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Urban wind energy futures in the making: Energy plazas, hotspots, and enclaves

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A B S T R A C T

This paper examines how alternative wind energy futures emerge in processes of implementing innovative wind energy projects in cities. Although future-making is central to energy transitions, the socio-material processes through which futures come into being are often only considered implicitly in futures studies. We analyse three cases of small-scale urban wind energy projects underpinned by visions of urban wind energy. In doing so, we examine how diverse wind energy futures are made through the assembling of urban wind energy visions, small-scale wind energy technologies, urban spaces, and practices of energy production and consumption at particular sites. We find that the assembling of human and non-human elements results in three distinct futures-in-the-making: the energy plaza, the energy hotspot, and the energy enclave. For the field of futures studies, this implies that understanding processes of future-making requires recognizing the material and spatial context in which such processes take place. For society, these energy futures-in-the-making contribute to the reimagining of wind energy ownership, and the ways in which we access, engage, and live with wind energy in cities. We also show that the future of wind energy can be small-scale, decentralised, and embedded in urban environments, which challenges the dominant future vision of large-scale, centralised, and remote rural and offshore wind energy systems.

1. Introduction

Although still marginal in comparison to large-scale wind turbines, alternative designs of urban wind energy technologies that resemble the shape of trees, flowers, or rooftop ‘crowns’ are gaining ground. These technologies are underpinned by visions of how wind energy installations can be integrated in cities and how and by whom wind energy can be produced and used there. In several European cities, small-scale wind energy technologies have already been implemented by municipalities, energy companies, and real-estate developers in urban spaces as diverse as residential areas, recreational areas, and mobility spaces. The practical attempts of these urban actors to embed innovative wind turbines in various urban environments suggest that wind energy futures can be imagined and made in a variety of ways. It points to an alternative future in which wind energy can be small-scale, decentralised, and located in close proximity to energy consumers in cities.

Examining the diverse ways in which futures are made is important for understanding how alternative futures can be realised (Hawxwell et al., 2024). Yet, the material processes and practices through which futures come into being are under-theorised

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(Friedrich & Hendriks, 2024; Oomen et al., 2021; Schneider & Lösch, 2019; Hajer & Pelzer, 2018; Groves, 2017). Most futures scholars tend to emphasise the role of humans and their actions and intentions in future-making, while underplaying material dimensions (Graminius & Haider, 2025; Schneider & Lösch, 2019; Groves, 2017; Anderson, 2010). As a result, the role of materials, technologies, and nature in shaping the capabilities of social actors to steer towards desirable futures remains in the background. With this article, we respond to a recent call to recognise the complex interplay of humans and their wider material contexts in shaping futures (Graminius & Haider, 2025; Schneider & Lösch, 2019; Groves, 2017; Adam & Groves, 2007). To understand the processes through which futures are shaped by human and non-human actors, we ask the following questions: how do wind energy futures unfold in processes of implementing innovative urban wind energy projects in urban environments? And what kind of alternative wind energy futures emerge in these processes?

To answer these questions, we focus on three small-scale and decentralised urban wind energy technologies that have been implemented in Northwest Europe. We use an assemblage perspective to analyse the implementation of these technologies as a process in which urban wind energy visions, wind energy technologies, urban spaces, and practices of energy production and consumption come together to form particular wind energy futures. We identify three different types of energy futures-in-the-making that we term 'energy plazas', 'energy hotspots', and 'energy enclaves'. We demonstrate how these wind energy futures redefine how and where wind energy can be produced, how and where it can be accessed, and how people can engage with wind energy technologies in cities. Our results highlight processes through which alternative futures are made and demonstrate how the material context of particular spaces shapes these future-making processes.

The remainder of the paper is structured as follows: the next section presents an assemblage perspective on processes of future-making. This is followed by a description of our methods for collecting and analysing empirical data. The results section then analyses the attempts of urban actors to integrate three distinct small-scale wind energy technologies - Wind Tree, Flower Turbine charging stations, and PowerNest - into urban environments. We demonstrate how these technologies connect to urban public spaces, mobility spaces, and residential buildings to assemble three alternative types of futures. In the discussion section, we elaborate on how futures depend on the socio-material and spatial context in which they are enacted, and also reflect on how energy futures can be made otherwise. The paper concludes by outlining the theoretical and practical implications of engaging with alternative future-making processes.

2. An assemblage perspective on the making of urban wind energy futures

The role of human actors in processes of future-making has received considerable attention in futures scholarship. Yet, future-making does not solely depend on the intentions and capabilities of human actors: when human actors envision and create futures, they encounter constellations of other actors, practices, discourses, and material artefacts which might have different goals and compete for the enactment of different futures (Aykut, 2019). These multiple constellations of human actors and material elements actively shape the way in which futures emerge (Graminius & Haider, 2025; Schneider & Lösch, 2019; Groves, 2017; Adam & Groves, 2007). As a result, envisioned futures may either fail to materialise or materialise in ways that diverge significantly from the original intentions of human actors.

