GrEnFIn

Greening Energy
Market and Finance

Project website: http://grenfin.eu

Energy, Renewables, Batteries and Financial Instruments to Hedge Delivery Risk

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Some Numbers

-> For millennia, the amount of CO_2 in the atmosphere had never been above 300 parts per million, the 1950 level; today, it is 416 ppm

-> Planet average surface temperature has increased by 2.1 degrees Farenheit (1.2 Celsius) since 1880

-> Arctic minimal ice has shrunk by 13.1% per decade

-> Ice sheets have decreased by 429 billion tonnes per year

-> Global sea level has risen by about 20 cms/8 inches in the last century. The rate in the last two decades is nearly double than that of the last century and still accelerating, endangering the housing of often poorer populations on the coast

-> Oceans have exhibited a warming of more than 0.6 deg Farenheit since 1969. They have absorbed between 20 and 30% of CO_2 emissions – between 7.2 to 10.8 billion tonnes/year and the acidity of surface waters has increased by about 30% since the beginning of the Industrial Revolution

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Ice and Glaciers Melting

-> Data from NASA show that Greenland has lost an average of 279 billion tonnes of ice per year between 1993 and 2019, while Antarctica ice sheets lost about 148 tonnes of ice per year.

-> The number of record high temperature events has been increasing in the US, while the number of recorded low temperature events decreased since 1950

-> Glaciers are retreating almost everywhere around the world, including the Alps, Himalayas, Andes, Rockies, Alaska and Africa

-> The beautiful snow cap of Mount Kilimanjaro is disappearing

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The Arc of Energy History

- From 1840 to 1900, coal went from 5% to 49% share of global energy supply
- From 1910 to 1970, oil share went from 2% to 39%
- From 1930 to 1990, Natural Gas went from 2% to 20%
- As of 2016, Renewables represented 4% of global energy supply

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CO2 Emissions 2019 vs 2018

Change in energy-related CO_2 emissions by region

2018-2019, Mt CO_2

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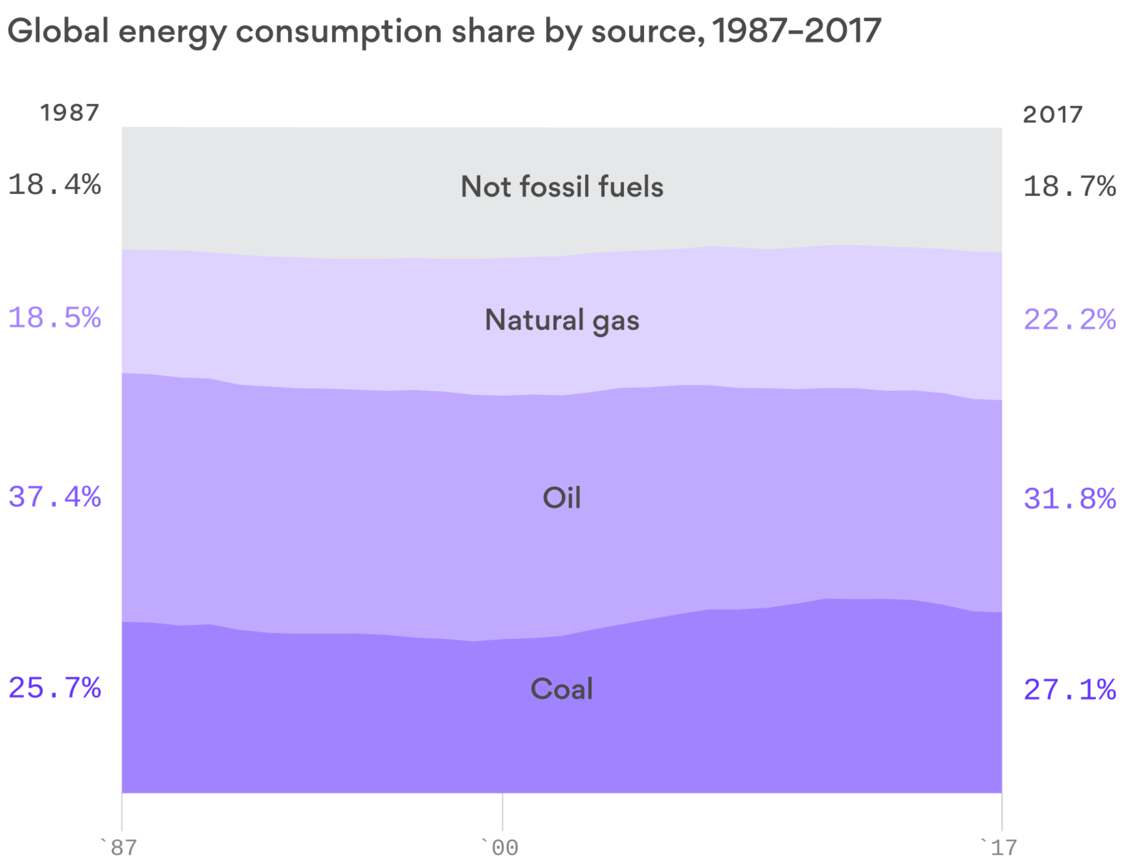
Global Energy Consumption :1987 to 2017



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The Price of Carbon

- The Group of 27 met on May 25, 2021 in Brussels to repeat the goal of ‘Zero Carbon’ target in 2050
- The tonne of CO_2 in the EU was 6 Euros in 2012
- It went to 31 Euros in December 2020
- It is forecasted at 100 Euros in 2030

And maybe at 500 Euros in 2050

There are presently 21 Carbon markets in the world presently.

-> China contributed to 28% of emissions in 2020, the US 18%,

Germany 2%.

-> The profits of Tesla from selling carbon permits was more than $1.7 billion over the last 10 years.

