Perspective on the energy transition

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Abstract

Primary energy masks the important role of electricity and the growth and future potential of renewable energy. The "Phase I" decarbonization technologies of wind, solar PV, electric vehicles and stationary lithium-ion batteries are all on track for another record year of deployment in 2019, as technology cost continue to fall with every unit deployed. Today wind or PV is the cheapest new-build electricity for two-thirds of the world population and will soon undercut commissioned coal and gas plants. Cheaper batteries help renewables reach higher value hours when the wind isn't blowing or sun isn't shining. Battery costs are down 87% since 2010 as auto manufacturers push more models into the market. Uptake should accelerate from 2023 when EVs start to hit upfront price parity with ICE alternatives causing oil demand from road fuels to peak around 2030. Cheap variable renewables form the backbone of the new electricity system reaching as higher as 80% in some markets when supported by smart EV changing, batteries and peaker plants. Coal-fired electricity peaks in 2026 undercut by cheaper renewable and batteries as well as more flexible gas. Achieving net-zero emissions however ask serious questions about energy transition pathways for industry and buildings. And while going electric isn't a universal solution and renewables are not a one-size-fits-all solution, deploying the "Phase I" technologies to their full potential can make a big dent in emissions and buy time for development of "Phase II".

Keywords: Energy transition, renewables, batteries.

Often we hear that wind and solar might be great and may be growing fast, but despite years of deployment and government support they are still just 1% of primary energy and so can't possibly replace fossil fuels in the world energy economy.

Primary energy might be the right lens through which to think about energy when there are few alternatives to fossil fuels, or if you're an oil, gas, or coal company, for which primary energy describes the product you sell. However the world economy does not run on primary energy, it runs on final energy. That's the energy we consume to heat and light our buildings, run our vehicles, and

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power industry. The major difference between primary and final energy is waste heat, though there are also some losses from energy transport. Altogether, around a third of primary energy is lost before it can do anything useful.

Thinking about the world in terms of primary energy also masks the important role of electricity where heat losses are highest at around 63%. It can also help to explain why many of the world's most eminent energy experts have underestimated the growth to date of renewable energy, and its future potential. If we consider that the electricity sector consumes about 38% of fossil fuel production; and that renewables make up 25% of electricity, and wind and solar PV make up 25% of that, it easy to see how these technologies can get lost in the noise of a much larger primary energy analysis.

Renewables are certainly not the one-size-fits-all solution that enthusiasts sometimes claim. However if we think of the energy transition in phases, then we need to think of wind, PV and lithium-ion battery storage as "Phase I" decarbonization technologies that, if deployed to their full potential, can make a big dent in greenhouse gas emissions and buy us time to develop something else for "Phase II".

The world has been adding more renewable power capacity than fossil fuel power capacity since 2015. Today, renewables (excluding large hydro) account for almost 68% of new additions, and make up 21% of total installed capacity and 13% of generation. In 2018 a record 108GW of PV was deployed worldwide, as well as 50GW of wind power. In 2019 the industry is on track to beat all records with 121GW of PV and 67GW of wind. Looking forward to 2020 we estimate another 138GW of PV and 70GW of wind. But how might this continue?

The *New Energy Outlook (NEO)* is BloombergNEF's annual long-term analysis of the future of energy. It draws together the work of over 65 in-house analysts across the world to describe a future, least-cost, electricity system. The headline conclusion is that a combination of cheap renewables, batteries, and other new sources of flexibility grow worldwide to reach almost 50% wind and PV in the electricity supply by 2050, with solar growing from around 2% to 22% of electricity, and wind from 5% to 26%. In contrast, the share of fossil fuels in power declines to 31% from 63% today while hydro and nuclear see modest growth or remain flat, the former constrained by resource availability, the latter by a combination of high costs and a lack of flexibility.