Recent work in the field of futures studies has emphasised the importance of examining how futures emerge through relational networks of humans, technical objects, materials, environments, ideas, and practices (Graminius & Haider, 2025: Friedrich & Hendriks, 2024; Schneider & Lösch, 2019; Groves, 2017). There is a variety of approaches, such as Actor Network Theory and the assemblage approach, that understand reality as emergent from associations between human and non-human elements and their collective agency (Müller & Schurr, 2016; Bear, 2013; Bennet, 2005). However, despite similarities these relational approaches also differ in a number of ways. The focus of Actor Network Theory is on how heterogeneous associations are built and maintained to lead to a certain, though potentially temporary, outcome (Müller & Schurr, 2016; Bear, 2013). In contrast, an assemblage approach is concerned not only with how associations of actors come to be, but also with "how ongoing flows and trajectories … continue to shape [an assemblage] and present different potentials for its future" (Bear, 2013, p. 24). In doing so, an assemblage approach emphasises the open-ended and anticipatory character of relational processes (Bear, 2013). For this reason, assemblage theory is particularly relevant for understanding future-making as processes of coming together of heterogeneous human and non-human elements (Schneider & Lösch, 2019; Groves, 2017; Palavicino, 2016).

Assemblages are continually emerging configurations composed of heterogeneous human and non-human elements, including technologies, nature, institutions, practices, and discourses (see also Bear, 2013; Anderson et al., 2012; McFarlane, 2009; De Landa, 2006; Markus & Saka, 2006; Murdoch, 1997). These associations of actors are not random, but deliberate and desirable (Buchanan, 2015). However, the desire is not a conscious wish of specific (human) actors, but it is instead a pre-subjective, pre-conscious force that is distributed between assemblage elements "connecting, animating and transforming them" (Malins, 2017). Thus, desire is a central force that brings socio-material relations into being (Müller & Schurr, 2016).

The relations between assemblage elements are "inherently unstable" (Haarstad & Wanvik, 2016) and subject to change. Assemblages are, as such, the result of relations between these heterogeneous elements that are continually being stabilised and destabilised (Bear, 2013; De Landa, 2006). Stabilisation refers to processes that increase internal coherence of relations between these heterogeneous elements across time and space. For instance, collaboration between different charging station operators might help to create a more coherent network of public charging stations for e-vehicles (e.g. Lunardon et al., 2023). Destabilisation, in turn, refers to processes that lead to the weakening of the relations (De Landa, 2006). For instance, if charging station operators each launch their own charging membership schemes, internal coherence between charging stations may decrease. Stabilisation and destabilisation can happen simultaneously, meaning that the continuous and incremental formation of assemblages is a function of the interplay between stabilising and destabilising processes. This means that processes that stabilise emerging assemblages might be counteracted by other processes that destabilise these relations.

An assemblage approach to understanding future-making thus helps to analyse how futures gradually emerge as the relations between human and non-human elements are formed (see also Schneider & Lösch, 2019). Applied to urban wind energy, we analyse how futures emerge from the assemblage of urban wind energy visions, novel wind energy technologies, urban spaces, and practices of energy production and consumption. These four elements are relevant for our analysis as visions are novel ideas of how wind energy technologies might look and where they might be installed. These visions guide actors into a certain direction to enact “the yet not present” (Brown, 2006). Visions are embedded into the designs of innovative wind energy installations that further shape how, where, and by whom the technology can be used. Urban spaces, in turn, provide the material and spatial context in which these technologies are implemented. Finally, practices are daily routines of energy production and consumption that emerge around wind energy technologies in urban spaces. As these four elements come together and new relations stabilise, distinct assemblages emerge. As such, these assemblages represent snapshots of envisioned futures that materialise in the here and now (Anderson, 2010; Durose et al., 2021; Groves, 2017). Using this assemblage perspective, the rest of the paper traces the processes of implementing innovative wind energy technologies in three types of urban spaces and examines how, in these processes, distinct wind energy futures unfold.

3. Methodology

To explore energy futures in the making, we take a case study approach. We selected three cases of innovative wind turbine technologies: the Wind Tree, the Flower Turbine, and the PowerNest (Table 1), each representing a distinct small-scale wind energy installation that also embeds a certain vision about the future integration of wind energy in the city.

Our first criterion for case selection was the diversity of visions embedded in the technologies concerning the spatial integration of wind energy in urban environments. The Wind Tree is a small-scale, tree-shaped installation that embodies a vision of wind energy that can be produced and consumed in public urban spaces. The Flower Turbines charging station is a stand-alone, off-grid unit equipped with a one-meter tulip-shaped wind turbine and two solar panels. It is designed for charging e-bikes and portable electronic devices, reflecting a vision of decentralised charging infrastructure powered by wind and solar energy, positioned alongside mobility infrastructure in urban and peri-urban areas. Finally, the PowerNest is a modular roof-mounted installation for residential medium- and high-rise buildings that combines wind and solar energy. It embodies a vision of directly powering urban residential buildings by renewable energy sources.

