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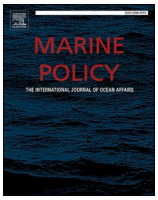

Gone with the wind? Wind farm-induced wakes and regulatory gaps

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ABSTRACT

Wind farm-induced wakes can propagate dozens of kilometres, decreasing the power production and the fatigue lifetime of wind turbines between neighbouring farms. This phenomenon termed hereinafter "wind theft", may lead to legal conflicts between wind farm operators and even States as power production from a wind farm is affected by the wake effects generated by another, reducing power output. Wind theft can substantially slow down the development of offshore wind if it is not regulated by a clear legal framework. In this study, we present the case of Sørlige Nordsjø II, a large offshore area that opened for wind turbine licensing application in 2020, is explored. This area is located in the Norwegian exclusive economic zone (EEZ) on the border to the Danish equivalent zone. Using state-of-the-art reanalysis data covering 1992–2020, it is shown that long farm-induced wake will likely propagate regularly from SN2 into the Danish EEZ and vice versa. This research shows how the United Nations Law of the Sea Convention 1982 leaves a regulatory gap regarding cross-border wind wake effects. As Europe crucially needs to expand its renewable energy production and work towards its net zero objectives by 2050, coastal States should cooperate to find regulatory solutions to wake effects such that wind resource management can be optimised. While some North Sea coastal States demonstrate a political will to cooperate, such policies must proliferate into legal instruments which lend certainty and predictability to wind resource management.

1. Introduction

The offshore wind impetus comes from a national and regional ambition to rapidly increase electricity generation to promote decarbonisation and energy security. In 2020, the European Commission presented the European Union (EU) strategy for offshore renewable energy, which aims to increase the EU's offshore wind capacity from 12 GW in 2020 to 60 GW by 2030 and 300 GW by 2050 [1]. Even more ambitiously, WindEurope estimates that the EU, including the UK and Norway, has the collective capacity to construct 450 GW by 2050 [2].

The offshore renewable energy strategy plays a key role to achieve a sustainable energy transition by 2050 but also to reduce Europe's energy dependency on Russian fossil fuels [3]. The offshore wind energy potential of the North Sea can meet a large share of European's electricity demand [4]. Averaging a nominal output of 12 MW per offshore wind turbine (OWT) with a modern design, reaching 300 GW of installed power corresponds to 16 new OWTs per week until 2050. This high ambition is reflected by Fig. 1, which shows that the number of planned areas for offshore farms (OWFs) in the North Sea is growing in size and numbers.

However, OWF generate wakes characterised by a reduction in mean wind speed and an increase in small-scale turbulence. These wakes have the potential to disrupt the operation of adjacent wind farms and can lead to inter- State/operator conflicts. Recent studies indicate that farm wakes can propagate downwind for distances ranging from 30 km to 55 km [5–7], with even longer wakes observed under specific flow conditions [8]. Satellite data from the North Sea already show evidence of such wakes (see Fig. 2). The loss of capacity factor for OWFs affected

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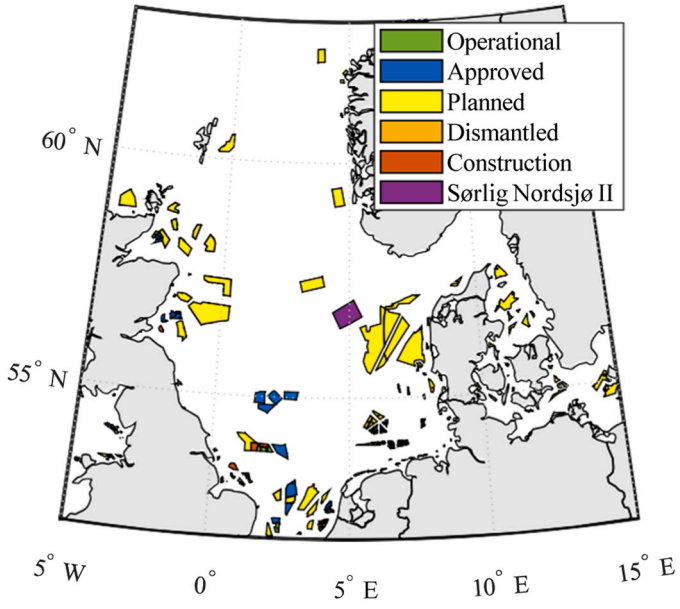

Fig. 1. OWF plans in Northern Europe. The wind farm data are taken from the European Marine Observation and Data Network (EMODnet) as well as Geonorge, which is the national website for map data in Norway. The area labelled "Sørlige Nordsjø II" corresponds to a 2591 km^2 area opened in 2020 for offshore wind licencing applications.

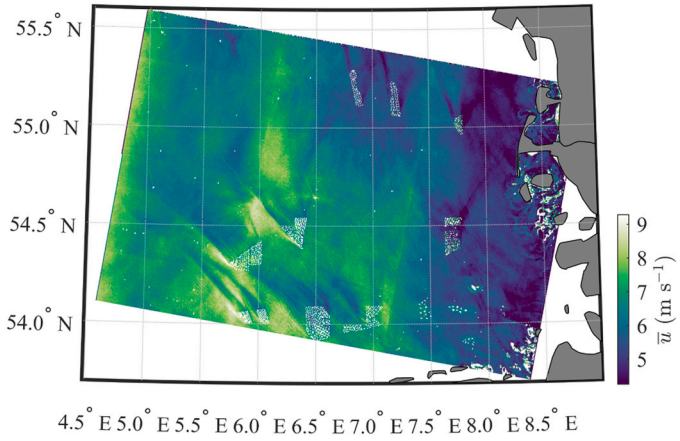

Fig. 2. Mean wind speed u at 10 m above the sea surface observed in the German Bight by the Sentinel-1A satellite on 2022–04–17. Farm-induced wakes spanning dozen of kilometres are visible as darker areas downstream of wind turbines, which are visible as white dots.

by wakes can be as high as 20% [9], resulting in significant production and revenue losses [10]. In another study, Pryor et al. [8] considered the case of (very) large offshore wind farms on the east coast of the USA and estimated power losses of approximately 33% when the wind farm layout is inadequate. In this regard, farm-induced wakes may become a major challenge for the development of the offshore wind energy industry worldwide.

This interdisciplinary contribution explains how OWFs located in different States may negatively impact each other's electricity production due to the existence of a wake effect that diminishes the intensity of winds. It also stresses that the current public international law regime is not well suited to deal with cases of 'wind theft'. "wind theft" is defined as the taking of a significant fraction of the wind resources of a wind farm by another one, located upstream, at a distance too short to allow full wake recovery. The term 'wind theft', which describes the physical phenomenon of wind wakes, comes with important legal implications. Legally speaking, according to Public International Law and Law of the Sea, the wind is not 'stolen' as neither coastal States or project developers own the wind. Coastal States, as discussed below, have sovereign rights to utilise wind currents to generate energy - this latter being the one subject to sovereign rights. The use of 'wind theft' illustrates the physical phenomenon, incorporates its legal implications, and makes this concept more understandable to the reader. These wind wake effects belong to an unexplored area of legal research and the objective of this paper is to demonstrate the regulatory uncertainty under public international law to effectively address this problem. Against the ambiguous regulation on wind exploitation and its resulting wake effects, this paper argues that the identification of likely wind theft should trigger obligations of cooperation between States and/or wind farm operators. Such cooperation may result in different solutions that can be advanced as alternatives: compensation mechanisms, the inclusion of these effects in national maritime plans, or adopting integrated planning procedures of offshore wind across neighbouring States. This paper argues that such measures are more likely to lead to effective planning procedures and thereby a more seamless energy transition which is more likely to cope with the rapid development of offshore wind in Europe.

