RWE Renewables UK Dogger Bank South (West) Limited

RWE Renewables UK Dogger Bank South (East) Limited

Dogger Bank South Offshore Wind Farms

Greenhouse Gas Sensitivity Analysis of Wake Effects

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Glossary

Term	Definition
Capacity factor	The ratio of average power generated by the windfarm under real-world conditions to its theoretical maximum output.
Carbon Dioxide Equivalent (CO_2e)	Carbon dioxide equivalent is a term for describing different greenhouse gases in a common unit. The unit takes the different global warming potentials of greenhouses gases into account. CO_2e is signifies the amount of CO_2 which would have the equivalent global warming impact.
Climate change	A change in global or regional climate patterns. Within this chapter this usually relates to any long-term trend in mean sea level, wave height, wind speed etc, due to climate change.
Dogger Bank South (DBS) Offshore Wind Farms	The collective name for the two Projects, DBS East and DBS West.
National Policy Statement (NPS)	A document setting out national policy against which proposals for NSIPs will be assessed and decided upon.
Sequential Scenario	A potential construction scenario for the Projects where DBS East and DBS West are constructed with a lag between the commencement of construction activities. Either Project could be built first.
The Applicants	The Applicants for the Projects are RWE Renewables UK Dogger Bank South (East) Limited and RWE Renewables UK Dogger Bank South (West) Limited. The Applicants are themselves jointly owned by the RWE Group of companies (51% stake) and Masdar (49% stake).
The Projects	DBS East and DBS West (collectively referred to as the Dogger Bank South Offshore Wind Farms).
Wakes	Flow regions behind wind turbines and wind farms that are characterised by lower wind

Term	Definition
	speeds and higher turbulence levels, caused by the extraction of momentum by wind turbines.
Wake effect	The impacts of wakes on energy production of downstream wind turbines and wind farms.
Wake loss	The loss in energy production from a wind farm due to wake effects, represented as a percentage of the expected energy production.

Glossary of unit Terms

Acronym	Definition
CO_2e	Carbon Dioxide Equivalent
CO_2e/GWh	Carbon Dioxide Equivalent per Gigawatt-hour
GWh	Gigawatt-hour
kg	Kilogram
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
t	tonnes

Acronyms

Acronym	Definition
AEP	Annual Energy Production
BaU	Business as Usual
DBS	Dogger Bank South
DESNZ	Department for Energy Security and Net Zero

Acronym	Definition
EIA	Environmental Impact Assessment
ES	Environmental Statement
ExA	Examination Authority
GHG	Greenhouse gas
OWF	Offshore Wind Farm
UK	United Kingdom

1 Introduction

1. This document provides an assessment of the impact on greenhouse gas (GHG) emissions from potential wakes effects from the Dogger Bank South (DBS) Offshore Wind Farm Projects (the Projects) on neighbouring offshore wind farms.
2. This document has been compiled to address Action Points 9 and 10 from Issue Specific Hearing 3: Offshore Environmental Matters, which are set out below:
   - Submit the sensitivity analysis that they are preparing, which considers the approach to the greenhouse gas assessment and environmental effects from wake loss.
   - Include the impact of wake effects on carbon payment back timescales in the sensitivity analysis/ technical note that is due to be submitted.
3. An overview of the background to the GHG assessment for the Project and potential wake effects is provided in **Section 2**. The methodology for the assessment is presented in **Section 3**, and results and a discussion in **Section 4**.

2 Background

2.1 GHG Assessment for the Projects

4. A GHG assessment for the Projects is presented in Chapter 30 of the Environmental Statement [APP-222]. The assessment quantified emissions released from activities from the Projects across its full lifecycle, including the construction, operation and maintenance, and decommissioning phases. A range of parameters were then evaluated to contextualise the outcomes of the assessment, which included the consideration of a 'Do Nothing' scenario, the concept of which is discussed below.
5. The Projects will produce renewable energy, which will result in the displacement of other forms of more intensive forms of generation. GHG savings from the displacement of emissions were calculated using an emissions intensity factor provided by The Department of Energy Security and Net Zero (DESNZ) for electricity supplied from natural gas, as this is the most common form of new plant in terms of fossil fuel combustion. This scenario was adopted to highlight the level of emissions savings that would occur if renewable energy from the Projects replaced fossil fuel-based forms of generation supplying the grid at the time of assessment. This scenario aligns with the United Kingdom (UK) Government policy to support the transition from fossil fuel generation towards renewable energy.
6. At the time of assessment, the emissions intensity of electricity from natural gas was 370.79 tonnes CO_2 per GWh (DESNZ, 2023). It is noted that the electricity supplied by gas emission factor is in units of carbon dioxide (CO_2) rather than carbon dioxide equivalent (CO_2e). While CO_2 is likely to form the main contribution to generation of electricity from gas, the factor is likely higher if other GHGs are to be included.

