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Club goods and a tragedy of the commons: the *Clean Energy Package* and wind curtailment[1]

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Ambitious plans to decarbonize electricity will require very high levels of variable renewable electricity (VRE) generation, mainly on- and off-shore wind and solar PV. Both decarbonisation and supporting VRE are global public goods, VRE through its learning externalities that lower the cost of future investment. To solve the problem of financing such public goods, the EU requires (in its *Clean Energy Package*) member states to agree to targets for emissions reduction and VRE penetration - an excellent example of turning these into club goods. The UNFCCC Paris Agreement and *Mission Innovation* are examples of widening the club, ideally to the whole world. The EU's targets are set out in the *2030 Climate and Energy Framework*

The paper argues that once high levels of wind penetration have been reached so that curtailment is inevitable, this creates a mismatch between the social and market value of wind investment. The social value depends on the *marginal* curtailment caused by the additional investment, which is 3-4+ times the *average* curtailment, , but even in an efficiently designed market, price signals for wind investment are given by average not marginal curtailment, creating a "tragedy of the commons" that requires a corrective charge to restore efficiency.

For the targets of decarbonisation and increased VRE penetration to be delivered efficiently in liberalized electricity markets, a number of market failures and distortions will have to be addressed. The first and most obvious is that the external costs of fossil generation, and particularly CO_2 emissions, will need to be properly charged as in most countries the current carbon taxes are below the social cost of carbon.

The second is that the external learning benefits of deploying VRE should be appropriately rewarded. As learning depends on developing, designing and installing

[1] This paper revises and replaces an earlier version entitled "The distortionary cost of marginal wind curtailment" (EPRG 2036) dated 1 December 2020.

reliable capacity, the learning benefits are a function of cumulative installed capacity, not subsequent output (when the electrons are the same as those from fossil generation). That implies the subsidy should be paid to reliable capacity (e.g. for the first 25,000 MWh/MW) and not to output, which would distort the market. Unfortunately, most subsidy systems create considerable distortion costs.

The third implication of a high VRE penetration is to threaten the efficiency of investment decisions in flexible plant required for capacity reliability in an energy-only market. There is growing consensus that, while an energy-only market with prices capped at the Value of Lost Load might, in ideal circumstances, deliver the right level of reliability, some form of capacity reliability mechanism with capacity payments auctioned, reduces the risk (particularly of future policy uncertainty) and hence the cost of delivering reliability. This paper highlights the difference between the way in which conventional plant, whose outages are uncorrelated, and VRE, whose output can be highly correlated, should be treated in de-rating for procuring adequate capacity, and provides a simple formula for de-rating wind.

The fourth implication is that system costs (providing inertia and other ancillary services, storage, more transmission and interconnection, and additional back-up reserves) will increase and their costs are logically targeted on the source of these costs. While there are empirical estimates of the systems costs of VRE, there is little by way of simple modelling that can give quicker estimates. The critical role of some of these system costs is addressed in this paper.

While all of these are widely recognized in the literature, there is an additional cost that does not appear to have been either recognized or quantified. Beyond some level of penetration, curtailment of excess supply will be needed. If wholesale prices are efficiently set, this will cause the price to fall to the avoidable cost of the marginal VRE, encouraging them to self-curtail, otherwise mandatory curtailment will be required. While efficient markets provide the necessary operating signals to self-curtail, this paper argues that, because the marginal curtailment is many times higher (3-4+) than the average level of curtailment. For investment decisions it is marginal curtailment that is relevant, while the market only values (or penalizes) average curtailment, resulting in a “tragedy of the commons”. A relevant feature that gives bite to the “tragedy” is that marginal analysis usually assumes that supply and demand schedules are smooth, so a small change is supply leads to a small change in equilibrium prices. In this case the move from curtailment, when the efficient price is the avoidable cost of wind, to non-curtailment, means a discrete and rather large jump in the efficient price to the avoidable cost of flexible generation.

The paper also argues that the normal way of de-rating conventional capacity to estimate its equivalent firm capacity that can be relied on is scarcity periods is not appropriate for VRE. The forced outage rate of conventional capacity is typically low (below 10%) and together with maintenance outages can provide a fair measure of

its maximum likely capacity factor and its equivalent firm capacity, the same is not true for VRE, which is dependent on both availability and the external resource (wind or solar strength). Thus the average capacity factor of wind in winter, when scarcities are more likely in northern climes, may be well above its annual average, wind cannot be relied upon to deliver a sufficiently high proportion of the time then to count as firm. If VRE is paid the full scarcity price in scarcity hours, it will earn considerably more than its de-rated capacity suggests, so that unless its unpredictability is properly taken into account, it will be overpaid, inducing excess entry.

The paper sets out a simple model to show the source of this unpredictability cost and points to the deficit between social value that depend on marginal curtailment and market revenue that is only reduced by average curtailment. It derives the formulae for the subsidies and charges needed in a liberalized market to deliver the desired level of renewables penetration and estimates their magnitude. The data for the empirical estimates is taken from the Single Electricity Market (SEM) of the island of Ireland. The SEM is a particularly important market to study, as it is widely recognized as being at the forefront of addressing the challenge of high VRE penetration in a small, isolated system.

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