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- **A call to historicize wind and site studies,**
  Rémi Gandoin
- **Réponse à "A call to historicize wind and site studies",**
  Matthias Heymann

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A call to historicize wind and site studies

Résumé
Cet article appelle les historiens à inclure les études sur le vent et les sites dans leurs investigations relatives à l'énergie éolienne. Il fournit un certain nombre d'éléments intrinsèques et extrinsèques sur ces études qui pourraient faire l'objet de recherches plus poussées dans un contexte académique. Du design des turbines éoliennes à la perception par le public des renouvelables, ces sujets importent à l'heure où l'on tente de rendre nos sociétés plus adaptées aux énergies non-fossiles, intermittentes mais illimitées. La vaste majorité des documents mentionnés ici sont accessibles en ligne, notamment sur le site web de l'auteur: aeolians.net.

JEHRHE a invité Matthias Heymann, historien spécialiste de l'énergie éolienne, à commenter ce texte.

Remerciements
It appeared after a pleasant discussion with the editors that my considerations were relevant to the Journal of Energy History. I would like to thank them for reviewing this article and giving me the opportunity to publish it. In addition, I would also like to thank Matthias Heymann for his inspiring work and his comment on the present "interpellation".

Plan de l'article

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Katsushika Hokusai (1760–1849), Ejiri in Suruga Province, circa 1830 for the first publication (here circa 1930). Wikimedia Commons.

CONTEXT

1 I have been working as an engineer in the wind industry for about ten years, first with onshore wind and for the last seven years almost only with offshore wind projects. My specialty is the study of wind, waves and other site conditions, in relation with the design of wind farms (the design of foundations and substructures, turbine layouts, the analysis of expected and achieved production-, wind- and metocean measurements). It is referred to commonly as "wind and site assessment studies", or in short "wind and site studies", but other denominations exist.[1]

2 For the past three years, I have been collecting documents and testimonies from the last decades, aiming at sketching the contours and boundaries of my field of expertise. I am gathering very concrete and detailed studies from the past, highlighting their context within the wider history of wind energy on a website: aeolians.net. This approach provides a factual basis for identifying the boundaries of my discipline, which interfaces with several other fields of engineering and science (meteorology, turbine design, project development and spatial planning, marine industry, energy policy, etc).

3 From a wider perspective, this project allows me to think about my work in its societal and epistemological context. That is in concise terms: to understand what there is to know, what needs to be known and what for, how it can be known and how this relates to the daily life in the office. Besides being relevant for providing some technical insight into a small subset of the energy industry, drawing up a genealogy of wind & site studies helps explore the relationship between technology and the study of nature.

1 Are also common: "wind resource and layout", "wind resource assessment", "metocean studies" (for offshore work), "site conditions" (in design standards). The term "wind & site" is used by Vestas Wind Systems and is, in my personal opinion, a well-suited expression.

INTRODUCTION

4 Wind & site studies are, in short, studies of the general and site-specific properties of the wind that are relevant for wind turbine and wind farm design. The work consists in characterizing these conditions by means of in-situ and remote sensing measurements (when relevant), carrying out subsequent analysis work (expected production, derivation of design parameters), and other affiliated tasks (turbine data analysis for instance). As such they form a relatively well-defined field of wind energy engineering, relatively young (it started after the second world war, together with the first modern turbine prototypes, but emerged commercially only in the late 1970s). The present article provides an insight into some aspects of wind and site studies that could be relevant to historical studies of wind energy.

5 Before looking into these aspects, it is important to mention that there exists already a great deal of publications (books, articles, dissertations, but also websites) dealing with the history of wind energy and wind turbine design in particular. To name a few key contributors: Heymann, Karnøe and Nielsen in Denmark, Gipe and Righter in the US, Rogier in France. These publications focus on wind turbine design or the wind energy market in general, and wind & site studies are not generally treated in detail. While acknowledging that all disciplines involved in wind energy form in reality a continuum of activities and that separations between them may sound artificial, the present article puts wind & site studies at the centre of the analysis and derives therefrom its relationships to other fields. By doing so, it neither challenges the existing literature, nor proposes alternative narratives on the wind energy history; on the contrary it proposes a vision of wind energy history, seen from a wind & site studies perspective, that is consistent with the existing works.

6 The article is structured as follows: first, through specific examples, it suggests that the relatively large corpus of wind and site studies (spanning the 20th century), could complement historical studies of wind turbine technology. In essence, the present article argues that the study of wind quantity and quality has been, to some extent, necessary to develop nowadays turbine technology and to support its global development, planning, and integration into the energy mix. Secondly, this article focuses on wind energy meteorology as a field of science. Since the late 1970s, the field of wind and site studies consists of both commercial and project-specific consultancy work, but it also includes applied and fundamental research in atmospheric sciences and fluid dynamics. This research work is typically carried out not in national meteorological institutes and atmospheric science laboratories, but instead in separate wind energy meteorology institutions. This article proposes to investigate whether/how the scientific knowledge created by the wind energy meteorology research is transferred to the wider atmospheric science research world, and suggests that studying the interplay between the wind energy industry, wind energy meteorology research, national weather institutes and the rest of academia could help understand the interplay between engineering and science, as well as the differences between engineering and scientific knowledge production. Lastly, this article proposes to explore how wind and site studies, as well as other pre- and post-construction surveys (for instance in offshore wind: soil, met ocean, preventive archaeology, fishing, fauna and flora impact surveys) provide to a wider audience a new set of information that can change its perspective on a territory, from a "natural" to an "energy resource" perspective. Examples are taken from the North Sea and Denmark and may be relevant for environmental historians.

WIND AND SITE STUDIES, DESCRIPTION AND TEXT CORPUS

Wind turbines are immersed in the atmospheric boundary layer, a fluid which differs in many aspects from the controlled experimental setup of aerodynamic studies, and from modelling results. Therefore, it was and still is, a necessity for the turbine designer and/or operator to consider the general and site-specific wind conditions to ensure technical and financial reliability 7 of a project. The study of these wind characteristics is referred to, since the late 1970s, as: "wind and site studies".[2] It is a field of engineering which aims at answering the following questions:

- *How much wind is there?* This involves accurate and precise measurement of wind speed and direction, as well as other atmospheric variables (temperature, pressure, humidity).
- *How much does the wind vary spatially and temporally?* Derivation of the wind climate at a site (statistical distribution of the wind speeds and directions, turbulence), or in a given area.
- *How much energy will the turbines produce, how to place them in an optimal way?* Energy production calculations, layout of wind farms.
- *How are these wind conditions affecting turbine design?* In particular for the first small and large prototypes, but also for the turbines nowadays (including offshore conditions), understanding the structure of wind (and waves) is a key to success.
- *How to optimize the design of a park?* This is especially true for offshore wind parks, where the study of wind, wake effects, waves and soil plays a large role in the reduction of the costs. Onshore, the study of the spatial variation of the wind resource, turbulence or other wind features helps optimize the production.
- *How to bridge the gap between expected and actual production?* A great deal of analysis is carried out in order to re-analyse production data, explain differences between expected and actual production, and carry out updated uncertainty estimates of the long-term and short-term production.