At its core, *NEO* is a story of technology disruption and nothing reflects this better than solar PV. Since 1976 we have seen a rapid fall in the price of crystalline silicon PV modules, down from $80/W to $0.27/W in 2018, and around $0.25/W in 2019. Just since 2010 PV module prices have fallen 85%. Driving this are manufacturing scale and ongoing deployment. The relationship between price and volume can be represented by an experience curve. For PV, the experience curve describes a 28.5%, decline in cost for every doubling of capacity. That's perhaps not as steep as equivalent curves seen in the semi-conductor industry, but it's of a similar order of magnitude. How long this relationship will hold is unknown, but bottom-up analysis looking at innovation in PV manufacturing on a component-by-component basis makes us confident that the industry won't hit technical limitations anytime soon. Looking out to 2025 and 2030, we expect all-in cost of energy from new solar PV to drop another 14% and 22% respectively.

Wind technology has also been getting cheaper. The price of wind turbines is down 40% since 2010 on a per megawatt basis with an experience curve of around 11%. But while unit declines are less impressive than PV, wind remains competitive with solar energy because each MW of wind yields more energy. This improvement in capacity factor comes from taller turbines that can access faster wind speeds, and bigger swept-area-to-power-output ratios that increase the energy captured where the wind is weaker. Newer turbine models are also widening the range of locations where wind parks can be developed economically. Overall, onshore wind energy has a 15% learning rate. Recent years has also seen the cost of offshore wind come down faster than most expected. This is the combination of larger turbines that offer better park layouts as well as fewer foundations, less cabling and less maintenance; larger projects pushing the 1GW mark that offer economies of scale; growing global supply chains and developer experience; as well as better policy design.

Both solar PV and wind are the product of large-scale modular manufacturing industries that find continuous micro-innovations in production efficiency, materials and energy use. The cost of these technologies declines with every unit deployed. And this is fundamentally different to large, fuel-based power plants which are pieces of complex system engineering, and where 50% of the lifetime cost of a coal plant and 70% of that for gas plants are due to fuel prices, themselves subject to commodity cycles.

By taking technology costs, balance of plant, operations, maintenance and financing costs into account, we can calculate the levelized cost of electricity (LCOE) for new renewable and fossil fuel assets alike. The LCOE is the average offtake price needed across a project lifetime for a developer to meet its equity hurdle rate of return. When we do this, we find that the cost of renewable projects have now fallen to such an extent, that today two-thirds of the world population live somewhere where wind or PV, or both, are the cheapest new-build electricity option. And in Japan, Poland or Turkey where coal remains cheaper, or in Russia where gas remains cheaper, this first tipping point in the economics is imminent.

We are also seeing firm downward pressure on new wind and PV project costs from more and more capacity being awarded via tender or auction. Here, competition between developers continues to reveal incredibly low prices, which in turn has squeezed margins all along the supply chain. Most recently, on November 21, the Dubai Energy and Water Authority awarded a contract for 800MW of PV to Saudi-based ACWA Power and Kuwait-based Gulf Investment Corporation with an impressively low bid of $16.95/MWh. This followed the lowest bid on record of $16.30 (€14.80/MWh) from French developer Akuo Energy which won 150MW in Portugal's first solar auction in August.

Already this year we have seen 63GW of new renewable capacity awarded via auction – more than ever before – with a further 97GW announced for future rounds. The lowest bid for new onshore wind energy to date is in Mexico where Italian utility Enel won a total of 593MW, including a bid of $17.70/MWh. These prices need to be read cautiously as they hide a long list of contract particularities that obscure the full lifetime cost of the projects. For example, some bids are for delivery in future years and developers can bake-in an expectation of cheaper equipment; projects also usually have a longer life than the length of contracts awarded; and some include inflation factors or differential tariffs. However, even if we levelize these bids, they remain incredibly cheap and the costs are generally much lower than those of new coal or gas plants.

If we expect renewable technology costs to continue to decline along their experience curves, then it's a matter of when, not if, new-build wind or PV drops below the cost of running existing, commissioned coal and gas plants. This second "tipping point" happens at different times in different countries, depending on the quality of renewable resources and fuel prices, but it happens sooner than most people might think. In China, our calculations suggest new onshore wind will be cheaper than running existing coal-fired power as early as 2024. And in the U.S., which has the cheapest gas in the world, new-build wind and PV look likely to be cheaper than running most existing combined-cycle gas plants by 2030. As these critical points are reached, renewables can start to take market share from commissioned coal and gas plants, which consequently see lower capacity factors and higher generation costs.