In 2019, the average annual electricity consumption in the European Union was 3.7 MWh per household [11]. For a 4.5 GW wind farm, such as the initial concept of Sørlige Nordsjø II in the North Sea, a reduction of the capacity factor from 60% to 40% implies an annual energy production loss of 7.9 TWh. This represents the average annual electricity consumption of two million households. So-called wind theft is therefore liable to have significant economic consequences on part of States and wind farm operators, all of them pressed for space [12]. If wind theft would proliferate, wind farm operators would think twice before deploying turbines next to each other or initiating litigation for compensation claims.

Wind turbine wakes and the mitigation of their effect on wind farm power production are part of two of the three grand challenges in the science of wind energy [13]. An underestimated challenge is the possible conflict between wind farm operators and owners when the far wake of one wind farm affects the performances of another one, thus "stealing its wind". Because wind farm wakes depend on the wind direction, the same wind farm can be both perpetrator and victim of wind theft.

The topic of wind theft is scarcely addressed in literature but has been mentioned in a recent study by Lundquist et al. [10]. Further, to date, no interdisciplinary research efforts have been conducted on this topic. Due to the consequences wind theft pose for wind farms located near each other, anticipating such possible conflicts is crucial to achieving the milestones set by the EU strategy for offshore renewable energy.

The paper describes the physical phenomenon of wake effects to then set it in a legal context. It inquires if the existing rules applicable under Public International Law deal with wake effects or if this remains an unexplored area of the law. Although wind theft is likely to be a global issue on an intra- and inter-State level, the scope of this contribution is limited to transboundary wind wake effects which fall subject to the governance of public international law and the United Nations Law of the Sea Convention 1982 (UNCLOS) in particular. Answering this, it is discussed if wind resources can be 'stolen' and whether likely transboundary conflicts may be minimised through existing regulatory frameworks. Lastly, the paper will stress that wind theft may pose a threat to maritime and energy policy in the future if not addressed.

The forthcoming discussion is centred on an international dimension, with a North Sea focus, for two reasons. First, such a study has global relevance and its conclusions may be extrapolated to any two neighbouring wind farms. Secondly, wake effects within one single country are to be addressed and ought to be addressed by national site selection and licensing, which varies from State to State.

The paper is organised in the following way: Section 2 shortly reviews wind turbines and wind farm wakes and their influence on the

power output of other wind farms. Here, the case of Sørlige Nordsjø II is introduced, which is a 2591 km^2 offshore area that opened in 2020 for wind development at the border between Norway and Denmark.[6] Where States and/or operators do not cooperate and coordinate offshore development, marine areas may become associated with significant farm-to-farm wake interactions leading to financial losses and legal conflicts. Section 3 examines the legal concept of wind resources and whether it falls subject to regulation in UNCLOS. In particular, it is examined whether the 'due regard' standard in Art 56(2) UNCLOS impose procedural constraints on coastal States with regards to offshore wind development. After having observed that the application of the 'due regard' standard has potential but yet ambiguous implications for transboundary wind theft, the following sections will demonstrate that wind resources do not, on their own, fall subject to categorical regulation in UNCLOS. Taking into account this regulatory deficit, an analogy to shared resources under public international law is drawn on, where it is shown that there are compelling reasons for why offshore wind resources could be comparably regulated. After having drawn on examples of cooperation in transboundary fisheries management and oil and gas exploitation in the next section, Section 4, concludes that whilst coastal States, particularly in Europe, are evincing an emerging political will to cooperate toward joint management of wind resources, such political aspirations do not sufficiently address the regulatory gap found under public international law.

2. Wind-farm wakes near transboundary regions

Wind does not have an adherence to artificial, jurisdictional boundaries. As a type of energy resource, it is non- exclusive and not spatially fixed considering it is subject to uncontrollable natural variables [14]. Due to its natural features, it is therefore fungible, intangible and not exclusive [14]. Wind energy, like solar energy, may be described as a common resource; it is incapable of physical possession or to be rendered excludable, either by way of proprietary ownership or by sovereign claims [14]. It is, therefore, not wind itself which falls subject to a complex environment of regulation in relation to OWF-related activities, but the capture of wind.

To illustrate the concept of wind theft and to demonstrate that it will likely occur regularly in the North Sea, the case study of Sørlige Nordsjø II (SN2) is referred to hereinafter. To be self-contained, it is first considered appropriate to initially define wind farm wakes and how they affect the power production of neighbour farms. Secondly, the wind climatology at SN2 is used to show that stable atmospheric stratifications, which are associated with longer wakes, are commonly observed near SN2. This gives rise to the presumptions that offshore wind development in this marine area is likely to have transboundary wakes.

Fig. 1 gives an overview of current and planned offshore wind parks in Europe. The planned Danish wind farm Nordsren III vest is located only 22 km southeast of SN2. According to the published literature [5,8], this distance is short enough so that farm-induced wakes affect significantly the power production of both SN2 and Nordsren III Vest, with an effect between States. More generally, Fig. 3 shows that most of the offshore areas displayed in Fig. 1 are located less than 50 km away from their nearest neighbour. Thus, the problem of wind theft is unlikely to only apply to SN2 and Nordsren III Vest.

2.1. Wind turbine and wind farm wakes

The power output of a wind turbine can be estimated by

$$P = \frac{1}{2}\rho A U^3 C_P \tag{1}$$

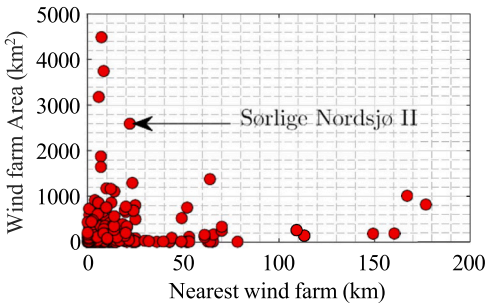

Fig. 3. Minimal distance between the existing and future offshore areas dedicated to wind energy in Northern Europe. Large areas are associated with longer farm-induced wakes, possibly reaching several dozens of kilometres.

where ρ is the air density; A is the area of the disk swept by the rotating blades, i.e., $^1\ \pi D^2$ being D the disk (rotor) diameter; U is the mean wind speed at hub height and $C_P > 0$ is the power coefficient, the value of which cannot exceed 0.59 [15]. The value of the power coefficient depends not only on the wind turbine's aerodynamic properties but also on the operational and environmental conditions.

Eq. (1) can be used to estimate the capacity factor of a wind turbine, which is defined as the ratio between the average energy produced E_{average} and the nominal energy E_{nominal},

$$C_F = \frac{\int_0^T P(t)dt}{\mathrm{P}_{\text{nominal}}\, T} = \frac{\mathrm{E}_{\text{average}}}{E_{\text{nominal}}} \tag{2}$$

where $P(t)$ is the instantaneous power at time t and T is the time window of interest, typically one year or more. Site locations with large extensions, good wind conditions and high C_F values are required to ensure the success of wind projects [16,17]. Although more sophisticated models are used to estimate the energy generation of wind turbines and the surrounding flow field [18,19], the basic model we use here is sufficient to introduce the main concepts required in the present work.

How, then, do the operational and environmental conditions of an OWF determine whether project operators and/or States may find reason for legal claims? Wind turbine wakes correspond to the area downstream of wind turbines associated with a reduced mean wind speed and increased turbulence. Wakes reflect the extraction of energy from the wind and that the wind resource has been partly and temporarily depleted. The capacity factor of wind turbines and wind farms can thus be reduced because of farm-induced wakes. Such wakes can lead to a loss of revenues on part of the affected OWFs, possibly combined with a reduced fatigue life due to increased turbulent wind loading [20].

The wakes propagate downstream of wind turbines, and as air with higher velocity from above is mixed downward into the wake, the velocity deficit decreases. This process, known as wake recovery, is strongly influenced by the thermal stratification of the atmosphere [e.g. [8,10,21–23], which refers to the vertical layering of air with different temperatures and affects air mixing.

