 35-hectare solar farm on the reclaimed Sarom and Eni sites, creating a buffer zone of trees and solar panels between the Port and the urban centre.

Alongside these sites for energy facilities and the spaces for their compensation, the deployment of new energy systems is driving the expansion of traditional manufacturing and the construction of new industrial areas. For example, the new Marcegaglia power plant is the first phase in the expansion of the steel mill over 15 hectares recently acquired south of the present factory (Interview 2 2023). In parallel, new energy facilities are being built in combination with energy-intensive logistics activities. For instance, a new 16-MWe solar plant is to be built on the roof of an 85-hectare agrifood hub centred on a cold-storage terminal for the conservation of fresh produce. The hub, connected to the railways, is to be realised in two phases. At present, two plans have been developed for the first site of intervention, which extends over 40 hectares: one is for the optimisation of the built-up space, which will all be consolidated into a single 26.5-hectare unit; the other is for a fragmentation of the logistic park into nine warehouses (Interview 3 2023). Both plans entail a reorganisation of the port mobility, and are contingent on the relocation of the container terminal to a new 40-hectare platform, including five 1.5-hectare warehouses, which is to be built due to the increase in port traffic (Fig. 2). These many spaces for energy and logistics are all located on the former silt storage facility of the Port.[8] This facility is however fundamental for the reclamation of 8 million cubic metres of mud which is currently being dredged to deepen the water of the LNG plant to − 15.50 m, as well as the port canal to − 13.50 m. As a result, 70 hectares of agricultural land between the Port and the city of Ravenna have been transformed into deposits to dry out soil sediments.

[6] Similar to the many initiatives undertaken in ports worldwide (Lawer et al. 2019), Ravenna Green Port is a project to turn this hub into a sustainable, low-emissions facility. To this end, cold ironing plays a fundamental role: it is a process to connect docked ships to onshore electrical power sources instead of keeping their engines running to generate power. This allows ships to turn off their diesel generators, reducing greenhouse gas emissions and noise.

[7] The lack of oxygen is seriously damaging the marine environment of the Adriatic Sea.

[8] Silt storages are designated areas where sediments dredged from port canals are temporarily stored and treated. The Port of Ravenna, given its proximity to the Po River delta, is prone to silting that obstructs its waterways, making regular dredging necessary to keep channels navigable.



Fig. 1 Ravenna energy landscape. Map by the author

Finally, due to the growing energy-related economy, an eco-friendly urban expansion is occurring in the oldest part of the Port, known as Darsena di Città. Beginning in the 1960s, this 100-hectare industrial site near the city centre and the railway station was gradually abandoned. In the mid-1990s, the municipality approved a master plan by Marcello Vittorini for the redevelopment of the area into a new residential district. The proposal was, however, oversized with respect to the demographic trend and the market demand of that period, and it was never implemented (Codecasa and Ponzini 2011). In the mid-2000s, Stefano Boeri Architects was entrusted with a new project. The vision foresees the location of vertical buildings and towers along the waterfront, and a linear park between these new sites and the consolidated city. Following these guidelines, a social housing project by Cino Zucchi Architects was realised by the end of the 2000s, together with the new offices for the Port Authority and a small part of the park. Thereafter, progress was slowed by the lack of resources and the real estate crisis. Today, however, the growth in port operations and the



Fig. 2 New container terminal under construction on the former silt storage. Picture by the author

establishment of new industries is reviving this urban transformation. The CIA-Conad Cooperative has invested 100 million euros to convert seven hectares of former industrial sites into a new urban area. This will include 27,000 m^2 for public spaces, 8500 m^2 for commercial activities, 6000 m^2 for social housing and luxury residential towers along the canal, and 4000 m^2 for offices. Contemporarily, commercial activities, sport facilities, and advanced manufacturers have expanded over 20 hectares between the city and Port. To date, these novel buildings host two hectares of rooftop solar panels, and plans have been made to cover another 1.5 hectares of restored buildings. Indeed, these new urbanisations are expected to be sustainable and self-sufficient as part of the municipal attempt to cut CO_2 emissions by 40% by 2030.[9] This goal has to be achieved by means of infrastructural projects which connect urban and port infrastructures, in turn, combining a variety of spaces and functions within the Port area (Fig. 3).

