ENERGY MODELLING

Clean grids with current technology

The need for new energy storage is often seen as an obstacle to integrating renewable electricity into national power systems. Modelling shows that existing technologies could provide significant emissions reductions in the US without the need for storage, however.

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With the new UNFCCC Paris Agreement as a foundation, the world is looking to clean, renewable energy solutions to global warming. Such solutions, if successful on a global scale, could avert millions of premature deaths associated with outdoor and indoor air pollution each year, create more jobs than are lost, allow countries to become more energy independent, and take billions of people out of energy poverty — including the 1.3 billion who currently have no access to energy. However, critics of highly renewable energy systems point to the potential high costs of storage to provide power when there is not enough intermittent wind and solar energy generation to meet demand.

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Many studies examine whether high penetrations of clean, renewable energy combined with storage can allow the grid to remain stable[1–9]. Although most focus only on current electric grids, one recent study[9] examined the effect of electrifying all energy sectors (electricity, transportation, heating/cooling and industry) and using low-cost electricity and heat/cold storage along with hydrogen and demand response to find low-cost, no-load loss solutions to the problem across the continental United States. However, no study had considered the limit to which wind and solar can be applied with zero storage to the current electric grid (before electrifying other sectors) by aggregating wind and solar generation over a super-large catchment area (namely the continental United States).

MacDonald, Clack and colleagues[10] have now performed such a study. They use the National Electricity with Weather System (NEWS) model to assess wind and solar generation at 13 km horizontal resolution and 1 hour temporal resolution. The model provides lowest-cost solutions to match power demand with supply, considering intermittent wind and solar generation, high-voltage direct current (HVDC) transmission and time-varying energy demand. They find that, under various scenarios, these contemporary wind, solar and transmission technologies could reduce CO_2 emissions by 80% compared with 1990 levels (or 81% compared with 2030 levels) with no storage, at a 9% lower cost than the baseline fossil fuel grid cost. Smaller CO_2 reductions can be obtained at even lower cost.

One of the fundamental reasons for this is that whereas the intermittency of wind is significant over small catchment areas, power output becomes smoother with increasing catchment size[11]. Another reason is that a large catchment area allows locations with huge low-cost renewable energy resources to be connected to many high-energy-demand centres, thereby reducing the cost of energy compared with a scenario where only higher-cost resources are used. As such, although storage has an advantage for small catchment areas (because weather systems cause greater variation in renewable supply and low-cost generation may be limited), transmission can significantly replace storage for large catchment areas to provide lower-cost and less intermittent generation.

Interestingly, in the model's high-renewable scenario, wind plus solar generators take up less than 0.1% of land in the continental United States. Furthermore, HVDC costs are only 4% of total electricity costs, and the use of wind and solar energy reduces water consumption in the electricity sector by 65%.

One limitation of the study, which could be addressed with future research, is that it considers the electric power sector before the electrification of other energy sectors (transportation, heating/cooling and industry). Electrification of other sectors has already started, and may occur even more in the future. Further, it assumes the excess electricity generated by wind and solar is discarded rather than used for some other purpose (for example, hydrogen production or district heating), thereby increasing overall costs slightly.

Whereas the model optimizes resource location based on cost and considers several types of land use limitations, it also does not consider societal constraints on areas of beauty that might prevent development in some of the proposed locations. Future work on this topic may also benefit from considering storage to eliminate the remainder of CO_2 emissions.

Despite these limitations, the study pushes the envelope to show that intermittent renewables plus transmission can eliminate most fossil fuel electricity while matching power demand at lower cost than a fossil-fuel-based grid, even before storage is considered. This finding — alongside previous modelling that suggests the electrification of all sectors combined with the use of low-cost electricity and heat/cold storage, hydrogen and demand response can result in 100% decarbonization of all US energy sectors — provides confidence that the goals of the Paris Agreement are within reach if high percentages of clean, renewable energy can be integrated worldwide.

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CLIMATE CHANGE ECONOMICS

Reacting to multiple tipping points

When setting carbon prices in a warming world, policymakers must be cognizant of the potential economic and environmental consequences of the risk of multiple, interrelated catastrophes.

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The optimal carbon price, whether it is a tax or the price of a permit, must be set to the social cost of carbon[1,2]. This corresponds to the current discounted value of marginal damages to aggregate production, resulting from higher temperatures in the future that are caused by emitting one additional ton of carbon today. This price is higher if society places a higher value on future generations, if current generations are more willing to cut fossil fuel use and sacrifice consumption to limit future warming, and if future generations are richer and society is more risk adverse. This approach to climate policy is concerned with damages around 2–3 °C, but ignores tail risks of catastrophes that rapidly arise at higher temperatures. The optimal carbon price then must be marked up[3], which can double the carbon price[4]. Society also must accumulate precautionary capital to cope when calamity strikes[5]. But what happens when there is more than one tipping point and society has to anticipate the potential damage caused by multiple catastrophes? This issue is addressed by two studies now published in *Nature Climate Change*[6,7].

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In the first study, Derek Lemoine and Christian Traeger[6] consider three tipping points in a simplified version of the integrated assessment model DICE-2007 (discussed in ref. 1): (i) a sudden increase in the climate sensitivity from 3 °C to 5 °C due to melting of the permafrost or retreating land ice sheets (implying that a doubling of carbon stock would lead to a rise in temperature of 5 °C instead of 3 °C); (ii) sudden halving of the rate of atmospheric CO_2 removal; and (iii) sudden increase in severity of production damages, say, due to weakening of the Atlantic conveyor belt. Policymakers use Bayesian learning of the unknown thresholds for each of these irreversible tips. Ignoring catastrophes requires a carbon price of US\$6 per ton of CO_2 (tCO_2), whereas allowing for all three catastrophes pushes up the price to US\$11 per tCO_2, with the biggest contribution coming from the third tipping point leading to a sudden increase in production damages. As a result of the extra mitigation efforts, peak temperature would be brought down from 4 °C to 3 °C. The optimal carbon price adjustment is 50% higher than simply adding the effects of the individual tipping points, but this adjustment by more than three quarters in 2050. This effect is especially strong for the temperature and damage tipping points. The domino effect arises because crossing the threshold for the temperature tip or the carbon sink threshold boosts the risk of crossing the threshold for the damage tip, but not vice versa. Delaying carbon pricing is 60% more costly than in the scenario without tipping points.

In the second study, Yongyang Cai, Timothy Lenton and Thomas Lontzek[7]