In contemporary OWFs, wind turbines are commonly placed at distances of 6–10 times their diameter (D) [24]. For cutting-edge North Sea offshore turbines with a rotor diameter of 164 m, this results in spacing ranging from 1.0 km to 1.6 km between turbines. While increasing the distance between turbines helps reduce wake effects, it can also raise the cost of energy production due to the efficiency loss. Finding the ideal turbine spacing aims to optimise the wind farm's profitability by balancing wake recovery for maximum energy output and the cost of longer submarine power cables required for turbine connections.

The wake behind a wind turbine can result in a reduction of power production when the wind speed within the wake area falls below the rated wind speed. The rated wind speed is the minimum wind speed at which the turbine is designed to generate its maximum power output. Consequently, if the wind speed remains sufficiently high, there will not be a significant decline in power within the wake region.

[6] Royal decree (kgl. res.) on 12 June 2020

The atmospheric boundary layer (ABL) is the lowest layer of the air above the Earth's surface where the surface characteristics have a significant impact on the wind flow. Above the ocean, the ABL depth range from a few hundred of meters to a few kilometres. A shallower boundary layer restricts the vertical extent of wind turbine wakes. This causes the wakes to remain closer to the surface and to slow down the wake recovery. Conversely, a deeper boundary layer allows for more vertical mixing, leading to greater dispersion and dissipation of the wake over a larger vertical and horizontal area.

Wake recovery is thus directly related to the depth of the ABL, the mean wind speed and the ambient turbulence. Under convective conditions, also known as unstable conditions, vertical mixing of the air creates large turbulent eddies that mix more easily with the wake. This helps to break up and dissipate the wake more quickly. Under stable conditions, turbulence is more stratified, reducing vertical turbulent mixing and leading to slower wake recovery. Stable conditions often coincide with moderate to weak wind in the marine ABL [25]. These unfavorable conditions can significantly impact the performance of large clusters of wind farms, especially when the spacing between them is insufficient for wake recovery. To address potential conflicts between wind farm operators and neighboring States, it is crucial to identify wind directions associated with stable flow conditions.

As pointed out by Hansen et al. [22], reducing the spacing between wind turbines increases the sensitivity of the power deficit on the atmospheric stability. Reducing the distance between turbines will also significantly reduce the farm-induced wake recovery [26], which negatively impacts neighbour wind farm power production. It should therefore be assumed that certain project-specific planning measures can mitigate potential legal conflict across operators and/or States, considering the placement of individual turbines can create varying and lessened wake effects.

For the case of the so-called infinite OWF, whose dimensions correspond to one to two orders of magnitude of the ABL depth [27], the optimal distance between wind turbines may be as high as 15D to minimize operational costs and maximize profits [24]. It should be noted that this optimum distance applies to OWFs with low profitability, such as OWFs in transitional waters (30–60 m depth) and at a distance of more than several tens of kilometres from the shore. The area covered by the offshore site Sørlige Nordsjø II (SN2) satisfies the definition of an infinite wind farm. Indeed, the characteristic length of SN2 is 50 km, which is $\sim 10^2$ times larger than the average depth of the marine ABL. Following Antonini and Caldeira [28], the spatial dimensions of wind farms themselves may also affect the wake recovery. Their study suggests that limiting the maximal length of wind turbine arrays to 10–30 km may be advisable to mitigate farm-to-farm wake interactions.

In summary, OWFs and their corresponding wakes are sensitive to various parameters, including the mean wind speed, wind turbine spacing, wind farm dimensions and atmospheric stability. In the following, the paper proceeds to focus mainly on the influence of atmospheric stability on expected wind farm wakes using the example of Sørlige Nordsjø II. The latter case study illustrates how such an area may be associated with conflicts between OWFs both bilaterally and multilaterally in terms of States' marine borders.

2.2. Case of Sørlige Nordsjø II (SN2)

In June 2020, the Norwegian government opened two areas on the Norwegian continental shelf (CS) for license applications related to offshore wind energy projects. By late March 2023, applicants have formally been invited to pre-qualify for the upcoming tender and qualitative assessment for SN2 and Utsira Nord.[7] The first one, Utsira Nord, is suitable for floating wind turbine technologies. The second one, SN2, is adapted to bottom-fixed wind turbines due to its shallower waters.

SN2 covers an area of 2591 km^2 and is located approximately 150 km from the Norwegian coast. It is positioned right at the border of the Norwegian EEZ with the Danish EEZ. Due to its location, SN2 is suitable for cross-border connections with Denmark and continental Europe where feasible. However, a strategic environmental impact assessment showed that this area was principally allocated due to the excellent wind and water depth conditions [29]. Turning to potential wake effects arising from developing SN2, the Norwegian licensing authorities have in a white paper sought that at least a 5 km buffer zone between individual OWFs is adequate to mitigate wind wake effects.[8] A 5 km buffer zone between individual OWFs may be insufficient spacing to mitigate wake effects. Further, the white paper did not assess the implications of wake effects on the Danish side of the border.

According to a recent report from the United Nations on the energy transition [30], cross-border integrations play a key role in the achievement of SDG7 and net-zero emissions. From the observations presented in this paper, it may potentially lay the groundwork for cooperation between States, which may mitigate wind theft issues. Combined grid solutions, such as for the Kriegers Flak wind farm at the border between Germany and Denmark, are known to improve the resilience of offshore wind farms and to increase the revenues of the wind farm operators [31]. In February 2022, the Norwegian government announced that the preliminary design of the wind farm layout for SN2 favours a single connection to Norway only. The total installed capacity at SN2 will be 3 GW following a two-phase commissioning approach, each being associated with 1.5 GW of installed wind power. The power capacity of SN2 will be significantly larger than that of OWFs commissioned in the North Sea between 2000 and 2021.

The sea depth at SN2 ranges from 53 m to 70 m, which is suitable for both floating wind turbines and bottom-fixed turbines mounted on jacket structures. Floating offshore wind turbines are relatively new but have shown promising potential through pilot wind farm projects, e.g. Hywind Scotland [32]. Further, they have been promoted by the Norwegian State for offshore wind projects in Norway in connection to oil and gas platform electrification, with the Hywind Tampen project [33]. In 2021, the largest wind turbine commissioned in the North Sea had a capacity of 9.5 MW (Triton Knoll Wind Farm, United Kingdom). In 2023, the Dogger Bank offshore Wind Farm (United Kingdom) will be commissioned with GE Haliade-X 13 MW wind turbines. The rapid increase in the power capacity of offshore wind turbines implies that the nameplate capacity of the turbines installed at SN2 will exceed 13 MW. The rotor diameter of a 13 MW wind turbine is ca. 220 m leading to a capacity factor above 50%. This high-capacity factor compensates for the higher-than-average Levelized cost of energy (LCOE) associated with offshore wind energy [34]. The LCOE refers to the average cost of producing electricity from a particular energy source over its lifetime. It takes into account various factors such as initial investment costs, operating and maintenance expenses, fuel costs, and the expected energy production over time. The LCOE provides an insight into energy investment decisions by estimating the long-term cost-effectiveness of different generation technologies.

Reducing the impact of wind farm wake is one element that may keep wind-generated electricity prices affordable as production is increased. Surprisingly, a review on the LCOE of offshore wind by Johnston et al. [34] did not consider the effects of wind farm wakes. This shows a lack of awareness about the interactions between neighbouring wind farms and the potential legal consequences it may have.