The governance of the energy projects and spatial transformations

The spatial heterogeneity arising from the reconfiguration, upgrade, and integration of the numerous energy systems in Ravenna requires effective governance. To this end, a coalition of actors, including the regional, provincial, and local administrations, in collaboration with the Port Authority and terminal operators, has been set up to harmonise, as well as to foster, development over the entire territory. This effort culminated in 2024 with the establishment of a simplified logistics zone (ZLS)[10]: an area that benefits from financial

[9] Ravenna municipality joined the EU Covenant of Mayors for Climate and Energy in 2019.

[10] In 2020, the Italian government instituted a number of special economic zones (ZESs) and simplified logistics zones (ZLSs). The ZESs are to be established in the southern regions, aiming at stimulating the development of marginal areas as part of the trans-European transport networks; conversely, the ZLSs are to be located in the cen-

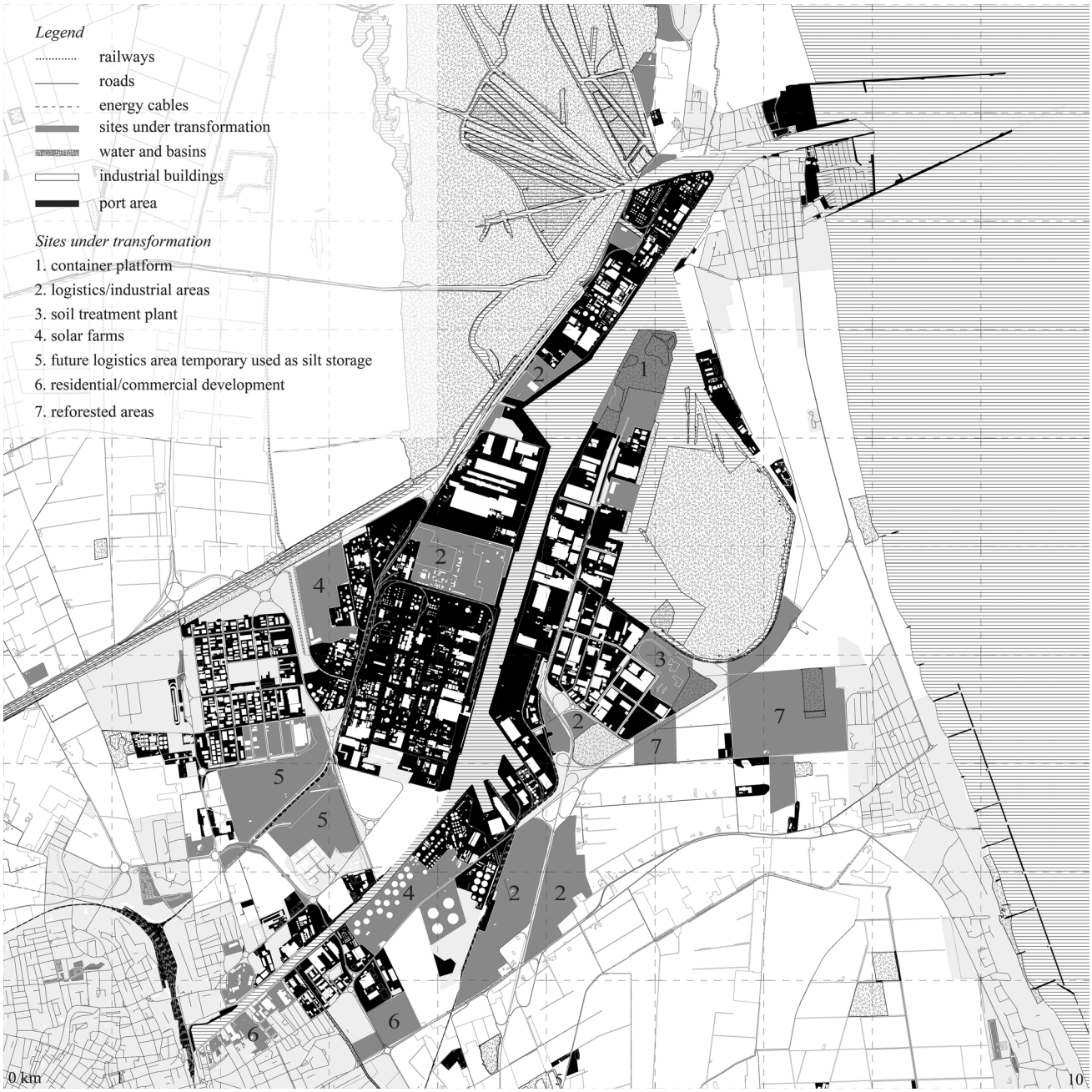

Fig. 3 The heterogeneous spaces forming the Port of Ravenna. Map by the author

aid and reduction in bureaucracy. Even though ZLSs are primarily to develop logistics and industry, it is no secret that Ravenna has energy at its core: the energy projects currently underway—particularly, the offshore wind farms, the many solar/hydrogen facilities, and the CCS hubs—have been included in the ZLS to reduce red tape, avail financial incentives, share know-how between industries, and improve private–public partnerships.

The procedure for obtaining this special statutory status was set in motion in 2021, and the strong ties between local stakeholders were fundamental in achieving this result. While all ZLSs have to be centred around port infrastructures, the Port Authority of Ravenna does not possess its own land for new development. The project was thus supported by the municipal, provincial, and regional governments,

Footnote 10 (continued)

tral/northern regions to consolidate existing industrial and logistics sites within port hinterlands.

with the objective to "extend the concepts of 'port hinterland' and 'port infrastructure' to cover the entire territory of Emilia-Romagna" (Interview 4 2023). As a result, the ZLS now covers 4500 hectares, most of which is located in the Ravenna municipality: 1715 hectares is earmarked for logistics and transport facilities, and 564 hectares for industry and manufacturing (Regione Emilia-Romagna 2022). However, although the recent establishment of the ZLS demonstrates the potential for fruitful cooperation between public and private actors, the effective spatialisation of energy projects over the last few years has been undermined by legislative discrepancies among different levels of governance, the clash of projects and stakeholders' interests, and difficulties in managing the spatial and environmental complexity of the emerging urbanisation.