7. Predicted GHG savings associated with the Projects were presented in Table 30-26 of Chapter 30 of the Environmental Statement [APP-222], which are reproduced in **Table 2-1**.

Table 2-1 Predicted GHG Savings Associated with the DBS Offshore Wind Farms as Presented in the Environmental Statement

Baseline scenario	Project's total operation and maintenance GHG emissions (tonnes CO_2e)	GHG emissions from 'Do Nothing' scenarios (tonnes CO_2 / CO_2e)	GHG emissions saved by operation of the Project (tonnes CO_2e)
Sequential Scenario	998,171	184,459,713	183,461,542

8. The assessment predicted that there would be a GHG saving of approximately 183.4 million tonnes CO_2e during the operational and maintenance phase of the Projects when compared to the 'Do Nothing' scenario. The figures presented in **Table 2-1** only account for the emissions released during the operation and maintenance of the Projects, and not the full lifecycle.

9. To provide a complete lifetime assessment, emissions from the construction and decommissioning phases of the Projects were also included as part of this indirect effects assessment. Across its full lifecycle, the Projects were predicted to release 7,222,645 tonnes CO_2e, as stated in Table 30-28 of Chapter 30 of the Environmental Statement [APP-222]. This figure is based on a number of conservative assumptions that were adopted in line with the Rochdale Envelope approach to calculate emissions arising from project related activities.

10. Other relevant parameters that were used to contextualise the outcomes of the assessment include:

- Emissions intensity of electricity generated by the Projects, which under the Sequential Scenario was 14.5 g CO2e per kWh;
- The GHG payback of the Projects, which under the Sequential Scenario was 1.2 years.

11. The assessment concluded that the overall significance of effect in GHG terms would be beneficial, which is significant in EIA terms.

2.2 Wake Effects

12. Wake effects, whilst being known as a phenomena for a long time, have become a recurring topic at recent examinations for offshore wind farm projects. In the context of the GHG emissions, submissions by Interested Parties into this examination (see REP1-071:4 and REP1-086:6 of **The Applicants' Responses to Deadline 1 Documents** [REP2-058) have stated that the assessments submitted as part of the application did not account for the reduced generation at neighbouring wind farms as a result of wake effects, and therefore this indirect effect should be accounted for when estimating the GHG savings of a project.

13. The conventional approach for GHG assessments at a project level for offshore wind farms in the EIA process has primarily focused on estimating direct emissions associated with the project under application. Modelling of wake effects is also a complex process, and requires the use of commercially sensitive data to be able to provide figures with a degree of accuracy, which is dependent on transparent data being shared between developers. It is also understood that there is no standardised guidance on how wake effects should be assessed, and therefore an agreed approach between developers is also required. Hence, up until recent case studies, the inclusion of wake effects has not been commonly adopted as part of GHG assessments.

14. The assessment presented in this document provides a sensitivity analysis of hypothetical scenarios to determine whether there is a potential for the outcomes of the GHG assessment, presented in Chapter 30 of the Environmental Statement [APP-222], to be affected by the incorporation of any loss in yield from potential wake effects at neighbouring offshore wind farms.

3 Methodology

3.1 Wake Effects Assessment

15. The GHG sensitivity analysis of potential wake effects considered eight nearest offshore wind farms, as listed below:

- Dogger Bank A,
- Dogger Bank B,
- Dogger Bank C,
- Sofia,
- Hornsea 1,
- Hornsea 2,
- Hornsea Project Three; and
- Hornsea Project Four.

16. These projects were selected as they are either in operation, under construction or have been consented, and sit either partially or wholly within 100 km of the Projects. Any offshore wind farm projects that had not been consented at the time of this assessment (April 2025) were not considered as part of the assessment.

