PRELIMINARY
As of June 1st

LFSCOE

LEVELIZED FULL SYSTEM COSTS OF ELECTICITY

9 Jun 2021 – IAEE Online – Robert Idel

Levelized Costs of Electricity (LCOE)

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Definition of LCOE

- Levelized cost of electricity represents the average costs per unit of generated electricity.
- (Simplified) Calculation: Total lifetime costs divided by total lifetime generation.

LCOEs of current technologies[1]

Technology	LCOE [USD/MWh]
Biomass	94
Coal (USC)	76
Natural Gas CC	38
Nuclear	82
Geothermal	37
Hydroelectric	53
Solar	36
Wind, onshore	40
Wind, offshore	122

Fundamental misunderstanding of LCOEs

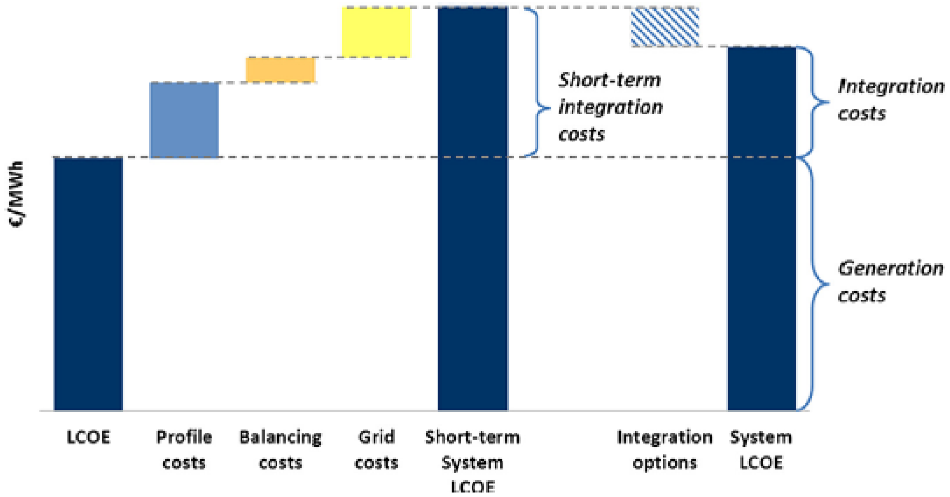
- "Solar is the cheapest source of electricity."
- "The reason there is no transition to renewables are subsidies for dispatchable generation."
- LCOE are the costs to *generate* electricity.
- What should be relevant are the costs to *provide sufficient electricity to meet demand*.
- For dispatchable sources, LCOE are a good measure to compare the cost of providing the market.
- For intermittent sources, they are highly flawed.[2]

[1]Source: IEA Annual Energy Outlook. Fuel Prices as in the U.S.
[2]See, among others, Joskow (2011). "Comparing the Costs of Intermittent and Dispatchable Electricity Generation Technologies."

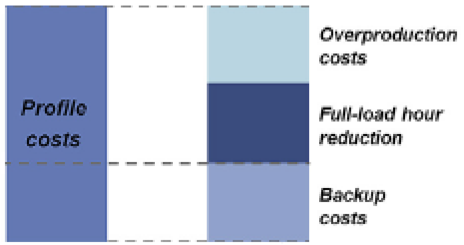
System Levelized Costs of Electricity

System LCOE according to Uerckerdt et al (2013)