But there is an obvious problem – wind and PV are not always available, so looking at the LCOE alone is not enough. Ultimately what's needed is additional flexibility, both on the supply and the demand side to help support variable renewables and ensure security of supply. Demand response, including both capacity turn-down and time-of-use load shifting; large reservoir hydro and pumped hydro; network interconnection; and gas peaker plants that run on-call for a small number of hours per year, can all offer flexibility. However the most compelling technology story is lithium-ion batteries. Batteries can shave peaks and can help PV meet demand when the sun has gone down, and wind meet demand when it's not blowing. However most importantly, like PV and wind, lithium-ion batteries are getting cheaper, fast.

The price of a lithium-ion battery pack is down 87% since 2010 on a volume-weighted basis from $1,160/kWh, to $156/kWh according to BNEF's December 2019 annual survey. At the same time, battery energy density and cycle life continue to improve – the former up more than 67% since 2011. Like PV and wind, this decline in costs is the result of manufacturing scale and innovation, with battery pack demand rising 100-fold from 2010 to 2018. The relationship between price and volume here describes an 18% learning rate, so as manufactured volume increases over time, we expect costs will continue to fall to around $94/kWh in 2024 and $62/kWh in 2030. Right now there is 366GWh per year of commissioned lithium-ion battery manufacturing capacity worldwide, and based on manufacturer commitments, by 2022 that number is set to rise more than three-fold, to 1,239GWh. To give a sense of future scale-up, in 2018 demand for lithium-ion batteries for electric vehicles overtook demand for lithium-ion batteries for consumer electronics, and in most markets EVs currently only make up 2% or less of the on-road fleet.

While lithium-ion battery chemistries aren't always a perfect fit for stationary energy storage applications in the power sector, they have a significant cost advantage over other technologies. Today, a four-hour lithium-ion battery system charging from the grid has an average levelized cost of around $167/MWh, and as battery costs decline we expect this to fall to $79/MWh by 2030. Today most business cases for large-scale batteries rely on stacking revenues from a combination of energy, capacity and ancillary service markets, depending on what's available. They are also being used in some markets by large energy users to lower demand charges, and grid operators to avoid costly network upgrades.

However, in the future we expect most batteries will find value in load shifting – that is, charging when renewables are abundant and prices low, and discharging during high value hours when renewables are offline and prices spike as more expensive generation ramps up. We can already see a pipeline of co-located renewables-plus-storage projects. If the battery is small enough, these can be competitive today, with lower costs larger batteries. Our calculations suggest the cost of co-located wind-plus-storage and PV-plus-storage projects with larger four-hour storage systems will fall over 40% by 2030. That means renewable energy can reach more high-value hours when they would otherwise be unavailable, competing directly with new coal or gas projects for capacity by the mid-2020s. In India, for example, we think these co-located systems will look more economic than new pithead coal-fired generation by 2024. And by the mid-2030s batteries charging either from the grid or from a co-located coal asset could be cheaper then running existing coal or gas plants.

The fall in battery prices is the result of growing demand from the electric vehicles industry. EVs sales growth has slowed a little in 2019, but we still expect a record 2.2 million vehicles, up from 1.9 million in 2018, and just over 1 million in 2017. At the end of Q3 2019 there were 6.5 million EVs on the road, over half of those in China. The uptake is being driven in part by tighter tailpipe emissions standards in U.S., China and Europe that require auto manufacturers to sell more EVs to balance sales of their internal combustion engine (ICE) models. There are currently 370 battery-electric and plug-in hybrid EV models on the market worldwide, and by this time next year there will be 428. More models means more choice, and more likely a buyer will find an EV option that suits their needs. On the other side of the ledger, purchase subsidies, tax breaks and scrappage schemes are helping drive consumer uptake. Governments are also starting to send longer-term signals to the market. So far 13 national governments, as well as 30 states and municipal governments, have announced phase-out plans for internal combustion engine vehicles. Norway is the most ambitious country-level target, aiming to ban ICEs by 2025, other European countries such as Denmark, Sweden and Netherlands are aiming for 2030, and the U.K., France and Canada at 2040. Cities tend to be more ambitious, with Madrid, Rome, Athens and Mexico City aiming to be ICE-free in six years. Los Angeles, Cape Town and Brussels are some of those aiming for 2030.

