

WIND AS MODEL, MEDIA, AND EXPERIENCE

From Wind Turbines to Energy Islands: Wind as Model Power in Denmark

May Ee Wong^{1a}¹ Digital Design and Information Studies, Aarhus University, Aarhus, Denmark

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This article explains how the fluctuating, ever-changing elemental entity of wind is constructed as a stable renewable energy resource through a global wind energy infrastructural model promoted by the Danish wind energy industry. Examining Denmark's project to build the world's first "Energy Islands," or offshore wind energy hubs, the article accounts for how wind is shaped into "energy" as a media environment, just as wind as medium and milieu shapes the infrastructural forms of wind power. The article thinks through wind with the elemental orientations of "matter," "molecule," "milieu," and "medium," as well as the mediated conditions of its legibility, to explicate the global wind infrastructural model as a multimodal elemental media assemblage. Wind's ontological qualities as an infrastructural medium are transduced through apparatuses of environmental data, such as graphical "island" figures and models of landscape featured on promotional websites, wind turbine test sites, and wind atlases that are constructed with numerical data and statistical models. The article argues that the metonymic visibility and invisibility of wind energy infrastructural components enable the territorialization as well as deterritorialization of wind through the strategic projection and displacement of spatial boundaries and geographical situatedness. This extends the infrastructural scope of wind power across various scales, which also contributes to a milieu of geopolitical and economic speculation. Although wind energy is projected as a stable resource, it should be described as a speculative milieu of long-term projections, intermittent changes, and sudden crises, which renders the "Green Transition" an uncertain landscape of environmental futures.

Wind emerges from the dynamic pressure differences that result from the heating and cooling of various parts of the Earth's surface. An ever-changing force that is often felt rather than seen, it is an elemental medium that becomes sensible and perceptible through forms of media. Identified and measured as meteorological phenomena from observable consistent weather patterns and forms such as clouds that materialize and dissipate, wind also includes unpredictable variations in direction and speed that emerge from ongoing shifting temperature and pressure changes. It is a material medium

^a May Ee Wong is Assistant Professor of Urban Mobile Media at Utrecht University. She is a member of the Aarhus University Research Foundation-funded project Design and Aesthetics for Environmental Data (2022 - 2024). Her interdisciplinary research interests lie in planetary urban futures and critical conceptions of infrastructure and the built environment, drawing from feminist Science Technology and Society (STS) studies, environmental humanities, contemporary media theory and visual aesthetics and culture.
mayee.w@gmail.com

of what Derek McCormack (2018) terms “envelopment,” which is the affective condition of a body being immersed in an atmosphere, and the condition of sensing in response to the milieu. The capacities of bodies, sensors, and materials to capture the various qualities and experience of the wind can be partial or even unavailable; articulating the wind inevitably involves some speculation and/or estimation. Despite its “resist(ance to) any reduction, either in terms of individual experience, or to the status of an object” (McCormack 2018, 6), wind has become extracted and stabilized into the discrete resource of wind energy, which is being promoted as a key renewable energy strategy of the “Green Transition.”

How has wind become regarded as a stable resource of renewable energy? This article examines how wind is discursively and materially constructed through the Danish global wind energy infrastructure model, which is exemplified in Denmark’s project to build the world’s first *energigrøer*, or “Energy Islands.” In 2020 the Danish government announced in an international climate agreement that it would build two “Energy Islands” or energy hubs that would consolidate and distribute “green electricity” from offshore wind farms: one in the North Sea, and one on the island of Bornholm facing the southern tip of Skåne County, Sweden. Drawing on concepts and expertise from existing Danish wind energy infrastructure, these energy islands are promoted as offshore wind energy innovations that would push Europe toward the wider adoption of wind energy as part of a global energy transition.

The case of the proposed Danish Energy Islands demonstrates how wind is mediated as projective power through various *dispositifs* or apparatuses of environmental data that formulate wind into “energy”: a technoscientific, ideological, political, and material figuration¹ that is channeled toward the generation of work and profit (Daggett 2019, 3). The Danish global wind energy infrastructure model reflects how wind is promoted as an energy source as well as geopolitical and financial power in the context of the “Green [or Energy] Transition,” in which the planetary climate crisis is being addressed by the notion of a technological shift toward the replacement of fossil fuels. Denmark is widely considered a global pioneer in wind energy development; a country with one of the highest proportions of wind energy penetration, it exports global wind energy expertise and infrastructural technology around the world. As a traded commodity, wind energy is entangled with the “energopolitics” (Boyer 2019) of capitalist practices of wind energy extractivism, especially in the Global South (Alkhalili, Dajani, and Mahmoud 2023; Dunlap and Correa Arce 2022; Franquesa 2018; Howe

1 Daggett defines figuration as “‘a semiotic trope’ that provides ‘a condensed map of contestable worlds,’ a map that traces ‘universes of knowledge, practice, and power.’ ... [F]igurations ... condense diffuse imaginaries about the world into specific form or images that bring specific worlds into being” (6).

2019), and the implementation of data-driven processes through public-private partnerships that “render the world legible to capital” (Bresnihan and Brodie 2021).

While wind energy has been critiqued as a vehicle of financial speculation and the site of political contestation, this article focuses on wind energy as an ontologically and epistemically speculative elemental entity. Engaging with analytical concepts from elemental media theory, this article explicates the Danish global wind energy infrastructural model as a multimodal elemental media assemblage that features apparatuses of environmental data, such as graphical “island” figures and models of landscape featured on promotional websites, a wind turbine test center site, and wind atlases, which are constructed with numerical data and statistical models contributing to a milieu of economic and geopolitical speculation. This article accounts for how wind is shaped and/or territorialized by the global wind energy infrastructure model into “energy” as a media environment, just as wind as medium and milieu shapes the infrastructural forms of wind power. As Derek McCormack (2017, 418) notes, the elemental is not just a material resource that is acted upon by infrastructure, but it is also an environmental or ontological condition influencing the capacity of infrastructure itself.

