Deep decarbonisation requires deep pockets

trillions required to make the transition

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Executive summary

The world has 12 years to limit greenhouse gas emissions or face severe impacts from global warming

So proclaimed the Intergovernmental Panel on Climate Change in its updated report on climate change in October 2018, setting off alarm bells around the world. A growing list of countries, states, local communities and global businesses has heeded the call to action and adopted more aggressive measures to limit their carbon footprints.

The sense of urgency in stepping up policy efforts is palpable, including in the United States, where climate change is emerging as a central issue amongst Democratic presidential contenders. Primary frontrunners are proposing multi-trillion-dollar investments in support of their "Green New Deal" initiatives. Elsewhere, in one of her final acts as Prime Minster, Theresa May has brought forward legislation to upgrade the UK's existing 2050 emissions reduction target from 80% to 100%.

Wood Mackenzie estimates full decarbonisation of the US power grid at US$4.5 trillion, given the current state of technology – nearly as much as what the country has spent, since 2001, on the war on terror. From a budgetary perspective, the cost is staggering at US$35,000 per household – that equates to nearly US$2,000 per year if assuming a 20-year plan.

Price tag may not be the highest hurdle to overcome

Eliminating fossil fuels represents a transformative investment opportunity for stakeholders of the new energy economy. But for legacy participants in the energy industry, it also creates an existential crisis. Companies – and in some cases, whole industries – must evolve or perish. Although decarbonisation timelines differ, it is increasingly clear that utilities, the oil and gas industry and other energy market participants must account for the implications of these impending policy decisions in their current strategic planning activities.

Consequently, difficult choices must be made by political leaders, regulators, CEOs and energy consumers alike. For any country to embrace a nationwide transition to 100% renewable energy (RE100) or zero carbon (ZC100) emissions constitutes a massive disruption with far-flung economic and social repercussions. Nimbyism is inevitable and forecasted increases in consumer energy costs may result in public backlash against aggressive climate change policies.

The scale of the challenge is unprecedented, requiring an upending of fossil fuel industries and a complete redesign of the power sector. Recent experience of growth in renewable electricity is a clear example of change already delivered and full decarbonisation of power must be regarded as a prerequisite of any meaningful progress towards deep decarbonisation of the overall energy system. The requirements to be placed on the global renewable energy supply chain are also noteworthy, and include substantial R&D spend to address shortcomings in energy storage and distribution technology.

Wood Mackenzie concludes that RE100 goals remain largely aspirational, but attainable given a reasonable time horizon to allow for technology development, regulatory realignment and socio-economic reforms. Further, adoption of ZC100 or even ZC80 goals increases the likelihood of success, incentivising the development of next-generation nuclear and carbon capture technologies.

Full decarbonisation of electricity is a prerequisite of any deep decarbonisation of the overall energy system.

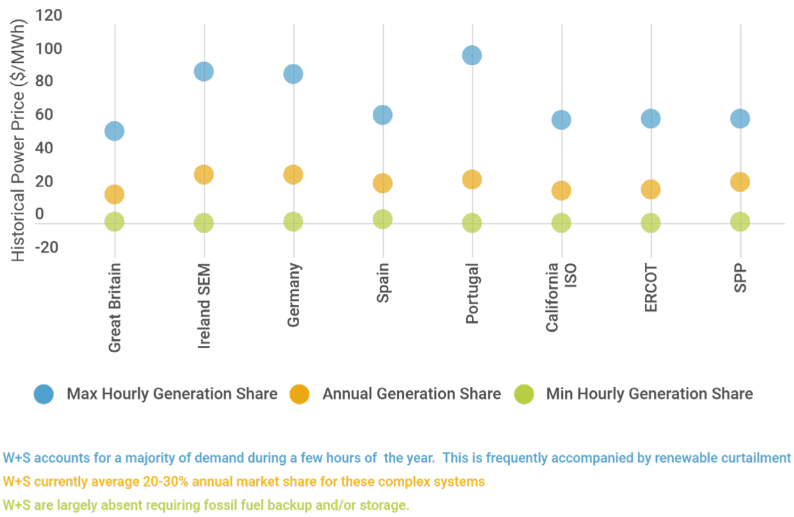
Today, no large and complex power system (LCPS) in the world operates with an average annual penetration of greater than 30% wind and solar (W+S). RE100 policies for an LCPS represent uncharted territory. There is little to no historical precedence for dealing with the technological and commercial disruptions that would accompany the mass deployment of variable energy resources.