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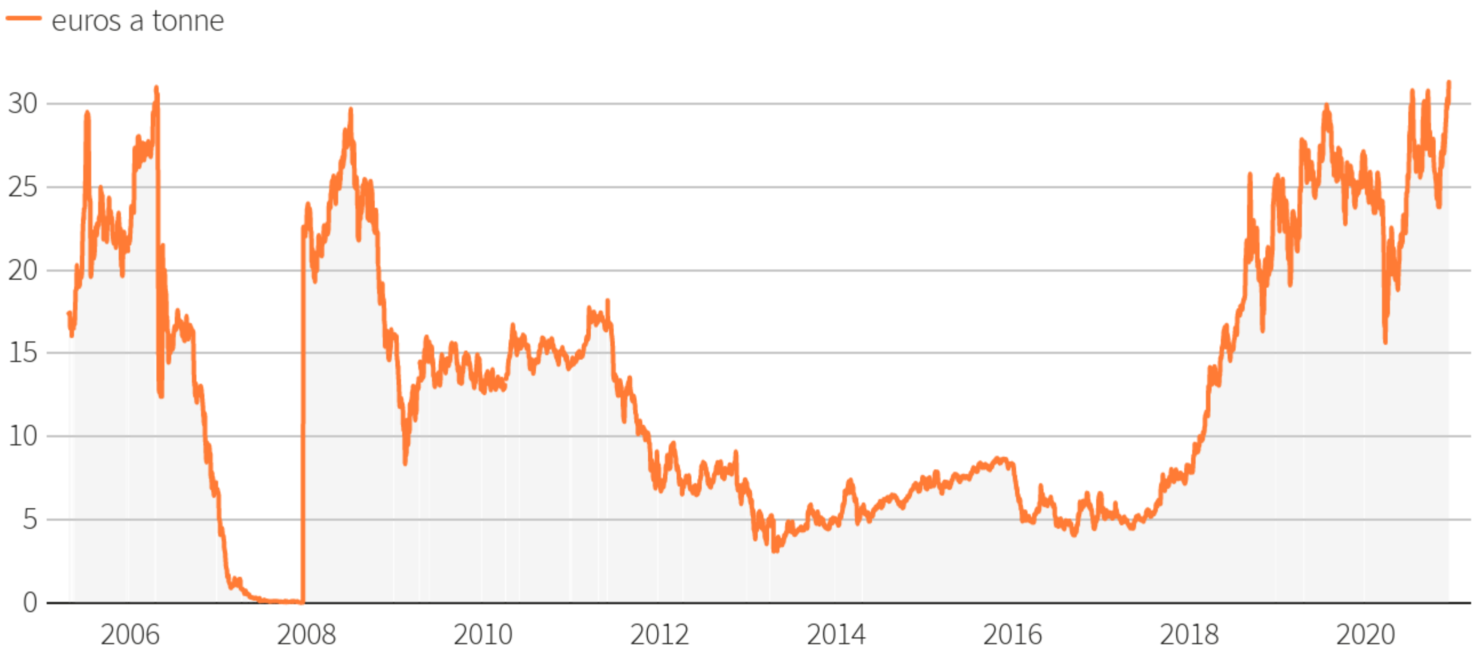
Price of EU Carbon tonne

EU carbon price rises to all-time high



Note:

Source: Refinitiv

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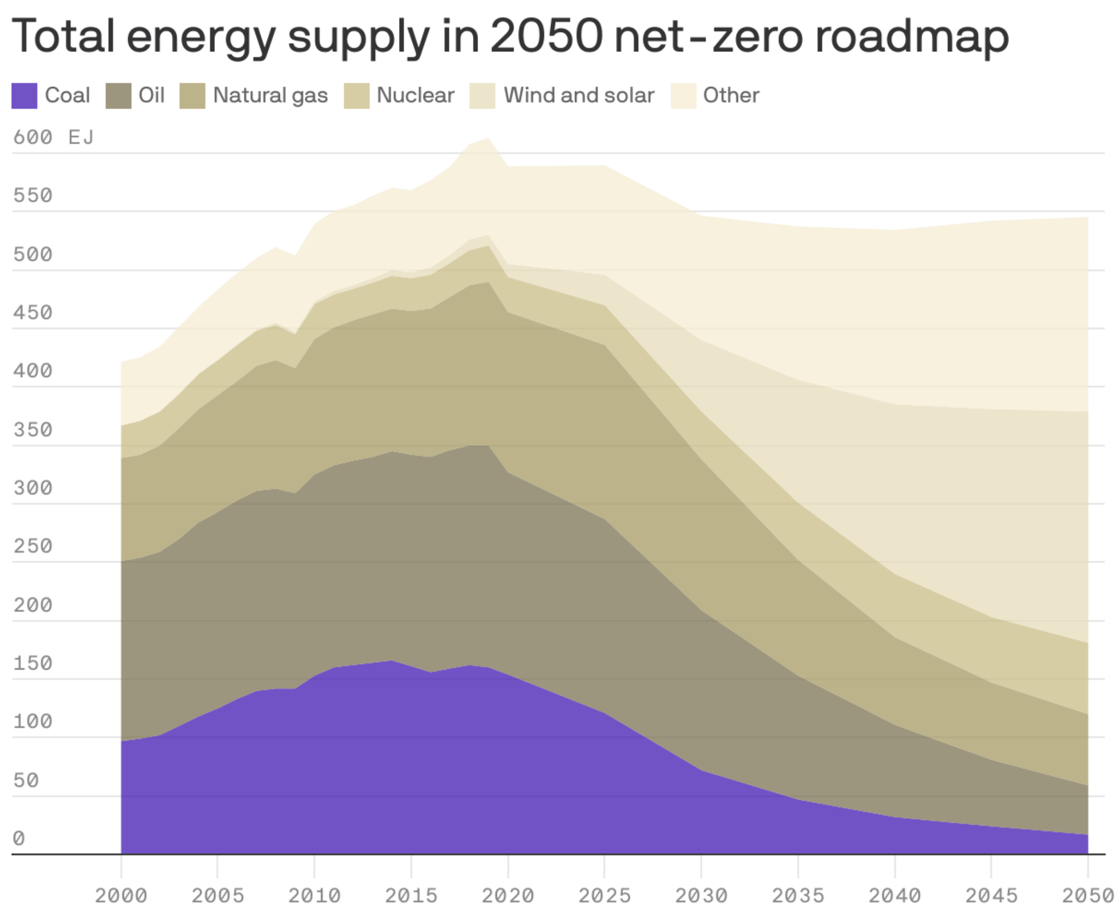
Global Energy Supply in 2050



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Bitcoin Electricity Consumption (2019)

- United Kingdom : 301 Twh
- Norway : 124 Twh
- Bitcoin : 123 Twh
- Pakistan : 90 Twh
- Greece : 54 Twh
- New Zealand : 41 Twh

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Copper for Renewable Energy

- The world's transition to renewable energy and electric vehicles will require unprecedented amounts of copper from potentially new mining operations that may harm vulnerable species and ecosystems: 925,000 tonnes in 2021 to 4.2 mn in 2030!
- The global need for ‘green’ copper could increase by an estimated 350% by 2050, with current reserves depleting some time between 2035 and 2045, as wind and solar deployment grow and more people use EVs.
- Worldwide copper usage had already jumped 38% over the last decade, from 17.8 mn of metric tonnes in 2009 to 24.5 mn in 2019, largely driven by demand for renewable energy and cleaner vehicles.
- Wind energy requires on average 2,000 tons of copper per GW, while solar needs about 5,000 tons per GW — several times higher than fossil fuels and nuclear energy.
- Electric vehicles can contain between 40 kg and 83 kg of copper, while an internal combustion engine needs an average of 23 kg.
- In order for the benefits of renewable forms of energy not to outweigh the costs of obtaining the materials to produce them, good mining practices should be followed and recycling rates improved – today copper recycling rates are between 40 and 50%