17. Three scenarios were considered as part of the sensitivity analysis on GHG emissions, which assume a uniform wake effect at each of the eight neighbouring offshore wind farms within the scope of the assessment: 0.5%, 1.0% and 2.0%. The offshore wind farms within the scope of assessment are situated at different distances and locations to the Projects, therefore wake effects will not be uniform across each of the offshore wind farms. Consequently, these scenarios are hypothetical only.

18. It is considered for the purposes of the GHG sensitivity analysis that the 2.0% Wake Effect scenario at each offshore wind farm is highly conservative. This is based on the distance and direction of a number of the offshore wind farms within scope, and a review of other recent wake loss assessments completed for offshore wind farms during examinations.

3.2 Scenarios

19. Two scenarios have been considered to calculate the net effect of wake effects on GHG emissions:

- **Business as usual (BaU):** annual energy production from the neighbouring offshore wind farms, in the absence of the Projects.
- **Presence and operation of the Projects**: energy production from the Projects, accounting for the potential reduction in energy production at the neighbouring offshore wind farms due to wake effects. This is measured from the operational start date of the Projects, until the expected decommissioning date of the Projects, or the neighbouring wind farms if this occurs before that date.

20. The following methodology was adopted to determine the effects on GHG emissions associated with wake effects:

- Annual electricity production at each of the neighbouring offshore wind farms was calculated without the Projects in place.
- Annual electricity production at each of the neighbouring wind farms with the Projects in place was calculated, based on the assumed wake effect scenarios of 0.5%, 1.0% and 2.0%.
- The difference in yield (in MWh) over the lifetime of when both the Projects and the neighbouring offshore wind farms were operational was calculated.
- The change in emissions was calculated by using the difference in yield (MWh) by the emission factor used in the GHG assessment to calculate avoided emissions (370.79 kgCO_2e / MWh).
- The outcome was a change in avoided emissions in units of tonnes CO_2e.

21. The change in GHG emissions was subtracted from the value of avoided emissions compared to the Do Nothing scenario, reported in Table 30-26 of Chapter 30 of the Environmental Statement [APP-222], reproduced in **Table 2-1** (i.e. 184,459,713 tonnes CO_2e)**.**

3.3 Data Sources

22. Data sources used to conduct the calculations are presented in **Table 1-1**.

Table 1-1: Data sources used in the wake effect calculations

Data source	Data contents
Renewable UK wind energy database	Capacity of neighbouring wind farms Expected operational start date of neighbouring wind farms
The Contracts for Difference (Standard Terms) Regulations 2014, Cfd Standard Terms Notice for the Sixth Allocation Round	Assumed load factor for Offshore Wind, for Hornsea Project Three and Hornsea Project Four
The Contracts for Difference (Standard Terms) Regulations 2014, Cfd Standard Terms Notice for the Third Allocation Round	Assumed load factor for Offshore Wind, for Dogger Bank A, Dogger Bank B, Dogger Bank C, and Sofia
The Contracts for Difference (Standard Terms) Regulations 2014, Cfd Standard Terms Notice for the Second Allocation Round	Assumed load factor for Offshore Wind, for Hornsea 2
Energy numbers: UK offshore wind capacity factors	Assumed load factor for Offshore Wind, for Hornsea 1
DBS Offshore Wind Farms Environmental Statement Chapter 30 – Climate Change – Volume 7 [APP-222] Table 30-15 *Energy Produced by the Projects* Table 30-26 *GHG Emission Saved by the Sequential Scenario*	The Projects' anticipated electricity production and avoided emissions (Sequential Scenario)

3.4 Business-as-Usual scenario

23. Electricity production for the neighbouring wind farm projects within the scope of the assessment was calculated based on the information provided in **Table 3-2**.