[7] The conditions surrounding the tender process for SNII and Utsira Nord were recently announced and the deadline for pre-qualification has been set to August 2023. See https://www.regjeringen.no/no/aktuelt/na-lyser-regjeringen-ut-de-forste-havvindomradene/id2969473/ accessed 24/03/2023´

[8] Høringsnotat om tildeling av fase én av Sørlige Nordsjø II (2022) available at https://www.regjeringen.no/no/dokumenter/horing-av- prekvalifiseringskriterier-og-auksjonsmodell-for-sorlige-nordsjo-ii/id2949763/?expand=horingsnotater accessed 13/07/2023

2.3. Wind climatology at SN2

The climatology of SN2 is assessed using two state-of-the-art wind databases: ERA5 from the European Centre for Medium-Range Weather Forecasts [35] and NORA3, which is made with the HARMONIE-AROME model [36,37]. In the context of wind resource assessment, the term climatology refers to a statistical description of the mean wind speed and mean wind direction at heights relevant for the design of wind turbines.

ERA5 provides climate data at a global scale with a horizontal spatial resolution of 31 km and a temporal resolution of 1 h. NORA3 shrinks the information from ERA5 to provide atmospheric data with a horizontal spatial resolution of 3 km and a temporal resolution of 1 h.[9] NORA3 was found reliable offshore [37], especially compared to other wind databases [38].

In this study, 753 grid points in SN2 were examined for mean wind speed and direction from NORA3 at a height of 100 m. It was found that the wind patterns were similar throughout the area. Therefore, the average of the mean wind speed and direction was taken. The height of 100 m is widely used for wind energy applications and corresponds to the hub height of modern offshore wind turbines. However, the hub height of the next generation of wind turbines will likely be located between 150 m and 200 m asl.

The sea surface temperature (SST) and air temperature at 2 m above the surface are obtained from ERA5 for the SN2 area. In this study, we use the air-sea temperature difference as a simplified measure of the thermal stratification of the atmosphere. This temperature difference, denoted as ΔT, is calculated as

$$\Delta T = T_2 - T_{sea} \tag{3}$$

where T_2 represents the air temperature at 2 m above the sea surface and T_{sea} represents the sea surface temperature.

Jacobsen and Godvik [32] have shown how the measured wind-induced response of floating wind turbines is influenced by both the air-sea temperature difference and the presence or absence of wind turbine wakes. When the ambient air is warmer than the sea surface ($\Delta T > 0$), stable conditions are more likely to be observed. Such stable conditions are commonly found in early spring and when the wind speed is lower than the rated wind speed. Conversely, if the ambient air is colder than the sea surface ($\Delta T < 0$), potentially unstable conditions can occur.

Fig. 5 presents the directional distribution of wind speed conditions at SN2 using data from 29 years (1992–2020). As mentioned in Section 2.1, wind turbine wakes dissipate more quickly under unstable atmospheric conditions. Specifically, Fig. 6 highlights the association of northwesterly and easterly wind directions with such conditions.

In Fig. 6, stable atmospheric conditions occur in more than 20% of the cases for various wind directions. These conditions promote long wake effects and may have a significant impact on the future power production of SN2 and nearby wind farms located within the Norwegian and Danish economic zones.

The results presented in Section 3 show that transboundary farm-induced wakes will be regularly observed in the vicinity of SN2, possibly disturbing the power production of neighbouring wind farms, in particular at the border between Norway and Denmark. To facilitate the development of offshore wind in the North Sea and to mitigate potential legal conflicts, it is thus necessary to regulate transboundary wind wake effects.

The prediction of wind farm wake losses is subject to significant uncertainties. According to Cañadillas et al. [39], current state-of-the-art numerical models may not fully capture the impact of wind farm wakes under stable atmospheric conditions. The complexity of the issue arises from various physical factors, such as the wake effect of individual turbines, the layout of the wind farm, interactions between neighbouring farms, and the influence of environmental conditions on wake propagation. To address these complexities and uncertainties, further dedicated research is needed, specifically focusing on the wakes in the Sørlige NordsjøII wind area. While this paper does not specifically address the detailed research required for the Sørlige Nordsjø II wind area, further dedicated investigations in this area are crucial to provide more specific information on the magnitudes or frequencies of wake impacts and help mitigate power losses in downstream wind farms.

3. The regulation of wind wake effects under Public International Law

3.1. Is there a logic behind regulating 'wind theft'?

Wind theft produced by wake effects is likely to create legal conflict between States and OWF operators and lead to poor marine area management across coastal States where regulation does not require or encourage cooperation. In the following sections, it is assessed to what extent public international law mandate principles of cooperation or cooperative management related to wind resources or whether it is omitted in a regulatory gap. In particular, it is inquired whether UNCLOS has any rules requiring specific conduct when a proposed or existing OWF in one State is likely to affect the resource potential in adjacent States. As has been demonstrated already, where one OWF is deprived of its resource potential due to the wake effect arising from an adjacent OWF, it will produce less power and generate less revenue, which further increases the cost of energy delivered to consumers for end consumption. In addition to the economic effects caused by wind wakes, a decrease in renewable wind energy production may imply that this 'missing energy' could be compensated by electricity generated from carbon-intensive sources, further exacerbating environmental concerns.

Two particular legal considerations arise in relation to wind theft which justifies the present analysis. First, wind resources may be seen as having economic value where technologies provide the means of exploiting winds for renewable electricity production. Where the indirect wake effect of one OWF affects the resource potential downstream to adjacent wind farms in other coastal States, the former may be seen as having been economically deprived of exploiting the same wind resource. Having been deprived of wind resources, offshore wind deployment becomes less financially feasible which may leave coastal States with less incentive to promote renewable energies.

Second, wind theft may lead to a 'race to the water' phenomenon in which coastal States rush marine planning procedures or licensing rounds to ensure that the marine project area still holds the best possible wind capacity before other States reduce the economic potential by virtue of their own OWFs [40]. Where coastal States rush such procedures in the allocation of sea spaces and resources, principles of environmental protection, marine management and the ecosystem-based approach, may be neglected which may leave States' in breach of their obligations under inter alia the OSPAR and ESPOO Convention and applicable EU/EEA law [40].

As demonstrated below, public international law prescribe broader principles of cooperation that are key when addressing cross-border wind theft issues. The responsibility not to cause transboundary harm and to take preventative action reflects such broader principles of cooperation which is well reflected in customary international law as can be traced to the influential 1972 Stockholm Declaration and the 1992 Rio Declaration [41]. While it is evident that wind theft can have economic effects on neighbouring coastal States, it is however uncertain whether this amounts to significant transboundary harm under