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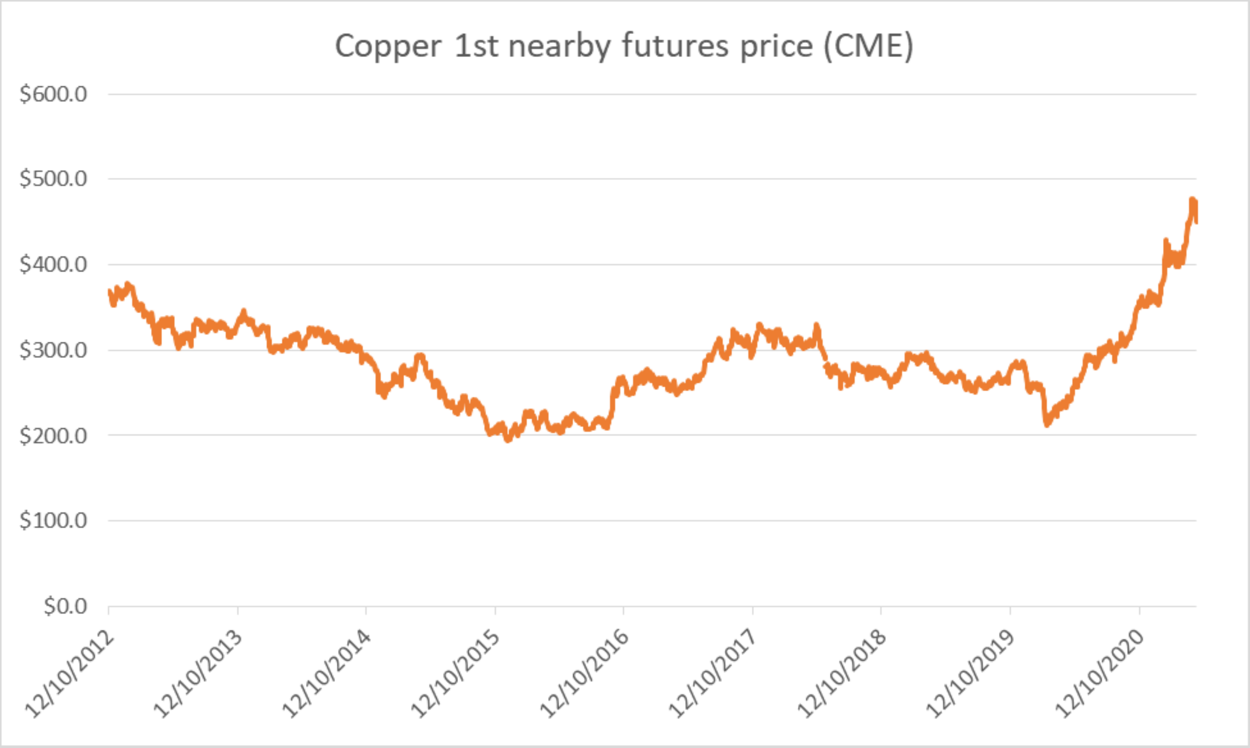
Copper Prices – 2012 to 2021 (for Grids, Construction, Evs)



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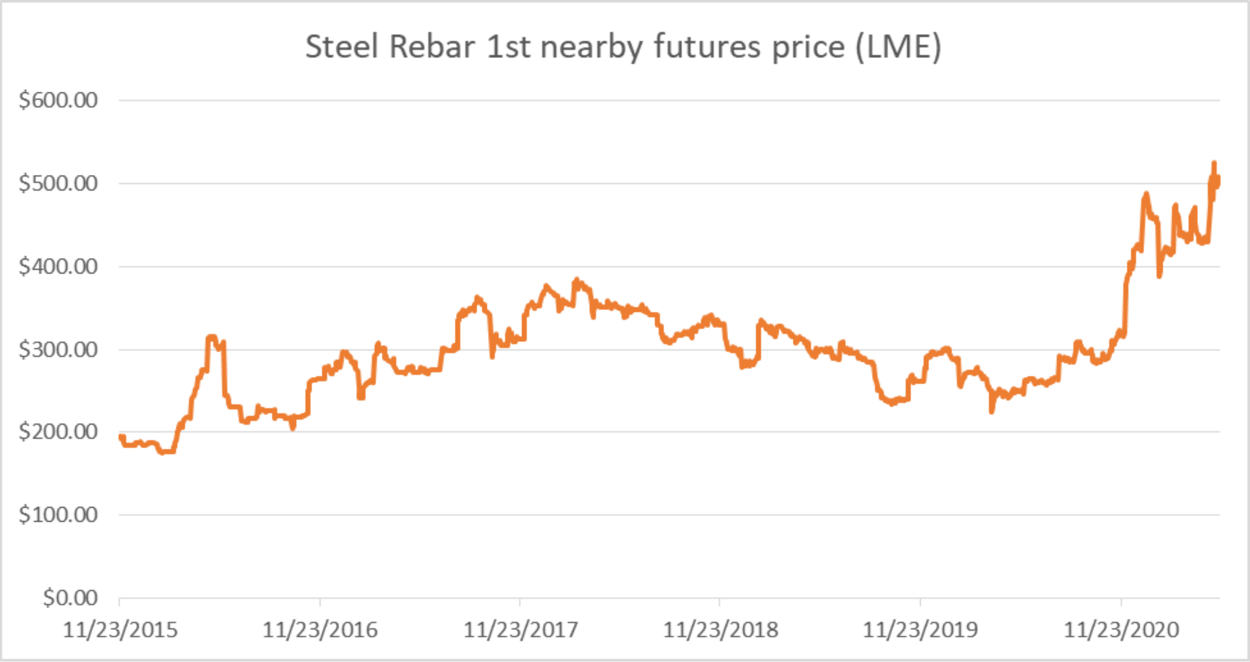
Steel Rebar 2015 to 2021 (for wind turbines and PV)



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HydroElectricity: Good & Bad News

- Hydro-Electricity has two merits:

  - Consuming water as the 'fuel', instead of coal, Natural Gas or Uranium

  - Providing a storage facility for electricity (water being kept in a reservoir), hence a '*hedge*' for intermittent Renewables such as Solar and Wind

- But large dams like the Renaissance dam just finished in Ethiopia on the Blue Nile River is diverting waters that Egypt and other neighboring countries need for their Agriculture and large population

