Implications of Renewable Electricity Curtailment for Delivered Costs

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Governments and other agencies setting decarbonisation targets and designing Variable Renewable Electricity (VRE) support mechanisms usually rank alternative technologies by their Levelised Cost of Electricity, LCoE. For VRE investment, the LCoE concept has been criticised as it excludes additional costs needed to integrate VRE into the system, such as providing inertia and other stability, back-up power, etc. Granted their importance, this paper addresses an additional and neglected aspect of VRE that becomes critically important at high penetration levels. As the ratio of peak to average output is high for VRE (3-4: 1 for onshore wind, 2-3: 1 for offshore wind and 9: 1 for solar PV in GB), high average penetration inevitably leads to the need to turn down or curtail VRE output, either because of transmission constraints or, increasingly important at high penetration, for system stability reasons.

Economists have long argued that it is *marginal*, not average cost that determines efficient allocation, and similarly with VRE it is the marginal cost of delivered power that determines their contribution to and cost of decarbonising electricity. That in turn depends on their marginal (delivered) capacity factor, MCF, which depends on marginal curtailment, as set out below. The new relevant cost metrics are the Levelised Average Cost of Electricity, LACoE, and the Levelised Marginal Cost of Electricity, LMCoE.

The LCoE is relevant for developers bidding for firm contracts in VRE auctions where they are compensated for curtailment. The LACoE is a suitable cost metric for merchant entrants in unsubsidised markets facing pro-rata curtailment. The LMCoE is relevant for such entrants experiencing priority access rights – last in, first curtailed.

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Only recently has any attention been directed to measuring and analysing marginal curtailment. Estimates for the island of Ireland by 2026 find that the marginal: average curtailment (*mc/ac*) ratio for wind was likely to be 3-4 or more. In a Renewable Energy Zones in Queensland, Australia, *mc/ac* lay in the range 3.2-3.6. Once multiple types of VRE are combined (on- and off-shore wind, solar PV), different VRE amplifies the *mc/ac* ratio as each VRE impacts on and increases the curtailment of other VREs. Models of GB in 2030 find ratios for offshore wind rising from 5 to 7.5, increasing as more options for absorbing surplus VRE are developed (interconnection and exports, storage), higher for on-shore wind.

The paper develops a simple but flexible geometrical model of average and marginal curtailment, demonstrating the $mc/ac = (V + V_0)/(V - V_0)$, where V_0 is the VRE capacity at which curtailment first becomes necessary and V is total VRE capacity. Average curtailment falls and mc/ac rises as V_0 rises (with increasing uses found for potentially surplus VER.

As the marginal levelised cost, MLCoE, of VRE is inversely proportional to the Marginal Capacity Factor, which falls as marginal curtailment increases, and as mc/ac rises with V_0, this raises the concern that reducing average curtailment may not lower the marginal cost of VRE. This paper proves that this is not the case, and that reducing curtailment has a magnified effect on marginal curtailment and does indeed lower the marginal cost of VRE.