Our second criterion for case selection was that urban stakeholders must have implemented these technologies with the explicit aim of engaging the public and facilitating the direct use of wind energy. Therefore, we selected cases where technologies had been taken up by municipalities, an energy company, and real-estate developers and installed in various urban environments. Although these technologies are not considered mature, the Wind Tree, Flower Turbine charging station, and PowerNest have progressed beyond the testing and prototyping phases and are commercially available. Installations of these technologies can be found in various cities and towns in the Netherlands, Luxembourg, and Sweden (see Table 1). Based on these criteria, we selected three specific installations as cases: the Wind Tree in Helsingborg (Sweden), Flower Turbines charging stations in Oostzaan, Leideirdorp, and Middelburg (the Netherlands), and the PowerNest in Eindhoven (the Netherlands).

For each case, we traced back how the relations between urban wind energy visions, wind energy technologies, urban spaces, and energy production and consumption practices were gradually assembled from the moment when urban actors decided to install wind energy technologies until the time of the fieldwork.

Data were collected through a mix of document analysis, semi-structured interviews, and direct observation (see Table 2). First, we studied webpages dedicated to the three selected technologies, technical data sheets, and social media posts produced by the

Table 1
Variation in cases.

Technology	Vision	Type of space in which technology is integrated	When and where the technology was implemented	The vision shared by and technology is implemented by
Wind Tree	Publicly available wind energy	Public space	• Helsingborg, Sweden (2022); • Södertälje (2023), Sweden; • Amsterdam (2021), the Netherlands; • Colmar-Berg (2021), Luxembourg	• Helsingborg municipality and energy company • Science center and museum in Södertälje • Dutch energy and petrochemical company • Colmar-Berg Municipality
Flower Turbine charging station	Wind energy charging infrastructure to support sustainable mobility	Mobility space	• Oostzaan (2021), • Leiderdorp (2023), • Middelburg (2024), the Netherlands	• Municipalities of Oostzaan, Leiderdorp, Middelburg • Netherlands Enterprise Agency (RVO)
PowerNest	Wind energy in residential buildings	Residential space	• Eindhoven (2022), • Rotterdam (2021), the Netherlands	• Real-estate developer in Eindhoven • Real-estate developer in Rotterdam

companies offering these technologies. These documents allowed us to identify and examine the visions behind the three selected technologies as they contain the statements of startups, texts, and images in which visions are embedded. Further, the analysis of websites and technical documents also provided insights into the design of the Wind Tree, Flower Turbines charging stations, and PowerNest, and the requirements for installation in specific urban environments. We also analysed articles in local newspapers and YouTube videos about the implementation of the three wind turbines in selected locations to understand how the urban wind energy technologies and their benefits are presented to local communities and potential users.

Second, we conducted semi-structured interviews with eleven stakeholders who were involved in the implementation and further management of the technologies, including representatives of municipalities (5), real-estate developers (2), representatives of energy companies (1), a national agency (1), an energy consultant (1), a software developer (1) (see the interview guides in appendix). The interviews were conducted between October 2021 and August 2023. The interviews took place either online or at the locations where the wind energy technologies were installed, which allowed for the real-time validation of the interviewees' statements.

Finally, direct observations were made at the sites where the technologies had been implemented between July 2022 and August 2023. The first author spent up to two days in each location observing how the technologies operated, what kind of activities took place around them, and how (and if at all) people interacted with the wind energy technologies. The first author had informal conversations with people who were present at the fieldwork sites and took photographs and short videos of the technologies. These observations were subsequently synthesized into fieldnotes.

Interview transcripts and selected documents were analysed through a combination of inductive and abductive approaches. First, the interviews and the documents were coded inductively in Atlas.ti through open coding. Next, these open codes were grouped into themes based on concepts from our theoretical framework: vision, wind energy technology, spaces, and practices. These codes were used to identify elements that forge relations between the assemblage elements and to analyse what affects the (de)stabilisation of the relations. We iteratively moved between theory and data, constantly refining our theoretical approach against empirical findings. This abductive approach (Morgan, 2007) allowed us to develop insights and explanations that are grounded in data. Further, the data analysis involved systematic cross-verification between interviews, selected documents, and observations, which allowed us to identify recurring patterns across the three data-sets. Thus, data triangulation enhanced reliability and validity of findings.

4. Assembling urban wind energy futures

4.1. Energy plaza: wind energy in public spaces

The Wind Tree was developed by a French startup company that envisioned the integration of wind turbines in urban public spaces to power public services. This vision was translated into a tree-shaped wind energy installation featuring vertical-axis wind turbines resembling leaves. The technology was designed to take up limited space, making it possible to install it in diverse urban public spaces such as parks or squares. The Wind Tree was also intended to provide additional urban services. It could be equipped with an adjacent bench fitted with USB ports to charge portable electronic devices or micro-mobility devices such as e-bikes or electric scooters. Through this multifunctional design, the startup intended to reconnect "inhabitants with the source of their electricity" and contribute to the development of "conviviality in cities" (New World Wind-USA, 2018). The following analyses how this wind energy installation

Table 2
Analysed data sources per case.