8 The field has evolved together with wind turbine design, and there exists a corpus of technical reports on wind & site studies at all the stages of the history of wind energy:

- Before the first world war, only sparse and individual studies of wind turbine efficiency in open air are available.[3]
- During and after the second world war and up to the late 1960s, a large number of surveys can be found beside the numerous reports of Johannes Juul[4] and Edward Golding[5] for instance. The main contributions identified so far are listed below:
  - * Works by Palmer Putnam[6] and Percy Thomas[7] in the US: the former describes in detail a number of wind & site studies during 1940-1945, as well as the reasons for making such studies (with contributions from Theodore Von Karman and Sverre Petterssen).
  - * Coordination effort as part of the OEEC Working Party n°1: in the proceedings[8] published in 1954, 19 papers (out of 45) fall under the topics "Wind Regimes and Studies, Selection of Wind Power Sites, and Wind Measurements and Measuring Instruments".
  - * UNESCO and UN[9] conferences: in the latter, 14 papers (out of 40) fall under "Studies of Wind Behaviour and Investigation of Suitable Sites for Wind-Driven Plants".
  - * Wind and site studies carried out as part of national and international research programs, see for instance the case of

2 See also "Context" in this article.

3 See for instance Vladimir Rafailovich Sektorov, "The Present State and Planning and Erection of Large Experimental Wind Power Stations", *NASA Technical Translation* (report NASA TT F-15, 512), April 1974 [1933].

4 See the very early and complete Johannes Juul, "Investigation of the possibilities of utilisation of wind power", *Elektroteknikeren*, Vol. 45, October 1949.

5 Edward W. Golding, *The Generation of Electricity by Wind Power* (London: E. & F.N. Spon, 1976 [1955]), covers wind and site studies in 10 out of 19 chapters.

6 Palmer Cosslett Putnam, *Putnam's Power from the Wind* (New-York: Van Nostrand Reinhold, 1982).

7 Percy Holbrook Thomas, "Harnessing the Wind for Electric Power", *in United Nations Scientific Conference on the Conservation and Utilization of Resources*. 17 August – 6 September, Lake Success, New-York. Volume III Fuel and Energy resources (Lake Success: United Nations Dept. of Economic Affairs, 1950-53)

8 Organisation for European Economic Co-operation, Committee for productivity and applied research. Working party n° 1 (Wind Power), *Technical Papers Presented to the Wind Power Working Party* (London: H.M. Stationary Office, 1956).

9 UNESCO, *Arid Zone Research. Wind and Solar Energy. Proceedings of the New Delhi Symposium* (Paris: 1956).

France,[10] the UK,[11] as well as studies of the global wind resource commissioned by the UNESCO.[12]

- From 1973 onwards, all conferences led and organized by the American research program include numerous papers on wind and site studies.[13]
- From 1978, the first commercial/consultancy reports were produced in the US.[14]

9 With only a couple of exceptions, this text corpus is available at https://aeolians.net/library.

INCLUDING WIND AND SITE STUDIES IN THE HISTORY OF WIND ENERGY

10 Works about the history of wind energy mainly report, rightly so, about the development of wind turbines. They highlight the pros and cons of the different concepts and narrate the parallel developments, in the 1970s, of the grass-root movements in Denmark and the large national R&D programs (USA, Germany). See for instance the work of Matthias Heymann[15] or by Preben Mægaard, Anna Krenz and Wolfgang Palz:[16] both references provide a detailed description of these two design traditions, that is: the successful 3-bladed upwind Danish turbine concept from Johannes Juul (1887-1969), and the now-abandoned 2-bladed downwind concept inspired by Ülrich Hütter (1910-1990). However, in these works, the study of site conditions (wind characteristics, siting of the turbines) is not reported in detail, nor identified as a separate field. Wind conditions are either shortly described together with other design constraints or presented in the context of a turbine mechanical failure.[17] In other works, site conditions are reported by practitioners in the form of anecdotes.[18]

It seems however that rare were the wind and site studies isolated from wind turbine design studies or renewable energy programs. Thereby, the text corpus above-mentioned is in itself rather well structured, making it already possible for the practitioner to build up a genealogy of wind and site studies. The examples listed below, together with a short argumentation, aim at making the wind and renewable energy systems' historians' community aware of these studies, as they could complement existing works and/or shed a new light on some possibly yet unexplored research topics. The first example focuses on the works by post-war wind energy pioneers, the second one focuses on the US wind turbine research program in the 1970s-1980s. Finally, when focusing on the period starting in the early 1980s, considerations on the role of wind & site studies for the development of the wind industry are provided. 11

Post-war pioneers

Taking as examples Juul and Golding, both published many wind and site studies results. Golding especially has worked mainly on these topics.[19] 12

10 United Nations, *Proceedings of the United Nations Conference on new sources of energy: solar energy, wind power and geothermal energy*, Rome, 21-31 August 1961 (New-York: United Nations, 1963).

11 Rémi Gandoin, "Ailleret, Serra, and the Wind Resource of France: 1946-1953", 09/03/2018. Url: https://aeolians.net/2018/03/09/ailleret-serra-wind-resource-france/ (accessed 12/03/2019).

12 Energy Research Agency, *Reports on Wind Power published by ERA, 1949 to 1968*, Volume 1: *Wind Measurements and Characteristics. 1975*. ADD vol 2, etc.

13 World Meteorological Organisation, *Technical Note n°4. Energy from the Wind. Assessment of Suitable Winds and Sites* (Geneva: WMO, 1954).

14 Rémi Gandoin, "Workshops and conferences, 1973-1980", 15/12/2017. Url: https://aeolians.net/2017/12/15/workshops-and-conferences-1973-1980/ (accessed 12/03/2019).