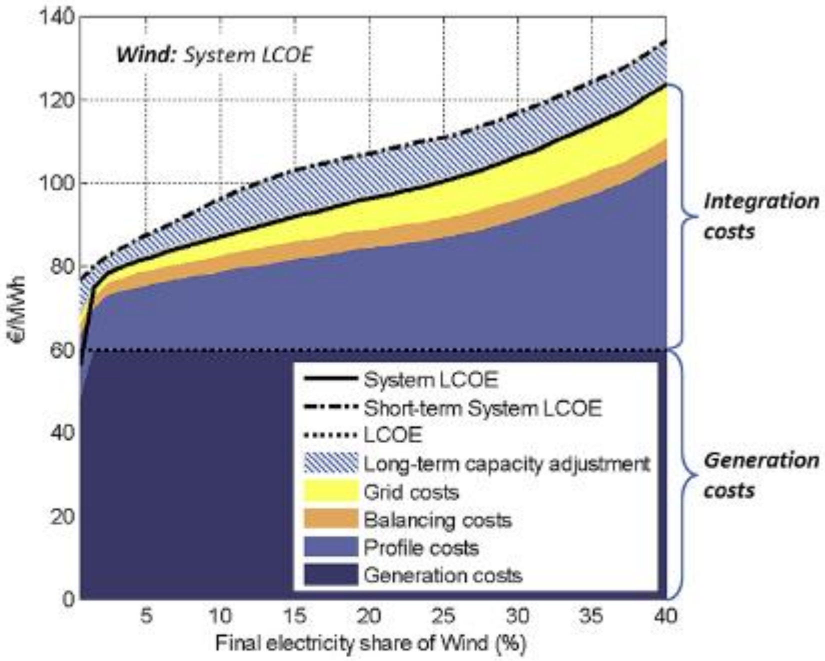
- Add balancing costs, grid costs, and profile costs.



- Profile costs consist of
  - Backup costs
  - Full-load hour reduction
  - Overproduction costs



System LCOE in Europe for Wind generation



Ueckerdt, Hirth, Luderer, Edenhofer (2013) introduce the System Levelized Costs of Electricity (System LCOE)

New Approach: Levelized Full System Costs of Electricity

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Levelized Full System Costs of Electricity (LFSCOE)

- Calculate minimal cost to supply the market if only one technology + storage can be used to supply the market.
- Approach to get the Levelized Full System Costs of Electricity:
  1. For each source, find cost minimizing investment in generation capacity and storage, and generation per hour, conditional on supplying the market in a certain year, i.e. for dispatchable sources:

$$\min_{gp,bp,gen\in\mathbb{R}_+^{H-1},x} gp\cdot cc_y + bp\cdot cc_{storage} + t_{inv}\cdot\sum_{i=0}^{H-1} mc_y\cdot gen[i]$$

$$s.t.\quad 0\le x[i]\le x[i-1]+gen[i-1]-D_{i-1}, \qquad (D.1)$$

$$-bp\le x[i]-x[i-1]\le bp, \qquad (S.1)$$

$$storage\_security\le x[i]\le bp\cdot storage\_factor, \qquad (S.2)$$

$$x[0]\le bp\cdot storage\_factor\cdot storage\_start, \qquad (S.3)$$

$$x[0]\le x[H], \qquad (S.4)$$

$$gen[i]\le maxcap_y\cdot gp, \qquad (G.1)$$

$$-rampdown_y\le \frac{gen[i+1]-gen[i]}{gen[i]}\le rampup_y. \qquad (G.2)$$

  2. For intermittent sources, we drop (G.1) and (G.2), replace $gen[i]$ in (D.1) by $capfactor_{i-1}\cdot gp$ and drop the last term in the objective function.
  3. Determine average costs (over 20 years) per MWh of demand.[1]

Assumptions on cost, market, and technology

Technology	Fixed Costs [USD/kWh]	Variable Costs [USD/MWh]	Ramp-up/down [% per hour]
Biomass	6,600	28	150%/50%
Coal (USC)	4,500	25	150%/50%
Natural Gas CC	1,400	18	150%/50%
Nuclear	8,700	26	150%/50%
Wind	2,000	0	-
Solar	1,300	0	-
Storage	1,400	0	-

- Dispatchable sources of generation may also use storage, have limits in the hourly output change, and work at maximal 90% of their capacity.
- Intermittent sources can perfectly forecast the hourly capacity factor and can dispose electricity.
- The storage factor is fixed at 3 MWh/MW.
- Intermittent sources require a minimal storage level of 1GWh.[2]
- Markets: Germany and Texas/ERCOT.

[1]Though 20 years are usually taken to evaluate intermittent sources, all technologies last longer than 20 years.
[2]The actual required backup for such a system will be very controversial.

