Reviewer#2' comments:

A clear and well-reasoned regional model study of ocean alkalinty enhancement in the North Sea. The study focuses on 3 "likely" hypothetical application scenarios with regards to potential EU or national implementations, which have largely been absent from previous global simulations.

This reviewer has 2 questions that they would hope the authors will consider and a very minor comment.

Response: We sincerely thank the reviewer for the constructive and insightful suggestions, which have greatly contributed to improving the paper. We have carefully addressed all points raised. Please find below our detailed responses. The original text of the review is presented in **black,** while our responses are presented in **blue**.

1. Given that the study is already constrained to the North Sea region, uses a model which has been published at finer scale and there exist global Earth System Model simulations at 1 km scale; why did the authors choose to perform simulations at ~4.5 km scales? The reviewer appreciates that the authors do discuss the necessity of further finer scale studies in future.

Answer: Indeed, high-resolution global Earth System Models (e.g., ICON (Adamidis et al., 2025)) and regional models (e.g. SCHISM-ECOSMO-CO2 (Kossack et al., 2024)) exist. However, we chose a setup at ~4.5 km resolution for the following reasons:

1) Computational efficiency:
High-resolution models require immense computational resources. For instance, the high-resolution version (20 km–500 m) of SCHISM-ECOSMO-CO_2**,** which covers the same domain as our current model, has approximately **386,205 grid nodes and 758,387 triangular grid elements**. Running a one-year simulation with this setup requires about **one day on 2,176 CPUs**. In contrast, our configuration reduces the grid size to **71,158 nodes and 134,753 elements**, cutting the computational cost significantly—**a one-year simulation now takes only 18 hours on 1,024 CPUs**. This balance allows us to conduct long-term and multiple scenario simulations efficiently.

2) Sufficient resolution for regional-scale processes:
The focus of our study is on the impact of alkalinity addition beyond the immediate application sites**,** where regional-scale processes (e.g., ocean circulation, vertical mixing) predominantly shape the system's response (see main text, lines -). Our chosen resolution is sufficient to resolve these key processes accurately, and the results remain **consistent with those from the higher-resolution version**, which has been validated and published (Kossack et al., 2024). To clarify this, we have added a brief summary of the model's performance in simulating DIC, TA, pCO_2, and air-sea CO_2 fluxes in the main text, see **lines 195–202.**

Considering both **computational feasibility and model performance**, we opted for this resolution as a well-balanced approach.

The necessity of finer-scale studies is explicitly discussed in **Section 4.3: "Sub-grid Scale Changes in Carbonate Chemistry,"** where we conclude:*"While these sub-grid scale perturbations are not captured by the current model, thorough evaluation through OAE modeling across multiple spatial scales is essential."* (lines) This point is further emphasized in the **abstract**, which states: *"The model's resolution (~4.5 km in coastal areas) limits its ability to capture rapid, localized carbonate responses, leading to a nearly tenfold underestimation of chemical perturbations. Thus, finer-scale models are needed to*

accurately assess near-source alkalinity impacts." These discussions highlight the importance of future high-resolution studies to better resolve localized carbonate chemistry dynamics.

References:

Adamidis, P., Pfister, E., Bockelmann, H., Zobel, D., Beismann, J. O., and Jacob, M.:The real challenges for climate and weather modelling on its way to sustained exascale performance: a case study using ICON (v2. 6.6). Geoscientific Model Development, 18(4), 905-919, https://doi.org/10.5194/gmd-18-905-2025, 2025.

Kossack, J., Mathis, M., Daewel, U., Liu, F., Demir, K. T., Thomas, H., and Schrum, C.: Tidal impacts on air-sea CO2 exchange on the North-West European shelf. Frontiers in Marine Science, 11, 1406896, https://doi.org/10.3389/fmars.2024.1406896, 2024.

2. Could the authors please clarify Figure 13? This reviewer is unclear how the plotted lines are represented in axes of Time, Area (km2) and Amount of added alkalinity (e-3 Gmol) at the same time.

Answer: In this simplified estimation, we assume that:

1. Each outfall continuously discharges the alkaline solution at a constant rate (R).
2. The discharged alkalinity disperses through the mean tidal current into a cylindrical area, with the discharge point located at the bottom center of this cylinder (schematic shown in Fig. S5 in Supplement S3).

As a result, the radius (and consequently the area of the bottom side) of the cylinder is determined by the mean tidal current velocity (U) and the time elapsed since the start of alkalinity discharge (t). Meanwhile, the total discharged alkalinity is a function of the discharge rate (R) and time (t). **Therefore, both the affected area (the bottom side of the cylinder) and the total discharged alkalinity are functions of time (t) and can be presented along the same a-axis.**

To improve the clarity of the description regarding Figure 13, we have revised the relevant section of the main text, see **lines 546-553.**

It is important to note that the a-axis is non-linear, meaning that Time, Area, and the Amount of added alkalinity are all illustrated in a non-linear manner. We have also added a notation in **the caption of Figure 13** to clarify this. See **line 579.**

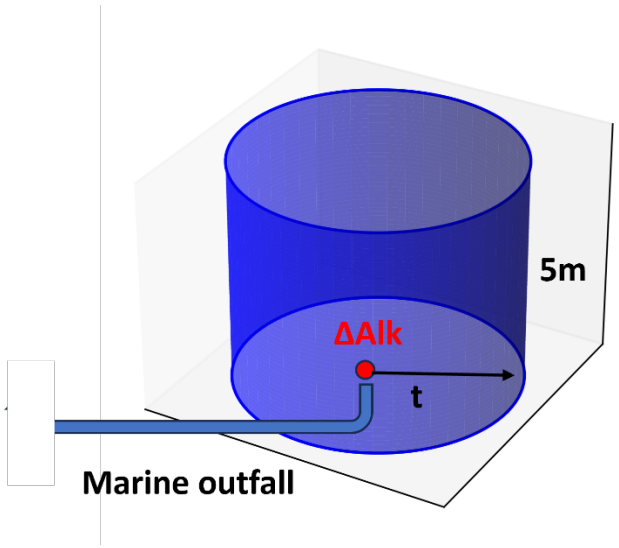

Figure S5: Schematic showing how the alkalinity is discharged through a marine outfall.

This reviewer wouold also like to suggest to the authors, with reference to line 11, that the effects of OAE are dependent upon the physical and biogeochemical conditions of a system.

Answer: Thank very much for the suggestion. We have improved the sentence by adding the 'biogeochemical' term. Now the sentence reads as '*The effect of OAE depends significantly on local physical and biogeochemical conditions*', **see line 11** in the main text.