Wind enacts “materialities, affects and sensations” (Engelmann and McCormack 2021, 1419), which are transduced into “grounded” structures and “logistical media” (Peters 2015, 37) that shape and constitute the speculative imaginaries and mechanisms of wind power. Wind energy needs to be manifested as an effective operational model for it to be implemented as a mobile technoscientific global assemblage (Ong and Collier 2004) in various countries and regions around the world. Spatial and temporal boundaries are strategically projected and displaced to extend the infrastructural scope of wind power through the abstraction of environmental aspects and landscapes into technoscientific and graphical models of environmental data. As illustrated in Energy Island–related discourse, wind is also literally made visible—and invisible—as an energy resource through metonymic part-whole associations (Gerson 2022; Lieberman 2017) to its infrastructure and its transduced outputs: primarily electricity and more recently “green” hydrogen. However, the successful materialization of these developments is often dependent on local and regional conditions. Although wind energy is projected as a stable resource, it should be described as a speculative milieu of long-term projections, intermittent changes, and sudden crises, which renders the “Green Transition” an uncertain landscape of environmental futures.

The Global Wind Energy Infrastructure Model as Elemental Media Assemblage

“The elemental” describes dynamic and processual fundamental compositional substances and substrates, ecological conditions, and media itself (Starosielski 2019) that cross ontological, epistemological, aesthetic, and

ethico-political concerns (Engelmann and McCormack 2021). As moving air, wind is an elemental figuration that could be described with the loose and overlapping orientations of “matter,” “molecule,” “milieu,” and “media” (Engelmann and McCormack 2021). Wind is a body or a substance of “matter” as it exists as a physical force that has a directional and spatial presence as well as material impact. It is the difference in movement between heated air molecules and colder air molecules. It is “milieu” as an inextricable part of the “open world” (Ingold 2007)—an immersive flux identified as part of “weather” that “mingles” (with) and envelops the environmental conditions of biological life, such as light, moisture, and earth. It is also a “medium” enabling the transformation of states of matter (i.e., in the case of cloud formations that eventually transform into rain) and the movement of bodies and other elements in and through itself, such as water droplets and pollen. Wind’s multifaceted and protean identity is reflected in its applicability to all the elemental orientations and its ability to shift between and exceed them.

These elemental orientations are starting points to consider how wind becomes made and promoted as “renewable energy.” Wind’s capacity for moving humans and nonhumans as a medium of forceful matter makes it a form of elemental “infrastructure,” especially as consistent planetary-scale circulatory wind patterns such as the trade winds, which have traditionally been used as natural transportation and communication channels. Defined as “large, force-amplifying systems that connect people and institutions across large scales of space and time” (Edwards, quoted in Peters 2015, 31), “infrastructure” is more commonly associated with “hard” human-centric physical, technological, and logistical systems such as roads and cables, and their “soft” discursive forms such as plans and protocols. Wind exemplifies “infrastructure” as elemental milieu systems: these systems are ontological “containers of possibility” (Peters 2015, 2) and “spatial arrangements of relationships that draw humans, things, words, and nonhumans into patterned conjunctures” (Murphy, quoted in Watts 2019, 17).

Wind energy production draws upon wind’s ontological infrastructural qualities and transduces them through apparatuses of environmental data. Wind’s movements are harnessed for wind energy production through the design of technoscientific apparatuses, such as the wind turbine, which extract wind as electron as the key universal component of electrical power. As Cara New Daggett (2019) explains, the Western concept of “energy” can be traced back to mid-nineteenth- to twentieth-century developments in thermodynamics and their applications to the employment of fossil fuels (i.e., coal) to the steam engine, which is channelled into producing work. “Wind energy” is a contemporary figuration that relates the capacity to do work with the generation of electricity produced primarily through the forceful impact of wind on the rotor blades of the wind turbine.

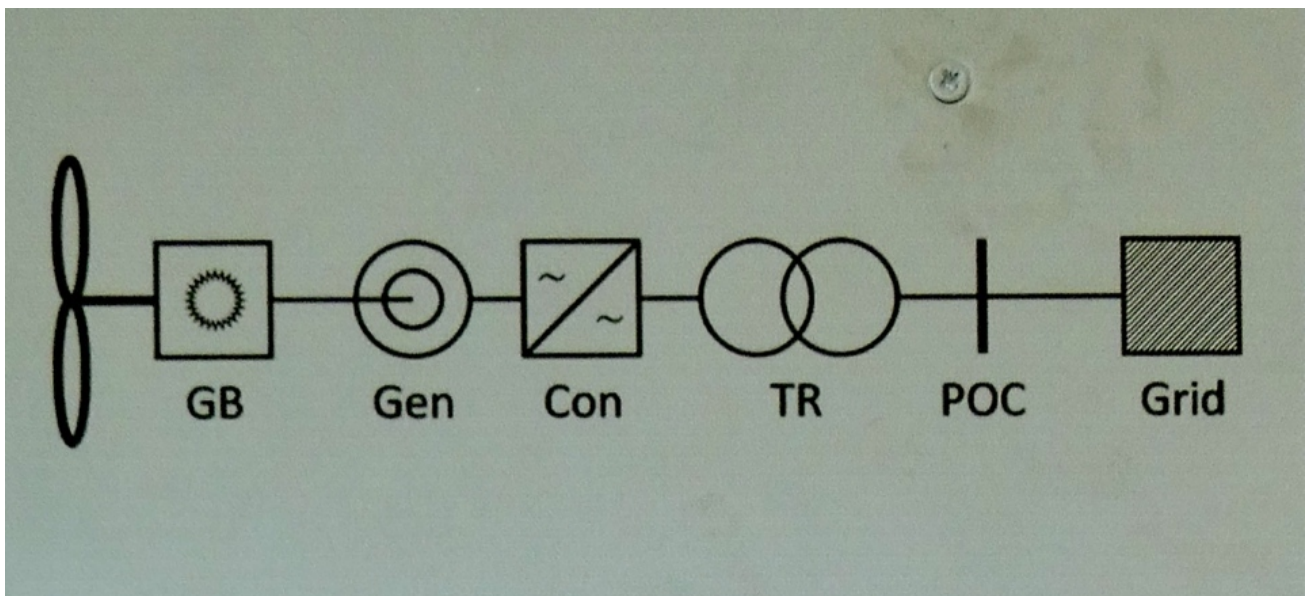


Figure 1. Image from Østerild Wind Turbine Test Center visitor exhibit on the processual chain of infrastructural components that transduce wind into wind energy (i.e., Wind Turbine Rotor – Gear Box (GB) – Generator (Gen) – Power Converter (Con) – Transformer (TR) – Point of Connection (POC) – Grid). Photograph by May Ee Wong.