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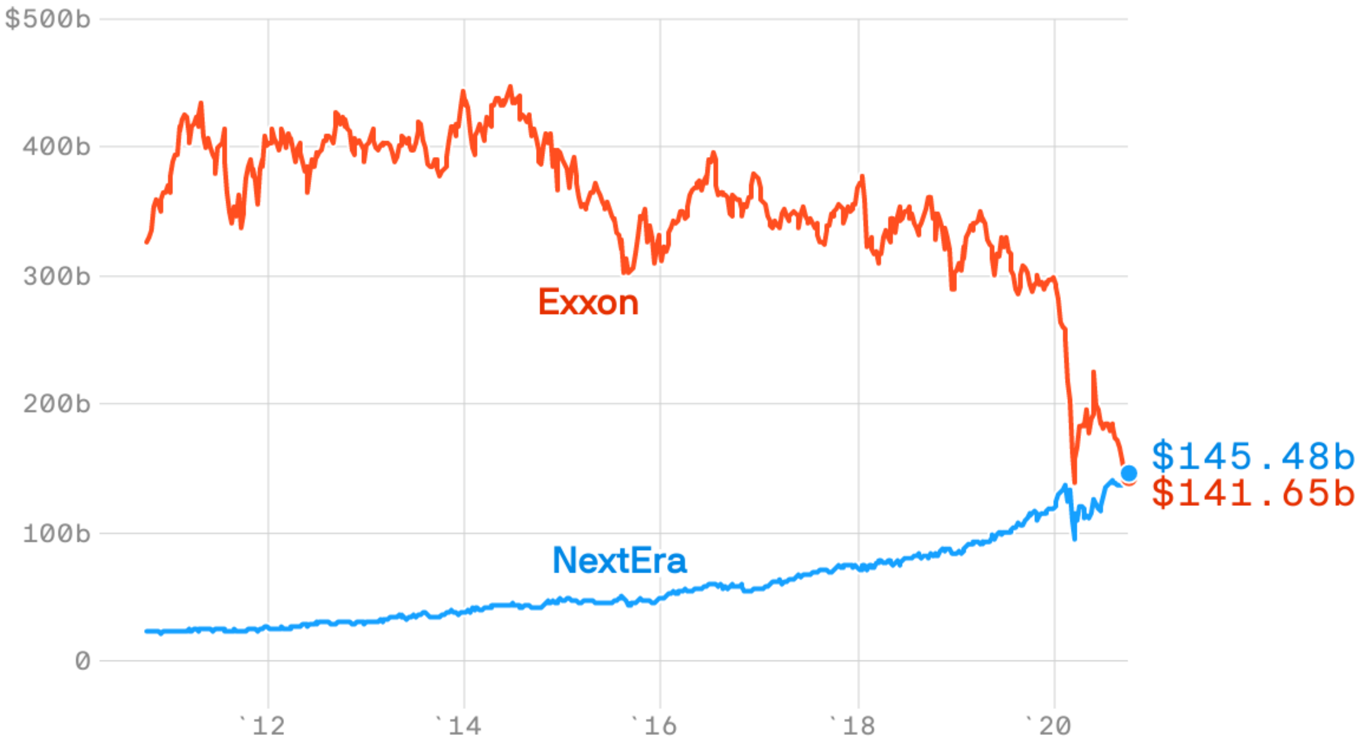
Exxon and NextEra Market Capitalization

Market value of Exxon Mobil Corp. and NextEra Energy Inc.

Oct. 8, 2010, to Oct. 7, 2020



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NextEra

- **NextEra Energy**, the world's largest solar and wind power generator, has surpassed ExxonMobil in market value, jumping from a $32 billion valuation in October 2010 to more than $145 billion
- **Why it matters:** The crash in Exxon shares reflects a similar crash in oil — in price and standing — over the past decade and investors' increasing bets on renewable energy.
- Once the world's most valuable company, ExxonMobil has lost more than half its value since the start of the year.
- Its market cap has dwindled from a peak of more than $500 billion in 2007.
- NextEra isn't only a renewables company by a longshot. The Florida-based utility and power producer describes itself as "one of the largest generators from natural gas in the U.S." and also has coal, nuclear and oil-fired assets.
- **The oil company Chevron announced early 2021 that it was expecting to capture nearly 5 million tonnes of CO_2 per year.**

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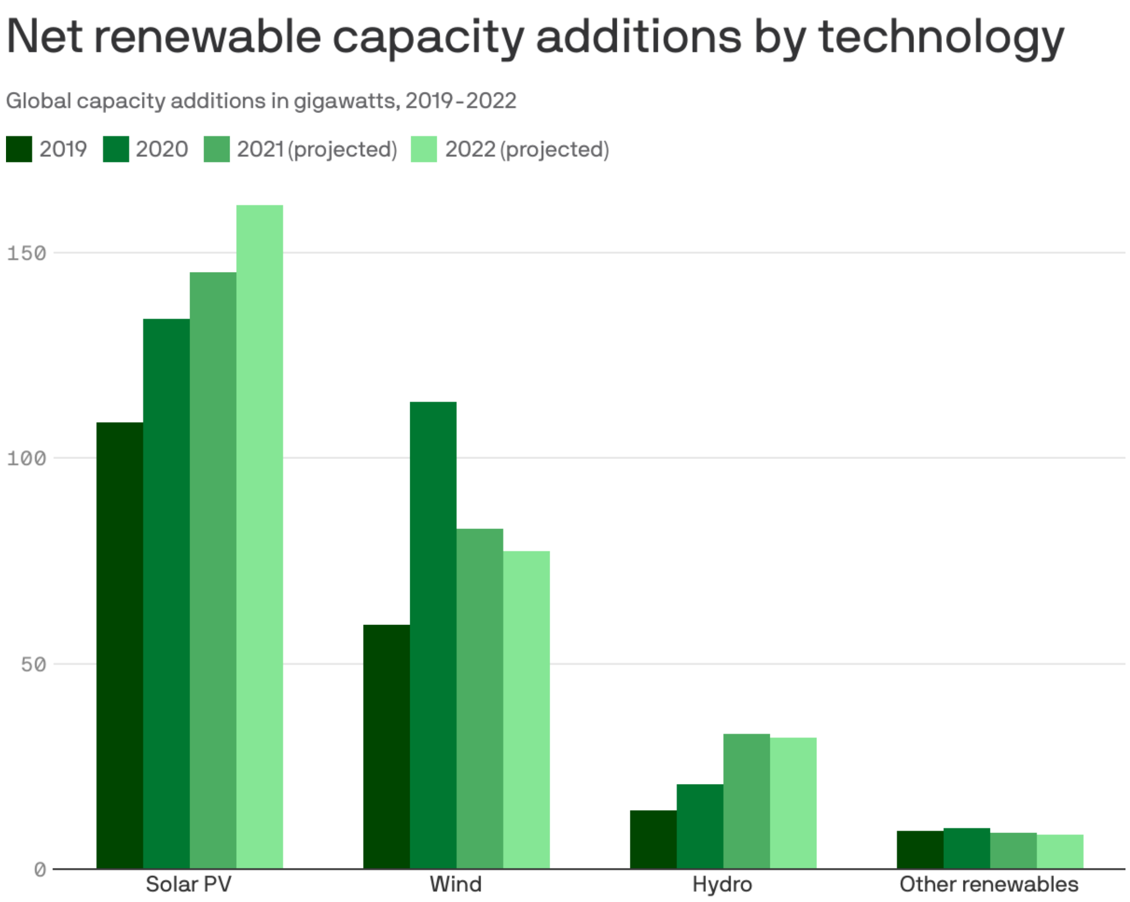
Energy Additions



New Renewable Energy

- **The International Energy Agency** just issued a big upward revision to estimates of near-term global renewable power growth.
- **Driving the news:** The agency's latest data shows that new capacity additions surged to almost 280 gigawatts last year despite the pandemic.
- That's 45% higher than 2019 and the largest YOY jump in two decades.
- IEA said that scale of new capacity additions is the "new normal."
- They project about 270 GW this year and another 280 in 2022, with renewables accounting for 90% of power generating capacity additions globally.
- Those combined gigawatt levels are 25% higher than their prior projections in November, with IEA boosting forecasts for all major markets. Their 2021-22 regional outlook sees growth slowing in China — the world's largest market — and slightly in the U.S. compared to 2020, but accelerating in Europe, India and Latin America.