[9] https://thredds.met.no/thredds/projects/nora3.html

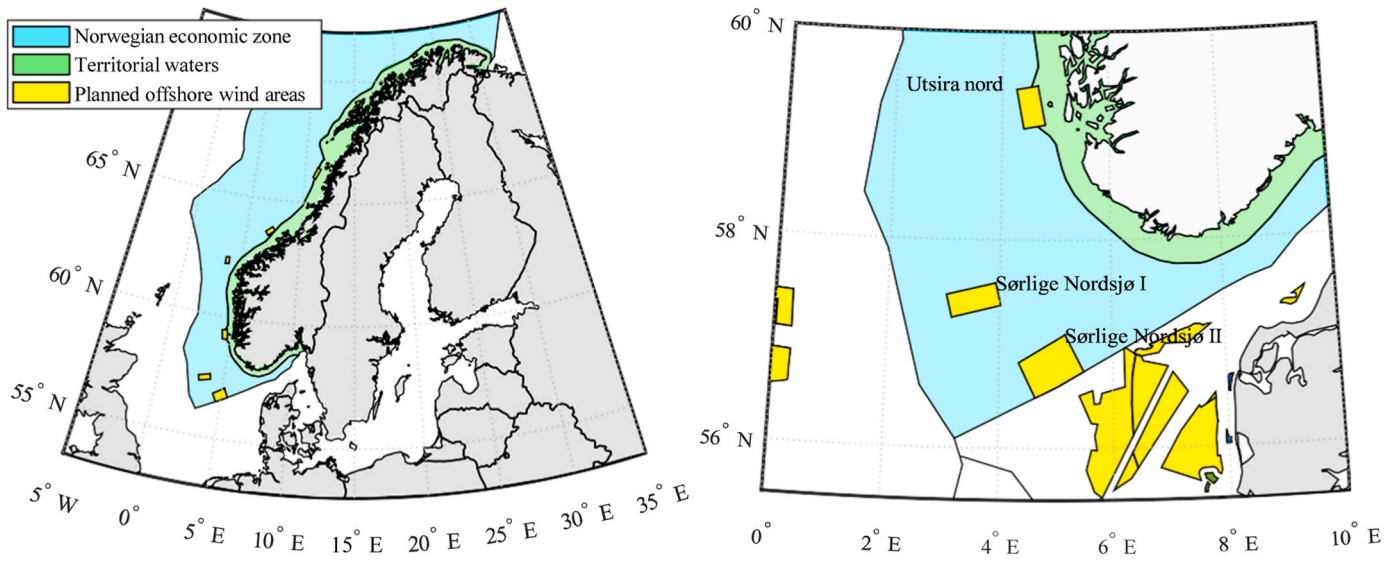

Fig. 4. Left: Areas opened for wind farm deployment in the Norwegian economic zone. Right: Close up on the Sørlige Nordsjø II, in the North Sea, at the border with the Danish economic zone.

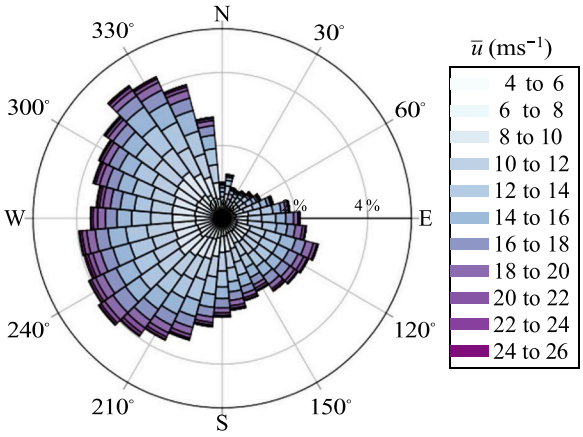

Fig. 5. Wind rose of the mean wind speed at SN2 at 100 m asl using hourly data from NORA3 between 1992 and 2020.

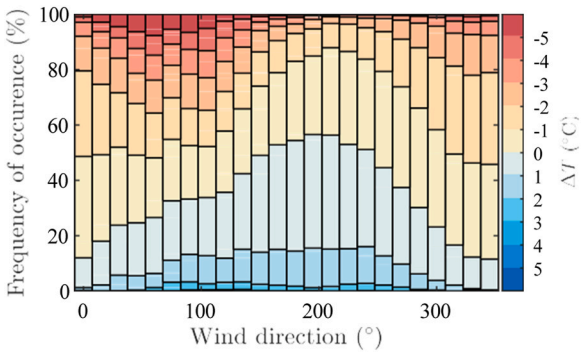

Fig. 6. Dependency of the air-sea temperature difference Δ_T on the mean wind direction at SN2. Hourly data provided by ERA5 and NORA3 between 1992 and 2020 were used. The mean wind speed and direction are provided at 100 m asl.

international law.[10]

Although the duty to cooperate may not mandate a substantive result, the procedural content of the obligation can be seen as limiting the sovereign right of the coastal State to exploit and explore certain natural resources. For instance, where principles of cooperation in UNCLOS have not been complied with in circumstances of likely transboundary harm, the International Tribunal for the Law of the Sea has been known to enforce UNCLOS provisions with the view of mandating consultations between States where they exchange information, monitor environmental effects and devise measures to prevent marine pollution.[11] Hypothetically speaking, coastal States' sovereign right to exploit wind resources in the EEZ would thus be limited if duties to cooperate would be triggered in circumstances of likely transboundary wind-theft.

3.2. *The Law of the Sea Convention and wind exploitation in the Exclusive Economic Zone and the 'due regard' standard*

Public international law and UNCLOS in particular regulate and recognise the exploitation of wind resources as an activity of energy production [42]. UNCLOS is the key regulatory instrument in this regard, being widely accepted by States, affording them rights and duties related to the exploitation of living, and non-living resources and renewable energy resources at sea. Widely recognised as a living instrument which progressively evolves through dynamic interpretation [43,44], UNCLOS was, during its inception, meant to capture the future uses of the sea.[12] UNCLOS distinguishes between sea spaces in which the State enjoys its jurisdiction and power - be it unlimited or limited in terms of sovereignty and sovereign rights. Starting with the territorial sea which stretches outwards to 12 nautical miles from the baseline,

[10] The question of whether wind theft indeed amounts to significant transboundary harm under the *Trail Smelter Arbitration* (United States v Canada) (Decision of 11 March 1941) 3 RIAA 1938 and the International Law Commission, 2001 Draft Articles on Prevention of Transboundary Harm from Hazardous Activities, with commentaries, to either persons, property or environment of other States exceeds the scope of this paper and will not be addressed

[11] *The Mox Plant Case* (Ireland v the United Kingdom) Provisional Measures Order 3 December 2001

[12] This can be deduced from the *travaux preparatoires* to UNCLOS. See Secretary General, 'Description of some types of marine technology and possible methods for their transfer: report of the Secretary-General' (27 February 1975) A/CONF.62/C.3/L.22, para 2

where the coastal State has sovereignty,[13] to the High Seas, an area belonging to mankind and in which States may only exercise the freedoms of the high seas, but with due regard for the interests of other States.[14]

In between these spaces of full and no sovereignty lies the EEZ where coastal States enjoy sovereign rights. The EEZ extends up to 200 nautical miles from the baselines and it can be defined as an area beyond and adjacent to the territorial sea.[15] This zone therefore finds itself at the end of the territorial sea at 12 nautical miles and out to 200 nautical miles measured from the baseline. Thanks to technological development, and to both maximize energy production by being exposed to stronger wind flow, and minimize conflicts with stakeholders, [45] OWF projects are expected to be located further ashore and typically within the EEZ. In Europe, for example, the average distance of existing projects is approximately 32 nautical miles from shore [46].

In contrast to the territorial sea where sovereignty is the prevailing jurisdiction, coastal States only enjoy sovereign rights in the EEZ. These sovereign rights are broadly summarized in Art 56(1)(a) as to involve:

> *exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds*

UNCLOS affords coastal States the right to *exclusively* manage and control all economically oriented activities within the EEZ, including the production of energy from the water, currents and winds [47]. Furthermore, Art 60 UNCLOS provides that the coastal State has jurisdiction (i) to establish and use artificial islands, installations and structures[16]; (ii)conduct marine scientific research; (iii) protect and preserve the marine environment and other duties and obligations stipulated elsewhere in the Convention.[17] Offshore wind farms and their respective turbines can be classified as either 'installations' or 'structures' under Art 60 UNCLOS [48,49]. This means that coastal States are the only ones that have the right to control, utilise and regulate these resources in a said area based their respective sovereign rights [42]. In the case of the territorial sea, the situation is the same, with further exclusivity and States having full sovereignty over these waters, the seabed and the subsea surface.

However, the sovereign rights of coastal States to develop offshore wind resources cannot be read in isolation from its duties toward other States. The concept of 'due regard', enshrined in Art 56(2) in UNCLOS for activities within the EEZ and Art 87 regarding the high seas, places limitations on States as it circumscribes general and specific duties toward other States, the concept of which may prove a regulatory tool to deal with issues of 'wind theft'. The concept of due regard and the limitations it might bring to a coastal State do not extend to the territorial sea as remarked in the literature [50,51]. Concerning the EEZ, Art 56(2) UNCLOS reads the following.