Current evidence shows that an LCPS tends to reach a 25% W+S market penetration with relative ease, assuming fundamental natural resource and grid infrastructure prerequisites. Beyond that point, operational and cost complexities progressively multiply, in large part due to the intermittent nature of renewables.

Operational challenges associated with RE100 policies

While the issue of intermittency is largely understood – no sun, no wind means no power – the broader ramifications are seldom appreciated. In the absence of storage, power generation and demand need to align on a second-by-second basis. At these lower time resolutions, the range of performance that W+S provides within a year becomes clearer. Figure 1 below shows select power systems in Western Europe and North America currently averaging between 20% and 30% W+S market share on an annual basis. Hourly W+S generations shares, however, range from a minimum of 0% to as high as 101% (with excess power exported).

Hourly wind and solar generation share for select LCPS (Figure 1)



Source: Wood Mackenzie

1. Feast or famine – coping with intermittency

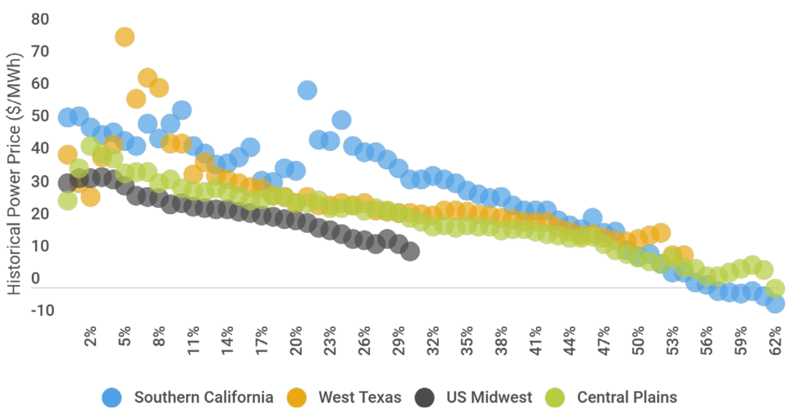
The amount of reliable capacity needed to backstop renewables intermittency ranges from near-100% backup to no backup. Wind energy's intermittency poses additional challenges on longer timescales, given seasonal differences in wind resource strength and random extended periods of low-wind resource availability. A vicious cycle emerges as W+S penetration increases without storage support and inadequate backup capacity raises grid resiliency concerns.

These issues are further compounded when fossil fuel generators are retired prematurely from the grid due to economic pressures from low-cost renewables. In the absence of energy storage, installed capacities of W+S must increase exponentially to provide sufficient reserve margins for an LCPS, dramatically increasing system costs and introducing massive generation inefficiencies.

Even moderate levels of renewables penetration can result in excess generation. This leads to renewable energy curtailment if there is insufficient transmission or storage capacity in the LCPS. For example, at 20% annual penetration of W+S, California experiences almost daily curtailment of renewables during the spring months. Furthermore, second-order issues relevant to policy, regulation and market structure start to emerge when W+S penetration approaches 50%.

Figure 2 shows historical price trends at various levels of renewables saturation for key regional US markets, which currently function at a 25% W+S average market penetration. Prices approach nil at higher levels of renewables generation, negatively impacting the profitability of fossil fuel generators and renewable generators alike. The same situation is unfolding in European markets such as the UK, where wind farm constraint payments -payments to curtail generation- topped US$150 million in 2018. These pricing dynamics clearly illustrate the need for power market redesign within any RE100 framework. Short-run marginal prices will inevitably go to zero, prompting a shift towards capacity payments instead.