Table 3-2 Neighbouring Offshore Wind Farm Details

Project	(Expected) Commissioning Date	(Assumed) De-commissioning Date	Capacity (MW)	Capacity Factor (%)
Dogger Bank A	2025	2060	1200	58.40%
Dogger Bank B	2026	2061	1200	58.40%
Dogger Bank C	2027	2062	1200	58.40%
Sofia	2026	2061	1400	58.40%
Hornsea 1	2019	2054	1218	47.30%
Hornsea 2	2022	2057	1386	47.70%
Hornsea Project Three	2027	2062	2955	61.00%
Hornsea Project Four	2030	2065	2600	61.00%

24. Annual electricity production for the BaU scenario was calculated using the following equation:

$$BaU\ annual\ electricity\ production\ (MWh\ per\ year) = Installed\ Capacity\ (MW) * Capacity\ Factor(\%) * 8760\ hours\ per\ year$$

25. Electricity production over the lifetime of the neighbouring wind farms was then calculated, assuming that each wind farm would have an operational lifetime of 35-years. This is five years more than the assumed lifetime of the Projects, which in the GHG assessment Chapter 30 of the Environmental Statement [APP-222] was assumed to be operational for 30 years. This approach was adopted to provide a conservative approach to the assessment.

26. It was assumed that the Projects would commence operations in 2031, which aligns with the Sequential Scenario considered in the GHG assessment in Chapter 30 of the Environmental Statement [APP-222].

3.5 Wake Effects

27. The reduction in annual electricity production at the neighbouring wind farms as a result of wake effects was calculated using the following equation for each wake loss scenario:

$$\begin{aligned} Annual\ electricity\ loss\ (MWh\ per\ year) \\ = BaU\ electricity\ production\ (MWh\ per\ year) \\ * wake\ loss\ percentage\ (\%) \end{aligned}$$

28. The reduction in electricity production across the lifecycle of each of the neighbouring offshore wind farms as a result of wake effects was calculated using the following equation:

$$\begin{aligned} Total\ electricity\ reduction\ (MWh) \\ = Annual\ electricty\ loss\ (MWh\ per\ year) * lifetime\ (\text{years}) \end{aligned}$$

29. To evaluate the impacts on GHG emissions, the total reduction in electricity generation across all of the neighbouring offshore wind farms was multiplied by the same emission factors for natural gas, as discussed in **Section 2**, which is consistent with Chapter 30 of the Environmental Statement [APP-222].

4 Results

4.1 Business-as-Usual scenario

30. The annual electricity production under the BaU scenario, across the lifetime of the neighbouring wind farm projects when the Projects are operational are presented in **Table 4-1**.

Table 4-1 Business-as-Usual Neighbouring Wind Farm Energy Production

Existing Project	Annual Electricity Production (MWh)	Years of Operation Alongside the Projects	Remaining Lifetime Electricity Production to Earliest Expected Decommissioning Date (MWh)
Dogger Bank A	6,139,008	29	178,031,232
Dogger Bank B	6,139,008	30	184,170,240
Dogger Bank C	6,139,008	31	190,309,248
Sofia	7,162,176	30	214,865,280
Hornsea 1	5,046,759	23	116,075,449
Hornsea 2	5,791,429	26	150,577,147

Existing Project	Annual Electricity Production (MWh)	Years of Operation Alongside the Projects	Remaining Lifetime Electricity Production to Earliest Expected Decommissioning Date (MWh)
Hornsea Project Three	15,790,338	31	489,500,478
Hornsea Project Four	13,893,360	34	472,374,240
Total	**66,101,085**	**-**	**1,995,903,313**

4.2 Wake Effects

31. The electricity lost (in MWh) for each of the neighbouring wind farms as a result of wake effects are presented in **Table 4-2** for the three scenarios considered in the assessment.

Table 4-2 Potential Electricity Loss due to Wake Effects on Neighbouring Wind Farms

Existing Project	0.5% Wake Loss		1.0% Wake Loss		2.0% Wake Loss	
	Annual Electricity Loss (MWh)	**Total Electricity Loss (MWh)**	**Annual Electricity Loss (MWh)**	**Total Electricity Loss (MWh)**	**Annual Electricity Loss (MWh)**	**Total Electricity Loss (MWh)**
Dogger Bank A	30,695	890,156	61,390	1,780,312	122,780	3,560,625
Dogger Bank B	30,695	920,851	61,390	1,841,702	122,780	3,683,405
Dogger Bank C	30,695	951,546	61,390	1,903,092	122,780	3,806,185
Sofia	35,811	1,074,326	71,622	2,148,653	143,244	4,297,306
Hornsea 1	25,234	580,377	50,468	1,160,754	100,935	2,321,509
Hornsea 2	28,957	752,886	57,914	1,505,771	115,829	3,011,543
Hornsea Project Three	78,952	2,447,502	157,903	4,895,005	315,807	9,790,010

