Maximising the mitigation potential of curtailed wind in the UK: A comparison between Carbon Dioxide Capture and Utilisation, and Direct Air Capture processes

Habiba A Daggash,[1,3] Clemens Patzschke,[2] Clara Heuberger,[1,3] Lingqiao Zhu,[2] and Niall Mac Dowell.[1,3]
[1]Centre for Environmental Policy, [2]Department of Chemical Engineering, and [3]Centre for Process Systems Engineering

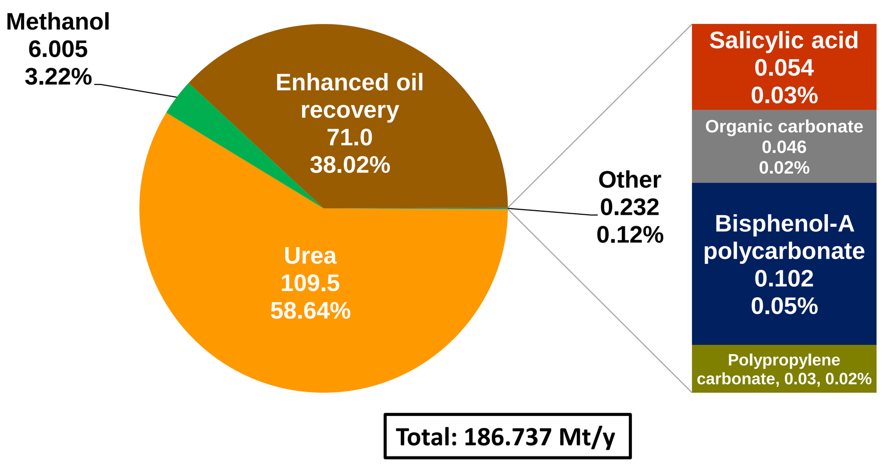
WHY CO_2 CAPTURE AND UTILISATION?

The Paris Agreement signalled global commitment to stabilise the Earth's climate by limiting average temperature rise to 2˚C. Carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies are considered critical to achieving this. However, CCS is yet to be deployed on the required scale due to cost challenges, and most CDR technologies are yet to be proven feasible at scale. Carbon dioxide (CO_2) capture and utilisation (CCU) purports to offer an alternative mitigation option with the potential to generate value from waste CO_2 emissions by converting them into valuable products. The purpose of this study is to evaluate the feasibility of this claim.

Carbon Capture and Utilisation Today

Annually, about 200 MtCO_2 is used for the synthesis of specialty chemicals and enhanced oil recovery (EOR), with urea production accounting for almost 60% [1]. This is just 0.5% of current anthropogenic CO_2 emissions of approximately 35 Gt/yr.

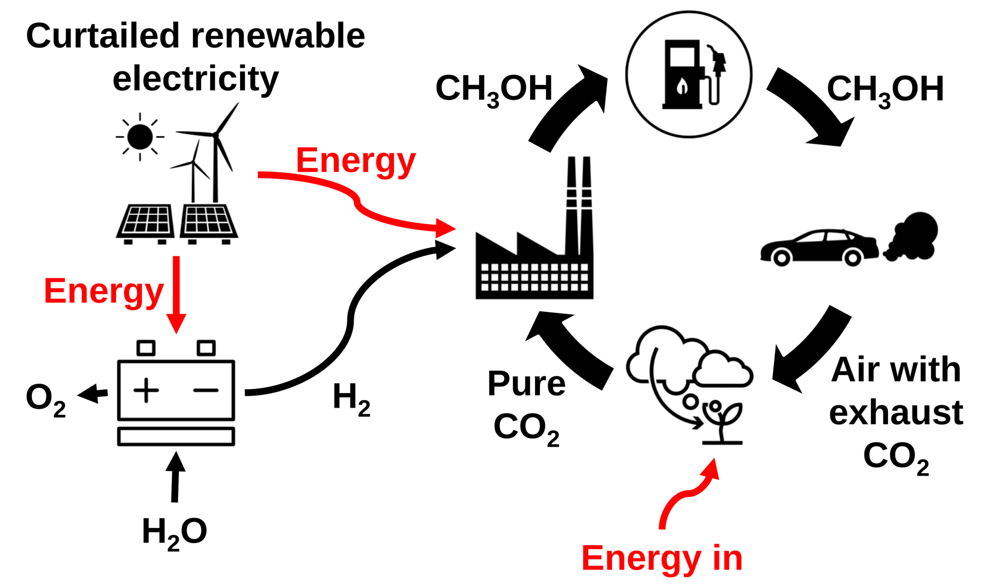
Figure 1: CO_2 utilisation in the world today



Circular Economy: CO_2 to Methanol

Global fuel consumption is two orders of magnitude higher than that of chemicals. Thus, CCU for fuel synthesis provides an important opportunity for value creation. Methanol has a high octane number and can be used in existing engines with little modification, making it a suitable substitute for gasoline.