15 Matthias Heymann, "Signs of Hubris: The Shaping of Wind Technology Styles in Germany, Denmark, and the United States, 1940-1990", *Technology and Culture*, Vol. 39, n°4, oct. 1998, 641-670.

16 Preben Maegaard, Anna Krenz, Wolfgang Palz, *Wind Power for the World: The Rise of Modern Wind Energy* (Singapore: Pan Stanford publ., 2013).

17 *Id*. Chapter 5 or Matthias Heymann, "Signs of Hubris: The Shaping of Wind Technology Styles in Germany, Denmark, and the United States, 1940-1990", 647 (cf. note 15) as well as Trevor J. Price, "Edward Golding's Influence on Wind Power", *Wind Engineering*, vol. 29, n° 6, 2005, 513-530.

18 See for instance Matt G. Hopkins, *The Makings of a Champion or, Wind Innovation for Sale: The Wind Industry in the U.S. 1980-2010* (Cambridge MA: Academic-Industry Research Network, 2013) or Peter Asmus, *Reaping the Wind: How Mechanical Wizards, Visionaries, and Profiteers Helped Shape Our Energy Future* (Washington: Island Press, 2001).

19 Edward William Golding, *The Generation of Electricity by Wind Power* (London: E. & F.N. Spon, 1976 [1955]).

He worked for instance on how to accurately measure wind speed distributions, assess the speed-up above hills and compute estimates of energy production using the turbine technology available at the time (that is, mainly from Palmer Putnam and Johannes Juul). He also worked on characterizing atmospheric turbulence and its effect on the turbine power performance. The work carried out by himself and his colleagues from the Energy Research Agency included advanced anemometry and extensive field study and data analysis.[20]

13 Johannes Juul, in Denmark, provided as early as 1949 some experimental results about wind conditions across Denmark, as well as their influence on turbine production.[21] In the OEEC Technical Report n° 38,[22] he includes experimental evidence of the different turbulence conditions onshore and offshore, and their effect on the turbine performance. Juul has also taken advantage of the OEEC Working Group Party to improve his testing procedures, for instance by using an anemometer developed as part of the French wind survey. He used his knowledge of the wind speed distribution and the turbine site, together with test results, to design optimal turbines in terms of rated power, rotational speed and rotor diameter. Anecdotally, he explained[23] how the Smith-Putnam turbine (famous for being the first MW-size turbine) was in effect not optimally designed:

> At 16 m/s wind, it developed 1500 kW and at 12 m/s about 700 kW. The plant, however turned out a disappointment. It soon appeared that powerful winds occurred with the same frequency at Grandpa Knob as at Zealand in Denmark and with the great tip velocity the plant did not supply any current till at about 9 m/s wind and with but a low usable energy, at that. Had the mill been constructed so as to rotate at barely half its speed, it might have supplied more than twice the amount of energy and it would not, then, have been necessary to dimension gears and generator for more than 600 kW. Actually, the plan corresponded in size to a 600-kW plant when adjusted to our wind conditions which correspond to those prevailing in U.S.A.

The unfortunate over-estimation of the mean wind speed at Grandpa Knob by Putnam and his team involved common challenges of wind & site studies: characterization of the vertical wind profile, spatial variation of the wind resource, lack of confidence in pre-existing nearby measurements, and an instrument calibration error[24]. Although not at the root of the Smith-Putnam turbine problematic design, the lack of knowledge of the impact of wind conditions on the turbine production and loading may have played a role in the fate of the project. As Palmer Putnam writes:[25] 14

> It was not until the summer 1945, […] that it was learned that the "anomaly" at Mount Washington had been caused by the application of an arbitrary correction to the anemometer records *(ed: used for the long-term correcting the on-site measurements)*. The correction had been applied by one of the observers without notification to the users of the published data. It is quite likely that we have this observer to thank for the Smith-Putnam Wind-Turbine experiment. If it had been known at the end of 1940 (ed: when they conducted on-site measurements) that not only was there no anomaly, but also little wind

20 Rémi Gandoin, "Golding and ERA (1949-1965)", 27/11/2018. Url: https://aeolians.net/2018/11/27/golding-and-era-1949-1965/ (accessed 12/03/2019)
21 Johannes Juul, "Investigation of the possibilities of utilisation of wind power" (cf note 4). See also Rémi Gandoin, "Wind works, Johannes Juul (1949-1962)", 05/03/2019. Url: https://aeolians.net/2019/03/05/wind-works-johannes-juul-1949-1962/ (accessed 12/03/2019)
22 Johannes Juul, "Results Obtained with the Experimental Windmill of Sydøstsjællands Elektricitats Aktieselskab-Seas", *Technical Paper* n° 38 in (OEEC, 1956).
23 Johannes Juul, "Results Obtained with the Experimental Windmill of Sydøstsjællands Elektricitats Aktieselskab-Seas", *Technical Paper* n° 38 in (OEEC, 1956).
24 Rémi Gandoin, "'Wind is not wind': Palmer C. Putnam wind studies (1939-1945)", 22/11/2018. Url: https://aeolians.net/2018/11/22/wind-is-not-wind-palmer-c-putnam-wind-s... (accessed 12/03/2019)
25 Putnam Palmer Cosslet, *Putnam's Power from the Wind* (cf. note 6).

> at those elevations below which we did not fear ice, it is likely that the experiment would have been abandoned out of hand.

15 And according to Sverre Pettersen:[26] *"The meteorology, the wind regimes, icing storms, and damaging gusts became my domain. This turned out to be the least explored area and it soon became the crux of the project".*

16 These few examples are provided in order to highlight that wind and site studies were an inherent part of the work in wind energy and turbine design in the post-war period, and that both Johannes Juul and Edward Golding - two of the "pioneers" - contributed significantly to this field. As also reported by Palmer Putnam, being able to quantify the wind conditions before and after the construction of the prototype was key to taking the right and cost-effective decisions. Juul discussed much of his trials and retrospective adjustments to his turbines in his papers, using observations of both wind and turbine structural conditions. Unlike Ulrich Hütter, Johannes Juul did not develop a detailed modelling of the wind/turbine interaction, but instead and with great talent quantified accurately and precisely the influence of wind conditions on the prototype. As this has proved to be a very good way to engineer wind turbines, it may therefore be relevant and interesting to consider wind & site studies of the wind energy pioneers in historical research work. Some very interesting research work[27] has compared the trajectories of Johannes Juul and Palmer Putnam, in a very detailed manner. Could some considerations about the wind & site aspects of their works maybe help understand better the similarities and differences between the two approaches? The contribution of Ulrich Hütter to the study of the wind conditions and their impact on turbine design could also be further developed, and/or advertised.[28]