In general terms, the kinetic energy of the spinning rotor is transduced into electrical energy in a generator that is eventually transmitted as electricity to the electrical grid ([figure 1](#)). As electricity is generated from the movement of electrons between atoms, wind becomes the planet-wide, geographically indeterminate source of electrons that is promoted as “abundant” and “inexhaustible” (“Advantages and Challenges of Wind Energy,” n.d.) as compared to the finite resources of fossil fuels.

Wind is being promoted by the global wind energy industry as an open “elemental commons” (McCormack 2018) from which electrons are prospected; in the words of Peter Jørgensen, the former head of Danish Transmission Service Operator (TSO) Energinet: “[e]lectrons do not respect national borders” (Safarkhanlou 2009, 21). However, the efficiency of the extraction apparatus—that is, the wind turbine—and its siting also determine the amount of electrons that one is able to “harvest” from the wind. The “optimum” production of electrons from wind energy depends on the enveloping and changing weather conditions of the geographical site as well as the design of the wind turbine, which includes control of its components such as the yaw. The interaction of these factors is projected and monitored through various apparatuses of modeling, which include technoscientific wind modeling software based on computational fluid dynamics (CFD) (Parikka, forthcoming), wind turbine testing sites, and wind atlases; I discuss the last two in this article as modeling apparatuses of landscape that produce the environmental data grist for the wind energy software simulation mill. Wind energy production would also not be possible without the unseen “Herculean efforts of grid engineers and load managers” (Watts 2019, 30), who set up and manage lengthy high-voltage cables to enable the

transportation of electrons from offshore regions to more central urban populated areas. They are one part of the larger electrical infrastructure, which includes an economically viable electricity market, immense financial resources to cover the cables' installation and maintenance costs, and geopolitical agreements that allow the cables to be physically installed in their sited locations as conduits of electricity, especially across countries.

Due to the milieu-specific (Jue 2020; Starosielski 2019), invisible, and fluctuating state of the wind, much of the visibility, extractability, and epistemic stability of wind energy is derived from wind's contact or contrast with visible and material forms of earth (or land) and/or water, as well as the operational aesthetics of electrical infrastructure, especially the grid, which is based on metonymic part-whole associations with its transduced outputs (Gerson 2022; Lieberman 2017). In metonymy, parts or associated aspects stand in or are substituted for wholes—that is, electricity is substituted by “power,” “current,” and “lights,” with interfacing devices such as electricity meters substituted for the larger power grid (Gerson 2022). Wind's presence is known only through its contact with surfaces and sensible impact on bodies and material substances. Unlike elemental media such as water and earth, its presence is always visibly mediated by traces of its contact with and through other forms of media. Wind energy is thus territorialized through physical forms of infrastructure, “grounded” spatial tropes, and landscapes, as well as digital (numeric) data registered through material locational sensors. It is now more speculatively projected as hydrogen, a future fuel derivative of the electricity that would be produced through the “Power-to-X” capacity of the Energy Island.

As Sage Gerson argues (2022, 7), metonymy is a mode of analysis that surfaces the sociopolitical power relations between the visible and invisible components of an infrastructural system, the totality of which exceeds our visualization (Parks 2015, 356). The visibility and invisibility of infrastructural components are contingent on the attention that we direct to them, which is partial and situational in terms of space and power (Gerson 2022, 5). Adding to Gerson, I argue that the metonymic visibility and invisibility of wind energy infrastructural components enable the epistemic and speculative territorialization as well as deterritorialization of the wind as environmental data. This territorialization and deterritorialization of wind as data is enacted through the strategic projection and displacement of spatial boundaries and geographical situatedness, which extends the infrastructural scope of wind power across various scales. Wind is deterritorialized through discursive techniques that exploit its invisibility and smooth and stabilize its fluctuations. As the presence and impact of the wind can only be estimated from its contact with surfaces, wind energy is calculated and extrapolated through the abstracting use of “immutable mobile” (Latour 1986) graphical and mapping devices and mathematical models that retain their form while applied to different geographical locations through digital platforms. Images

and graphs function as infrastructure in terms of “operational images” (Parikka 2023) that play an organizational and logistical role in wind energy production and promotion instead of a representational one.

Wind energy thus has to be thought of in terms of wind as elemental life being “reduced as a medium” and understood as “being in, and becoming with, the technological world, our emergence and ways of intra-acting with it, as well as the acts and processes of temporarily stabilizing the world into media, agents, relations and networks” (Kember and Zylinska 2014, xv). Sarah Kember and Joanna Zylinska argue that mediation is such that “the virtual does not substitute the real but rather produces it” (40). This is especially the case for wind energy in relation to its epistemic status and value, which performatively emerge from its circulation as forms of media, especially in the form of organizing images and numerical values, through different platforms that contribute to its further speculation. I now explain the Danish Energy Island and the “State of Green” Danish wind value chain infographic as examples of the Danish global wind energy infrastructural model as elemental media assemblage that display the metonymic (de)territorializing logics of environmental data in their projections.