	Interviewees (interview location and duration are indicated in brackets)	**Analysed documents**	**Observations**
Wind Tree	• Landscape architect at Helsingborg Municipality (online, 27 mins) • Representative of Helsingborg energy company (Helsingborg, 46 mins)	• Webpage and Instagram of the Wind Tree startup • Wind Tree technical data sheet • Three newspaper articles about Wind Tree in a local newspaper Helsingborgs Dagblad • Facebook group of Helsingborg	• Helsingborg, February 3–5, 2023
Flower Turbine charging stations	• Oostzaan Municipality representative (Oostzaan, 36 mins) • Leiderdorp Municipality representative (online, 29 mins) • Two Middelburg municipality representatives (Middelburg, 44 mins) • Senior advisor, Netherlands Enterprise Agency, RVO (online, 28 mins)	• Webpage and Instagram of the Flower Turbine startup • Flower Turbine technology guide • Articles from Middleburg and Leiderdorp local newspapers	• Oostzaan, July 11, 2023 • Leiderdorp, July 11, 2023 • Middelburg, July 24, 2023
PowerNest	• 2 project managers, real-estate development company (Eindhoven, 39 mins and 47 mins) • Manager of a software energy management company (online, 51 mins) • Energy consultant (online, 20 mins)	• Webpage and Instagram pages dedicated to PowerNest • PowerNest technical specifications • Subsidy regulations • Online materials about PowerNest on the webpage of the real-estate developer • Article in a local newspaper	• Eindhoven July 11, 2022 and January 23, 2023

was implemented by the municipality and an energy company in the city of Helsingborg (Sweden) where the Wind Tree was installed in the early spring 2022 (see Fig. 1).

The Wind Tree was installed for the bi-annual Smart City Expo in 2022, which aimed to showcase "*future welfare solutions aimed at improving quality of life in a smarter, more sustainable city*" (H22, 2022). For this Expo, the municipality developed several 'opportunity spots' along the waterfront in a newly developed mixed-use district. These opportunity spots functioned as outdoor stands for presenting smart city innovations, while also providing visitors and residents shelter from wind and rain, access to Wi-Fi, and charging facilities. In collaboration with a local energy company, the municipality installed a Wind Tree at one of these opportunity spots to stimulate dialogue about energy transformations and how and where renewable energy is and can be produced. As one of the interviewees explains:

> *"I think [we] want to make people curious about how a source of energy could look like. Cause we haven't seen anything like this [Wind Tree] before. Energy comes in many shapes, this is one of them. And so that was one of the approaches [to] start a dialogue about what would a source of energy look like for you" (Interviewee 2, representative of the energy company in Helsingborg).*

This vision was echoed by a representative of the Municipality who argued the Wind Tree was:

> *"a thing that could start and draw attention to the question of renewable energy and showing that you can do this in other ways and more locally than all these offshore areas, and like some big scale [wind turbines] that you normally think of connected to wind energy" (Interviewee 1).*

These respondents highlight the expectation that the novel nature-inspired design of the Wind Tree would help forge connections between renewable energy generation and the use of urban public space. They also show how these connections were enabled by the joint decision between the municipality and energy company to install the technology at the place where it would be visible and accessible to those using public urban spaces.

From the very start of the project, the energy company found it important that the installation would not become "*some sort of a statue*" (Interviewee 2) whose only function was to generate energy. As a manager at the energy company emphasised, "*it was very important that whatever we've produced here, we should share*" (Interviewee 2). To enable this, the municipality commissioned the Tree to

Fig. 1. Wind Tree in Helsingborg, Sweden *(the picture was taken by the first author)*.

include an adjacent bench with USB ports for direct and free charging of electronic devices. Thus, the bench directly connected the wind energy technology and its users in the waterfront area, thereby enabling direct access to wind energy in the city. The practice of using wind energy on-site, in turn, made the energy company reflect on energy ownership as well on the way the energy company connected to energy users:

> *"Who owns the energy? I would say that we as an energy company own the Tree. We are also in charge for the maintenance of the Tree and the bench. So I would say that… It's a really interesting question, who owns the energy. I mean, we share the energy that the Tree produces, so we own the Tree but we share the energy" (Interviewee 2).*

The relationship between the innovative wind energy system and user practices was further stabilised by an adjacent digital display providing information about the Wind Tree in both English and Swedish. For example, the display informed passers-by that the amount of energy produced by the Tree is equivalent to the amount of energy required to charge sixteen e-bikes per day. By presenting information about energy output "*in an inspiring and easily accessible way*" (Helsingborg International Connections, 2022), the display made the Wind Tree more comprehendible for wind energy users, thus, further connecting the two. At the same time, the display connected the Wind Tree to the wider urban public. Observations of activities around the Wind Tree demonstrated that passers-by regularly stopped by to check the information on the display. The screen, as such, connected the Wind Tree and city residents, giving wider meaning to the technology and the surrounding space beyond direct access to energy.

Positioned at the waterfront, the Wind Tree also creates new connections between practices of wind energy production and consumption and practices of using urban space. For instance, the Wind Tree was visible from a nearby restaurant, and runners and dog walkers in the area occasionally stopped to take a seat on the bench. As the representative of the energy company noted:

> *"I haven't heard of anything in terms of an energy source that you can actually sit so close to. I mean, here in Scania we have a lot of wind [turbines] and you can't go close to them. They are often located in the fields and you are not allowed to go near it. But here you can be really close to it" (Interviewee 2).*

According to the municipality representative, the proximity of the tree invited new encounters between the city residents and the wind energy technology: "*there were a lot of people* queuing *to sit, going around asking questions, there were a lot of elderly people wanting to take selfies with the Tree"* (Interviewee 2). The energy company representative suggested that installing the Tree in a public space encouraged people to reflect on energy production and consumption practices. They also recounted how a few people even inquired if they could buy a tree and install it in their own yards. This suggests that the Wind Tree represents a form of wind energy that fosters positive and direct engagement with the public, in stark contrast to large-scale wind energy technologies, which have often been met with opposition (e.g. Cashmore et al., 2019; Hirsh & Sovacool, 2013; Pasqualetti, 2012).