Data: Germany and Texas

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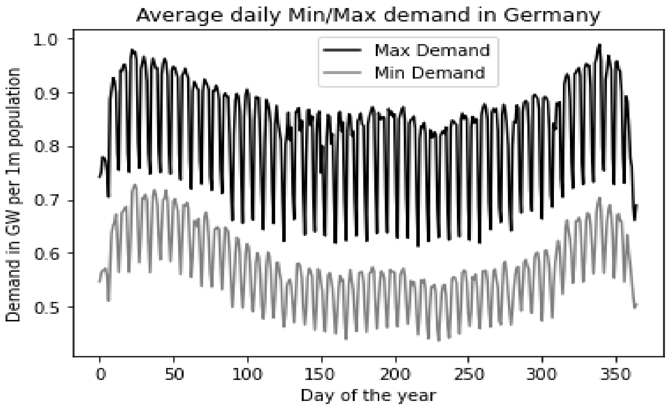
DATA

Hourly capacity factors for wind and solar in ERCOT/Texas (2013-2019) and Germany (2011-2017)

DEMAND

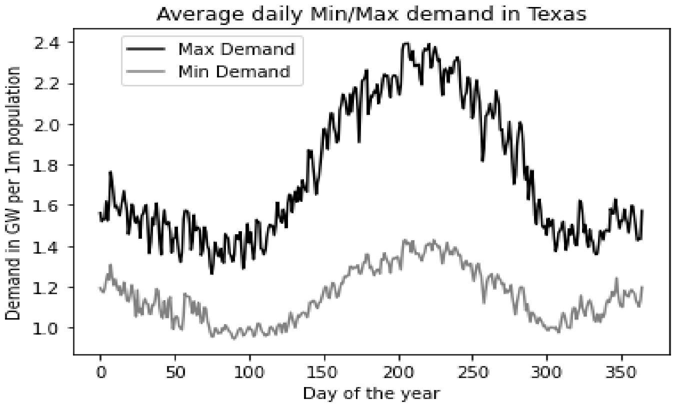
Average Demand in Germany:

- 58 GW total
- 0.7 GW/1mPop



Average Demand in Texas:

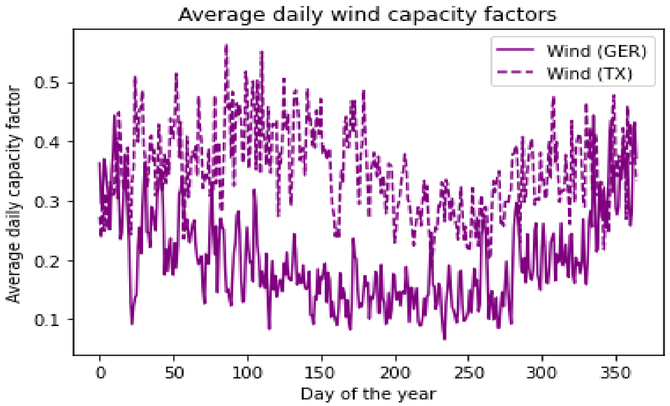
- 40 GW total
- 1.5 GW/1mPop



CAPACITY FACTORS

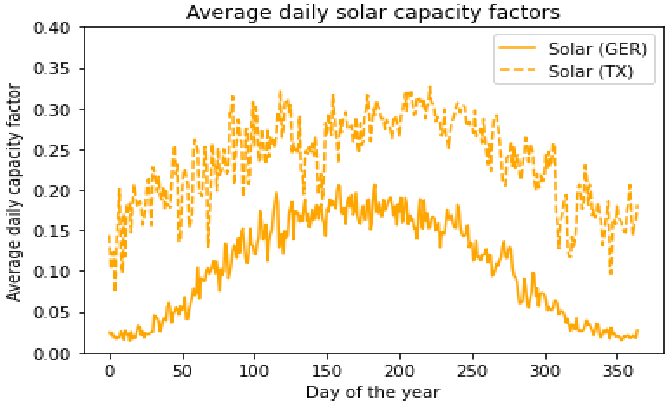
Average wind capacity factors:

35% in Texas, 20% in Germany



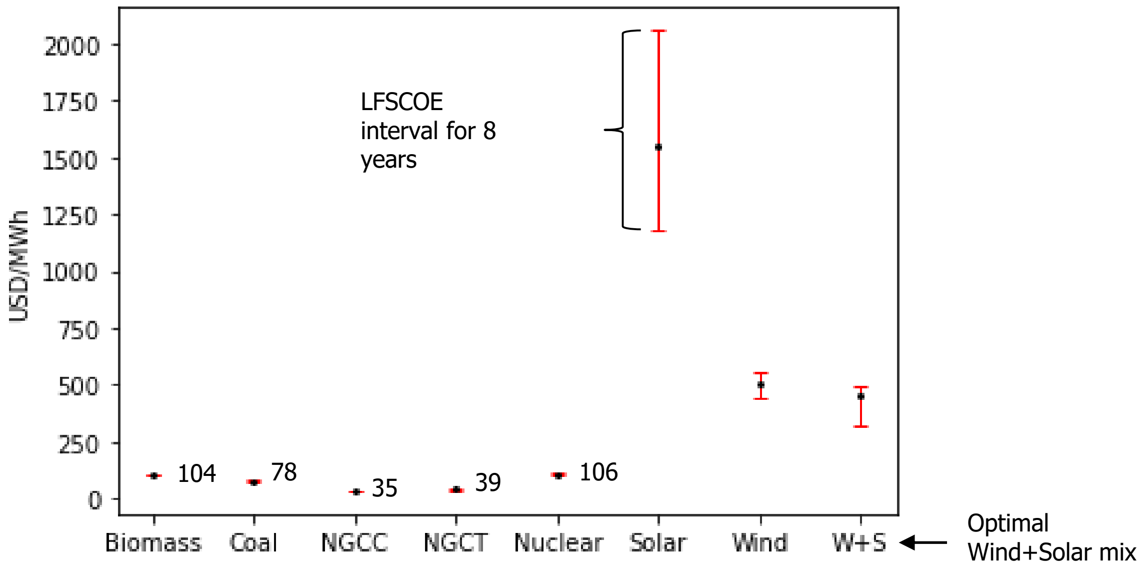
Average solar capacity factors:

23% in Texas, 10% in Germany

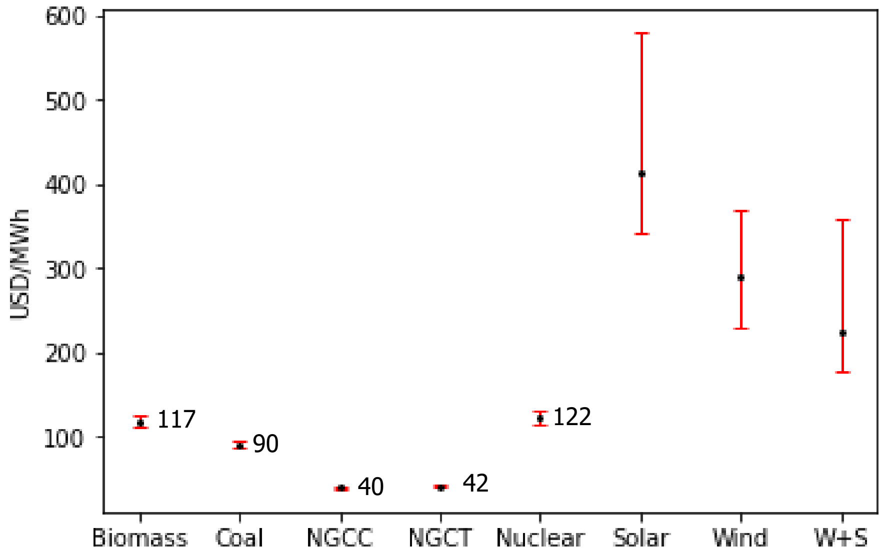


Results

LFSCOE with Market Data from Germany



LFSCOE with Market Data from ERCOT/Texas



Key observations

- LFSCOE for Wind and Solar much higher than for dispatchable sources.
- Very high LFSCOE for Solar in Germany (due to low capacity factor and "negative" correlation with demand).
- LFSCOE for dispatchable sources higher in Texas than in Germany (due to seasonal variance in demand).

Counterfactuals

- Include storage losses.
- What if storage costs drop significantly?
- LFSCOE-95: Only require to supply 95% of the demand.
- Installed capacity would have ensured sufficient supply during the Texas Snow Storm 2021.