The Metonymic (De)territorializing Logics of Wind Energy Infrastructure as “Island”

Expected to span at least 120,000 square meters and to provide three million Danish households with electricity in its first phase of development (“Denmark Decides to Construct the World’s First Windenergy Hub as an Artificial Island in the North Sea” 2021), the Energy Island, or the *energiø*, is an offshore wind energy connecting hub that is partly recognized as critical infrastructure. Targeted for completion in 2030 (“Energy Island in the North Sea” 2021), it follows the vision set out in 2016 by the Dutch-German TSO TenneT for the North Sea Wind Power Hub to connect various offshore wind farms located in the North Sea (“North Sea Wind Power Hub,” n.d.) through a power “highway” (“A Blueprint for the New Energy Highways | North Sea Wind Power Hub,” n.d.) of interconnected and integrated electricity grids between the surrounding countries. The Danish Ministry of Energy and Energinet have initiated market dialogues and invited tendering bids from private company consortia for the construction and investment in these Energy Islands. These consortia consist of a combination of Danish and multinational conglomerates, namely Danish pension fund companies, energy companies, and digital infrastructure companies as well as infrastructure engineering companies.²

² Two such examples of Energy Island consortia include VindØ and the North Sea Energy Island. The VindØ consortium is formed from Denmark’s two largest pension funds, Pension Denmark and PFA Danish energy, the distribution company Andel, the Danish-based international infrastructure contractor Copenhagen Infrastructure Partners, and the Danish-based international engineering and architecture consultancy COWI (“VindØ – The World’s First Energy Island,” n.d.). The North Sea Energy Island consortium is constituted by Danish

Although it is being described as an ambitious, unprecedented innovation, the Energy Island scales up and reconfigures many existing operational concepts pertaining to offshore wind energy technology, petroleum- and shipping-related infrastructures, and artificial islands. It is presented in Energinet media as a platform that might take the form of a jacket or gravity-based structure, caisson, or sand structure (Energinet 2020),³ depending on its location. Its construction follows an existing protocol of offshore wind farm development for which the Danish government and its various wind power-related companies claim international expertise and experience. As Energinet's director for the Energy Islands Hanne Storm Edlefsen explains, "there is no need for a lot of technological new findings and not those [*sic*] big differences between new regulation, etc." (Global Wind Energy Council 2020). What is new with respect to the Energy Island are its projected capacity to transmit electricity between the grids of different countries and its "Power-to-X" potential: the electricity generated from renewable sources would produce hydrogen (and other fuels) that would function as a clean fuel replacing fossil fuels.

The Energy Island prototype demonstrates how wind energy itself is discursively conceived and produced through various media in the form of policy, visual design, and technoscientific modeling, which function as an assemblage of discrete "immutable mobiles" (Latour 1986). Declared as an official project in the Danish Climate Agreement for Energy and Industry 2020,⁴ the Energy Island currently consists of infrastructural technical and planning images and discourses: proposed architectural designs of the Energy Island as part of consortium bids,⁵ a promotional video that features the documentation of the mapping of the seabed of the proposed Energy Island⁶ and data reports from preliminary site investigations,⁷ and maps of the proposed sites of the two future Energy Islands ([figure 2a](#) and [figure 2b](#)). While maps of the seabed determine where safe foundations for the energy island could be laid, maps of the potential site of the energy island also serve as "grounding" technoscientific schemas that establish the atmosphere as a stable empty catchment space for the offshore wind turbines that would be connected to it.

multinational energy company Ørsted, ATP, Denmark's largest pension and processing company, the Danish infrastructure specialist Aarsleff, the French international infrastructure engineering company Bouygues Construction, the Dutch marine contractor Van Oord, the multinational design company Arup, and GlobalConnect, a Northern European digital infrastructure company ("North Sea Energy Island," n.d.).

3 A video depicting this is viewable at <https://en.energinet.dk/Infrastructure-Projects/Energy-Islands/Visuals>.

4 The Overview to the Danish Climate Agreement for Energy and Industry 2020 can be accessed here: [https://en.kefm.dk/Media/C/B/faktaark-klimaaftale \(English august 14\).pdf](https://en.kefm.dk/Media/C/B/faktaark-klimaaftale%20(English%20august%2014).pdf).

5 See VindØ (<https://www.windisland.dk/>) as an example.

6 The video is accessible here: "First ship to the energy island," <https://vimeo.com/546342531>.

7 "Preliminary site investigations for the Energy Islands" (<https://ens.dk/en/our-responsibilities/offshore-wind-power/preliminary-site-investigations-energy-islands>).

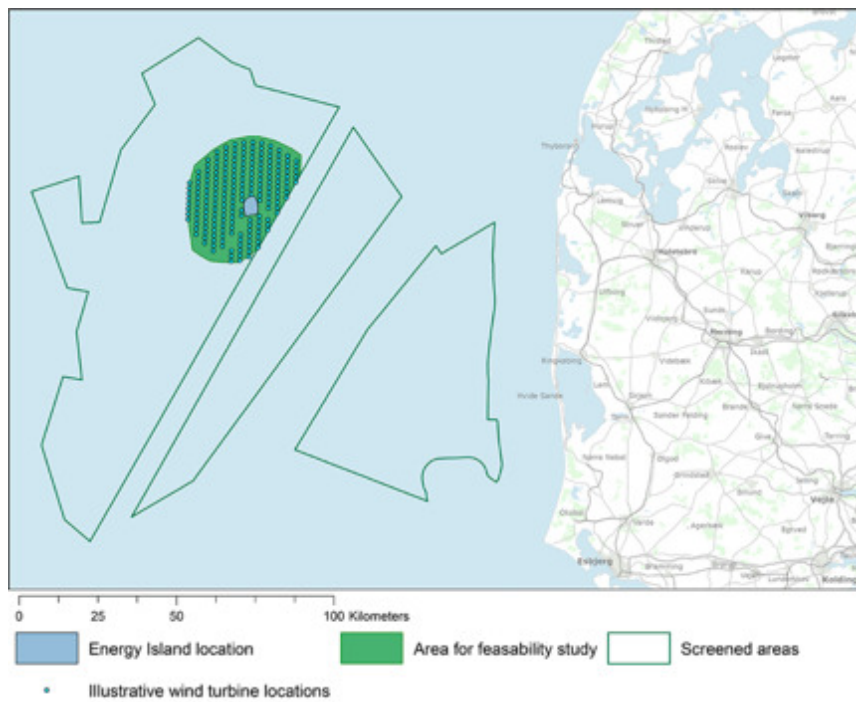


Figure 2a. Map of the location of the prospective Energy Island in the North Sea off the western coast of Jutland. Image downloaded from “The energy island in the North Sea” from the Danish Energy Agency website (<https://ens.dk/en/our-responsibilities/energy-islands/denmarks-energy-islands>).