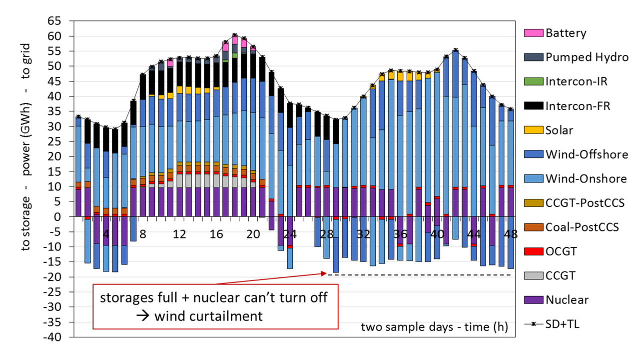
Figure 2: Recycling CO_2 from the transport sector



Curtailed Electricity in the UK Electricity System

Curtailment often occurs when there is surplus renewable generation during low demand periods or full storage capacity (see Fig. 3).

Figure 3: Two-day snapshot of curtailment in the UK



The ESO Model forecasts that no curtailed electricity will be available in the UK below 45% penetration of renewables [2].

Figure 4: Variation of curtailed electricity availability with penetration of renewables from ESO Model

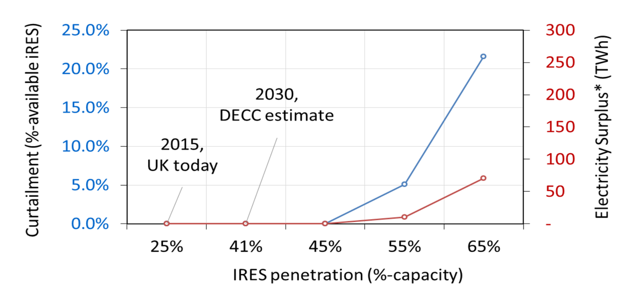


Figure 5: Process A – Curtailed wind for methanol synthesis

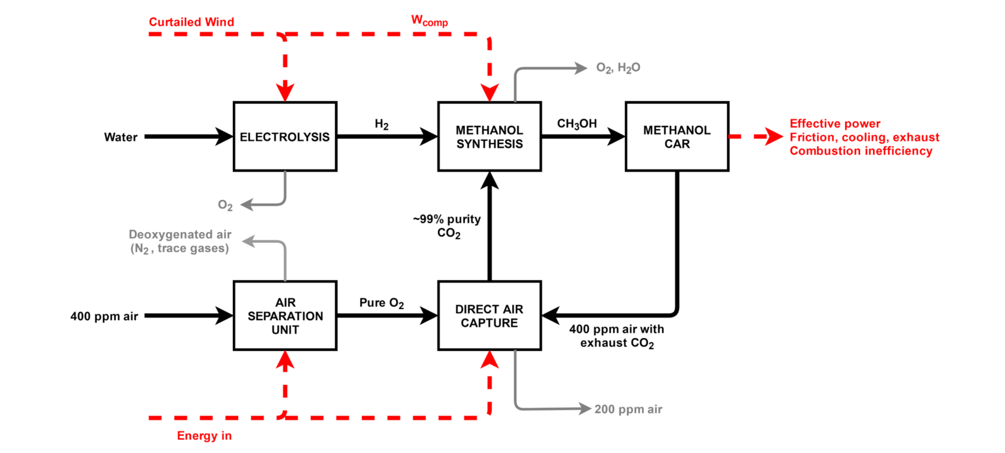
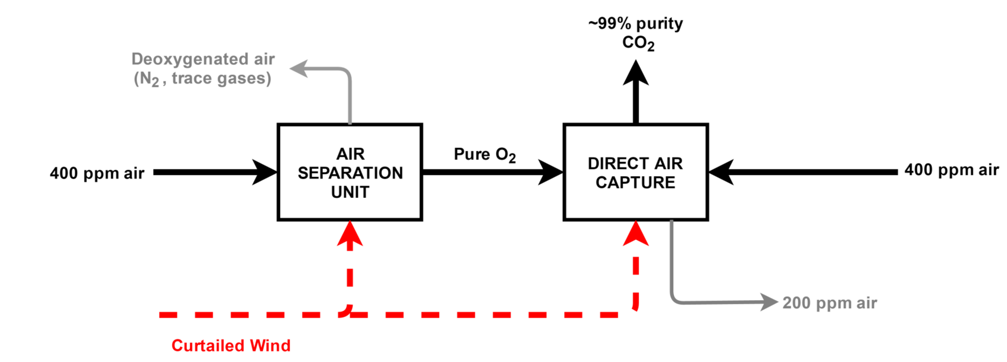