Storage losses

Three types of storage losses

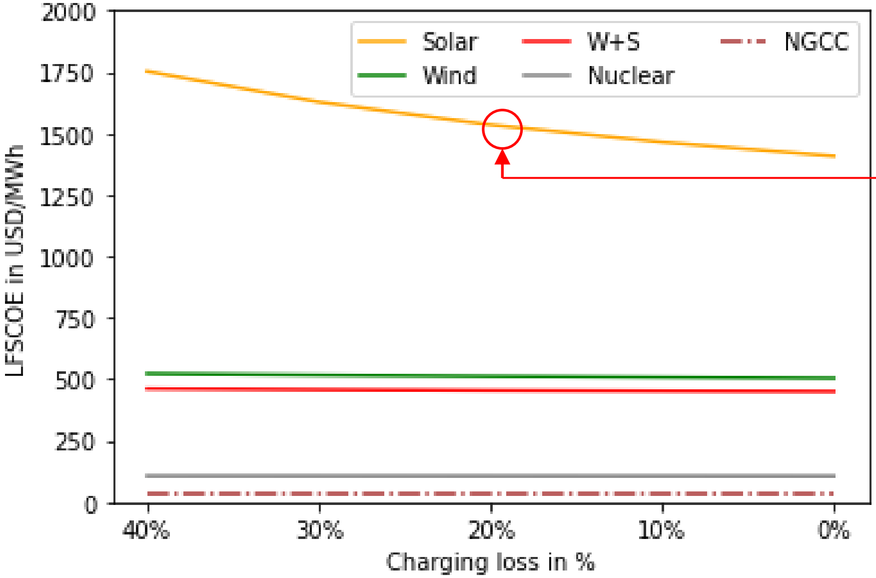
Ignore transmission or distribution losses.[1]

1. Charging loss

2. Discharging loss

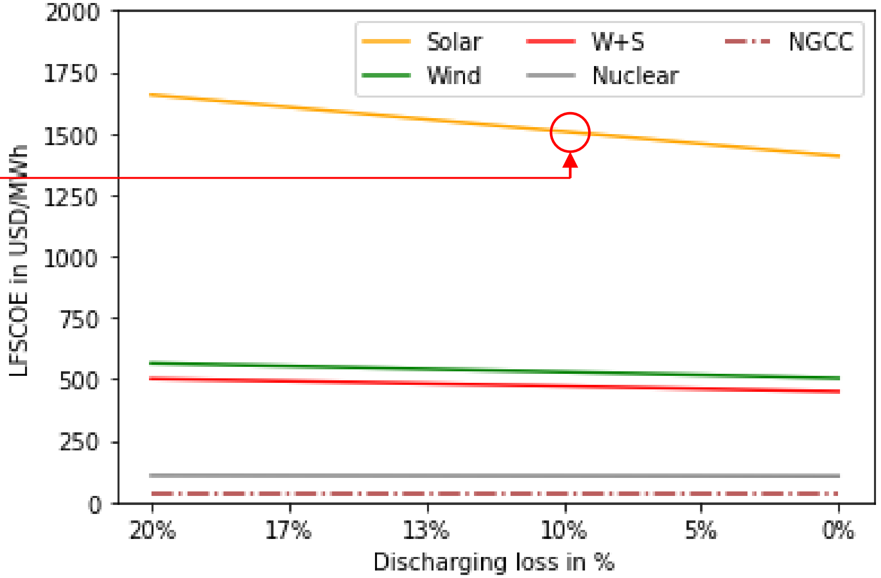
3. Storage depreciation

LFSCOE with charging losses (Germany)



Discharging losses are twice as costly as charging losses.