The discrepancies between different levels of governance are evident when examining the implementation of the major energy projects. The offshore wind farm by Agnes is an example of how such initiatives progress in fits and starts because of the lack of coordination among different administrations. It has been 6 years since the project was set in motion, and although the funding has already been allocated by private actors, and the plans approved by local governments, a regulatory framework is not yet in place to proceed with its development. This is due to maritime planning issues: the territorial sea (12 nautical miles from the coastline) was previously under the authority of the national government, and this changed only with the recently approved *Plans to Govern the Maritime Space* (Ministero delle Infrastrutture e dei Trasporti 2024),[11] which has made regional administrations responsible for the implementation of the national maritime guidelines as part of their landscape and urban plans. The same uncertainty characterises most of the inland initiatives, especially those which have to adhere to a strict schedule to receive institutional funding. This is the case of the development promoted by the Port Authority to produce green hydrogen by means of solar panels. The project was cofinanced by the NextGeneration EU programme, which requires its implementation by 2025. However, owing to delays, the proposal was only approved at the end of 2023, and there is a 15-month delivery time for hydrogen production equipment. Consequently, the Port Authority has been forced to revise the project: solar panels will now be installed on the site for the hydrogen plants, and this facility will be added at a later date. This, however, results in a 1.5-million-euro loss, and it is a blow to the Port Energy Community.

These issues in project implementation have been further exacerbated by the contrasting objectives of different stakeholders and the diverse requirements of the different energy facilities. This clearly emerges in relation to the occupation of energy spaces. For instance, Eni's CCS will prevent the completion of the Agnes' project, with implications for the local fishing industry. As reported by environmental associations such as Legambiente and Greenpeace, the injection of CO_2 into gas reservoirs that are near exhaustion maintains the high pressure needed to continue pumping fuel. However, this activity will delay the construction of Agnes' green hydrogen plants, which were to be installed on the decommissioned offshore platforms. The CCS will keep these facilities in operation and delay the start-up of green hydrogen production. This will also affect local fishing industries. According to the plan, mussel farming is due to replace trawling in the areas for offshore wind farms (Agnes 2024). This activity would benefit from the oxygen released into the water by the offshore hydrogen plants, which will now be halted by the CCS development.