Hourly power prices at varying levels of W+S market penetration (Figure 2)



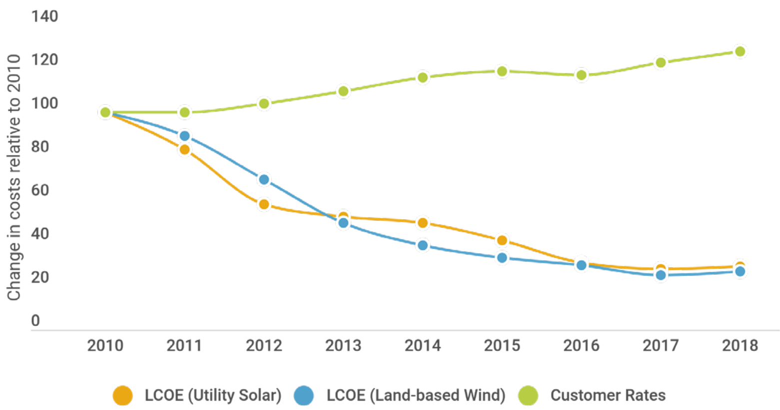
Source: Wood Mackenzie

2. Tallying the price of transition – a US example

The price of transitioning to 100% renewable energy is a complex issue. It's also one that is commonly confused with the levelised cost of solar or wind energy. Levelised cost of electricity (LCOE) is the per unit cost of building and operating a new generation asset. By contrast, the total price associated with transitioning to renewables is more akin to the impact on customer rates – assuming rate payers ultimately foot the bill.

In essence, the total price of transition includes everything needed to reliably produce and deliver clean energy to consumers. This price includes building and operating generation facilities, making capacity payments, investing in transmission and distribution infrastructure, delivering customer-facing grid edge technology and more. Figure 3 illustrates these opposing historical trends for W+S LCOE and customer rates in California.

Transitions costs vs levelised costs of renewables (Figure 3)



Source: Wood Mackenzie

3. Buildout of wind and solar capacity to meet RE100

The current US power grid has about 1,060 GW of nameplate capacity, including roughly 130 GW of W+S capacity. Adoption of RE100 would involve massive investments that could lead to significant transition costs and customer rate impacts, despite the falling cost of renewables. Wood Mackenzie estimates that about 1,600 GW of new W+S capacity would be needed to produce enough energy to replace all fossil fuel generation in the US.

This buildout is unprecedented. Aggressive climate policies with 2030 targets will require more capacity to be built every single year over the next 11 years than what has been installed collectively over the past two decades. Assuming the capital costs for W+S continue to fall, this represents a cost of roughly US$1.5 trillion.

4. Storage investments to backstop intermittency

Next, approximately 900 GW of storage investments would be required to ensure clean energy from W+S resources are available and reliable exactly when consumers need it. Worldwide, there are only 5.5 GW of battery storage in operation or under construction. The inadequacy of the energy storage supply chain is apparent and is compounded by technology gaps. The recent proliferation of smaller, short run lithium ion storage plants fails to deliver the longer duration storage capability critical to balancing seasonal swings in wind energy production or extended resource droughts stemming from major weather events. Assuming 24 hours of duration (16.8 TWh), these storage assets more than double RE100 costs to US$4.0 trillion.

5. Transmission costs

Transmission is central to ensuring renewable energy can be delivered to customers in areas where W+S resources are limited or areas of high population density where W+S facilities cannot be located. High-voltage transmission (HVT) requirements are a function of installed utility-scale generating capacity and the distance of generators from demand centers.

The US currently has about 200,000 miles of HVT. If we assume that RE100 requires doubling installed generating capacity, it could theoretically double HVT requirements. Assuming 200,000 miles of new HVT at an average price of US$3.5 million/mile adds US$700 billion.