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Costs of Renewables

- With the US federal tax credits, "the cost of onshore wind and utility-scale solar is competitive with the marginal cost of coal, nuclear and combined cycle gas generation," a summary notes.
- The "values average $31/MWh for utility-scale solar and $26/MWh for utility-scale wind, while the latter values average $41/MWh for coal, $29/MWh for nuclear, and $28/MWh for combined cycle gas generation”.
- The annual report looks at the "leveled" costs of power sources — that is, an inclusive cost comparison of building, running, supplying and maintaining different types of facilities over time

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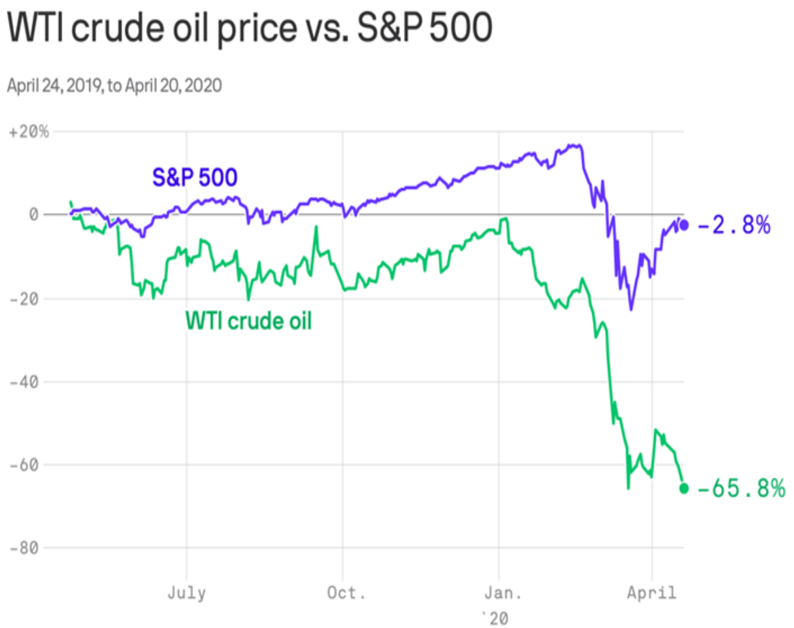
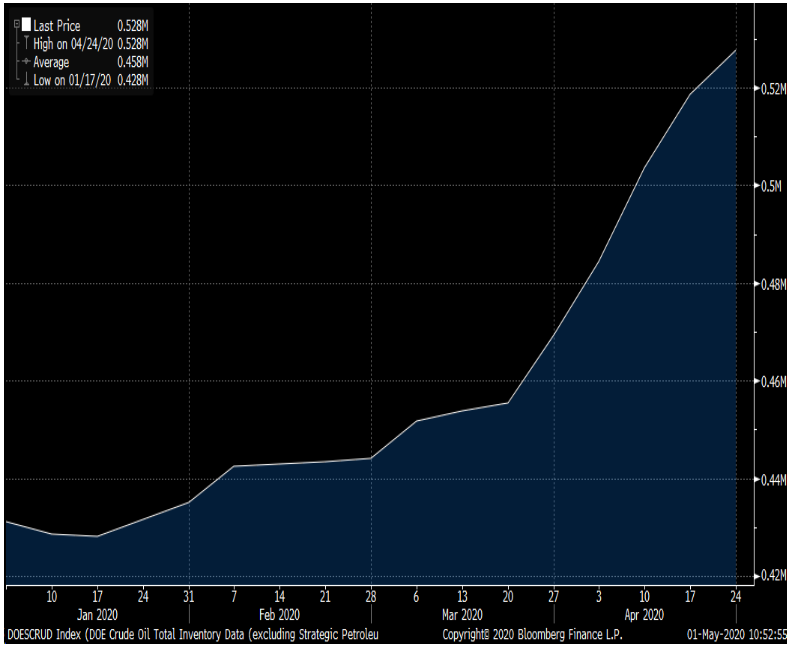
‘Why Storage Matters’
(Geman and Ma, 2020)

The US crude oil benchmark WTI May.2020 contract crashed to $-37 a barrel on April 20, 2020 the second last day before contract expiry, marking the greatest plunge of crude oil and first time negative oil prices in history. The fact that the crude oil storage was nearly completely full in the US created a massive fear in the market. We aim to explain crude oil Futures price with inventory data and the ‘Theory of Storage’ (Working 1949).





Commercial crude oil inventory data excluding US Strategic Petroleum Reserve are taken from Energy Information Administration and as part of their Weekly Petroleum Status Report at http://www.eia.gov/petroleum/supply/weekly/.

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Developments in Batteries

- The ongoing cost declines for lithium-ion battery tech is helping to make electric vehicles competitive against internal combustion models.
- Some studies see 2023 as the point where automakers "should be able to produce and sell mass market EVs at the same price (and with the same margin) as comparable internal combustion vehicles in some markets."
- That chart above shows an average across different types of vehicles, as well as stationary storage. BloombergNEF's Nathaniel Bullard points out that there's lots of variation.
- "In every application, though, these batteries are now making serious inroads into their respective markets of public transportation, personal vehicles, and electricity networks," Bullard writes.

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Batteries & Critical Elements

- Efforts to rapidly improve battery technology and make EVs more affordable could be hampered by a shortage of raw materials like lithium, cobalt and nickel. Many automakers are racing to lock up supply chains — and in some cases, to produce batteries themselves.
- Volkswagen, the world's second-largest automaker, took the boldest step yet with a plan announced Monday to build six giant battery factories in Europe by 2030.
- Together, the six plants could provide up to 240 gigawatt-hours of battery capacity — 12% more than the entire world consumed in 2020, according to Benchmark Mineral Intelligence.
- That's enough capacity just in Europe to build 4 million to 4.5 million electric vehicles, depending on the size of the cars' battery packs, Benchmark says.
- The effort will cost about $29 billion and would make VW (along with partner Northvolt) the world's second-largest cell producer after China's CATL

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The Complexity of Storage

- Crude oil : barrels, but in a regulated storage facility
- Natural Gas : Depleted Oil Fields and LNG tankers
- Hydro-Electricity: Water Reservoir
- Gas-Fired Turbines: with very short (7 to 30 Minutes) ramp times
- Renewables: Batteries or other Devices (DERs acting like storage : water heaters, Electric vehicles)
- And Bitcoins…

Batteries (continued)

- It marks an important shift by automakers to bring battery cell production in-house, according to the firm Benchmark
- Most automakers, even Tesla, the leading EV company, assemble battery packs from cells imported from Asia.
- But with demand expected to soar as more EVs come to market, manufacturers are taking steps to ensure they'll have needed supply.
- VW is not alone : Chinese carmaker Geely plans to spend almost $5 billion to build a new 42 gigawatt-hour battery plant in southern China. GM and South Korean partner LG Chem are investing $2.3 billion to build a 30 gigawatt-hour factory in Ohio, and are scouting a second location. Tesla kicked off the scramble last fall by announcing it would build its own cells and would produce a staggering 3 terawatt-hours a year by 2030.
- VW's six plants alone would consume more than 60% of the lithium produced globally in 2020, Benchmark estimates.