The NASA wind turbine program

17 From 1973 to the late 1980s, NASA developed a number of large (MW size) turbine prototypes, with the aim of making them industrial successes. The rationale that led NASA to choosing a 2-bladed MW-size turbine can be traced in conference proceedings, as early as 1974.[29] A General Electric (GE) parametric study[30] commissioned by NASA-Lewis,[31] and finalized in 1976, is the seminal study which recommended building MW-size machines. This recommendation was based on a parametric optimization model which concluded that small turbines are more than four times more costly than bigger turbines, for the same mean wind speed at a given site. Later, in the late 1970s and the mid 1980s, the large weight of the components caused issues to the MOD program and it was discontinued. The details of this calculation are provided in Vol. 2 Section 4 of the GE report from 1976[32] where the cost model is described in Section 4.3.1 of *Id*. as containing an optimization module of the rotor itself. It seems to have used rated power, rotor speed and rated rotor speed as independent variables, while the rotor diameter was only set thereafter as a dependent variable. This may have strongly biased the results against small rated powers: turbines with small rated power were assigned rated wind speed smaller than the large turbines and provided with larger (costlier) rotors compared to the previous practice[33]. As highlighted by the Juul' remark above about the non-optimal rated power of the Grandpa Knob turbine, care should be taken in designing

26 Rémi Gandoin, "'Wind is not wind': Palmer C. Putnam wind studies (1939-1945)" (cf. note 24).

27 Kristian Hvidtfelt Nielsen, "Technological Trajectories in the Making: Two Case Studies from the Contemporary History of Wind Power", *Centaurus*, vol. 52, 2010, 175-205.

28 Rémi Gandoin, "Ulrich Hütter's contributions (1942-1979)", 29/11/2018. Url: https://aeolians.net/2018/11/29/ulrich-hutters-contributions-1942-1979/ (accessed 12/03/2019)

29 Olle Ljungström (ed.), *Advanced Wind Energy Systems. Workshop proceedings. Stockholm, August 29-30, 1974* (Stockholm: Styrelsen för Teknisk Utveckling, 1976), 7-25 where the MOD-0 100kW prototype was announced.

30 General Electric Company, *Design Study of Wind Turbines 50kW to 3000kW for Electric Utility Application*. Volumes 1-3. September 1976.

31 And summarized in Frank R. Eldridge (ed.), *Proceedings of the second Workshop on Wind Energy Conversion Systems. Washington, 1975* (Washington: Government Printing Office, 1976).

32 General Electric Company, *Design Study of Wind Turbines 50kW to 3000kW for Electric Utility Application* (cf. note 28).

33 *Id*., Figure 4-5.

wind turbines, not only considering their average aerodynamic performance, but instead the total energy output. The optimization routine of the GE study seems to differs from these principles, and thereby may have favoured large turbines (technically complex), which proved to be detrimental to the MOD program. This episode of wind energy is discussed in detail in wind energy historical works.[34] As mentioned above, the NASA turbine prototypes suffered from a number of issues, some being related to the wind conditions:[35]

> *The following paragraphs quote a leading American wind engineer. He summarizes the technological experience from the first 10 years of wind technology development (Stoddard, 1986).The biggest lesson that we engineers have learned in California: the engineering problems are much more difficult than we originally thought (p. 84). This has largely boiled down to two areas of technical uncertainty: the aerodynamic loads and the dynamic motions. We were guilty of 'steady flow' aerospace-type thinking, and largely did not appreciate the range and difficulty of the wind environment (p. 85). Design risk is generally in the wind turbine industry because we still can't adequately predict rotor aerodynamic loading and rotor dynamic motions. Low speed Danish-type turbines have reduced this risk by: 1) limiting exposure to aerodynamic loads, 2) letting inertial (weight) forces overshadow the aerodynamic loads, 3) and preventing dynamic motions (p. 89).*

18 While a form of hubris can certainly be found in the ambitious MW-size MOD turbines program,[36] the technical conference proceedings and reports above-mentioned may help understand in greater detail how the GE parametric study possibly penalised small wind turbines by using an inappropriate set of optimisation criteria which did not consider past empirical results,[37] and how the knowledge of wind conditions (in particular turbulence) played a role in the design process. It is also interesting to note the evolution of the Danish wind energy meteorology research community during the 1970s compared with the one in the US: while the American research was already booming from 1973, a research program started in Denmark in 1976 only. However, within four years (1977-1981) it achieved more than the other programs: rapidly a number of key tools and methods were developed, which placed Denmark as leader in wind energy research, in particular within wind & site studies. This could be further examined and investigated using a similar approach to that of Heymann, that is by highlighting some Danish cultural specificities, and by complementing the argumentation with some insight into wind and site studies. One could for instance, while acknowledging the importance of the Danish grass-root movement which supported the early growth of the industry and by focusing on wind & site studies:

- Study how Danish researchers used the heritage of Juul's empirical results, together with the existing boundary layer meteorology research knowledge at RISØ, to bring up the engineering knowledge to a scientific level, and thereafter produce new and advanced knowledge.
- Reflect on the importance of linking and scoping wind & site studies for advancing wind turbine design, and compare the strategies developed in Denmark, Germany, Spain and the US[38] for instance.
- Consider the singular case of the French Wind Energy program, which developed very thorough and decent wind and site studies, as well as field turbine testing and aerodynamic studies, without success, thereby showing

34 See Matthias Heymann, "Signs of Hubris: The Shaping of Wind Technology Styles in Germany, Denmark, and the United States, 1940-1990" (cf. note 15).
35 Peter Karnøe, "Technological innovation and industrial organization in the Danish wind industry", *Entrepreneurship & Regional Development: An International Journal*, vol. 2, 1990, 105-124.
36 Matthias Heymann, "Signs of Hubris: The Shaping of Wind Technology Styles in Germany, Denmark, and the United States, 1940-1990" (cf. note 15).
37 These in turn, inspired directly the first Danish turbine makers, see Maegaard, Krenz, and Palz, *Wind Power for the World: The Rise of Modern Wind Energy* (cf. note 16).
38 In the US the national renewable energy lab (NREL) was founded very late (1991), about 10 years after its counterparts and main challengers in Europe.

an example where there may be non-optimal approaches to wind and site studies. In this way it resembles the first US program during the first world war.