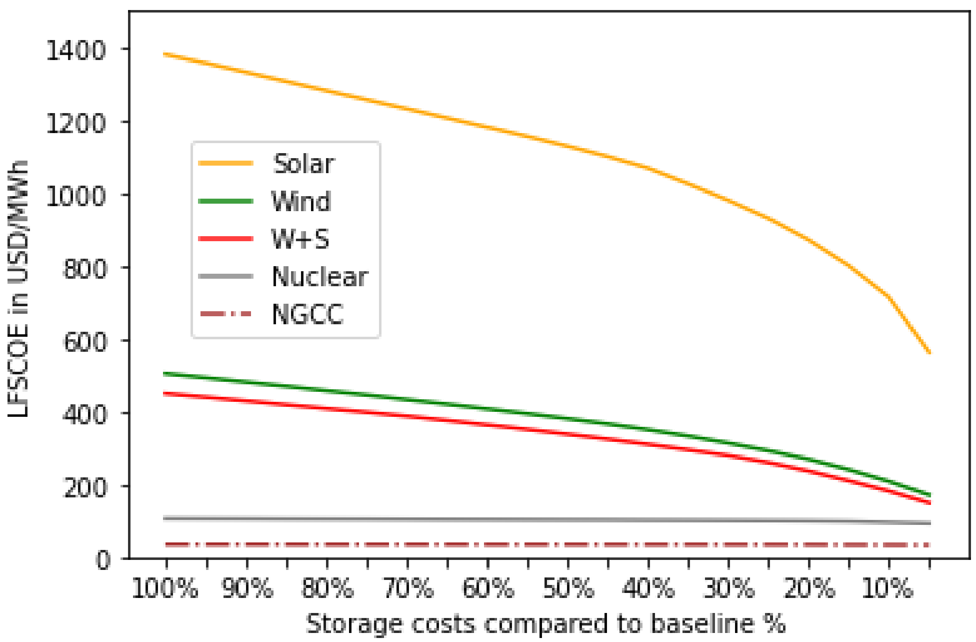
LFSCOE with discharging losses (Germany)



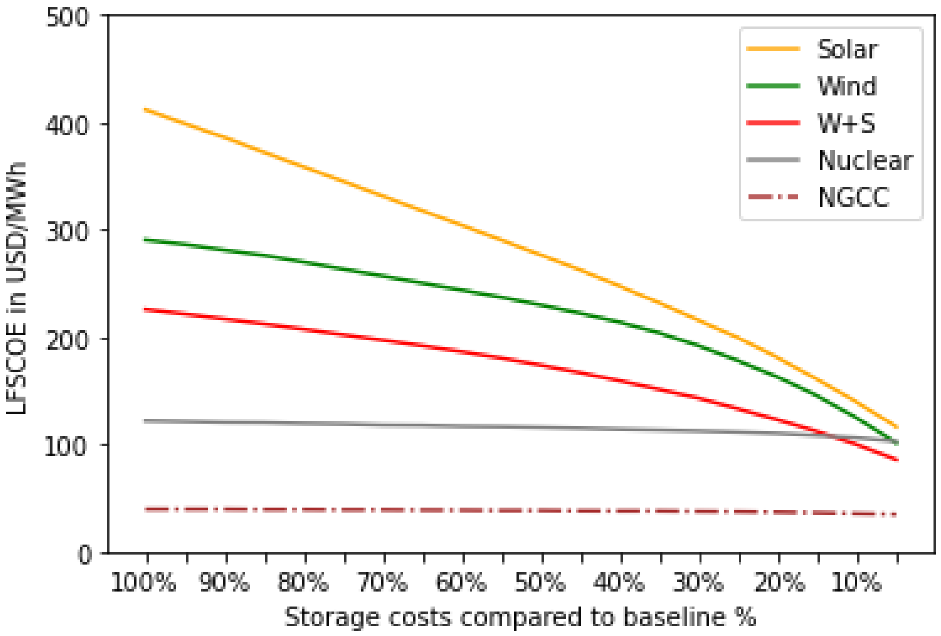
[1]According to EIA, the transmission and distribution losses are only around 4% - see https://www.eia.gov/tools/faqs/faq.php?id=105&t=3

Decrease in Storage Costs (no storage losses)

LFSCOE with decreasing storage costs (Germany)



LFSCOE with decreasing storage costs (Texas)



LFSCOE-95

LFSCOE-95

- Assume that only 95% of the demand has to be supplied by this technology + storage.
- (Up to) 5% of the demand are covered by a "flexible low-cost technology".

LFSCOE-95 (Germany)

Technology	LFSCOE [USD/MWh]	LFSCOE-95 [USD/MWh]
Biomass	104	90
Coal (USC)	78	67
Natural Gas CC	35	31
Nuclear	106	90
Wind	1548	849
Solar	504	279
Wind & Solar	454	220

~50% reduction

LFSCOE-95 are similar for dispatchable sources in different markets.

LFSCOE-95 (Texas)

Technology	LFSCOE [USD/MWh]	LFSCOE-95 [USD/MWh]
Biomass	117	95
Coal (USC)	90	72
Natural Gas CC	40	32
Nuclear	122	96
Wind	413	177
Solar	291	131
Wind & Solar	225	91