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Cold in Texas in February 2021

- The crisis that gripped Texas' power grid was different from California's wildfire emergencies in recent years, but there were connectivity issues as well. Electricity grids and infrastructure need to be better equipped for a changing climate
- Texas was reeling after a bitter blast of Arctic air and a related demand surge led to widespread outages, causing millions of customers to lose power
- Climate change is creating new challenges in the form of both extreme heat and polar vortex disruptions that push Arctic air southward. Extreme peaks in demand for heating and cooling make grid planning and resource allocation harder.
- Usually, extreme heat and stronger storms are the big problem in Texas
- Some climate scientists have also suggested that global warming could, paradoxically, bring more unusually fierce winter storms," they report.
- Some experts aren't certain that polar vortex disruptions are happening more, "making it even trickier for electricity planners to anticipate the dangers ahead."

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Electricity in Texas

- One question going forward is whether this disaster will lead to major changes in the way the Texas power grid is regulated or operated — and how the crisis is spilling into national energy debates.
- Meanwhile, the political dimensions of the crisis and also asks whether it "could be a boon to Biden's proposal to spend huge sums of money to harden the nation's electric grid as it connects giant wind and solar power plants to cities and states thousands of miles away."
- The state, unlike large swaths of the country, does not have a "capacity market" that compensates power generators for commitments of future supplies — even if they remain idle.
- Texas has an energy market that aims to have reserve capacity but relies heavily on

  market forces, which let prices soar during high demand periods.

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Oil Companies Blowing in the Wind

- BP is making its first move into offshore wind via a new deal and partnership with Norway-based Equinor (previously named Statoil), aimed at big U.S. projects.
- BP is paying Equinor $1.1 billion for a 50% stake in wind farms Equinor is developing off the coasts of New York and Massachusetts. The project will have a generating capacity of 4.4 GW, enough to power over 2 million homes.
- BP and Equinor — which are both making more moves into renewables — also announced a "strategic partnership" to jointly pursue other U.S. offshore projects.
- BP said it hopes to develop 50 gigawatts of renewable generating capacity by 2030, which is 20 times its 2019 level.
- The French oil company Total will team up with Macquarie Group’s green bank to develop more than 2 gigawatts of floating wind farms off the coast of South Korea
- To help address climate change, ExxonMobil is working on a plan that could capture and store roughly 100 million metric tons of CO_2 annually by 2040.
- All these companies try to improve their ESG Ratings to stay in the portfolios of pension funds and asset management companies

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Oil Companies and Climate

- "The Dutch government has granted a consortium that includes oil majors Royal Dutch Shell and ExxonMobil around 2 billion euros ($2.4 billion) in subsidies for what is set to become one of the largest carbon capture and storage (CCS) projects in the world, the Port of Rotterdam said on May 10, 2021
- A Dutch district court in The Hague ordered Shell to cut its carbon emissions by 45% by 2030 relative to 2019 levels. Shell is defending its current plans and says it will appeal.
- The court ruled Shell "violated its duty of care under Dutch law because its policies and emissions contributed to dangerous climate change."
- "Michael Burger, a litigation specialist who represents local U.S. governments in climate cases including against Shell, said while Wednesday's decision was based on Dutch law, the concept of a duty to care exists in legal systems in Europe and around the globe".

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Solar and Wind Growing fast despite Cov19

- **The downward march of solar and onshore wind** power costs mean they're now the cheapest source of new power development for at least two-thirds of the global population, the research firm BloombergNEF said in January 2021
- The annual survey of all-in costs for power projects underscores why analysts see COVID-19 slowing growth but not altering the fundamental trajectory of the technologies.
- The leveled cost of electricity for utility-scale solar and onshore wind projects has fallen another 4% and 9% since just the second-half of 2019.
- Wind has seen the steepest decline since 2015, they note, mainly due to a scale-up in turbine size, now averaging 4.1 megawatts, and priced at about $0.7 million per megawatt for recently financed projects.
- The analysis measures the all-in costs of creating power, which means "development, construction and equipment, financing, operation & maintenance

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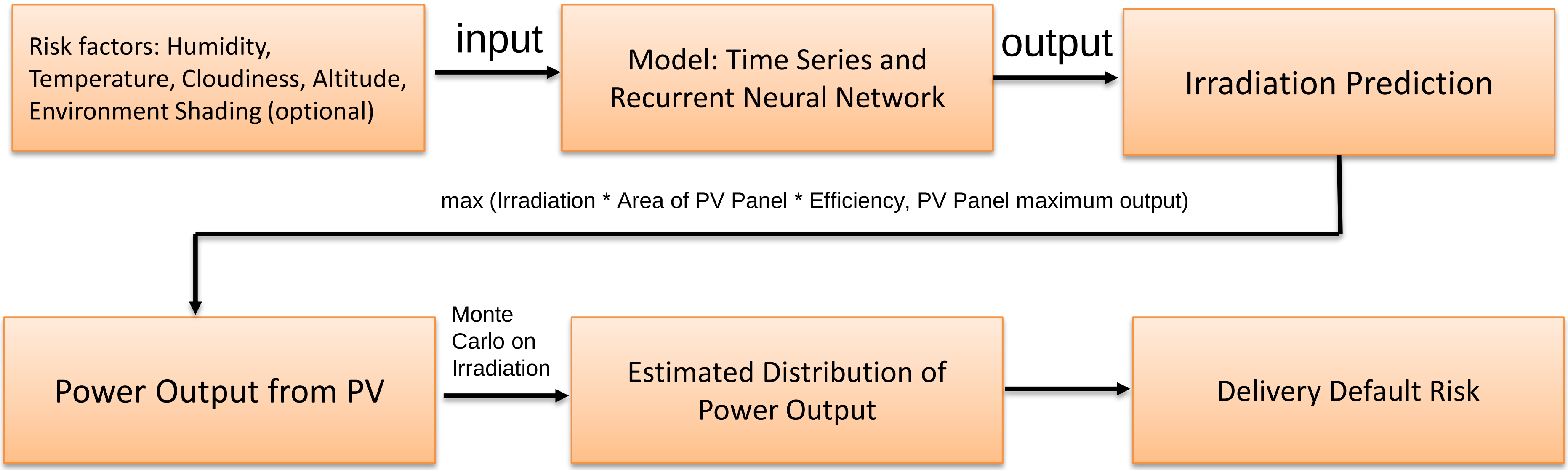
Distributed PV Delivery Risk

Roadmap:



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Google Data Centers Going Green

- The company AES announced in April 2021 First-of-Its-Kind Agreement to Supply 24/7 Carbon-Free Energy Data Centers in Virginia for Google
- This transaction will result in the construction of approximately 500 MW of renewable energy and storage projects to ensure Google's Virginia-based data centers will be 90% carbon-free when measured on an hourly basis

. AES said it would supply Google with a 500-megawatt mix of wind, solar, hydro and battery storage it will develop or contract.