Finally, difficulties and controversies emerge in the management of the ongoing spatial transformations, and the evaluation of their environmental impact. For instance, the conversion of the former Sarom refinery into a solar farm can be regarded only as a partial reclamation. This solution has been adopted because the soil tested safe in the first two metres, and the foundations of solar panels are less than one-metre deep. Thus, sustainability will increase thanks to the use of renewable sources, but at the cost of an incomplete soil decontamination. Such compromises can be found in the majority of the projects underway, which, due to their non-linear implementation, have ended up producing unexpected urban landscapes. The new 70-hectare site for silt storage is a perfect example of this. A soil treatment facility for dredged material was envisioned in the *Ravenna Port Plan*. Although some preliminary planning was undertaken after 2021 (AdSP MACS 2022), when the Port Authority finally received funding, the local administration granted permission only in late 2023. However, the dredging work for the LNG plants and the port canal could not be deferred in order to keep the Port operational, and to complete the LNG plant within the deadline established by EU in 2025. To overcome this impasse, the municipality has been forced to revise the urban plan, allowing the storage of the dredged materials in designated sites between the Port and the city, although this has raised complaints from the inhabitants of the nearby areas.

[11] Following the *Maritime Spatial Planning Directive* established by the European commission in 2014, The EU coastal Member States are required to transpose this directive into their national legislative systems, designate a competent authority to coordinate the planning process, and to develop and adopt a national multi-sectoral management plan for maritime space.

Conclusions

This paper has discussed how the urgent drive for sustainability is triggering transformations that, starting from the energy networks, generate heterogeneous landscapes which are difficult to govern. This trend is evident in long-established industrial sites that, after years of financial constraints, are now benefiting from major investment driven by sustainability policies and energy transition programmes. These have become laboratories for experimenting with ways to graft new energy facilities onto long-established hubs. Far from being confined to the energy system itself, this process affects the entire landscape: new spaces are modelled, new environments are formed, and new ecosystems are created. However, the enormous amount of money to be spent in an extremely short time, the contrasting interests of the players involved, and the lack of a strong institutional body to orchestrate transformations together carry the risk of poorly coordinated development. This results in a more problematic spatialisation of the projects underway, which calls for better (or alternative) planning approaches to effectively combine the different energy-related spaces as well as the novel infrastructures and urban environments.

The article has sought to provide evidence for this by drawing upon the current transformations in the Port of Ravenna and its hinterland. This can be viewed as a heterogeneous landscape composed of multiple energy facilities, which, spurred by the need to increase performance, embrace sustainability, and overcome the current shortage of non-renewable resources, are becoming increasingly interdependent. The composite infrastructure configuration resulting from this integration not only aims to secure energy supply, but also to attract capital, foster economies, and promote urban development. In all, it creates novel relationships with the existing landscape, which becomes increasingly heterogeneous and, consequently, much more difficult to govern: land consumption is worsened by this rush for energy, controversial effects arise from site exploitation, and inconsistent governance hinders coordinated development. The greatest challenge is the overall spatial planning of diverse energy systems, resource storage and waste recycling, natural reserves and protected areas, and new urban spaces.

This challenge is in part due to issues with harmonising different levels of governance. While the newly established ZLS aims to circumvent bureaucratic impediments, it is likely that these difficulties will persist. Indeed, the new regulations (both for ZLSs and maritime governance) have established neither a single framework nor a sole institutional body in charge of planning practices. As a result, fragmentation remains: the planning of the port areas and facilities is under the Port Authority, that of the inland is the responsibility of Ravenna municipality, the territorial sea is assigned to the regional government, and the portion of the sea between 12 and 24 nautical miles from the coastline depends on the national administration. However, energy networks and the landscapes produced by their externalities transcend these administrative boundaries, requiring a more integrated approach to this development. While this can be achieved via cooperation between stakeholders, as demonstrated in promoting the ZLS, the lack of a central governmental entity might hinder coordination and weaken cooperation—especially when project objectives have few financial benefits for the stakeholders involved.