Contributions to the modern wind industry

19 One needs to acknowledge that the contribution of wind & site studies to the early development of wind energy, in the post-war period, was probably minor compared to the other turbine design drivers. Although not anecdotal, their role was (in the case of Juul and Hütter for instance) limited to the characterisation of the wind turbine prototype response to the turbulent wind field, and to the high-level assessment of suitable wind turbine installation sites.

20 However, with the development of the modern wind industry, in particular in California in the 1980s, the need for specialist knowledge and independent consultancy services regarding wind & site studies increased suddenly.[39] It is only then that this field of engineering really emerged as a separate professional discipline. Although a relatively young profession, it would then be natural to study these actors and their role in the development of the wind energy industry. Typically, the services consisted (and still do so) in technical due diligence and risk assessment, optimisation of the wind farm project (choice of turbine, layout, installation and maintenance costs), follow-up and reanalysis of the performance (production, structural loads, turbine warranty contracts), sometimes research and development (data acquisition, calculation tools and methods), and also contribution to international standards. For instance, research topics could be:

- Study the market driving forces that led to the creation of these consultancy services (for example the need for the lender to assess the financial viability of the project) and assess whether it led to some particular need for consultancy services in different countries, and how that compared with other industries (for example oil and gas, but also solar power).
- Explore the evolution (if any) of the commercial and research wind & site studies and their impact on the wind industry (wind turbine design for instance), again in different countries or regions.
- Study the evolution of the different actors within wind & site studies (commercial companies, research centres providing also consultancy services, small consultancies, etc.), their relations to each other and to the other actors of wind energy (including institutional actors like energy agencies).

WIND ENERGY METEOROLOGY

Problematics

The emergence of wind & site studies has led to great developments in atmospheric sciences research, in particular within boundary layer meteorology, as briefly mentioned in the previous Section. Note that these activities are in their vast majority non-commercial and classify as public research work, in a very similar manner to other fields of atmospheric/marine science. The large amount of measurement datasets, the need for precise and accurate modelling, has driven the development of detailed meteorological studies that are of interest for the practitioner, for instance: wind profile modelling (how much is the wind changing with height), atmospheric turbulence (relevant especially for slender components like blades), or weather forecasting. A good example of such synergies is the meteorology department of RISØ in Denmark (now part of DTU Wind Energy) which initially worked on pollutant dispersion[40] in the 1960-70s and shifted focus towards wind energy in the late 1970's after the refurbishment of Juul's Gedser turbine.[41] These early research studies cover similar topics as in Juul's papers. Both microscale effects (turbulence) and large-scale patterns (wind maps over Denmark) have been studied in parallel. Similar developments took place in the Netherlands (ECN) and Germany. Furthermore, thanks to the large-scale 21

39 Rémi Gandoin, "Palm Springs-Whitewater, 1980" (cf. note 14).

40 RISØ was home for a demonstration nuclear reactor.

41 The longest-lasting wind turbine prototype experiment (1957-1967) that had been carried out prior to wind energy renewal in 1973.

development of wind energy, a great number of measurement data and model validations have been carried out by engineers and consultants in the past decades.

22 It seems unclear though, how this research work[42] has "fed back" into the major body of atmospheric science research. For instance, Copenhagen University has its own meteorology department, with little (if any) overlap with DTU Wind Energy; this seems to be the case in other countries. It is worth noting that a non-negligible part of the DTU Wind Energy publications deals with the most fundamental aspects of meteorology (for instance: atmospheric turbulence, wind profiles, mesoscale phenomena, measurement techniques), therefore they do not only cover wind energy-related applications. This raises the following questions:

- *How to characterise wind energy meteorology today, and historically?* Whether it defines itself as a subset of boundary layer meteorology,[43] or as an "applied science",[44] thorough and independent historical work seems to be missing. Also, the importance and role of wind energy meteorology research to wind turbine design and the wind turbine market could be investigated from a historical perspective.
- *How has wind energy meteorology contributed to other fields of science?* Provided that the field has been active globally for at least 40 years, and has benefited from relatively continuous funding (in Europe), how did this new knowledge disseminate in other fields of science, including boundary layer meteorology, but others as well?

23 Answering these questions may be relevant for both practitioners within wind energy meteorology and its interfacing fields, as well as the general public.

Relevance for practitioners

Practitioners may find a way to describe and map the actors of their field, understand what goals they pursue, what sort of organisations are present within their and others' field, what mechanisms bind them together, or in contrast take them apart. It may help identify, differentiate and eventually reconcile scientific and engineering aspects of the work. For instance, climate scientists have in recent years benefited from much research work on these problematics, including decision making under model uncertainty.[45] While the field of wind energy meteorology has a smaller impact on natural science and the global political debate than climate science, it is an active field of research with an ever-growing number of undergraduate, graduate students and researchers.[46] Therefore, it can be challenging for both industry and academic members to understand what the significant scientific and technological achievements are, where they are occurring and how to make use of them. Having a clearer definition of the field, as well as an understanding of its historical developments (not only of scientific and technical advances, but also of the evolutions of the field itself), could help connect the dots. 24

A recent example of a long multi-disciplinary project which had a large impact on the industry is the elaboration of the newest edition of the IEC 61400-12 standards[47] which prescribe how wind turbine performance should be measured. The topic is crucial to project financing, as it provides a way for the turbine owners to check and compare the power output of a turbine compared with the specifications from the 25

42 See for instance a summary in Alfredo Peña et al., "Ten Years of Boundary-Layer and Wind-Power Meteorology at Høvsøre, Denmark", *Boundary-Layer Meteorology*, vol. 158, jan. 2016, 1-26.

43 See Stefan Emeis, *Wind Energy Meteorology, Atmospheric Physics for Wind Power Generation*, (Springer-Verlag Berlin Heidelberg, 2013).

44 See Erik Lundtang Petersen *et al.*, "Wind Power Meteorology" *Risø National Laboratory*. Risø-I, N° 1206(EN), 1997.

45 See for instance Matthias Heymann, Gabriele Gramelsberger, and Martin Mahony, *Cultures of Prediction in Atmospheric and Climate Science* (London; New-York: Routledge, Taylor & Francis Group, 2017).

46 Elias Sanz-Casado, "Renewable energy research 1995–2009: a case study of wind power research in EU, Spain, Germany and Denmark", *Scientometrics*, vol. 95, 2013, 197-224.