- The portfolio will require roughly $600 million of investment and generate 1,200 permanent and temporary jobs.
- "Moving to a world where we are able to operate by sourcing clean energy for every location and where you are, and, and doing it across your operational footprint in everything you do" was the statement of Google CEO

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UK Electricity Market Reform (EMR)

- Implemented in 2013
- Great Britain Capacity Market
- Contracts for Difference (CfDs) for low-carbon electricity
- Carbon price floor (CPF) of £18.08 per tonne of carbon dioxide
- Emission performance standard (EPS) of 450 g/tCO2

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Contracts for Differences in Oil

-> They have been used for a long time in the world of Brent crude oil

-> In that setting, they are short dated swap agreements meant to minimize the *basis risk* between the daily published Platt's quote for dated Brent in a specific time window in the future and the forward price quote for a specific month.

-> The settlement of a CfD is based on the published price difference at a designated date

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Contracts for Difference (CfD) Scheme

Generators exchange daily payments with the UK government for the electricity they produce for 15 years. The payments are calculated as the difference between a set strike price and an indexed reference price:

- Strike Price > Indexed Reference Price generators receive the price difference
- Strike Price < Indexed Reference Price generators pay back the price difference

Protects Generators from volatile wholesale electricity prices
Protects Consumers from higher utility bills
Low risk investment with stable returns for investors

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Valuation of CfDs

VALUATION METHODOLOGY FOR CFD'S

The Contracts for Difference are contracts between a generator of new low-carbon electricity and the UK government for instance, in which the two parties will exchange daily cashflows over a period of 15 years with the floating leg being the price of electricity and the fixed leg, a strike predefined for each delivery year

We consider the case of an offshore wind generator for whom the underlying electricity price is the daily average of the hourly day-ahead electricity prices in the UK and the strike price is the final strike price set at the auction organized for each delivery year. The CfD is a strip of forward contracts maturing daily . Hence, the value of a CfD at date zero is:

$$\mathrm{V}(0) = \sum_{j=1}^{q} B(0,T_i)[Strike\ Price - F^{t_j}(0)]$$

where,

$B(0,T_i)$ is the zero-coupon bond price for maturity $T_i = 1, 2, \dots, 15$

$F^{t_j}(0)$ are the forward prices for maturities $t_1, t_2, \dots, t_q$

The value at date 0 – not null like in a swap - reflects the government's incentives and the auction results

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Great Britain Capacity Market Scheme

Generators sign a Capacity Market Agreement committing to provide electricity during a stress event and in return they receive a monthly payment equivalent to the clearing price set during the auction

- All technologies are eligible to participate
- Generators can trade in the wholesale electricity market
- Two auctions for each delivery year
- UK Government to examine other types of Capacity Mechanisms
- Auction design to be revisited

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Green Certificates

A **green certificate** – terminology predominantly used in Europe but now becoming more widespread globally – is a tradable commodity proving that certain electricity is generated using renewable energy sources. Typically one certificate represents the generation of one Mwh of electricity. What is defined as "renewable" varies from certificate trading scheme to trading scheme. Usually, at least the following sources are considered as renewable:

Wind (often further divided into onshore and offshore)

Solar (often further divided into photovoltaic and thermal)

Wave (often further divided into onshore and offshore) and tidal (often further divided into onshore and offshore)

Geothermal

Hydro (often further divided into small – microhydro – and large)

Biomass (mainly biofuels, often further divided by actual fuel used).

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Auctions in the Great Britain Capacity Market

-> The GB Capacity Market scheme is operating through auctions, where two auctions take place for each delivery year. The first auction is held four years ahead of the delivery year, to allow enough time to build any new capacity needed and where 95% of the expected capacity is procured; followed by a second auction a year before delivery to allow for any adjustments.

-> A price cap is set before the auction, which is then reduced in each bidding round at a set decrement until a clearing price is reached. The auction price clears when the remaining capacity in the auction is less than the required capacity, meaning that the targeted capacity has been secured through the auction for the given delivery year.

-> In the latest auction, in 2020, the price cap was set at £75/KWh/year with a negative increment of £5/KWh/year in each bidding round. After the auction clears, the auction system will check if there has been an exact match between the supplied capacity and the demanded capacity

- >. The clearing price and procured capacity in this case will be determined through the Net Welfare Algorithm (NWA) which compares the nearest points of supply on either side of the demand curve to determine which point is most beneficial to the consumer

All technologies are eligible to participate in the Capacity Market scheme. Successful generators sign a Capacity Market Agreement committing to provide electricity when required and in return they receive a monthly payment, equivalent to the clearing price set during the auction.

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Auctions in the GB Capacity Market

-> There exist three types of agreements:

- one year for existing projects, three years for generation in need of refurbishment, and 15 years for building new generation plants.

-> There have not been any stress events at this moment to check that the system can sustain electricity demand. Stress events may take place in the mid-2020s when all the coal power stations will close

-> National Grid ESO will notify Capacity Providers four hours ahead of a stress event, in which case Capacity Providers are required to deliver electricity against their Auction Acquired Capacity Obligation (AACO); failure to do so can lead to a financial penalty.

-> Generators participating in the GB Capacity Market scheme can still trade in the GB wholesale electricity market daily; the scheme's intention is to provide additional revenue to participators in exchange for capacity reserve in times when demand surpasses supply

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Distributed Energy Resources in the US market

-> DERs are physical or virtual assets that are deployed across the distribution grid, typically close to the load needs, which can be used individually or in an aggregate manner, to provide value to the grid, individual customers or both.

-> . DERs — such as solar, wind, hydro, batteries are aggregated to provide services to the electric grid.

-> 'DER Capabilities Matrix' details the technical capabilities of various DER types (solar, solar and advanced inverter functionality, storage, interruptible load, direct load control, behavioral load shaping, and energy efficiency) and their potential to provide grid services.

-> DERs also include Electric vehicles, Water Heaters and Thermostats which can be used as Electricity Storage

-> DERs are allowed to bid into the day-ahead wholesale markets or to sell electricity options; hence, modelling the capacity they provide is necessary

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Load Flexibility and Distributed Energy Resources (Solar, Electric Vehicles, Thermostats)

-> Energy value .DERs provide energy value when they displace the need to produce energy to another resource. The energy value has two components: (1) Avoided energy production by central generation resources, and (2) avoided losses on the transmission and distribution system, due to DERs' proximity to end-use loads.
-> System-level capacity. DERs provide system-level capacity value when they defer or avoid investment in generation and transmission assets. The system capacity value of DERs depends on the DERs' utilization capability during system *peak periods*.

-> Flexibility. DERs provide flexibility value when they operate in a way that allows grid demand and supply levels to balance. This value is realized at multiple timescales, from very fast (e.g., frequency regulation on the order of seconds) to longer-term (e.g., load shaping on the order of hours).

-> Operating reserves. DERs provide operating reserve value when they can be used to increase supply or reduce demand on the grid in place of central generators that would otherwise be used in case of contingencies (e.g., forced outages). DERs can provide both fast-response reserves (e.g., spinning reserves in the case of extreme events) and slower-response reserves (e.g., supplemental reserves in normal times).