Figure 2b. Map of the location of the prospective Energy Island in the Baltic Sea off Bornholm. Image downloaded from “The Energy Island in the Baltic Sea” from the Danish Energy Agency website (<https://ens.dk/en/our-responsibilities/energy-islands/denmarks-energy-islands>).

These schemas follow existing apparatuses of vertical territorialization that exploit the invisibility of the atmosphere to create zonal civil airspace from the demarcation of nation-state boundaries on the ground and in the sea (Lin 2018, 40).

These mappings are one visible metonymic part of a larger operational infrastructural assemblage featuring various sectors and actors of the wind energy supply chain whose activities are often not visibly apparent in popular media or to the public. Besides national government energy departments, TSOs, energy renewable companies, and infrastructural contractors, these actors sprawl across multinational conglomerations of consultancy firms that provide services such as wind power assessments, the modeling of wind turbine construction and grid connections, and the testing of equipment as well as the simulation of operations. These actors also include technology firms such as HVDC power cable providers and wind turbine producers, and ports that offer offshore wind-related infrastructure, facilities, and services. The infrastructural whole of the wind energy supply chain is collectively figured from a combination of these several parts, which is exemplified in “turnkey solutions” for wind energy. Categorically, “turnkey” describes a project or an installation that the client can use immediately after its completion. In the case of the wind energy “turnkey solution,” engineering procurement and construction procedures establish the multiple phases of installing the wind turbine as a complete process for ready operational use: from the surveying and clearing of the site for the construction of the wind turbine foundation to the laying of its cables.⁸

Even though the material design of the energy island has yet to be decided, Energinet’s naming of the energy hub prototype as “Energy Island” reflects how the spatial figure of the island functions as an epistemically territorializing mechanism for wind energy. The visualization of the wind value chain as an island ([figure 3](#)), as published on the website “Green Value Chains” by State of Green, a public promotional platform between the Danish government and the Confederation of Danish Industry, Green Power Denmark, and the Danish Agriculture and Food Council (“State of Green Value Chains” 2023), exemplifies this further by logistically functioning as a graphical organizer of the wind energy supply chain as a turnkey solution, which includes the prospective energy hub as a part of the chain. An interactive mode of promoting Danish wind energy industry expertise to the rest of the world, the “island” model visually organizes information on the different sectors of the wind value chain through the spatial juxtaposition of metonymic representations of these different sectors. It also evokes the cultural assumption (Gray et al. 2016) of the experimental “island” as a device to communicate to the viewer a total view of the technical production of wind energy.

⁸ An example of the wind energy turnkey concept is on the Stenger and Ibsen company website: <https://si-construction.com/about-sic/turnkey-concept/>.



Figure 3. Visualization of the Danish wind value chain published by State of Green (<https://www.greenvaluechains.com/event/#/wind/>). Screen capture by May Ee Wong.

The “island” wind value chain visualization anchors our attention to the figure of the island as a bounded technoscientific imaginary landscape of replicable modularity and self-sufficient containment. The defined edges of the “island” serve as discernible boundaries containing the whole infrastructure system or the boundary that an offshore entity could be measured from and placed in relation to. The “island” embodies a landform that demonstrates the terrestrial bias (Jue 2020, 11; Elden 2013; Schmitt 2003) that dominates Western thought and conceptions of space. In the context of offshore wind energy, the figural preoccupation with the “ground” of the island offsets a focus on the extended cyclical interaction between the dominant elemental realms of air and water. As a “visibly discrete object” for scientific experimentation (MacArthur and Wilson 1967, quoted in Gugganig and Klimburg-Witjes 2021), the island has functioned as the production site of scientific knowledge regimes (Gugganig and Klimburg-Witjes 2021, 324) and is more recently projected as a test bed for new technologies and policies (Watts 2019; Halpern and Mitchell 2023; Günel 2019).

The wind value chain visualization is a dynamic diagram featuring a singular floating island landmass that dominates the center of a rotating three-dimensional circular disc displaying the cross-section of sea. A mountain dotted with wind turbines and houses sits in the heart of the island, with a highway built around its contours that connects to various peripheral edges of the island siting different industrial activities pertaining to the different sectors and processes of the value chain. Offshore wind turbines

are also placed at the edges of the disc itself, indicating the operational boundaries of the wind energy system. As the disc rotates, hyperlinked labels indicating the different processes of the value chain, such as “Project Site and Preparation,” “Component Production,” “Installation,” “Post-Installation,” “Decommissioning and Afterlife,” and “R&D” move into the middle of the visualization, inviting the audience to click the label and zoom into the area in focus.

Although the visualization is an imaginary figural representation of the entire wind value chain, it has a performative epistemic role that “orders the world by calling it into being” (Van Loon, quoted in Kember and Zylinska 2014, 40) by enabling the viewer to understand the infrastructural components individually in themselves, in relation to each other, and the wind value chain as a territorial material whole. The speculative existence of the energy hub is infrastructurally and metonymically “grounded” and integrated as an offshore component of the entire wind value chain, which has been spatialized as a geological island. Each component depicted in the visualization is simultaneously indexical as it refers to the infrastructural sector/process and metonymic by standing in for the broader object category that is referenced. In this visualization, under the label of “Installation,” the yet-to-be-built energy island appears as the “energy hub,” a small three-hub structure lying on the distant horizon in line with thin offshore wind turbines. The viewer is presented with a detailed view of the island as positioned in the foreground, with the energy hub and offshore wind turbines at a perpendicular distance, facing the island’s coast. As an offshore structure visibly located in the water, the energy hub also serves as a metonym for wind infrastructure installation. Both “energy-hub-as-energy-island” and “wind-value-chain-as-island” figures separately reflect and reinforce, at different scales, the terrestrial bias that lends the energy island (or energy hub as island), and hence wind energy, elemental legibility and material stability.

The digitally visualized island projects the Danish wind value chain as a global turnkey apparatus by presenting the island as a singular whole entity and as a geographically indistinct landmass. As an indexical graphic, the visualization embodies wind energy infrastructure as digital environmental data and contextualizes the speculative energy island as part of Denmark’s existing physical and material wind energy infrastructural sites and processes, using sparse animations of rotating wind turbine blades and lines to indicate the presence of wind. While the metonymic character of the island visualization makes wind energy visible through its model terrestrial form, its geographically indistinct global character also deterritorializes it and suggests the replicability of its various components to any coastal area.