47 See https://webstore.iec.ch/publication/26603 (accessed 2019-03-12)

turbine contract. Eventually, the owner can be entitled to financial compensations from the manufacturer if the turbine does not pass the test. The former edition of the standards (2005) was 90-pages long, however the newest edition is 558-pages long. This six-fold increase denotes the increased complexity of the testing methodology, which includes a new measurement device (LiDAR) and a new analysis method (Rotor-Equivalent Wind Speed, RWES). This wealth of new procedures provides many advantages but also some challenges.[48] Wind energy meteorology has been at the heart of the elaboration of the scientific and technical basis for these new standards, it could therefore be interesting, retrospectively, to understand what the whole process consisted of, what goals were pursued by the participants (academia, manufacturers of turbines and measurement equipment, consultants), how the standards have been and are actually used, and what lessons can be learned for the next editions. Tools and methods applied elsewhere in the history of technology could help provide this overview, starting by working on the history of wind energy meteorology.

Relevance for the history of technology and innovation

26 Wind energy meteorology is composed of relatively small and atypical organisations, in the sense that research laboratories are a mix of university departments (f.ex. DTU-Wind Energy, TU-Delft, Texas Tech), state technology institutes (f.ex. ForWind, Fraunhofer IWES), national labs (f.ex. NREL, CENER, CRES), commercial research institutes (f.ex. ORE Catapult), consultancy companies (f.ex. DNV-GL, Wood Group, UL) and manufacturers (f.ex. turbines, measurement equipment). Innovation takes place in all these places, and there are many links between the agents themselves, across organisations. Since modern wind energy is a relatively young industry (40-years old), it could be interesting to understand whether, compared to other industries, the specific structure of wind energy meteorology has been influenced by the general historical context of the last 40 years, whether it has peculiar aspects or, on the contrary, generic aspects that apply to other fields. As mentioned earlier in this article, wind & site studies have been carried out at first from a wind-turbine design perspective, focusing therefore primarily on the turbine manufacturers. Considering wind energy meteorology in a historical study of wind energy could for instance question under what technical and financial conditions the large-scale development of wind energy has occurred.

- From a national policy planner perspective: how has the wind resource been established, on what basis, with what confidence level and for what result?
- From the project owner and turbine manufacturers perspective: how has the knowledge produced within wind energy meteorology been applied to de-risk projects and increase profitability?
- How have these parties benefited from wind energy meteorology, and has the above-mentioned "open"[49] structure of this organisation played a role?
- From a wider perspective, and considering that the wind energy meteorology has drawn a lot from meteorology (and in particular boundary layer meteorology),[50] can one map these "loans" historically, understand how this transfer happened and for what purpose? How has knowledge been exchanged and at what levels?
- Given the large progress in wind energy meteorology, for instance in the very fine characterisation of the wind profile or the atmospheric turbulence, has some knowledge from this field been transferred "back" to meteorology, or another field of science? An interesting

48 Not listed here, the curious reader can refer to https://aws-dewi.ul.com/knowledge-center/webinars/how-iec-standard-powe…

49 As opposed to "rational" of "natural" see Richard W. Scott, *Organizations: Rational, Natural, and Open Systems* (Upper Saddle River: Prentice Hall, 2003 [5th Edition]).

50 Turbulence spectrum characterisation (Jagadish Chandran Kaimal, John Corry Wyngaard, Yukata Izumi, Owen Reid Coté, "Spectral characteristics of surface-layer turbulence", *Quaterly Journal of the Royal Meteorological Society*, vol. 98, n° 417, july 1972, 563-589), pollutant dispersion models, the Weather Research and Forecasting model (WRF), reanalysis, etc.

technology from that perspective is the LiDAR, which has become a very common way to measure wind speed with great accuracy and precision in wind energy. The technology was used in meteorology 40 years ago but was heavy and expensive to use. Advances in telecommunications (fibre optics) in the late 1990s led to fast development of cheap, robust, accurate, precise and reliable LiDARs that suit the need of the wind energy industry. How has meteorology gained from this development? Is the use of LiDARs in meteorology influenced by its success in wind energy?

27 These are particular examples of the kind of questions that the study of wind energy meteorology history could trigger.

SOCIETAL ASPECTS OF SITE STUDIES

Problematics

28 Wind Energy, together with other means of renewable electricity production, are often discussed in public debates. It is often the case that discussions on wind projects relate to problematics that extend far outside the wind turbine technology itself, for instance: spatial planning and land/sea use, local employment and industry as well as carbon emissions and climate change, therefore wind energy often takes a disproportionate part in the discussion compared with other sectors relevant for climate policies (transport, housing, agriculture, etc). In other words, the spatial and societal "footprint" of wind energy is, relatively to the size of the industry, rather large.

29 Despite some opposition, a lot of work is being carried out and a great number of projects has been commissioned, each of them based on a number of site studies (not only wind, but also environmental and sometimes historical/geographical). Therefore, through the lenses of wind and site studies, it could be interesting to review how a large renewable infrastructure project (for instance an offshore wind farm) impacts societies and understand how this impact resembles or differs from other infrastructure projects. There exists already a great number of studies on the social acceptance of wind energy and its impact on territorial planning; it would be interesting to know how much wind & site studies have been considered in these, as they could lead to interesting discussions (possibly related to environmental history), for instance:

- *How do site studies change the way a territory is understood and perceived?* Together with other environmental studies (birds, mammals, benthic, archaeology, soil and metocean studies), a sum of engineering knowledge is created for every wind farm project. Does this change the way the territory is perceived and understood? If we are to meet the objectives of climate policies, a large share of the energy production needs to be moved from fossil fuels power plants to renewables. However, in practice, locally, issues arise often regarding land- and sea- use and property value for instance. Regarding large offshore wind projects, delays and issues are met when having to obtain consent from sometime several dozens of authorities.[51] Are there "wind & site specific" issues related to this project compared with other infrastructure projects?
- *How to characterise knowledge created by engineering wind & site studies*? As opposed to research studies, engineering studies aim at supporting technically a given, site-specific wind farm project. To do so, they use a number of data, tools and methods which may or may not have been produced by wind energy meteorology and oceanography sciences. Typically, the work consists in analysing measured data, running a number of models (wind, waves) and validating them, and finally drawing conclusions as to the site suitability of the expected energy production and the design of foundations. In the process, some information is created, which to some extent can be referred to as engineering knowledge, in the sense that it may well be considered as true and valid by other studies/actors, as well as become part of engineering standards, but not become scientific knowledge. How is such knowledge created, what does it consist

