Assessing The Impact Of Climate Change On The Offshore Production of Green Ammonia

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Overview

Chemicals such as like hydrogen and ammonia plays a vital role in as an industrial feedstock in processes such as fertilizer production, but their production is also a significant source of greenhouse gas emissions, with emissions from ammonia production being responsible for over 1% of global greenhouse gas emissions. In recent years, there has been growing interest in the production of ammonia using renewable sources, commonly referred to as "green ammonia," as it offers a sustainable, low-carbon alternative to conventional production methods. Green ammonia has also received significant attention as a long-duration energy storage technology to be paired with variable renewable energy (VRE) sources at scale, as once produced it can be directly combusted or cracked to release hydrogen to be used as a fuel at a later stage and does not suffer from the degradation of energy stored with time (unlike the self-discharge effect observed in batteries). Ammonia can also be transported and stored under less extreme conditions compared to hydrogen, with transport and storage infrastructure existing at major ports worldwide.

The cost of green ammonia will be a crucial factor that will determine the role that it will play in the future energy system as an energy storage technology, with techno-economic models typically developed to estimate and compare the levelised cost of green ammonia at different locations. Weather data is used to develop renewable energy generation profiles, which are then used in an optimisation model to design the ammonia plant as so to minimise the total system cost. Historical weather datasets such as the ERA5 reanalysis produced by the European Centre for Medium-Range Weather Forecasting are typically used [1].

However, it is becoming increasingly evident that climate change will have a significant impact on renewable energy generation [2], even if warming is limited to the Paris Agreement's goals of 1.5C on pre-industrial levels. Consequently, relying on historical data to model the future cost of producing green ammonia may not provide accurate estimates. To address this issue, this paper investigates the influence of climate change on the levelized cost of ammonia by utilizing bias-corrected climate projections for several offshore windfarm locations in the UK. It explores the extent to which locations of the UK's future wind farms may be vulnerable to the impacts of climate change and how this may affect the cost of storing energy produced through green ammonia production.

Methods

The methodology of this paper is divided into five steps. Firstly, four locations were selected for examination, based on the four regions identified for future offshore wind developments in Round 4 of the Offshore Wind Leasing Process by the Crown Estate. Offshore wind farms at these locations will be in operation until at least 2050 and so will experience the impacts of climate change on their operation. Secondly, climate data from the Met Office's UK Climate Projections data at a 2.2km scale was collated for three time periods under the Representative Concentration Pathway 8.5 (RCP8.5); 1981-2000, 2021-2040 and 2061-2080. Five ensemble members were selected for each time slice, which represent the potential influence of uncertainties in the climate model's physics. Thirdly, bias correction factors were generated by comparing the mean and standard deviation of the 1981-2000 time slice to historical data from the ERA5 reanalysis dataset. This was selected for verification purposes as it is widely considered one of the most accurate datasets for modelling renewable energy generation, particularly wind power. These factors were then applied to the 2021-2040 and 2061-2080 data, following the approach taken by Hawkins et al 2013. Fourthly, the bias-corrected climate data was then converted into hourly renewable energy profiles using the Vestas V90 3.0 MW turbine power curve for all time slices. Finally, the renewable energy generation profiles were then used as an input to a green ammonia optimisation model, presented in Salmon and Bañares-Alcántara 2021 [3]. This is a linear programming model that finds the optimal equipment sizes of the green ammonia plant to minimise the levelised cost of ammonia produced. The model was applied at geographical points within the four regions as close as possible to existing/planning wind farms. The results for the five ensembles were then collated and analysed to test whether climate change had a significant impact, through application of a two-tailed T test.

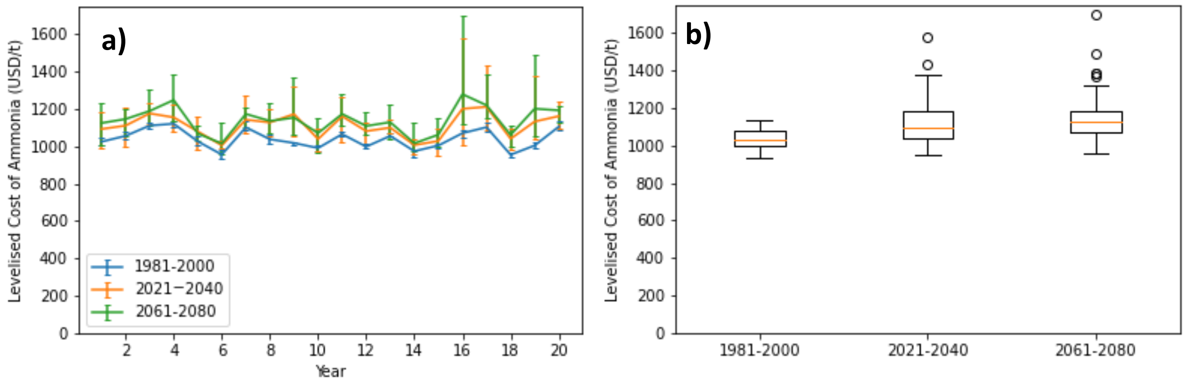

Figure 1. **(a)** Range of yearly LCOAs at the offshore location in the Northern Wales & Irish Sea region across the ammonia plant's twenty-year lifetime, with error bars showing the range of results between the five different ensemble members and lines plotted between the mean values. **(b)** Box plots of the range of distribution of the LCOA for the offshore location in the Northern Wales & Irish Sea region, calculated using each individual year with the five ensemble members. Distributions are compared for the three time slices of twenty years examined.

Results

Figure 1a shows the range of yearly LCOAs for the offshore location examined in the Northern Wales & Irish Sea region, which is where three of the six confirmed offshore wind farms in Round 4 of the Bidding Process will be sited. The average LCOA for the historical 1981-2000 scenario was 1038 USD/t and increased by 7% and 10% to 1,110 and 1,138 USD/t for the 2021-2040 and 2061-2080 scenarios respectively. Further analysis into the bias-corrected weather data showed that this was driven by a decrease of average wind speed in the summer months under the 2021-2040 and 2061-2080 scenarios, with the most significant change in the months of July – October. Figure 1b shows that the variability of the LCOA increases under both projected climate scenarios, with a significantly larger spread of results for the projected climate scenarios. Climate change could have a more significant impact on the cost of production than is represented by the change in the mean LCOAs.

Two-tailed T tests with a significance level of 5% were applied to assess if the difference in the yearly LCOAs for the 2021-2040 and 2061-2080 time periods were statistically significant relative to the results for the 1981-2000 time period. The change was found to be statistically significant for both scenarios, with a more significant change under the 2061-2080 scenario. These trends in the mean and variance of the yearly LCOAs were observed in the other three locations, with statistically significant differences found across all locations.

Conclusions

Techno-economic modelling can be used to identify sites with particularly strong potential for green hydrogen and ammonia production. As the impacts of climate change begin to become more widespread and more extreme, including analysis of the resilience of potential sites to climate change's impacts will be important; this could have a significant impact on the cost and operation of the chemical plant, as shown by this paper. Across the four sites examined, the LCOA increases by an average of 6.08% to an average value of 1,129 USD/t in the 2021-2040 time period and rises by an additional 1.79% to an average of 1,156 USD/t in the 2061-2080 time period. There is a clear impact of climate change on the economics of green ammonia production at these offshore locations in the UK.

References

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