> *In exercising its rights and performing its duties under this Convention in the exclusive economic zone, the coastal State shall have* ***due regard*** *to the rights and duties of other States and shall act in a manner compatible with the provisions of this Convention (emphasis added)*

The 'due regard' obligation, which is extensively discussed by Foster [52], is broadly recognised as an elastic standard which attempts to reconcile overlapping or conflicting interests between States by ensuring conciliation [53]. The standard principally require coastal States to balance their own rights and interests against those of other States and to consult with them in good faith accordingly concerning activities within the EEZ and eventually the high seas. The 'due regard' standard is an obligation of conduct and not result, considering it mandates procedural requirements which in some form should result in cooperation between States.[18] It would therefore appear that where coastal States exercise their sovereign right to exploit wind resources in the EEZ, it must have due regard to its adjacent States' equivalent rights under UNCLOS.

As noted in the Chagos Marine Protected Area Arbitation of 2015, the 'due regard' obligation does not impose a universal rule of conduct nor does it uniformly prevent the impairment of other States' sovereign rights.[19] Rather, the extent of 'due regard' must be quantified against the nature of the rights held by the other State, their importance, the extent of the anticipated impairment, the nature and importance of the activities contemplated by the coastal State in question, and the availability of alternative approaches.[20]

Based on this test and its evident emphasis on 'extent' of impairment and the nature and importance' of the activities planned, the 'due regard' standard does not necessarily apply to all conceivable circumstances of transboundary wind theft. What, then, is the reach of the 'due regard' standard and when does it not apply to transboundary wind theft? Unfortunately, this point of law was not addressed by the Tribunal considering Mauritius's rights to fish in the Chagos was suspended altogether due to the marine protection area set around it by the UK. The impairment of Mauritius's rights were therefore quantifiable at the far end of the scale, which did not require the Tribunal to contemplate other thresholds which, in the negative, would not trigger the 'due regard' standard and its inherent procedural requirements. However, it would appear that the threshold is reasonably low considering the Tribunal stated that 'In the majority of cases, this assessment will necessarily involve at least some consultation with the rights-holding State. [21]

The point raised in the paragraph above raises a paramount question; in relation to the legal effects flowing from Art 56(2), when is transboundary wind theft considered a sufficient impairment of other States' sovereign rights? The abstract and open-ended nature of the 'due regard' standard makes it difficult to give a conclusive answer. This is further complicated by the absence of relevant case law on the topic considering the contemporary issue of wind theft has not been brought before any international tribunals to date.

Additionally, the applicability of the obligations derived from the 'due regard' standard have limited geographical scope as they do not extend to activities taking place in territorial waters. This is another issue deserving of discussion and perhaps regulation.

The implications from the 'due regard' standard are unclear and due to the nature of wind theft, and its limited express governance, it seems as if they would have to be answered on a case-by-case basis. However, the standard of 'due regard', where applicable, imposes one clear-cut requirement on coastal States when acting within their EEZ regarding wind theft. It creates an obligation to consult with adjacent States that would be affected by wind theft in circumstances where Art 56(2) has effect. In more practical and perhaps normative terms, an extensive interpretation of the 'due regard' to the rights of other States in their own EEZ and/or territorial sea should ideally imply the creation of buffer zones within the EEZ of the coastal State authorising the OWF to mitigate transboundary wind theft. Although the creation of buffer zones goes beyond the current legal content of the 'due regard' standard

[13] UNCLOS, Arts 2 and 3
[14] UNCLOS, Art 87
[15] UNCLOS, Art 57
[16] These cannot, just as with artificial islands, installations and structures in the territorial sea, create an extraterritorial delimitation of some additional territorial sea, EEZ or the CS. See Art 60(8) in the Convention
[17] UNCLOS, Art 56(1)(b)-(c)
[18] Chagos Marine Protected Area (Mauritius v United Kingdom) (Award) (2015) Case no 2011–03 UNCLOS Annex VII Tribunal (hereafter Chagos Arbitration), para 322
[19] ibid, para 519
[20] ibid
[21] ibid

which has been interpreted as mainly having a procedural character limited to consultations,[22] their proximity to adjacent OWF and location should ideally be defined through transboundary cooperation as part of the obligation of consultation already mentioned. If not, States could alternatively explore options to enter into bilateral trade agreements in which upstream States can trade rights to consume less wind resources in favour of downstream States [54].

In addition to these considerations and potential limitations arising from the 'due regard' standard set by Article 56(2) UNCLOS, the following sections will investigate UNCLOS and international law more generally to see whether transboundary wind theft fall subject to other regulation, which perhaps is framed in more clear-cut terms than 56(2) which is otherwise open-textured and relatively indeterminate [55].

3.3. The lacking legal status of wind resources

In furtherance of Art 56(2) and its ambiguous 'due regard' standard which places procedural limitations on the sovereign right of coastal States to exploit wind resources insofar as transboundary consultations are concerned, the forthcoming paragraphs will investigate whether offshore wind exploitation fall subject to other limitations by virtue of the categorical approach UNCLOS takes in relation to natural resource regulation.

The explicit reference to winds in Art 56(1)(a) above is important as it demonstrates that UNCLOS regulates the rights, and limitations, to the exploitation of natural resources. This adds another layer to wind theft and its regulatory complexity. While Art 56(1)(a) UNCLOS strikes a clear distinction between living and non-living resources, a purely textual approach to treaty interpretation would suggest that renewable energy resources, such as the express mentioning of 'winds', are mentioned as a third and separate category of resources due to the wording of 'and with regard to other activities' in the legal provision fully quoted above. Except for the solitary reference to wind resources in Art 56(1), and the implied limitation flowing from the 'due regard' standard in Art 56(2), UNCLOS makes no direct mention of how the sovereign right to exploit such resources may be limited in furtherance of requiring transboundary consultations as per Art 56(2), i.e. by requiring or encouraging cooperation with affected adjacent States.

The classification of resources is important as UNCLOS implies differential treatment and assignment of sovereign rights relative to different natural resources. Whereas UNCLOS impose clear-cut rights and obligations regarding the conservation and utilization of living resources in the EEZ,[23] there are no equivalent limitations to sovereign rights in respect of the exploitation of mineral and other non-living resources of the seabed and subsoil on the CS under Part VI of the Convention.[24]

Concerning living resources in particular, Art 64(1) imposes certain obligations of cooperation with other States in relation to the conservation and management of highly migratory species with the view of achieving optimum utilisation. The living resources referred to are listed under Annex I as inter alia various tuna species. Art 63(1), which regulates the exploitation of fish stocks occurring within the EEZ of two or more coastal States, also reflects a similar obligation to cooperate [41].[25] Fish stocks, like wind resources, move indiscriminately across delimited territorial borders. Therefore, it seems appropriate to entertain the comparable features of the natural resources in which both are characterised by indiscriminate movement across delimited borders. Without entertaining the comparison any further, one may contemplate the duty to cooperate concerning living resources under Part V of UNCLOS as a fitting transposition to the exploitation of wind resources under Art 56(1)(a).

Despite this duty to cooperate, UNCLOS appear to treat non-living resources differently. There is no explicit obligation of cooperation in respect of non-living resources on the CS unless a coastal State exploits a resource on a territorial boundary which is yet to be delimited. It can be deduced from the language used in Art 74(3) that States 'shall make every effort to enter into provisional arrangements of a practical nature and, during this transitional period, not to jeopardise the reaching of the final agreement'. Although the provision does not require States to unitize or share a straddling deposit, a unilateral move to exploit it could most certainly be seen as contravening or jeopardising the reaching of a final agreement. Notwithstanding the former provision, such agreements have been reached on a regional basis in the North Sea concerning the cooperation of cross-boundary petroleum deposits between the UK and Norway.[26] At first, this may reflect the nature of some non-living resources as exhaustible once utilised: the crude oil that is extracted from the CS and then processed in refineries is gone. Further, these exhaustible resources are subject to appropriation and the property of the coastal State, so these can be exploited following their natural interest.[27]

Returning to wind energy, both coastal States and wind-farm operators have not consulted with adjacent States with regard to likely transboundary wind wakes. As the only limitation to offshore wind exploitation and transboundary wake effects in UNCLOS, it remains to be seen whether Norway will engage in consultations with Denmark concerning offshore wind development in SN2 which will likely have transboundary wake effects on the Danish EEZ, and the legal basis which will be invoked for such conduct.