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Risk Measures in Electricity

- Loss Of Load Expectation (LOLE) represents the number of hours per annum in which it is statistically expected that peak demand won't be satisfied by supply
- LOLE is acceptable if is 0.1 day per year
- LOLE does not measure the total shortfall in capacity that occurs at the time of extreme weather or plant outages
- This would involve the measure of Expected Energy Not Served (EENS) which would be expressed in MWh over a specific time period (e.g., a year), a risk measure mentioned in the EU Trading Schemes (Dec 2020)
- These measures can also be expressed in dollars or Euros to account for the cost of the lost load – in the worst part of the crisis in Texas in February 2021, prices went as high as $9000/ MWh

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Financial Instruments for an Aggregator to hedge Intermittent Electricity Delivery Risk

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- Plain Vanilla options on Electricity
- Plain Vanilla Options with a cap, or Call Speads
- Asian or Average Rate Options
- Swing or Volumetric Options

In all cases, a model for electricity spot prices is necessary, with parameters calibrated on liquid instruments, forward/Futures contracts on the EEX

Also, Weather Derivatives can be used

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Possible Models for Electricity Prices

- Mean reversion and Seasonality (represented by a deterministic term) are chosen in many models:
- Ln S(t) = X(t) + f(t)

  where X is an Ornstein Uhlenbeck process

$$f(t) = \gamma \cos\left(\delta + \frac{2\pi t}{365}\right)$$
$$dX(t) = k\big(a - X(t)\big)dt + \sigma dW(t)$$

- k is the speed of mean reversion
- a is the level of mean reversion
- σ is the price volatility
- $W(t)$ is a Q-Brownian motion

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Identifying the Future Prices

Filtering out seasonality, we get

$$lnS(T) = lnS(0)e^{-kT} + a\left(1 - e^{-kT}\right) + \sigma\sqrt{\frac{1- e^{-2kT}}{2k}}W(T)$$

Observing that the Future price is a Q – martingale,

and that $F^T(T) = S(T)$, we obtain that

$$lnF^T(0) = lnS(0)e^{-kT} + a\left(1 - e^{-kT}\right) + \frac{\sigma^2}{4k}\left(1 - e^{-2kT}\right)$$

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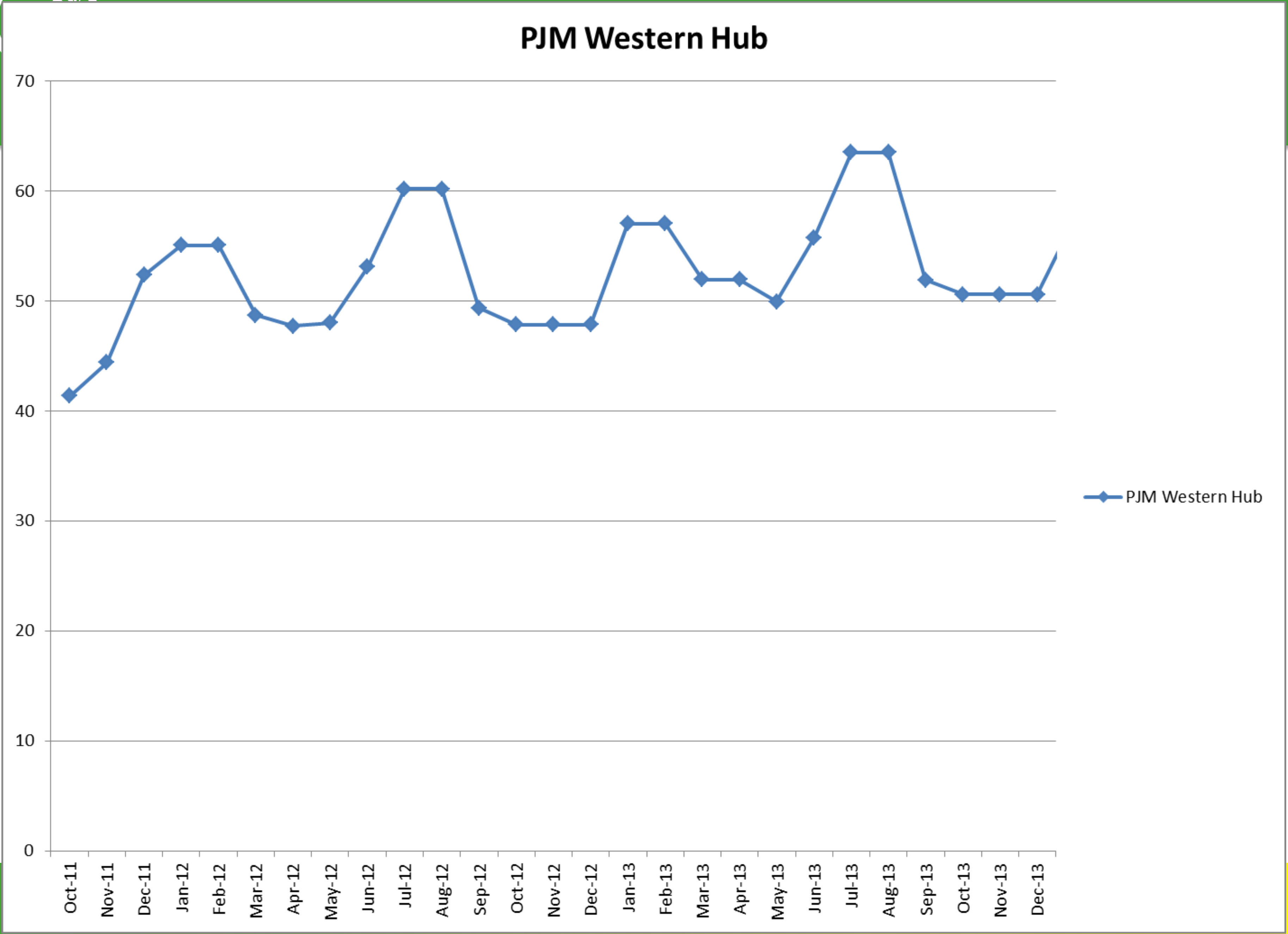

PJM Western Hub
70
60
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PJM Western Hub

Calibrating the Price Process under the Pricing Measure

Using Futures contracts traded on the EEX for instance, one has to solve the optimization problem

- $Arg\ Min\ \left\{\sum_{i=1}^{5}\left[lnF_{Market}^{T_i}(0) - lnF_{Model}^{T_i}(0)\right]^2\right\}$

in order to find the 3 parameters of the Ornstein Uhlenbeck process driving ln S(t) and proceed to the valuation of the options - plain-vanilla or Asian – to be purchased as a hedge for the Renewable electricity delivery risk.

Electricity Price Modeling

- Introduction of a Poisson process to represent positive jumps in the case of extreme weather
- In order to bring prices down after the crisis, the coefficient of mean reversion must be very large
- Geman & Roncoroni (2005) propose a *jump-reverting model* to bring prices down by a jump as well; the calibration is challenging
- The calibration uses

  a) The Futures prices (EEX for instance)

  b) The fact that F(t, T) = Q-expect [S(T)]

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