The integration of the Wind Tree in an urban public area connected a vision about wind energy in public spaces, a tree-shaped wind turbine, urban public space, urban dwellers, and practices of using energy and urban public space. The assemblage of these elements opens up a distinct future, which we label an 'energy plaza'. In this energy plaza, urban residents gain first-hand experience of wind energy, combine leisure practices with practices of energy consumption in urban public space, while also becoming informed about the working of wind energy technology. While the energy plaza unfolds at a very specific urban waterfront location, its influence extends beyond the public space in which it is located, shaping public energy practices and values. Our analysis reveals that the relationships between various elements that assemble the energy plaza have become relatively stabilised. This stability has been fostered by the ongoing involvement of the municipality and energy company, who maintain the Wind Tree and its adjacent infrastructure, allowing the relationships that assemble the energy plaza to persist after the conclusion of the Expo.

4.2. *Energy hotspot: wind energy in mobility spaces*

The Flower Turbines charging station was developed by a startup in the United States and the Netherlands, with the vision of accelerating the adoption of electric micromobility through the development of green charging infrastructure (Flower Turbines, 2024).

Fig. 2. Flower Turbine charging station in Leiderdorp, the Netherlands *(the picture was taken by the first author)*.

According to the company's CEO, "*enabling e-bikes and scooters to operate on renewable energy is a "double-green" enterprise*" (Flower Turbines, 2024). This vision materialised in the design of a charging station that combines a tulip-shaped wind turbine (300 W) with solar panels (60 W). Equipped with batteries, power sockets, and USB ports, the station allows for off-grid charging of e-bikes (see Fig. 2). According to the company, the Flower Turbines charging station is suitable for installation in urban and semi-urban areas due to its compact size, aesthetic design, and its ability to start rotating at low wind speeds (Flower Turbines, 2024). The following section examines the implementation of the Flower Turbines charging stations in three Dutch municipalities – Oostzaan, Leiderdorp and Middelburg – which were awarded with a Flower Turbines charging station by the Dutch Ministry of Economic Affairs and Climate Policy in recognition of their effort in sustainable energy generation and installed in 2021, 2023, and 2024, respectively.

When the three municipalities were awarded a Flower Turbine charging station, their first challenge was to connect the technology to a specific location in their towns:

> *"We had a little bit of an issue like where are we going to put it in our municipality? Our town is really small and it's really compact so we do not have a lot of spare ground". (Interviewee 8, representative of a Dutch municipality).*

Initially, one of the municipality teams considered installing the charging station in front of the City Hall, but quickly concluded that installing it there "*was more for the visibility than for the actual use*" (Interviewee 8). Given that most visits to the city hall were for administrative purposes, such as collecting or handing in documents, there would not be enough time for effective charging. Another concern was whether there was sufficient demand for public bicycle charging stations in urban areas. As a representative of the municipality noted, "*you really have to think like, where do we have spots where people would not charge their bikes at home?*" (Interviewee 8). In considering suitable locations, all three municipalities had to navigate between the functionality of the wind turbine, the exact functions of specific urban spaces, and the spatiotemporal rhythms of charging practices. These deliberations ultimately led the municipalities to abandon the idea of installing Flower Turbines charging stations in the inner city and instead opt for placement in recreational zones in peri-urban areas.

The recreational areas that the three municipalities selected had long been popular with cyclists and were already equipped with cycling infrastructure, such as bike racks, benches, and rest areas. In two of the three locations, there were also cafés located close to the charging stations. Representatives of two municipalities explained that cafés and cycling facilities located next to the charging stations afforded cyclists the opportunity to spend quality time while charging their bikes: *"It is a recreational place already with a small bench where people can sit and have a picnic. And then we thought it has a nice view on the lake and it's a resting place, so maybe that's a logical place where you would stop and you could use the turbine*" (Interviewee 9). Thus, the recreational facilities and the existing cycling infrastructure facilitated the connection between wind energy technology, mobility, recreation, and charging practices at the city's green outskirts.

Another important element connecting the technology, wind energy users, and charging practices was a battery that supplied the electricity from the charging station to the user on on-demand basis. To get access to energy, users had to push a button on the pole after which they got one free hour of off-grid charging from the charging station. However, in one of the cases this function did not work due to battery malfunction, as a waitress from a nearby café explained. She recounted how a resident contacted the municipality to request the repair of the charging station, but the municipality did not take action. This was later explained by a representative of the municipality as an issue of remoteness. As the charging pole is located in the peri-urban area, municipal workers do not know about the project and, therefore, they do not go and check if it works. This example demonstrates the active maintenance and care needed to maintain relations between the technology, mobility space, and user practices. A lack of care for maintaining and repairing the technology can thus destabilise the relations between Flower Turbines charging stations and users.