3.4. Can wind be shared? The analogy of shared resources and international watercourses

Notwithstanding Art 56(2) and the limitations that may derived from the 'due regard' standard, another regulatory avenue worthy of exploration is whether offshore wind resources can be termed as a shared resource under public international law. The analysis is pertinent considering the regulation of shared resources under international law compels certain obligations of cooperation, reflecting customary international law, on States [41].[28] The concept of shared natural resources stresses the need for cooperative management such that riparian States are not deprived of an equitable share of the resource in question [56]. In this regard, the wording of 'transboundary' in the context of international watercourses is synonymous with the wording of 'shared'. States have generally refrained from endorsing the wording of 'shared' as it encroaches on notions of sovereignty – hence why the wording of 'transboundary' is used [57].

Watercourses which permeate artificial boundaries affect both the geographical and economic interests of two or more States [58]. The rationale for coining an international watercourse as a shared resource is

[22] Chagos Arbitration, para 322

[23] UNCLOS, Arts 61 and 62

[24] UNCLOS, Art 77(4)

[25] Also see Request for an Advisory Opinion submitted by the Sub-Regional Fisheries Commission (SRFC), para 175

[26] Art 3.2 in the Framework Agreement Between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway Concerning Cross-Boundary Petroleum Co-Operation which requires that each State to '... to require its Licensees to enter into a Licensees' Agreement to regulate the Exploitation of a Trans-Boundary Reservoir in accordance with this Agreement'

[27] General Assembly resolution 1803 (XVII) of 14 December 1962, "Permanent sovereignty over natural resources"

[28] See inter alia UNGA Res 32/81 (XXIX) Art 3, UNEP Draft Principles 1978, Stockholm Declaration 1992 Principle 21, Rio Declaration on Environment and Development Principle 14 and 19, UNGA Report of the World Commission on Environment and Development – "Our Common Future" (Brundtland Report) 1987 A/42/427 Part III para 50, International Law Commission 2001 Draft Articles on Prevention of Transboundary Harm from Hazardous Activities Art 3 and 4

that unilateral exploitation delimits the possibility of riparian States to exploit the same resource. The analogy to shared resources is thus a fitting one as the effect of wind exploitation may have a comparable effect to that of international watercourses. The case of *Pulp Mills* concerning facilities which processed wood chips, illustrates this point.[29] On the River Uruguay, pulp mills facilities would have discharged materials which in effect would have significant environmental effects on the water quality flowing downstream into the territory of the downstream State. The environmental impact on the water quality and the ecosystem would thus negatively affect the riparian State's right to a reasonable share of the same resource.

It was observed above that wind farms proximate to a delimited boundary have the effect of reducing the downstream flow of wind resources to adjacent States. The environmental effect does as such reduce the affected State's right to a share of the same resource. Although it may seem difficult to equate the wind speed deficit with the notion of 'theft', it may result in reduced access to the affected State's reasonable share of an otherwise undisturbed resource. In respect of the abstraction of water resources, the notion of which may be analogous to wind theft, the International Court of Justice (ICJ) has recognised in a dispute between Hungary and Slovakia that the resource is not limited to the water itself, but also the flow of the water or its "motive force" which enables the State to produce hydroelectric power [59]. Although the analogy to wind resources seems appropriate in this regard, the regulation of shared resources has evolved in line with international watercourses as its subject matter and wind resources do not fall within this category. Although most legal sources which initially addressed the concept of shared resources were resource-neutral, subsequent binding legal instruments have classified international watercourses as either a transboundary resource or shared resource. For instance, the International Law Commission's previous work on international watercourses led to the codification of the 1997 UN Convention on the Law of the Non-navigational Uses of International Watercourses which regulates the management of transboundary watercourses. Preceding the 1997 Convention, the notion of transboundary watercourses also appeared in the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

International tribunals have also played a significant part in coining international watercourses as a shared resource. The classification traces back to the landmark River Oder case in which the court famously stated that a navigable river adjacent to riparian and upstream States creates a basis of a common legal right, otherwise known as the 'community of interest'.[30] From there, disputes over the use of international watercourses have to varying extents addressed such resources as being shared. It was not until the Gabcikowo-Nagymaros case that the ICJ explicitly proclaimed that an international watercourse constituted a shared resource by stating that 'The Court considers that Czechoslovakia, by unilaterally assuming control of a shared resource, and thereby depriving Hungary of its right to an equitable and reasonable share of the natural resources of the Danube ... failed to respect the proportionality which is required by international law'.[31] In the following *Pulp Mills Case*, the court explicitly acknowledged the River Uruguay as constituting a shared resource.[32]

It would nevertheless seem that, much like the regulation of living resources under UNCLOS, the regulation of shared resources under international law is a fitting analogy to how one might regulate wind theft. This is due to the comparable transboundary effect in which unilateral exploitation may deprive riparian/adjacent States of an equitable share of the same resource. Having established this, the next section will review how coastal States have historically cooperated towards managing common living and non-living resources.

4. Implications for wind farm management

The high probability of wind farm-induced wake effects, (Section 2) combined with the unclear implications of the 'due regard' principle of Art 56(2) UNCLOS or the lack of specific public international law obligation of the phenomenon, suggests that conflicts between wind farm operators and/or States may arise in a near future. As implied by the study of Lundquist et al. [10], a coordinated effort is needed not to obstruct the development of the offshore wind energy industry in the North Sea. This challenge is addressed hereafter by focusing on some of the recommendations summarised in a theme report on the energy transition by the [30]. Some of these recommendations explicitly recognise the role of regulation and policies which can aid towards facilitating cooperation for long-term integrated energy planning and cross-border grid solutions. The potential for implementing such solutions for OWF is shortly addressed below.

4.1. What might the cooperative management of natural resources look like?

Where legal uncertainty has previously existed concerning natural resources straddling boundaries, States have cooperated in various ways regarding living and non-living resources. These forms of cooperation may serve as inspiration for solutions regarding wind theft and/or to interpret the content of the 'due regard' principle for activity within the EEZ and perhaps even in the territorial sea of coastal States. We discuss this more in detail below.

First, the regulation of living resources under UNCLOS, as discussed in Section 3, have paved the way for international cooperation through framework treaties establishing so-called Regional Fisheries Management Organisations (RFMOs) [60]. An example of such cooperation in the North Sea in particular is the Agreement on Fisheries Between the European Economic Community and the Kingdom of Norway which has remained in force since 1980. Although RFMOs have varying mandate to adopt binding decisions between its members, some can set a total allowable catch (TAC) and allocate quotas accordingly [61]. These cooperative mechanisms impose limitations to which a resource can be exploited to promote the objective of the UN Fish Stocks Agreement 1995, Art 2, which is to ensure the long-term conservation and sustainable use of straddling fish stocks and highly migratory fish stocks.

Second, non-renewable energy sources (non-living resource under UNCLOS) such as oil & gas, have been exploited through the above-mentioned Joint Development Zones (JDZ) where coastal States have endeavoured to cooperate towards the management of common deposits [62]. While these agreements tend to be provisional, they nevertheless proliferate beyond delimitation which evinces a political will to cooperate in sharing resources despite delimited boundaries [62]. Not only may such agreements prescribe mandatory unitisation for reservoirs straddling the boundary, but it goes further in limiting intergovernmental field-by-field negotiations and also improved coordination between licensing authorities to facilitate a more effective unitisation procedure [63].