Existing Project	0.5% Wake Loss		1.0% Wake Loss		2.0% Wake Loss	
Hornsea Project Four	69,467	2,361,871	138,934	4,723,742	277,867	9,447,485
Total	**330,505**	**9,979,517**	**661,011**	**19,959,033**	**1,322,022**	**39,918,066**

32. The annual energy loss from the assumed wake effects were calculated to be between 330,505 MWh for the 0.5% scenario, to 1,322,022 MWh for the 2.0% scenario. It should be noted that the Projects are expected to generate 16,583 GWh per year, providing a much higher quantity of renewable energy than any potential wake loss (i.e. between 331 – 1,322 GWh in the scenarios assumed in this assessment) that would occur at the neighbouring wind farms.

4.3 Avoided GHG Emissions

33. Based on the results in **Table 4-2**, the effects on potential GHG savings from the Projects as a result of wake loss to the neighbouring offshore wind farms for each of the scenarios considered in the assessment are summarised in **Table 4-3**.

Table 4-3 Impact of Wake Effects on Avoided Emissions

	0.5% Wake Loss	1.0% Wake Loss	2.0% Wake Loss
Loss in Avoided Emissions from Neighbouring Offshore Wind Farms (tonnes CO_2e)	3,700,284	7,400,568	14,801,136

34. The results from the assessment highlight that under the scenarios considered in the assessment, there could be a loss of avoided emissions between 3,700,284 tonnes CO_2e (0.5% wake loss scenario) and 14,801,136 tonnes CO_2e (2.0% wake loss scenario).

35. The figures presented in **Table 4-3** assume that each of the neighbouring wind farms would be operational for 35 years, whereas the avoided emissions from the Projects have been derived assuming a lifespan of 30 years, therefore presenting a conservative scenario.

36. The impact on avoided emissions during the lifecycle of the Projects is provided in **Table 4-4**.

Table 4-4 Avoided Emissions Accounting for Wake Effects

Parameter	0.5%	1.0%	2.0%
Emissions avoided by the Projects assuming natural gas generation is replaced	184,459,713		
GHG Emissions Released by the Projects across the lifecycle (Sequential Scenario	7,222,645		
Loss in Avoided Emissions from Neighbouring Offshore Wind Farms (tonnes CO_2e)	3,700,284	7,400,568	14,801,136
Total Avoided Emissions	173,536,784	169,836,500	162,435,932

37. The results in **Table 4-4** highlight that when accounting for potential wake effects at neighbouring offshore wind farms, there is still predicted to be a large GHG saving associated with the implementation of the Projects. The figures presented in **Table 4-4** are based on the scenario adopted in Chapter 30 of the Environmental Statement [APP-222], which assumes that electricity generated by the Projects replaces generation from natural gas, which is aligned with policies such as EN-1 to replace fossil fuels with renewable sources. In the context of the wake effects assessment, these outcomes also assume that any lost yield from the neighbouring offshore wind farms is replaced by natural gas generation, as this is the most common form of fossil fuel generation in the UK.

38. It is noted that the figures presented in **Table 4-4** account for emissions arising from the Projects, but no emissions contribution from any of the neighbouring offshore wind farms. This includes emissions released during construction including embodied carbon in materials and construction plant and equipment, operation and maintenance activities such as the provision of spare parts, and marine vessel and helicopter movements, and decommissioning.

39. As the assessment considered eight neighbouring offshore wind farms, it is likely that lifecycle GHG emissions across all of these projects would be similar or greater than the level of emissions predicted for the Projects.

4.4 GHG Payback

40. The GHG payback period for lifecycle emissions under the Sequential Scenario, as reported in Section 30.6.1.4.2.1 of Chapter 30 of the Environmental Statement [APP-222], was 1.2 years from the time when the Projects become fully operational. This was based upon the lifecycle emissions value (7,222,645 tonnes CO2e) being divided by volume of GHG's saved by the Projects per year (6,148,657 tonnes), assuming generation by natural gas is replaced.