Another practical issue with the Flower Turbines charging stations was related to their findability and accessibility for users. At the time of fieldwork, no road signs or information boards to help cyclists in the area find the charging stations were installed. The Flower Turbine charging units were also not marked on any online maps or navigation software. The poor findability of the charging stations does not detract from the technical utility of the turbines, but does undermine the practices of potential users of the Flower Turbine charging stations. The lack of information about the location of charging stations meant that the newly emerging relations between the wind energy technology and user practices remained fragile.

While the Flower Turbines charging stations did not always function as expected and were sometimes underused, the municipal authorities observed positive effects from connecting the charging stations to recreational areas and their users. They argued that the Flower Turbines charging stations helped promote both wind energy and sustainable mobility within their municipalities. One municipality representative in particular noted that the charging stations demonstrated that wind energy can be small, nature-friendly, and adaptable to different locations. As she emphasised, "*hey, a wind turbine doesn't need to be like this colossal thing in the middle of a natural area*" (Interviewee 8). She viewed the Flower Turbine charging station in their area as the first step "*towards getting more support for wind energy*" (Interviewee 8) from both residents and municipal authorities. A representative of another municipality expected that the installation of a charging station in their area would encourage more people to cycle. She explained, "*there are people that don't like cycling, but they buy an e-bike, then it's a good thing that they have a turbine in the natural area as well*" (Interviewee 9). This demonstrates that the assemblage of wind energy technology, recreational areas, cyclists, and practices related to charging, mobility and recreation could prefigure broader urban energy transformations.

The implementation of the Flower Turbine charging station in peri-urban recreational spaces has brought together a vision about wind energy in mobility spaces, renewable energy technology, cycling infrastructure, recreational areas, cyclists, recreational practices, mobility, and charging practices. When these diverse elements are assembled, they give rise to a wind energy future that we label an 'energy hotspot'. The energy hotspot represents a configuration in which traffic passes by and renewable energy consumption is temporary and aimed at "charge-and-go". While the relationships between the elements in this configuration are somewhat unstable, as demonstrated above, it presents a snapshot of the future centered around the new ways of accessing and using wind energy in mobility spaces, while also promoting sustainable mobility practices.

4.3. Energy enclave: energy within a building

The Dutch startup company behind the PowerNest technology envisioned it as a "solution towards energy producing buildings and cities" (Ibis Power, 2024). This vision was embodied in the design of the PowerNest rooftop wind and solar energy system, which comprised a steel box containing 3 kW vertical-axis wind turbines and topped with solar panels (see Figs. 3 and 4). The system was designed to service medium- and high-rise residential, commercial, and public buildings with flat rooftops. By developing this wind and solar energy technology unit, the startup aimed to solve "complex sustainability issues in real-estate … beautifully and easily" (Ibis Power, 2024). The company's vision was embraced by real-estate developers who envisioned the integration and distribution of energy produced by the PowerNest system across their own buildings. The following section details the installation of a PowerNest system on a building rooftop in Eindhoven, the Netherlands, in 2022, and the attempts of a Dutch real-estate developer to organise energy self-consumption at a building scale.

In this project, the rhetoric of energy efficiency in buildings played a central role in elements linking the PowerNest system with the building infrastructure. This rhetoric was inscribed in municipal regulations and guidelines for zero-energy buildings, which, in turn, shaped the ambitions and practices of real-estate developers. As a representative of the real-estate developer explained, "*we are always looking for new ways to use renewable energy [in buildings] and [are concerned] about sustainability in general*" (Interviewee 10). Therefore, they were open to the opportunities to incorporate renewable energy technologies beyond solar into the design of a new high-rise building. As the company manager explained:

> *"[we thought] maybe we can do other things to use more sustainable techniques. And especially in high-rise building areas, it's hard to find a solution, so that's why we always look into new things" (Interviewee 10).*

Because the offices of the startup company and the real-estate developer were located in the same city district, the real-estate developer was already familiar with the PowerNest and became interested to install it on their building. However, they soon realized that the installation costs would be high, limiting their return on investment. As a result, the company sought financial support through energy subsidies provided by the Dutch government (OPZuid and SDE++). By reducing the overall financial risk of the

Fig. 3. Power Nest system on a building in Eindhoven, the Netherlands *(the picture was taken by the first author)*.

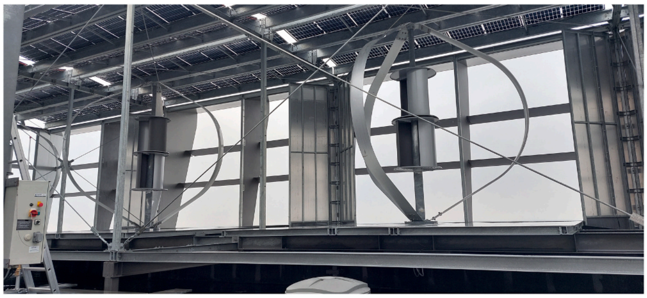

Fig. 4. PowerNest turbines integrated with solar panels *(the picture was taken by the first author)*.

project, the subsidy helped stabilise the relationship between the Power Nest, the new high-rise building, and the real-estate developer.