Figure 6: Process B – Curtailed wind for capturing CO_2 directly from air



Two processes were considered. In **Process A**, curtailed electricity is used to run electrolysis and methanol synthesis plants. It is then integrated with a direct air capture (DAC) plant so emissions from vehicles are recycled. **Process B** assumes curtailed electricity is used to run a DAC plant directly.

This work has taken a base case curtailment level of 2.5% of the UK total electricity demand from [3], this is equivalent to 390 GWh/y. The processes were compared based on their mitigation potential and profitability.

Mitigation potential

The mitigation potential of each process is defined by the proportion of CO_2 emissions from gasoline vehicles that are avoided. Process B was found to avoid more emissions (0.184%) compared to Process A (0.122%) if the lower bound DAC energy requirement was used. The reverse was true when the upper bound used.

Economics

All costs are provided per tonne of CO_2 avoided. All units incurred significant losses, with methanol production being the costliest. This rendered CCU unfeasible as a mitigation option.

Figure 7: Variation of substitution potential with curtailment

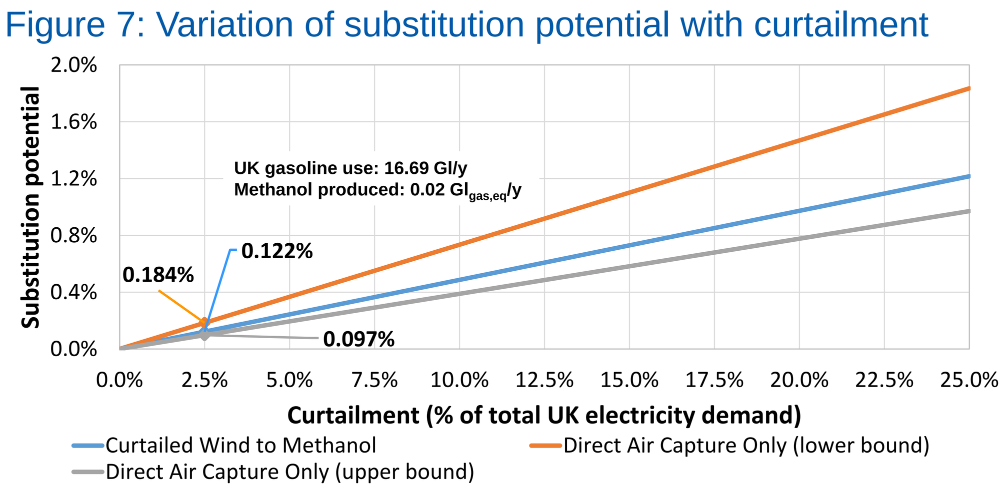


Figure 8: Variation of substitution potential with efficiency

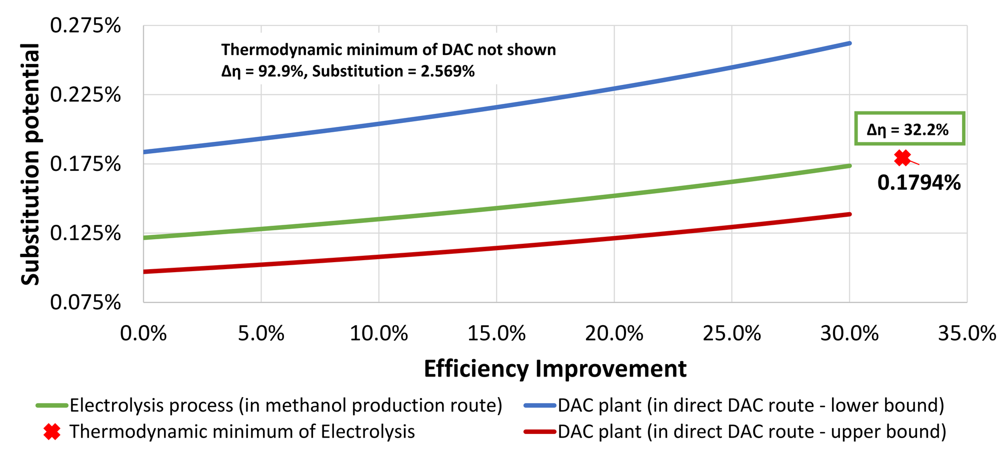
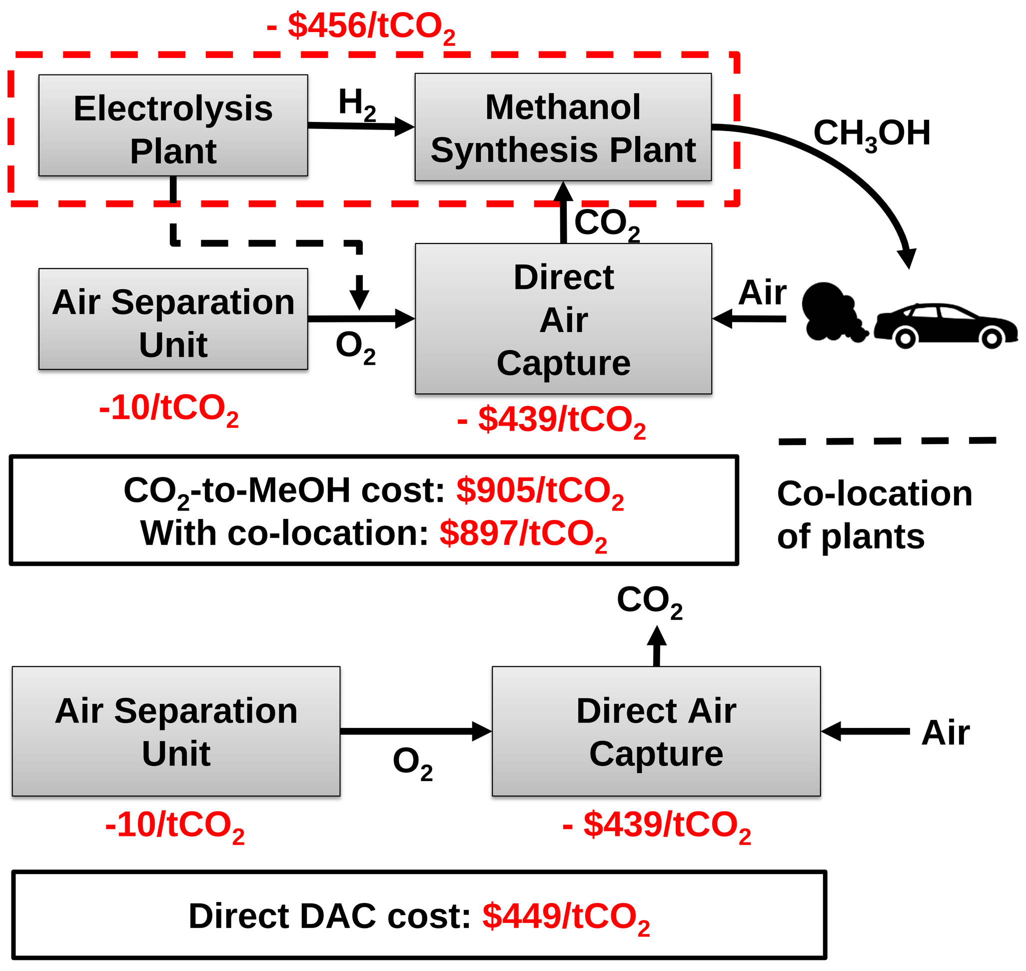