Indeed, as State of Green reports, the Danish government and various Danish multinational infrastructural firms have signed memorandums of understanding with various governments of other countries to survey and

develop their offshore wind and renewable energy potential. In 2021 the Danish Ministry of Climate, Energy and Utilities and the Indian Ministry of Power launched a Centre of Excellence for Offshore Wind and Renewable Energy, which would accelerate the development of a turnkey 3GW wind turbine project modeled after the Danish Østerild Wind Turbine test center,⁹ which is an international public showcase of wind power expertise in the Danish wind energy value chain. A model landscape that stands out as a test “island” in the middle of thick forest, Østerild Wind Turbine test center demonstrates how wind energy operations rely on the elemental stability of land to capture and extrapolate wind as energy resource. It also reflects how wind energy becomes abstracted into “enumerated entities” (Verran 2015) of measure and value circulated between landscapes, platforms, and markets that contribute to and extend wind energy’s speculative dynamics.

Model Landscapes of Wind Power

Established in 2012 and run by the Department of Wind and Energy Systems of the Technical University of Denmark (DTU), Østerild Wind Turbine test center projects Danish wind infrastructure expertise as the site where multinational wind turbine manufacturer conglomerates install and test new wind turbine prototypes; these include some of the largest wind turbines in the world. It also hosts a visitors’ center, opened in 2017 as a site of energy tourism (Winthereik et al. 2019), that features explanatory exhibits on the principles and mechanics of wind power. Denmark is a country with its largest landmasses bordered by the North Sea and the Baltic Sea ([figure 4](#)). With mostly flat terrain used for industrial agriculture, it regularly experiences strong winds. The wind turbine test center is located in the countryside of western Jutland and approximately 20 kilometers away from the North Sea; it sits off a lone road running across Thy, one of the windiest districts in Denmark.¹⁰ Once occupied by heather and sand dunes in the eighteenth century, it is now a flat grassy area that is physically unobstructed by other buildings or installations but is otherwise surrounded by forest.

The standardized layout of the physical site emphasizes its deterritorializing capacity to produce consistent test results that are applicable to wind turbines installed at other places, while capitalizing on its exceptional geographical location, which has “optimum” wind conditions. The test center promotes itself as having access to stable westerly winds and as located in “Europe’s

⁹ The planned Wind Turbine test center modeled after Østerild is called Dhanushkodi National Offshore Wind Test Center. The March 2021 report “Østerild Test Center: Lessons Learned in Setting up a Wind Test Center for Offshore Wind Energy,” prepared by DTU Wind Energy and the Danish Energy Agency, is accessible here: <https://coe-osw.org/wp-content/uploads/2021/04/Report-on-Osterild-Test-Centre-Lessons-Learned-final-December-m.-forside-v-2.pdf>. Other examples of international agreements on Danish wind energy expertise include Danish wind power investment firm Copenhagen Infrastructural Partners’ agreement with the mayor of Barranquilla to develop Colombia’s first offshore wind project (“Offshore Wind Outside Barranquilla - Potential First Offshore Wind Project in Colombia and Latin America” 2022), as well as the Danish TSO Energinet agreement with the Chinese TSO, State of Grid Corporation of China to integrate 1000 GW of variable renewable energy in 2030 (“New Cooperation Agreement Strengthens Sino-Danish Green Partnership” 2022).

¹⁰ My field visit was conducted at Østerild Wind Turbine Test Center on 17 May 2023.

best wind field,” with the average wind speed of the site quantified as being “significantly higher” than the average wind speed needed for the testing of wind turbines (“Testcentret”).



Figure 4. Physical features of Denmark. *Encyclopædia Britannica*, <https://www.britannica.com/place/Denmark#/media/1/157748/62456>. By courtesy of Encyclopædia Britannica, Inc., copyright 2002; used with permission.

The test center site holds up to nine wind turbines, which are arranged in a straight line oriented to face the predominant wind direction ([figure 5a and 5b](#)). Each wind turbine occupies a testing stand or a cleared area surrounded by cranes and scaffolding structures separated from each other by 600 meters, with a meteorological mast placed 500 meters in front of it to record wind speeds.¹¹ The test operations at the site illustrate how wind is abstracted into discrete circulatable environmental data: sensors are installed with cranes into parts of the wind turbine, such as the blade, and in the tower. These remotely transmit various data on wind turbine load factors to wind turbine manufacturer staff onsite and offsite as well as DTU engineers located over 300 kilometers away in Roskilde. Once the wind turbine prototype components are fully tested, these components are dismantled, transported, and reinstalled in another location. Their dimensions are subsequently used to produce wind turbines of the same model, which are permanently installed on both land and offshore sites.

¹¹ Østerild Wind Turbine Test Center is featured in the first two minutes and fifteen seconds of the “360° Tour – Test Sites for Wind Turbines” video produced by State of Green: <https://stateofgreen.com/en/news/new-danish-test-centre-to-install-450-meter-high-wind-turbines/#video>.

The Østerild Wind Turbine Test Center epitomizes how wind energy production depends on geographical factors that are captured and communicated as environmental data, processed and subsumed through mathematical/statistical models, and recursively applied to the design of the test site and the turbines.



Figure 5a. Pedestrian view entering Østerild Wind Turbine Test Center. Figure 5b. Map of the site of Østerild Wind Turbine Test Center taken from exhibit in the Visitor Center. Photographs by May Ee Wong.

Statistical models, such as the Weibull distribution, a continuous probability distribution that is used to measure and analyze the reliability or the risk of failure of a certain product, help to smooth and stabilize data fluctuations between readings. Wind turbine testing can be sited only on land for measurements and adjustments to be made to the sensors.¹² The testing landscape is also specifically designed to (re)create “the proper turbulence and roughness in (the) wind turbine’s field,”¹³ which are abstract factors related to fluctuations in wind velocity and surface area texture, respectively, that help determine the wind conditions at a particular site.