51 See an example of consenting document for the Dogger Bank offshore wind area in the UK: http://www.oceanologyinternational.com/__novadocuments/49180?v=63531001...

of? What does it take for it to become trustworthy by third parties,[52] and is uncertainty (measurement, model) dealt with?[53]

30 These two problematics are further developed below.

Perception of a territory as a renewable energy resource

31 If we are to meet the objectives of the climate policies, a large share of the energy production needs to be moved from fossil fuels power plants to renewables. Transmission system operators are preparing for this shift[54] and it is unlikely for other countries than the already-existing nuclear energy leaders to develop nuclear programs (an alternative low-carbon energy production method). In this perspective, the large-scale development of renewable electricity production needs to continue, thereby increasing the presence of renewable power plants on land and at sea. It could be interesting to interrogate how the general public sees the renewable energy potential of a given region or local area. For instance, some local opposition movements to wind energy have coined the term "*industrial wind energy*" projects,[55] while wind energy advocates refer to *locally* sourced energy.[56] What is at play in this narrative? How is the current, fossil-based energy production perceived? Is it possibly a type of acceptable industry for some, and a non-local product for others? "Forces of the Nature" are still nowadays a source of admiration for the natural environment, however their modern, physics-based equivalent (thermal or kinetic energy for instance) may not be seen in all countries, places and cultures in the same way. These issues seem well-suited to being studied historically.

For the specific case of wind and site studies, how has the general public been aware of the "windy" places on a local, regional, and global scale? Many have a general and high-level knowledge about fossil fuel resources and their global distribution, but what about renewable energy? How does an improved knowledge of renewable energy sources favour or hinder the development of renewable energy technology? Examples could be taken from Denmark and France: Denmark has a modest size, but is rather uniformly windy, whereas France is in some places windier than Denmark but in some places much less windy. What is the role of the real and perceived variability (in time and space) of the wind resource in the elaboration of renewable energy policies and the engagement of the public? For instance, it may be easier for a country to plan the exploitation of a renewable resource when this resource is uniformly spread over the territory, as this makes it easier for the population to reach consensus on how much wind there is to exploit.[57] This question is also relevant from a historical perspective: how has the picture of a territory as a renewable energy resource emerged and changed, historically? One could imagine that before the industrial age and the electrification of Europe, this perception was different. Similarly to the concept of landscape, the concept of "energyscape" and how it relates to forces of nature and the territory we live in, is likely to be different nowadays from what it was 50 years, or 200 years ago. 32

Furthermore, comparisons could be made, for the specific case of offshore wind, between the spatial planning approaches of different countries: in what way have people in these places, throughout history, perceived the marine territory as (energy) resource? How has this perspective changed with the evolution of technology and science?[58] In old maritime nations like 33

52 Typically, certification bodies, who provide a certificate that the design of the park is sound, as well as third-party advisors who provide financiers with some level of certainty about the return of the project. In particular for offshore wind where investments are in the order of billions of euros, the quality of wind & site studies has a big impact on these financial transactions and technical risk assessment.
53 Links could be made with the work of Wendy Parker on climate models' uncertainty and decision making, https://www.dur.ac.uk/philosophy/staff/?id=11577.
54 See https://tyndp.entsoe.eu/tyndp2018/.
55 In France: "l'éolien industriel".
56 The validity of the expression, when it comes to electricity, is questionable.
57 In the case of Denmark, intuitively: enough.
58 For a similar, yet non-historical approach, see for instance Vanesa Castán Broto and Lucy Baker, "Spatial Adventures in Energy Studies: Emerging Geographies of Energy Production and Use", *Energy Research & Social Science*, vol. 36, 2018.

England, Denmark or the Netherlands, what was known about the wind and the sea prior to offshore wind, and what role has this played in the development of this new technology?[59] What about other nations that do not have a strong maritime tradition? The singular case of offshore wind may help understand the link between production of knowledge about a given territory (what is known about it from natural sciences, and humanities) and advances in technology: while it is trivial to say that the English or Dutch maritime tradition helped foster offshore wind from the very first days, it may be relevant to analyse these topics from a historical perspective, building up on past technological developments that have had the same, or different, characteristics.

Characterising engineering knowledge

34 During the development, construction and operation phases of a large renewable energy infrastructure project, a number of studies are carried out, and thereby some knowledge is produced. For instance, it is usual for an offshore wind farm project to carry out the following studies:

- Wind and metocean measurement campaigns, modelling and analysis,
- Spatial planning studies (f.ex: fisheries, shipping),
- Environmental impact assessment (f.ex: benthic and non-benthic, mammals),
- Geophysical and geotechnical measurement campaigns and analysis,
- Archaeology and heritage (both for offshore and onshore works)

35 These studies are not scientific and do not aim at being such. However, while their content is not necessarily “scientifically right”, it is not wrong either; a number of quality checks and certification processes are carried out to make sure the results are sound and provide a good basis for technical, financial and political decisions.

For instance, for the particular case of the wind and site studies, an accurate and precise depiction of the wind and waves is demanded by certification bodies for the design of foundations and substructures. Conservatism and safety margins are eventually added to some design loads (extreme loads), as well during detailed design of the steel structures, to account for the unforeseen fabrication defects, but a great deal of effort is spent on deriving the best and most correct site conditions in the first place. As the work involves a number of comparisons between models, measurements and theoretical results from the standards and the scientific literature, a great deal of engineering knowledge is produced. It is produced under a different knowledge regime than if it were science, and can therefore hardly be compared with it, yet such studies are made for every project, using different models and measurements, and span a much wider and more detailed range of environmental conditions than most scientific studies (which typically focus on much narrower datasets - for valid reasons). How to characterise this knowledge, as it is not scientifically true, nor engineeringly wrong? One obvious limit to knowledge-sharing is confidentiality of some studies, but there are a number of studies publicly available, and it may be interesting to study how these are being considered. In itself, the rationale for keeping some wind and site information confidential could be further explored as well: could there be better approaches? 36

Compiling the results from the studies above-mentioned equates to compiling site specific knowledge about the site, in many aspects. Does this come on top of pre-existing knowledge, or complement it? Does it sometimes infirm the pre-existing knowledge? Once the project is realised, how is this knowledge transferred to the general public, or scientists? Parallels could be drawn with the archaeological exploration of Doggerland thanks to seismic surveys from oil and gas companies,[60] where these large industry projects had an unforeseen beneficial impact 37

59 Anecdotally, the very interesting Günter Dietrich, *Wind Conditions over the Seas around Britain during the Period 1900-1949* (Hamburg: German Hydrographic Institute, 1952) is available on aeolians.net.