Once the real-estate developer had installed the PowerNest on the building rooftop in 2022, they discovered that their ambition to use the generated energy for the building itself was more challenging than anticipated. In order to explore various scenarios for distributing wind energy within the building, the real-estate developer partnered with a software company to develop a smart energy management system. This system monitored both the output of the PowerNest and the energy consumption of the building, using the data to test different scenarios for energy distribution within the building. The first scenario involved connecting the PowerNest units to the apartments in the building, feeding wind and solar energy directly to the tenants. In practice, however, the PowerNest and tenants could not be directly linked due to a number of technical and legal issues. As explained by a representative of the software company:

> *"It would require separate cabling to each apartment [185 apartments in total], which was a mission impossible, and legally it's also complex because you basically have to distribute what the real-estate developer would be generating to individual tenants. And how do you invoice that or how do you compensate that?" (Interviewee 11).*

The second scenario was to connect the building with the PowerNest installation on the rooftop with a neighbouring building belonging to the same real-estate developer and share energy between the two buildings. However, connecting two buildings into one energy system also turned out to be unfeasible. As the real estate developer explained:

> *"it's not easy to use the energy we produce as [a real-estate developer] in another building from [the real-estate developer]. We first thought to make our renters benefit the most from the renewable energy, but that's really hard to do that with all the regulations" (Interviewee 10).*

In line with Dutch regulation, it would require the real-estate development company to register as an energy supplier: a new role they considered to be too complicated.

Furthermore, the subsidy that had initially alleviated the costs of installation turned out to include a requirement to feed the produced energy into the grid rather than allowing it to be used for self-consumption. As a result of these regulations, the real-estate developer was unable to deliver energy directly to the building tenants. However, as the developer was committed to ensuring that the tenants benefited from the PowerNest system, they decided to exempt the tenants from paying for energy used in communal spaces of the building, such as elevators and corridors.

When the intended relations between the technology, building residents, and energy use practices proved difficult, the real estate developer sought to create a symbolic connection between the building residents and the PowerNest in order to "*make inhabitants more aware of their own energy use*" (Interviewee 10). To support this, they asked a software company to develop a digital dashboard that showed real-time wind and solar energy production by PowerNest, along with overall energy consumption and cumulative production since installation. This dashboard was made available to tenants through a community mobile application. For the general public, the company's website featured annual production figures by PowerNest, translated into more relatable metrics such as the number of kilometers an electric car could travel and the amount of microwave meals that could be prepared using this energy (Trudo, 2023). While the dashboard facilitated a cognitive link between the PowerNest and the building residents, it did not impact their daily energy production and consumption practices.

In the case of PowerNest, the new relations between a vision about wind energy in residential spaces, a rooftop wind and solar energy system, a building, its residents and the wider public give rise to a wind energy future that we label an 'energy enclave'. This 'energy enclave' aspires to localise energy production, distribution, and consumption within a single building or network of buildings, controlled by private actors, and used by residents as privileged consumers. Although technical and regulatory challenges hindered the direct integration of wind energy within the building, the relations between the wind energy technology, the building, and energy producing practices were realigned. Furthermore, this energy enclave challenges prevailing assumptions about the ownership and control of both wind energy technologies and the energy they generate, as demonstrated by the real-estate developer ambitions to assume the role of an energy supplier.

5. Discussion

By employing an assemblage approach to analyse the implementation of innovative wind energy projects in cities, we identify three emerging futures – energy plazas, energy hotspots, and energy enclaves. The energy plaza embodies a future in which wind energy is integrated into public urban spaces, providing direct access to urban residents for charging their electronic devices or e-vehicles. The energy hotspot, by contrast, represents a future where wind energy technology is connected to public mobility spaces, supporting "charge-and-go" practices. Finally, the energy enclave embodies a future in which wind energy production and consumption are confined within a building or a network of buildings. Unlike the two other assemblages, where wind energy is publicly available, the energy enclave restricts access to residents only. The three identified assemblages thus represent different urban energy futures and illustrate varying ways of connecting wind energy technologies to urban spaces, delivering wind energy to users, and connecting to urban infrastructure supporting mobility, housing, and recreation.

Despite evident differences between the three emerging futures, each configuration contributes to a wider transformation in how wind energy infrastructures are owned and engaged with. First, the material practices of embedding wind energy technologies within urban spaces, where it is directly consumed, are accompanied by the reimagining of energy ownership. Each configuration introduces new actors, such as municipalities and real-estate developers, into the domains of energy production and provisioning, thereby raising important questions about the decentralisation of (wind) energy ownership. On the one hand, decentralisation of wind energy aligns with existing societal and policy ambitions for community-based and peer-to-peer models of energy production (Gjorgievski et al., 2021; Zhang et al., 2017). On the other hand, private ownership risks reproducing inequalities around the energy provisioning in cities, and fuelling long-standing concerns about the "fragmentation of the social and material fabric of cities" (Graham & Marvin, 2002, p.33). Second, the energy plaza, hotspot, and enclave allow urban residents to engage more directly with wind energy technologies and the energy they generate. This contrasts sharply with the abstracted and often invisible connection most urban dwellers have with wind energy distributed via national grids (see Hirsh & Sovacool, 2013). The three energy futures thus align with broader ambitions to cultivate awareness of the fluctuating availability of renewable energy – what Ryghaug et al. (2018) term local resource sensitivity. Third, linking to observations made by Shaftoe (2012), by introducing artistic and radically redesigned wind turbines into urban public spaces, these wind energy assemblages foster the emergence of convivial energy spaces that promote values of inclusivity, playfulness, and curiosity.