Around 30% of the cost of a battery electric vehicle is the battery pack, so cheaper batteries means cheaper EVs which, according to our analysis, should reach upfront price parity with equivalent ICE models as soon as 2023. From that point we expect uptake to accelerate, reaching 30% of new vehicle sales worldwide by 2030, and 57% by 2040, up from just 3% today. By 2040 around 42% of cars on the road in the U.S. are expected to have a plug. In Europe its 38%. Worldwide there are set to be around 576 million EVs on the road in 2040. All these EVs do two things: they add electricity demand, and they reduce oil demand.

Growth in electric vehicles accounts for 3,950TWh, or 9%, of electricity demand in 2050. Again, this differs by region. In the U.S., EVs draw 16% of electricity in 2050, in Europe 15%, in Australia 13%, and in China 10%. However the hours of the day when EVs charge will ultimately be as important as how much load they add. Many energy suppliers in the U.S. and Europe already offer EV-specific rate structures that provide a strong incentive for off-peak charging at night. If an EV can be plugged in during the 95% of the time a normal car is stationary, whether that's at home, at work, or out-and-about, then owners can charge at the cheapest times, and the power grid benefits from greater demand-side flexibility. With the growth of close-to-zero marginal cost PV and wind, we expect these tariffs to shift more vehicle charging to the middle of the day when solar generation is at its best.

Growth in EVs, and fuel economy improvements, means we think oil demand from road fuels should peak in around 2030, with the combination of alternative drivetrains and growth in shared mobility displacing around 15 million barrels of oil per day by 2040.

Consumers are not just starting to buy EVs, they are also changing the energy system by installing their own PV, and in some places they are also now adding batteries. Small-scale PV deployed on rooftops and commercial buildings has grown strongly in markets with good solar resources and high, or rising, retail electricity prices. In Australia one in five households already has rooftop PV. In the state of South Australia where I'm from, it's one in four and rooftop PV accounts for more than half the system load at certain times. As solar gets cheaper more households and commercial facilities will add PV to offset their retail electricity bills. And as the cost of lithium-ion batteries continues to fall, adding storage alongside PV also starts to look more and more attractive. Consumer uptake can be rapid when price and market penetration meet critical thresholds and a copycat effect drives steep adoption s-curves where uptake accelerates from early adopters to the mass market, before reaching saturation. Our diffusion modelling for consumer PV, and PV-plus-battery products, shows that by 2050, 10-30% of power capacity assets could sit behind-the-meter in major markets, highlighting a massive shift in system value downstream.

Looking at the *New Energy Outlook* results at a regional and country level to 2050 shows that Europe transitions furthest towards renewables, and does so fastest. The combination of low cost bulk renewables, carbon pricing, and competitive batteries, propel wind and PV to over 80% penetration by 2050 in some European states. Those where nuclear, hydro or biomass can play a major role get close to 100% zero-carbon. An 80% variable renewable energy system looks very different to the power systems with which we are familiar. No longer do large coal or gas plants run around-the-clock at high capacity factors, supported by smaller peakers. Instead, cheap variable renewables form the backbone of the system, supported by batteries and conventional plants running at low capacity factors. This configuration is characterized by large amounts of PV during the day, supported by wind in the evenings and batteries that charge and discharge over short timeframes. In this new system, back-up and curtailment are a feature, not a bug.

Firstly, there are limits to what wind, PV and batteries can do together. This is because there are days and weeks during the year when wind and PV simply can't produce enough electrons to meet demand, no matter how many batteries are installed. Some of the peakiest parts of the load might be met with demand response, but that's limited. That means these systems need to call upon dispatchable back-up.

Secondly, there are weeks and months when renewables are running flat out producing more electricity than is needed in real time and more than the battery fleet can store. At these times we have too much capacity and get curtailment. But this is still least-cost, because as PV and wind get cheaper, they remain competitive despite not producing useable electricity during every hour of operation, that is, at lower and lower capacity factors.