6. Cost inflation given supply chain requirements

Under RE100, cost reduction trends for W+S may reverse given the sheer magnitude of investment required across the supply chain. The US wind supply chain, for instance, supports 8 to 10 GW a year, and would require an increase of more than seven times that capacity to achieve RE100 by 2030, or three-and-a-half times that by 2040.

That annual level of demand could exceed the 50 GW global investment peak for the wind industry – just in the US. Requirements for associated logistics, such as transport and cranes, would be enormous. The cost of raw materials, like steel and copper, would, in turn, likely increase.

In summary – excluding supply chain impacts and other items, such as stranded costs – an investment of US$4.5 trillion would be required to fully transition the US power grid to renewables over the next 10 to 20 years. That implies an investment of roughly US$225 to US$450 billion a year – a scale comparable to the total US defense budget. Further underlying the scale of this endeavor, the IEA estimates global power sector spending averaged US$675 billion from 2007 to 2017.

Crafting compromises – charting a path forward

An attainable RE100 policy must incorporate solutions to these operational and cost complexities, among other concerns like cybersecurity. Various approaches could make this happen; we outline four below:

1. Allow time for new technologies to be commercialised

With time, human ingenuity and technology advancements, RE100 achievements may end up costing much less than the above estimates. After all, storage costs are decades ahead of what was previously anticipated. The solution will likely include a larger role for one or many technologies listed below:

- Grid edge technologies (customer-facing monitoring and control, grid analytics, power-flow controls)
- Demand response
- Next-generation storage technologies (solid state, new anode chemistries, flow batteries)
- Power-to-gas technologies (renewable hydrogen)
- Carbon capture and storage, or carbon removal
- Next-generation nuclear fission or fusion
- High-temperature superconductor transmission and solid-state transformers

2. Extend time horizons to 2040 or 2050

Two places with extensive experience of integrating renewables into electricity, California and Germany, do not have RE100 targets before 2045. Their respective 2030 targets are only 60% to 65%. The underlying principle is that a 2040 or 2050 target allows for new technologies – like those listed above – to incubate and reach commercial scale. A 2030 target, meanwhile, would preclude many technologies that are still in the development phase.

3. Allow for inclusion of zero-carbon technologies

Nuclear power currently provides 60% of total clean energy in the US, with W+S accounting for 20%. Including existing nuclear plants to achieve ZC100 (instead of RE100) goals would reduce W+S investment needs by almost US$0.5 trillion. Inclusion of more non-intermittent renewable sources would also mitigate transmission and storage investment needs while also easing supply chain constraints.

4. Reduce mandates from ZC100 to ZC80

Allowing 20% of the power mix to come from existing natural-gas-fired generation (ZC80) would reduce RE costs by roughly20% and energy storage costs by at least 60%.

Conclusions

“Twelve years isn’t a deadline, and climate change isn’t a cliff we fall off — it’s a slope we slide down.” Kate Marvel, Climate Scientist, NASA

The IPCC has raised awareness of the potentially cataclysmic impacts of global warming. The impacts of climate change are already upon us and will worsen unless aggressive measures are taken to combat global warming. Decisions made, or not made, over the next 10 years will have generational impacts. Political leaders are taking action, but must balance the rallying cries of campaign rhetoric against sound policy decisions, or run the risk of exacerbating cost and operational challenges. Or worse yet, incite public backlash to climate initiatives and derail these efforts in their entirety.

Wood Mackenzie concludes that RE100 goals remain largely aspirational but attainable given a reasonable timeframe to allow for technology development, regulatory realignment and socio-economic reforms. Decarbonization dynamics are accelerating and it is imperative that power market stakeholders take the necessary steps to participate in the energy transition.

“To an extent, it’s about survival,” summed up Maarten Wetselaar, Director, Shell New Energies. “But it’s also about, of course, playing a positive role in energy transition.”

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