Wind energy futures are assembled through the (de)stabilisation of relations between urban wind energy visions, wind energy technologies, urban spaces, and practices of energy production and consumption at specific urban sites. These new relations are actively shaped not only through the actions of conventional energy transition actors – such as municipalities, energy companies, or real-estate developers – but also a diverse range of heterogenous human and non-human elements. For example, in the case of the energy hotspot, the spatiotemporal rhythms of mobility made the installation of the Flower Turbines in the inner city impractical, while the socio-material elements in peri-urban recreation spaces enabled their integration. In the case of the energy enclave, the availability of government subsidies facilitated the integration of wind energy technology into a building's structure. At the same time, local urban regulations prevented the on-site use of wind energy and, thereby hindering the real-estate developers' vision of (at least partial) self-sufficiency. Reflecting the findings of Groves (2017), these examples underscore how the socio-material reality of specific sites affects the unfolding of energy futures.

By foregrounding the relations between particular visions, technologies, spaces, and practices, an assemblage approach demonstrates how futures can unfold in multiple ways and can take different forms. The idea that imagined futures are place-specific is not new. Scholars in the fields of future studies, science and technology studies, and transition research have shown that "what is perceived as possible or impossible" is shaped by "specific regions and places" (Friedrich & Hendriks, 2024, p. 4; see also Chateau et al., 2021; Feola et al., 2023; Späth & Rohracher, 2015). However, we extend this argument by demonstrating that it is not just the content of imagined futures that is place-specific, but also the process of future-making itself. Wind energy futures do not emerge in abstract, idealized spaces (Chateau et al., 2021; Watkins, 2015) with universal characteristics, but are instead assembled within concrete material settings. The material context of these specific spaces actively shapes the capabilities of actors to realise envisioned futures (see also Anderson, 2010; Groves, 2017). An assemblage approach thereby invites futures scholars to pay more attention to the material and spatial dimensions of energy futures-in-the-making (Adam & Groves, 2007).

Finally, an assemblage approach shows how future-making is a messy, contested, and open-ended process. The emergence of the three energy futures did not follow a predetermined plan orchestrated by human actors. Instead, these futures emerged through dynamic and open-ended processes of interaction and contestation between heterogeneous human and non-human elements in urban environments. These open-ended processes enable the articulation of alternative wind energy futures that challenge dominant imaginaries of large-scale, centralized wind energy systems. We argue that foregrounding these processes of emergence and contestation is important in understanding future-making processes. Rather than a linear trajectory guided by predefined steps and targets, future-making is a contingent and situated process shaped by space and circumstance (see Groves, 2017). This insight implies that there are multiple and diverse ways in which (wind) energy futures can unfold that go beyond what is envisioned by incumbent actors (Friedrich & Hendriks, 2024; Hawxwell et al., 2024). Recognising the diverse ways in which (wind) energy futures emerge is crucial for identifying practices and processes that hold the potential to catalyse transformative change in energy transitions.

6. Conclusion

In this article, we used an assemblage approach to analyse the implementation of innovative wind energy technologies in cities as processes of future-making. We asked how wind energy futures unfold through these processes, and what kinds of alternative wind energy futures these lead to. We found that as innovative wind energy projects are being realized, relations between urban wind energy visions, wind energy technologies, urban spaces, and energy production and consumption practices are formed. Based on our cases, we identified three distinct examples of energy futures: the energy plaza, the energy hotspot, and the energy enclave. Each of these emergent futures illustrates how wind energy can be made differently. They present the possibilities for (public) energy provisioning across various urban settings, and demonstrate the potential for decentralised, small-scale wind energy that enables people to perform a variety of existing and new energy practices. As such, these wind energy futures can challenge dominant wind energy imaginaries of large-scale, centralised, and remote wind energy projects.

Our paper highlights the value of further academic engagement with the assemblage approach on future-making through empirical studies that illuminate diverse and situated processes and practices of performing energy futures. Such empirical studies of energy projects with alternative technologies reveal experimental and open-ended processes of future-making that extend beyond the dominant logics of techno-economic optimization and upscaling energy systems. We argue that these studies are essential for diversifying the futures and sustainability transitions literature, which still tends to focus on future-making by incumbents (Hawxwell et al., 2024). Exploring and identifying alternative future-making processes can help broaden debates about what kind of energy futures are desirable and who stands to benefit from them, and how these futures might be enacted.

CRediT authorship contribution statement

Iryna Lunevich: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sanneke Kloppenburg:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Mattijs Smits:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization. **Simon R. Bush:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.futures.2026.103763.

Data availability

The authors do not have permission to share data.

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