What is more, current planning instruments appear ill-prepared to address the challenges brought about by heterogeneous energy landscapes. In 2020, the Municipality of Ravenna developed the *Sustainable Energy and Climate Action Plan*, which contains useful guidelines regarding environmental adaptation and mitigation, including energy targets and strategies. Particularly, landscape scenarios for the integration of energy facilities were developed to address the complexity of the urban spaces and everchanging environmental features (Comune di Ravenna 2020b). However, little consideration has been given to these visions, and in the *Ravenna Municipal Plan* energy systems are solely considered technical elements, and their spatialisation in landscape is disregarded (Comune di Ravenna 2020a). The same goes for the *Ravenna Port Plan* (AdSP MACS 2024a) and the *Maritime Plan for the Adriatic Sea* (Ministero delle Infrastrutture e dei Trasporti 2022). All these planning documents privileged a more traditional zoning approach, partitioning the land/maritime regions into (quasi) monofunctional areas. This zoning is based on the definition of horizontal surfaces, which tends to oversimplify the complexity of energy landscapes: energy infrastructures are viewed as stand-alone, aspatial, and immutable technical devices; little consideration is given to the 'volumetry' of infrastructural realms (i.e. the vertical integration of energy facilities in land and maritime environments, and their superimposition over other land uses); and scant attention is paid to energy uses and energy-related practices. In all, although most of the landscape and urban transformations in Ravenna are driven by energy-related projects, energy systems and facilities are considered ancillary: nothing more than technical means to fulfil sustainability targets.

Even though some of the planning difficulties found in Ravenna can be attributed to site-specific conditions, there is also a wider picture. Heterogeneous energy landscapes have been appearing in infrastructure-led developments worldwide. For instance, in consolidated regions for energy and resources exploitation, such as the North Sea, current energy projects are generating controversial

"anthropogenic seascapes" (Jørgensen 2020) melded into an "urban sea–land continuum" (Couling and Hein 2020); similarly, in emerging hubs, such as Lanzhou New Area and Masdar City, the construction of large-scale renewable energy projects is the prerequisite for logistics zones and new towns (Cugurullo 2016; Williams 2017). These energy-led urbanisations show, in different ways, a complexification of layouts, land uses, and urban spaces, with implications for people's lives and the environment. Their common issues illustrate the difficulties in governing current landscape transformations. This is partially because energy transition projects are still primarily based on technical solutions. The role of energy infrastructures in shaping heterogeneous landscapes is mostly overlooked; hence, problematic externalities and controversies emerge during the implementation of these projects. At the same time, while urban plans include detailed projects for city development, the same cannot be said for the spaces for energy and related usages due to their technical complexity.

With respect to these issues, a landscape approach is useful to understand the heterogeneity in spaces and infrastructure configurations (their layouts, artefacts, and interactions), the relations they establish with existing urbanities and people practices, and their indeterminacy and everchanging nature. The complexified and textured picture that emerges by adopting this lens overcomes the sectoral approach persisting in energy-intensive urban settings, such as port cities where "challenges and solutions are often discussed in isolation from each other […], rather than with reference to a holistic framework to sustainable development" (Carpenter and Lozano 2020). On this basis, spatial planning and urban design might eschew piecemeal, utility-based interventions, to address the current energy challenges in a more systemic way, and in turn encouraging energy operators to adopt a place-based design and an effective combination of uses, functions, and spaces. Ultimately, this lens might open vistas on the future of energy landscapes and their urban implications. Indeed, given the transitory state of energy facilities (as shown by the case of Ravenna), questions arise regarding the integration of emerging technology into existing energy sites, and the adaptation and reuse of current spaces for power generation and exploitation. In this respect, a landscape approach could help in developing future scenarios which address the relational, performative nature of energy landscapes in time, and the heterogeneity of spaces and uses this generates.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Interview 1 with a representative of the Port Authority, March 6th, 2023, sentence translated by the author
Interview 2 with a representative of Marcegaglia Company, March 8th, 2023
Interview 3 with a representative of Sapir Company, March 7th, 2023
Interview 4 with a representative of the Port Authority, April 26th, 2023, sentence translated by the author

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