Figure 9: Costs of CCU vs DAC



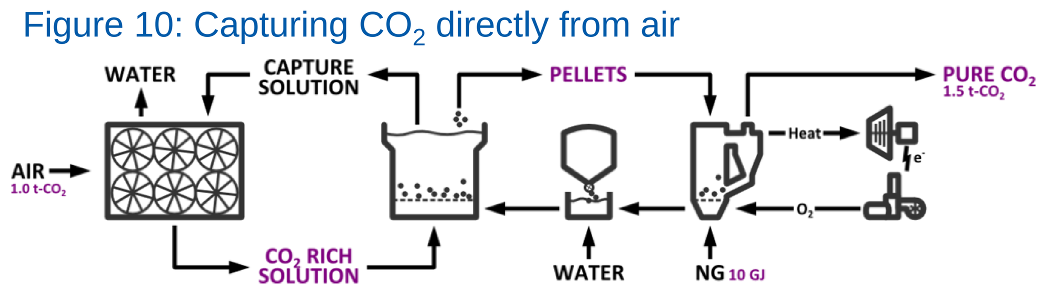
Conclusions

The process that maximises mitigation potential depends on the DAC process considered; using the lower-bound energy requirement, surplus electricity for DAC only is preferable. Neither process is economically viable. As CCU costs are double the DAC-only costs, it will remain financially-unattractive unless the methanol production becomes profitable. This is unlikely as it requires methanol price to double, a carbon price of $313/t to be in effect, or H_2 price to reduce to a third of today's price.

Direct Capture of CO_2 from Air

Using a hydroxide solution, CO_2 from the atmosphere can be captured via the process illustrated below [4]. A range of energy requirements were identified from literature. The lower and upper bound estimates of 6.7 GJ_e/tCO_2 and 12.6 GJ_e/tCO_2, for capture rates of 80% and 50%, respectively, have been used in this work.

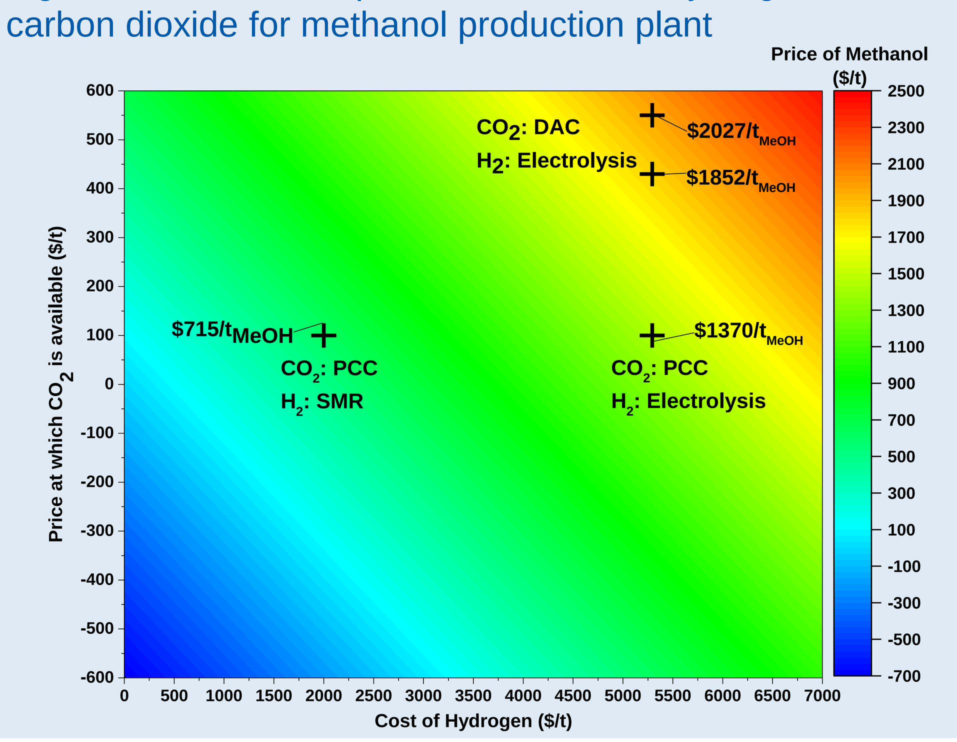
Figure 10: Capturing CO_2 directly from air



Methanol synthesis

Methanol production incurs a loss of $156 million annually. The contour plot illustrates a range of scenarios for which the plant will breakeven after its 20-year lifetime. Highlighted are the methanol prices when CO_2 is obtained from post-combustion capture (PCC) or DAC, and H_2 from steam methane reforming (SMR) or electrolysis.

Figure 11: Breakeven prices of methanol, hydrogen and carbon dioxide for methanol production plant



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