Østerild Wind Turbine Test Center physically operationalizes the Danish wind turbine siting apparatus of wind atlases that generalize topographical factors into statistical values to determine the amount of wind energy that would be produced at a particular location. Wind atlases are programs that facilitate the transduction of wind into economic wind resource by mapping the frequency distribution (or the probability density distribution) of the

¹² This is generally true for large wind energy infrastructure installations.

¹³ This information is derived from one of the visitors’ center exhibits.

wind at a given height over a given specified terrain, to determine the average energy production a wind turbine would produce at a location. They codify the topography of locations into “terrain types” and “roughness classes” to calculate wind power production, with the “roughness” determined by the size and distribution of elements that cause friction within a particular surface area, such as vegetation (Lundtang Petersen and Ib 1989, 56). Denmark’s first wind atlas, *Wind Atlas for Denmark*, was published in 1980 following public concerns over the profitability of local wind turbines that would affect wind power’s economic viability as a national power source (Lundtang Petersen et al. 1980, 194–95). Consequently, the *European Wind Atlas* was commissioned by the European Community as a tool to promote the use of wind energy in Europe. This atlas used different mathematical models (Hvidtfelt 2001, 201) that took into account the physical effect of terrain to transform and extrapolate local wind speed data registered from over two hundred meteorological stations in Europe to project a generalized climate across the region (Lundtang Petersen and Ib 1989, 7), which would be used to determine the wind resources at a particular site. From 2015, together with the World Bank Group, the DTU Wind Energy Department has also produced the Global Wind Atlas,¹⁴ a web-based wind atlas that makes wind maps at various scales such as the global, country, and state/province unit accessible for policymakers, planners, and investors to identify “potential high-wind resource sites” around the world.

These model apparatuses operationalize the communication of wind energy as measure, value, and thus resource, in the form of what Helen Verran terms as “enumerated entities,” numbers or values that routinely perform established relations within and between measurable dimensions enabling correlations to be made between the past and future for predictions (Verran 2015, 368) across geographical scales. Wind energy is organized as an exchangeable value through the transduction of data as enumerated entities that circulate in media environments of empirical, statistical, financial, and governance platforms and contexts. The energy trading market is a complex networked platform of data apparatuses that gathers operations of financial speculation, weather prediction, and wind turbine control. These apparatuses are utilized by different actors to stabilize wind energy’s fluctuations; at the same time, they also set up the conditions of possibility for what Kember and Zylinska (2014, xvii) term “liveness,” or the emergence of new forms, as well as unanticipated connections and events, especially as interfaces of environmental events. Wind power is traded as a physical commodity or as virtual future output through power exchange platforms (i.e., for the Nordic countries, Nord Pool), where wind power producers pitch the lowest possible

¹⁴ See “Global Wind Atlas,” <https://globalwindatlas.info/en>.

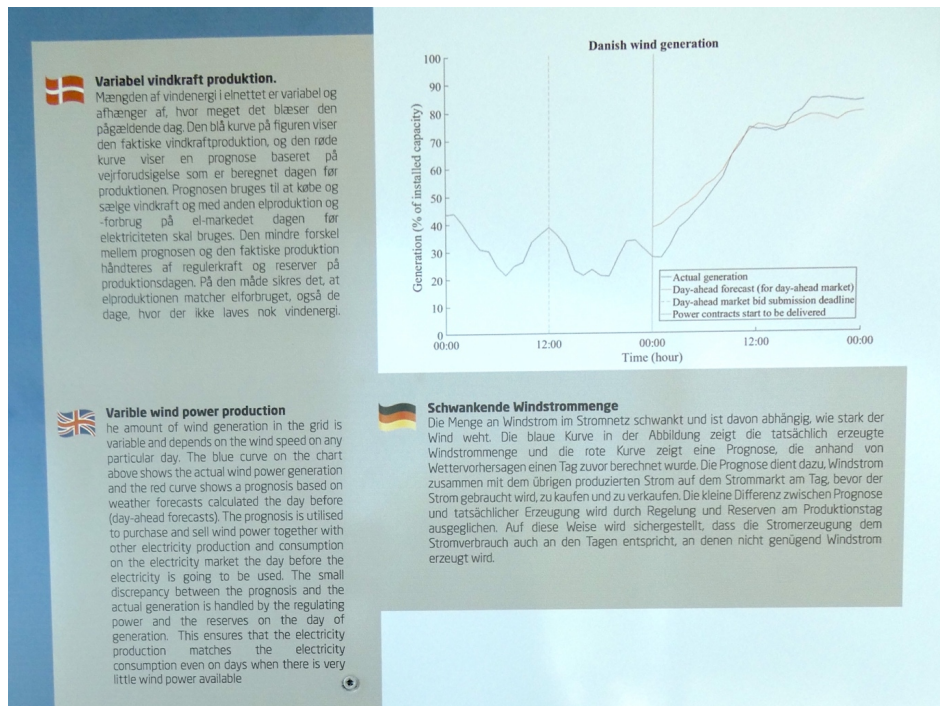


Figure 6. Image from Østerild Wind Turbine Test Center exhibit on “Variable wind power production.” Photograph by May Ee Wong.

market prices under contracts of varying time intervals (i.e., one day ahead, hour to hour, five-minute contracts) based on estimations of wind-generated electricity supply to meet consumer electricity demand (figure 6).

The ready availability of wind energy and its values are collectively projected by different actors who use numbers as securitizing and coordinating devices across data platforms to control the physical fluctuations of wind energy and electrical production and their effects over scales of space and time. Fixed-term prices and futures derivative prices are used as a preemptive means of establishing predetermined monetary values on unpredictable wind power output, alongside local and more immediately responsive calibrations of energy production. TSOs monitor the daily population energy consumption statistics from a control center, consult real-time weather forecasts from the day before, and calibrate wind power production from any deviation from the forecasts through calculation. Wind power production is subsequently regulated upward or downward by TSO balance supervisors who communicate information about the state of wind power supply (e.g., extra power produced) through the exchange market (Safarkhanlou 2009, 14–15). This information serves as signals of incentivization or de-incentivization to wind power producers to influence subsequent electricity production.