Interestingly, the framework agreement also requires the States to use their best efforts in coordinating their licensing procedures and whereby such licenses are given to developers, they must be given simultaneously and must also be compatible with each other.[33] It thus

[29] *Pulp Mills Case* (Argentina v Uruguay) Judgment ICJ Reports 2010

[30] *River Oder Case* (UK v Poland) No 16 PCIJ (1929) Series A No 23, para 74

[31] *Gabcikovo-Nagymaros Project* (Hungary v Slovakia) Judgment ICJ Report 1997, para 85

[32] *Pulp Mills Case* (Argentina v Uruguay) Judgment ICJ Reports 2010, para 103

[33] Framework Agreement Between the Government of the United Kingdom of Great Britain and Northern Ireland and the Government of the Kingdom of Norway Concerning Cross-boundary Petroleum Co-operation 2005, Art 1.4(2)

follows that unitisation [34] of straddling deposits to a great extent affects and influences licensing procedures. Such an agreement allows developers to exploit a shared resource under a common framework.

Although unitisation in joint developments have been the favoured approach to cooperative management of straddling petroleum resources in the North Sea, there are principally three other ways in which cooperative mechanisms can manifest in bilateral treaties. Lagoni [64] identifies these as (i) Geological Cooperation, (ii) Joint operations and (iii) Functionally Limited Condominium. These methods of cooperative management can be drawn from State practice and whichever approach is adopted by the States depends on the legal and factual circumstances.

It must however be appreciated that the exploitation of oil & gas resources in fixed deposits straddling delimited boundaries is a reasonably measurable operation in which it can be more easily calculated how the natural resource should be equitably shared between coastal States. This is not necessarily the case with wind resources and bespoke legal mechanisms would presumably have to be catered for cooperative management of wind resources which in physical terms are dynamic and not static.

4.2. Is there sufficient political will to foster legal cooperative management?

Keeping in mind that the North Sea States have historically entered into bilateral agreements promoting cooperative management of non-living resources straddling boundaries, the following question may thus be asked; have coastal States in the North Sea demonstrated a political will which may eventually translate into legal instruments which promote cooperative management of wind resources in a transboundary context?

Although the above may give the impression that cooperation between coastal States concerning wind exploitation is entirely unfamiliar to international relations, this is not true. While UNCLOS and other sources of public international law may omit wind theft from its scope and its categorical approach to the regulation of natural resources, coastal States have still endeavoured to cooperate towards integrating marine planning procedures and implementation of OWFs with interconnectors respectively. Although most of these are regional and in one case bilateral only, it nevertheless evinces a political will toward cooperative management emerging in European marine waters.

Germany, Denmark, the Netherlands and Belgium recently signed the Esbjerg Offshore Wind Declaration 2022 in which the signatory parties have agreed to jointly develop the North Seas for future offshore wind exploitation. A similar declaration was signed for the Baltic Sea in which the 9 Members aspire to 'develop a better-coordinated approach to comprehensive planning and implementation in view of harnessing this potential whilst taking into account other uses of the sea and environmental protection'.[35] Additionally, the North Seas Offshore Grid Initiative comprising ten members including the European Commission seeks to develop integrated grids by way of harmonizing national marine spatial plans. It is important to note in this regard that the Initiative works specifically towards integrating grids and not OWFs per se. Grid infrastructure is however ancillary to OWFs which demonstrates relevance in terms of offshore wind cooperation.

Furthermore, the European Commission issued a grant in 2020 in favour of a joint offshore wind project between Denmark and Germany.[36] Both coastal States will cooperate towards a combined grid solution between Kriegers Flak and Baltic 1 and 2 in the Baltic Sea spanning the EEZ of Denmark, Germany and Sweden. Such hybrid connections traversing delimited boundaries can be seen as a first-mover in terms of cooperative management of wind exploitation.

Marine spatial planning can perhaps act as a catalyst towards offshore wind cooperation in circumstances of wind theft. Marine spatial planning is a process, practically resulting in a plan or map in a larger marine area in the marine waters falling under the jurisdiction of a coastal State, which facilitates coordination and facilitation of different offshore activities which may or may not include offshore wind exploitation [65,66]. At the regional level, cooperation through coordinated marine spatial planning is encouraged by the OSPAR Commission of the Marine Environment in the North-East Atlantic.[37] At the supranational level in the EU, even more encouraging legal commitments can be observed which require Member States to cooperate 'with the aim of ensuring that maritime spatial plans are coherent and coordinated across the marine region concerned', particularly in relation to issues of a transnational nature.[38]

It is evident that political will is present amongst North Sea coastal States but it awaits to be seen whether this will proliferate into specific legal mechanisms which either encourage or require cooperative management of wind resources in circumstances of wind theft.

5. Conclusions

To achieve the energy transition, Europe aims to significantly increase the number of wind farm clusters in the North Sea by 2050. This development will likely be associated with farm-induced wakes that reduce the performances and revenues of neighbour wind farms. The creation of wake effects in wind exploitation may be interpreted as wind theft. The issue of wind theft described in this paper is evident and it will, with great confidence, result in legal issues and conflict in the foreseeable future.

This paper has focused on farm-to-farm wake propagation across international borders. To illustrate this phenomenon, the case study of SN2 was used. This 2591 km^2 area, as was recently made available for pre-qualification applications, is located on the territorial border in the EEZ between Norway and Denmark. Using the wind climatology provided by the state-of-the-art wind atlas NORA3, it was showed that long-farm wake promoted by stable atmospheric stratification will be commonly observed near SN2, with a frequency of occurrence between 20% and 50%, depending on the wind direction. Based on this observation, this paper aims to raise awareness about the lack of a legal framework regulating wind theft. Anticipating and adopting laws which recognise wind theft as a phenomenon is crucial to allow for more effective deployment of OWF in the North Sea. Whether such preventative measures adopted in planning procedures for offshore wind result in coordination efforts and/or compensatory methods remains to be seen.

North Sea States should be incentivized and encouraged to cooperate on a bilateral and multilateral basis where it is suspected that a proposed OWF is likely to have transboundary effects in terms of wind theft. Taking into account the discussion of Art 56(2) UNCLOS above and the 'due regard' standard which may impose procedural limitations to offshore wind development liable to transboundary wind theft, implementing certain principles of cooperation and/or buffer zones between North Sea coastal States or between OWF operators in an intra-State context should be seen as necessary to minimise the potential for conflict in circumstances of likely wind theft.

A regulatory gap, or legal uncertainty in relation to existing

[34] Unitization can be defined the 'the joint, coordinated operation of an oil or gas reservoir by all the owners of rights in the separate tracts overlying the reservoir or reservoirs', see Fjærtoft et al. [63]

[35] 2020 Baltic Sea Offshore Wind Joint Declaration of Intent

[36] See Commission Decision (EU) 2020/2123 granting the Federal Republic of Germany and the Kingdom of Denmark a derogation of the Kriegers Flak combined grid solution pursuant to Article 64 of Regulation (EU) 2019/943 of the European Parliament and of the Council

[37] OSPAR Commission, Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic (NEAS) 2030 (2021)

[38] Directive 2014/89/EU Establishing a Framework for Maritime Spatial Planning, Art 11 and 12

frameworks, in circumstances of wind theft is likely to trigger conflict between adjacent coastal States and also lead to poorer marine management at the national level. In times when our seas are liable to act as hubs for offshore wind development with the view of decarbonizing energy sectors, States must look beyond political aspirations and strive for regulatory solutions to wind theft to optimise resource management and thereby a more seamless energy transition.

CRediT authorship contribution statement

Eirik Finserås: Conceptualisation, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Ignacio Herrera Anchustegui:** Conceptualisation, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Etienne Cheynet:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Cristian Guillermo Gebhardt:** Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Joachim Reuder:** Methodology, Formal analysis, Investigation, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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