60 See Vincent L. Gaffney, Fitch Simon, Smith David, *Europe’s Lost World: The Rediscovery of Doggerland* (York: Council for British Archaeology, 2009).

on the way we think of the long-term history (by making it possible to describe the geography of now-submerged settlements of the Mesolithic).

CONCLUSION

38 To conclude, this article provides a number of intrinsic and extrinsic elements of wind and site studies, that could be investigated further in an academic context. From wind turbine design to the public perception of renewables, these topics may be relevant to the ongoing work aiming at making our societies more fit to non-fossil, intermittent but unlimited, power generation. The vast majority of the documents in the reference list are either available on the respective publishers' websites, or at aeolians.net.

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RÉPONSE À "A CALL TO HISTORICIZE WIND AND SITE STUDIES"

Wind and site studies have not been treated in much detail in historical work about wind energy technology and wind power use. I appreciate the authors' observations and arguments and the questions he raises. The author is not a historian, but an engineer. We had a useful and productive exchange, after I wrote a review and allowed the editors to reveal my identity. The exchange was productive and very agreeable. Both of us – historian and engineer – learned from it. I thank the author for his openness and interest in historical work. Historians of science and technology have ample and not always fruitful experience with engineers. Some engineers seek to challenge historians' accounts for their critical narratives and the lack of appropriate detail and appreciation of engineering accomplishments. This exchange was clearly different. The broader message to make is that conversations across disciplinary boundaries are necessary and profitable. Fruitful they can be, if the dialogue is on both sides not understood as an opportunity of teaching (or convincing) the other, but of exploring and learning from each other. Asking questions, like the author has amply done in his article, is not the worst for a start. 1

As the author is an engineer, it is not surprising, and for the scope of this journal fully acceptable, that he does not provide a full account of the state of wind power historiography. Many historical publications on the history of wind power have become available in recent years; and many of the examples the author mentions have been covered to some extent in this literature.[1] Still, the author has a valuable point to make. His emphasis on wind and site studies is a valid argument. This domain had skipped my and other historians' attention for at least two reasons. 2

First, historical actors partly neglected wind and site studies in their investigations, or did not pay much attention to it. During the 19th century, for example, American turbines emerged in the American Midwest, because farmers needed power for pumping water. Their design originated from practical experimentation rather than any engagement in wind and site studies. In the early 20th century, Saxony (a hilly region in 3

[1] A first wave of major publications comes from the 1990s: Karnøe 1991; Heymann 2018 (1995); Gipe 1995; Righter 1996; Heymann 1996; Heymann 1998; Verbong 1998. A second wave focusing on various aspects of innovation and policy in recent wind power developments started in the 2000s: e.g. Ibenholt 2002; Kamp 2002; Garud and Karnøe 2003; Neukirch 2010; Nielsen 2010; Nielsen, Heymann 2012; Heymann 2015; Chlebna 2017.

central East Germany) became a center for the production of American turbines in Europe, most of which were exported to other places. Saxony, however, was a place not known for windy coasts (which are several hundred kilometers away), but for a productive and innovative metal industry adopting this technology. Wind and site studies were not an issue for this industry. In the 1930s, a controversial pioneer such as German engineer Hermann Honnef planned to construct huge towers for wind power use in the middle of large cities. In this case, solid wind and site studies also lacked. Siting followed political interests rather than scientific results or technical reasons.

4 Second, partly, on the other hand, wind and site studies and their roles are only little visible in the historical sources, even though pioneers such as Johannes Juul and Ulrich Hütter paid attention to it. The author shows that a range of wind power pioneers in the 20th century indeed engaged in wind and site studies. Most importantly, however, the author clarifies the significant role of wind and site studies not only for optimizing energy production through appropriate siting but for optimizing turbine design. Turbine design, a delicate and demanding engineering task, has caught a lot of attention in historical accounts with focus on different design approaches, learning experiences, etc. Wind and site studies, however, remained neglected as an important piece in the puzzle of building reliable turbines. Turbine structure and generator dimensions requires wind and site studies. Wind conditions also cause atmospheric turbulence, which defines fatigue loads at the blade roots and needs to be accounted for appropriately. The case of Putnam's experimental turbine in the USA during the 1940s shows the importance of these points.

5 On the other hand, historical precursors to wind and site studies still appear marginal compared to the explosive expansion of wind technology since the 1970s, in which wind and site studies slowly became a crucial and increasingly professionalized element. Initially, during the 1970s and 80s, wind studies mainly served for pushing the narrative that abundant wind power resources were available and represented a competitive energy source compared to large fossil power plants. It served for siting decisions rather than turbine design. Most governmental wind power programs, launched after the first oil price crisis in 1973, focused on very large wind turbines (hugely transcending power ratings of historical turbines). Not wind and turbine design studies, but the politics of energy pushed the focus on large turbines, notably the competition against much larger conventional power plants. In Germany, it was the government's decision (not an engineering decision) that the largest experimental turbine in its research program, built in the early 1980s, had to reach a height of 100 m (called GROWIAN project). Wind and site studies, though an emerging discipline, hardly affected the misguided and ill-fated GROWIAN.

6 Only more recently, wind and site studies have become a crucial element for turbine design and the optimization and prediction of wind power yields. It would be interesting to investigate more in detail how this special domain of wind technology developed and expanded. When did wind turbine builders start to develop in-house expertise in wind and siting? At which point in the history of wind turbine innovation did it receive attention? Who were the drivers of this discipline? What disciplinary background prevailed? The author suggests that wind and site studies have become a specialized discipline pursued and developed within wind turbine companies. How did this development play out for different wind turbine developers? What expertise did wind and siting departments develop? Which trajectories of institutionalization and professionalization did wind and site studies take? Are there significant national differences? These are historical questions about the differentiation of knowledge production in the history of wind technology.

7 The author raises many further questions. He experiences, it appears, the emergence of wind and site studies as a new research domain also as a challenge. Differentiation constructs boundaries and creates distances. It raises questions

of professional identity and about the relation to other knowledge domains. Is he a meteorologist or an engineer (or both)? Is the knowledge he and his colleagues produce relatable, even usable in other domains? Historical research can help to find answers and deepen the understanding of this knowledge domain. Engineers, like the author, who sense these open questions and seek broader understanding, help historians, on the other hand, to ask new questions and develop new historical narratives.

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