Ultimately, we think almost every country could technically get to around 80% wind and PV before reaching seasonal limitations, but most would need to deploy new renewables much faster to do so this side of 2050.

For example, the U.S. energy transition is dominated by cheap natural gas which grows to 45% of generation in 2030 as it replaces aging coal infrastructure. Once new gas plants are commissioned, they are cheap to run and tend not to face strong competition from battery systems for their dispatchable hours this side of 2050. Wind and PV grow too but more slowly, making up just 35% of electricity by mid-century. In China, coal generation grows with electricity demand in the short to medium term, but we think China will build its last coal plant by 2025 and sees peak coal generation in 2027. After which, coal declines at around 2% per year, and by 2050, wind and PV makes up 48% of China's electricity supply.

Coal-fired power is the first fossil fuel casualty of the transition, according to our modelling – peaking globally in 2026 and falling to just 12% of electricity in 2050, from around 37% today. This transition is most stark in Europe and the U.S., where coal-fired power continues its recent decline, down 90% to 2050 in the U.S. where it's undercut by cheap natural gas and renewables, and down 97% in Europe where coal-phase out plans, cheaper renewables and batteries, as well as carbon pricing, force it out of the mix. Coal continues to grow in China and South East Asia into the mid-2020s, and India until the late 2030s.

The outlook for gas-fired power remains relatively flat, as growth in the U.S. is offset by longer-term decline in Europe where it is increasingly beaten on cost by the combination of renewables plus batteries. In Asia gas is beaten by cheap coal and renewables. Gas grows 0.6% per year, supplying system back-up and flexibility rather than bulk generation in most markets. However, gas capacity doubles to help ensure security of supply, with combined-cycle plant up 37%, and peaker units that can ramp quickly to meet daily and seasonal extremes up 350%.

From a climate perspective, the *New Energy Outlook* is somewhat optimistic. It concludes that a least-cost deployment of renewable energy would keep power sector emissions on track for a 2-degree trajectory, but only until around 2030. Beyond that, decarbonization would need to be hastened by policy intervention. To achieve a 1.5 degree trajectory as envisaged by the Paris Agreement will need much more rapid transition than economics alone can deliver.

Achieving net-zero emissions by the second half of the century means there is nowhere to hide for those slow on the uptake, and no room for unabated fossil fuels. In particular, net-zero emissions targets ask serious questions about energy transition pathways for industry and buildings. One pathway is to switch to electricity to hitch a ride on the back of the renewable energy juggernaut. As discussed, this is already well established for road transport, even some of the commercial vehicle segments. It is also possible to use more electricity for space heating in buildings, as well as low —and medium— temperature industrial processes.

However, going electric isn't a universal solution. Yes, there is interesting progress being made in short-haul electric aviation and shipping, but moving heavy loads long distances is going to need something with better energy density than a battery. Heating is also highly seasonal which means a lot of energy demand is concentrated in a few months of the year. It also has a particular intraday pattern, ramping up in the morning as people wake up and turn on their heating, and again in the evening when they arrive home. If a country like the U.K. were to shift to 100% electric heat, the coldest days might drive a three-fold increase in winter peak power demand, right at the time when solar generation is at a nadir. In industry, high temperature heat is required for iron and steel production, chemicals, cement, aluminum and glass, among others. While electricity can technically provide high temperature heat, most technology options are still at early stages of development. Furthermore, in chemicals manufacturing, for example, fossil fuels also provide the raw materials, and in iron and steel production, they are chemically involved in the process itself. Even in the power sector, we've seen that around 20% of electricity demand is going to be very difficult to supply with wind, PV and batteries –our "Phase I" decarbonization technologies– alone. To get to net zero we are going to need a "Phase II".

Perhaps the answer is nuclear, hydro or solar thermal? Perhaps it's carbon capture with permanent sequestration? Or perhaps we are going to need a clean molecule such as hydrogen? What we know for sure is that right now, all the options we can list have limited potential or are far from commercially viable.

The good news is that "Phase I" can buy us time. But only if PV, wind, batteries and EVs are deployed as fast, or faster, than the New Energy Outlook suggests. At the same time, government needs to start making a market for the "Phase II" decarbonization technologies. And let the private sector start investing.