41. To determine the impact of potential wake effects on the GHG payback period, the loss in avoided emissions as reported in **Table 4-4** have been considered additional emissions to the lifecycle emissions of the Projects (Sequential Scenario). The results of the GHG payback review are summarised in **Table 4-5**.

Table 4-5 Impact of Wake Effects on Lifecycle Emissions and GHG Payback Period

	0.5%	1.0%	2.0%
Loss in Avoided Emissions from Neighbouring Wind Farms (tonnes CO_2e)	3,700,284	7,400,568	14,801,136
Total Lifetime Emissions of Projects (including Wake Effects) (tonnes CO_2e)	10,922,929	14,623,213	22,023,781
Emissions avoided by the Projects per year (tonnes CO_2e)	6,148,657	6,148,657	6,148,657
GHG Payback Period (including Wake Effects) (years)	1.8	2.4	3.6

4.5 Discussion

42. The assessment highlights that there is still a significant benefit from the provision of Projects in GHG emissions, even when accounting for potential wake effects at neighbouring offshore wind farms. The assessment is based on the assumption that electricity from the Projects replaces natural gas as a generation source, a scenario which aligns with the Overarching National Policy Statement for Energy (EN-1) and the Net Zero Strategy to transition from fossil fuel generation to renewables.

43. The assessment highlights that there would be a saving of 162.4 – 173.5 million tonnes CO_2e, accounting for lifecycle emissions from the Projects, and potential wake effects on neighbouring offshore wind farms.

44. The assessment is considered to be conservative in the following aspects:

- The wake effect scenarios applied the same level of wake loss at each of the neighbouring wind farms, which is likely to be higher than the true values, particularly for the 1.0 and 2.0% scenarios;
- The figures presented in **Table 4-4** only account for lifecycle emissions associated with the Project, and none arising from the eight neighbouring wind farms;
- A 35 year lifecycle for was assumed for each of the neighbouring offshore wind farms, in comparison to a 30 year operational lifetime for the Projects; and
- The emission factor for natural gas to calculate avoided emissions only accounts for activities at the source of generation, and not upstream emissions associated with the extraction, manufacture and transport of the natural gas fuel. This emission factor is compared against lifecycle emissions for the Projects.

45. The GHG payback period, accounting for potential wake effects and neighbouring offshore wind farms, is predicted to be between 1.8 years (0.5% wake effect scenario) and 3.6 years (2.0% wake effect scenario) from the time when the Projects become fully operational. Therefore, the whole lifecycle emissions including the loss in avoided emissions resulting from wake effects would be fully offset within the Projects' operational lifetimes.

46. The analysis presented in this note highlights that the outcome of the GHG assessment in Chapter 30 of the Environmental Statement [APP-222], which highlighted that there would be a net benefit in emissions associated with the Projects, would remain when accounting for potential wake effects on neighbouring offshore wind farms.

47. The implementation of the Projects will have the largest benefit to the UK's GHG emissions, and to the rollout of renewable energy production, despite any indirect emissions (or reduction in avoided emissions) such as those resulting from the potential wake effects causing small losses in yield to neighbouring wind farm projects.

5 Summary

48. This sensitivity analysis has been undertaken to determine the potential for wake effects associated with the Projects on neighbouring offshore wind farms to affect potential GHG savings predicted in Chapter 30 of the Environmental Statement [APP-222]. The assessment considered three hypothetical scenarios of a uniform wake loss at eight identified neighbouring offshore wind farms, the highest of which are considered to be very conservative.

49. As noted in paragraph 32, any loss of generation at the neighbouring offshore wind farms is far outweighed by the annual of generation of renewable electricity by the Projects.

50. This sensitivity analysis of potential wake effects on GHG emissions, and the results presented in **Section 4** demonstrate that the wake effects would not have a material impact on the outcomes of the GHG assessment, which was an overall beneficial effect on national emissions. The change in reported GHG savings associated with potential wake effects of the Projects on the neighbouring wind farms is outweighed by the avoided emissions from the Projects replacing the generation of electricity by natural gas with renewable energy.

6 References

Department for Energy Security and Net Zero (DESNZ) (2023) Digest of United Kingdom Energy Statistics (DUKES): electricity. Estimated carbon dioxide emissions from electricity supplied (DUKES 5.14). [Online] Available at: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

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