Even with the securitization of fixed price points, the collective interactions of the energy market engender different forms of risk for the producers and consumers and create their own emergent landscape of changing value. Moreover, wind energy prices shift according to the impact of long-term and intermittent global and regional environmental, geopolitical, and financial

developments and sudden crises. Even the mechanisms of the energy market are unable to mitigate the more extreme and unpredictable planetary weather patterns induced by climate change, which transform the milieu; these planetary weather patterns have been projected to cause “a significant, generalised decline in wind resources, particularly in the mid-latitudes of the Northern Hemisphere... which encompass the largest markets for wind energy” (Martinez and Iglesias 2024, 7). Denmark itself was subjected to one of its sunniest and driest summers in 2018, which led to Østerild’s turbine blades slowing down to a halt (Højlund and Riis 2020, 90).

In the case of the developments of the prospective Danish energy island, the shifting governmental discourse surrounding the energy hub prototype reflected the impact of the 2022 Russian invasion of Ukraine. In 2020 the Danish government’s announcement of the Energy Island followed the prevailing trend pushing for a global “Green Transition” toward renewable energy, with “Power-to-X” as a potential technical feature of the Energy Island. But after the advent of Russia’s invasion of Ukraine, the Energy Island was promoted as an urgent securitizing solution to the ensuing European energy crisis. This was declared through political agreements signed by Denmark and various European countries, such as the May 2022 Esbjerg Declaration, which stated the agenda of developing the North Sea as a “Green Power Plant of Europe” to replace Russian oil, coal, and gas through “multiple connected offshore energy projects and hubs, offshore wind production at massive scale as well as electricity and green hydrogen interconnectors.”¹⁵ While the Russian invasion was deemed as sudden, it surfaced underlying energy security tensions and conflicts between Russia and various European countries that have existed since the official end of the Cold War.

Despite the political momentum generated by the regional geopolitical crisis, in June 2023 the Danish government decided to postpone the invitation for tenders for constructing the North Sea energy island as it decided that “an artificial island owned by a public-private partnership [would] likely be too expensive and risky for the State” (“Energinet Must Investigate Whether the North Sea Energy Island Can Be Erected on Platforms,” n.d.). The Danish government’s budget considerations have resulted in the indefinite stalling of the North Sea energy island’s development. But that has not stopped consultancies from producing proposals on the energy island, such as COWI and Brinkman’s concept plan for the energy island to become a system-integrated energy island for production and transportation of hydrogen

15 The Esbjerg Declaration is accessible here: "[https://www.kefm.dk/Media/637884617580584404/The_Esbjerg_Declaration_\(002\).pdf](https://www.kefm.dk/Media/637884617580584404/The_Esbjerg_Declaration_(002).pdf)."

instead of electricity to become cost-effective.¹⁶ Although the energy island has yet to physically materialize, its existence continues to evolve in speculative forms of environmental data.

Conclusion: Wind Energy as Speculative Milieu

In this article, I have engaged in an elemental analysis of wind as a stable renewable energy resource as projected through apparatuses of the Danish global wind energy infrastructural model. In analyzing the prospective Danish energy island, the State of Green “island” visualization, the Østerild Wind Turbine Test Center, and wind atlases as parts of the infrastructural model, I have argued that the Danish global wind energy infrastructural model relies on the part-whole substitutive logics of metonymy as strategic modes of territorialization and deterritorialization that are enacted through the extraction, extrapolation, and application of environmental data. As wind fluctuations become “grounded” through territorializing media and incorporated into statistical probability, wind’s variability becomes invisible, especially when wind energy production is scaled up with the overplanting of multiple wind turbines and increased wind turbine capacity. Wind energy is created as a stable planetary resource from the coherence of images and numbers circulated between platforms and landscapes as environmental data. Its articulation as value emerges from the constant negotiation between projecting long-term climate patterns, energy use (of wind, also in relation to other forms of energy),¹⁷ and energy market patterns, as well as responding to intermittent changes or sudden crises at more local and regional levels.

Instead of identifying wind energy as isolated through physical infrastructural components, I have explained how wind energy draws its definitional stability from in/visible performative configurations of environmental data such as landscapes and numbers, which are circulated, subsumed, and replicated through various material and digital platforms. In doing so, I also draw attention to the ontological and epistemic instability inherent in various wind energy infrastructural processes that emerges from managing the wind itself. While the technoscientific apparatuses of wind energy are designed to produce the optimum amount of electrical energy from the wind, the elemental nature of the wind affirms that its full capture as matter, molecule, milieu, and medium is impossible. We can know wind only through modes of speculation. On closer examination of its apparatuses, wind energy needs to be considered as a dynamic, speculative milieu rather than a stable infrastructure that is subjected to the pressures of external forces. An

¹⁶ “Energy Islands: Danish Energy Islands and the Realization of the North Sea’s Energy Potential,” <https://www.cowi.com/media/qcqpka/m/cowi-brinckmann-energy-islands-english-version.pdf>.

¹⁷ It is worth noting that although wind energy produces over 40 percent of Denmark’s electricity today, more than two-thirds of Denmark’s renewable energy is supplied through bioenergy sources (“Facts about Bioenergy in Denmark” 2017) with its energy supplies supported by hydroelectric power imported from Norway and Sweden.

elemental analysis of wind energy thus invites us to consider apparatuses of financial and geopolitical speculation as part of an epistemically speculative and processual media milieu rather than discrete economic and political factors acting on wind energy infrastructure.

This elemental approach has implications for how we understand the technology-driven “Green [Energy] Transition,” which promotes renewable energy sources as the “abundant” and, hence, better alternatives to fossil fuels. It sheds light on how the promises of renewable energy infrastructure mobilize metonymic logics to suggest the direct and neat substitution of fossil fuel-free energy sources (and their derivatives) for our current fossil fuels. It also reminds us of how renewable energy results from the interaction of different elements that are present and inextricable from the planetary milieu, which is ever-changing, even as they are extracted, transduced, and stabilized for storage and distribution. Instead of an energy infrastructural revolution for sustainable growth, the “Green Transition” should be considered as an uncertain landscape of environmental futures.

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