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MINISTRY OF POWER GOVERNMENT OF INDIA CENTRAL ELECTRICITY AUTHORITY

Master Class on Energy Transition Strategies and Pathways to Net Zero Power Systems

Presented By

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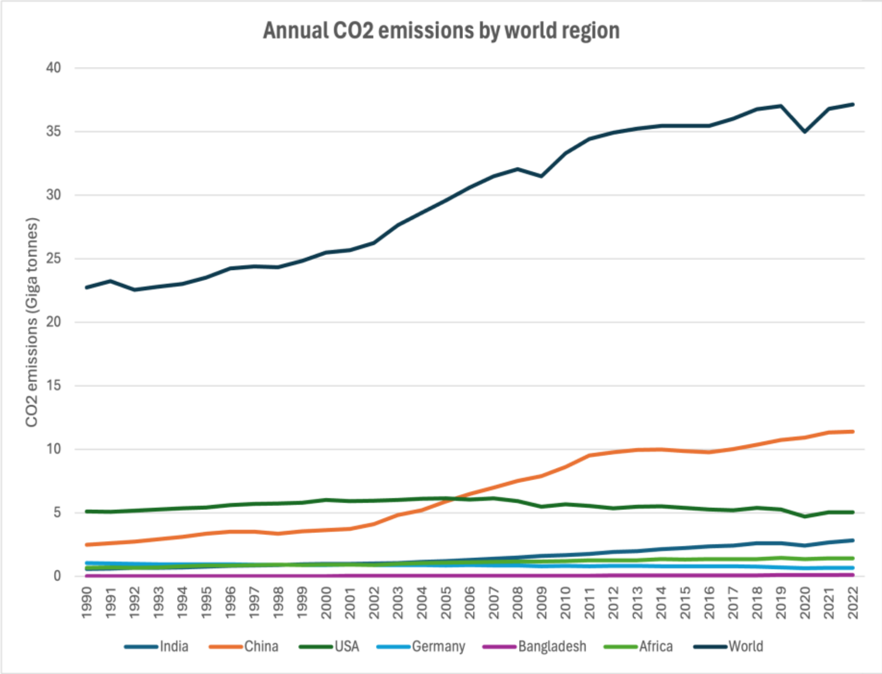
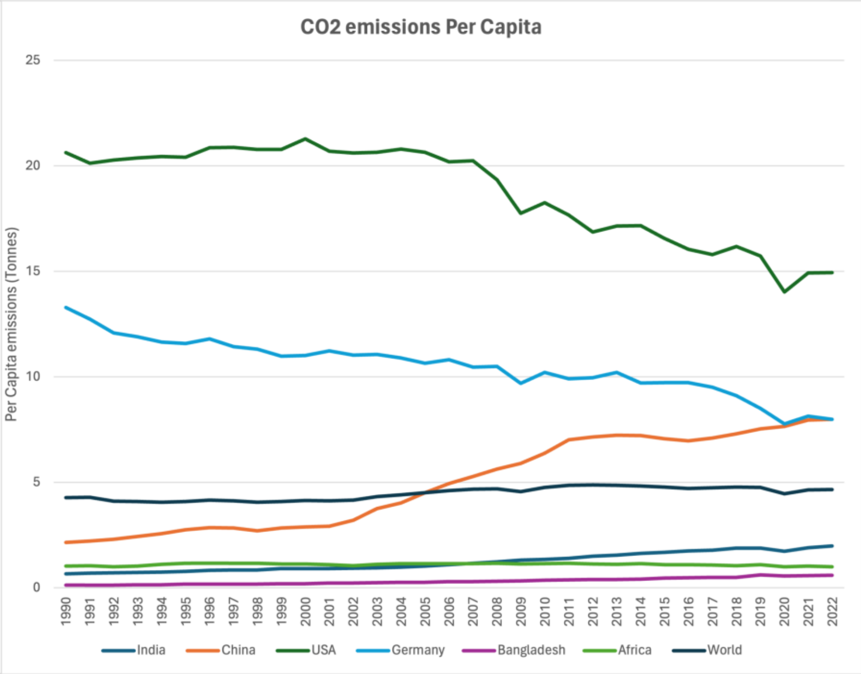
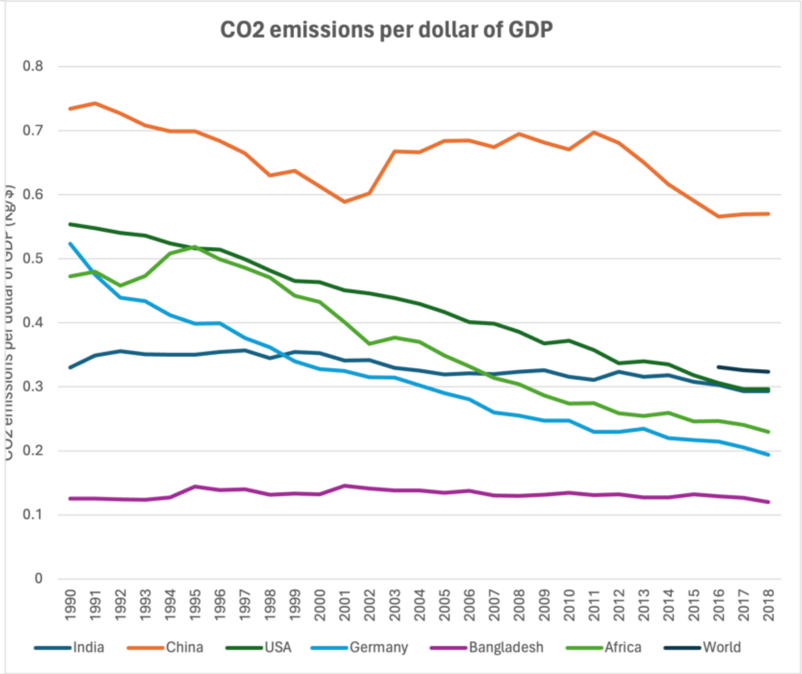
INTRODUCTION

- Keeping global temperature rise within 1.5°C requires all countries to zero their emissions by 2050
  - Most countries have announced net-zero pledges; India has pledged 2070
- Our focus
  - What do the pathways mean?
    - We mainly care about cumulative emissions
  - What are the ways to get there?
    - Sectoral decarbonization
    - There are an infinite ways to get there – which is “best”?
  - What are the issues/challenges?
    - Scaling up (technology, manpower, finance)
    - Efficiency and Equity are not the same (aka winners and losers)

Lies, Damn Lies, and Statistics – Metrics matter







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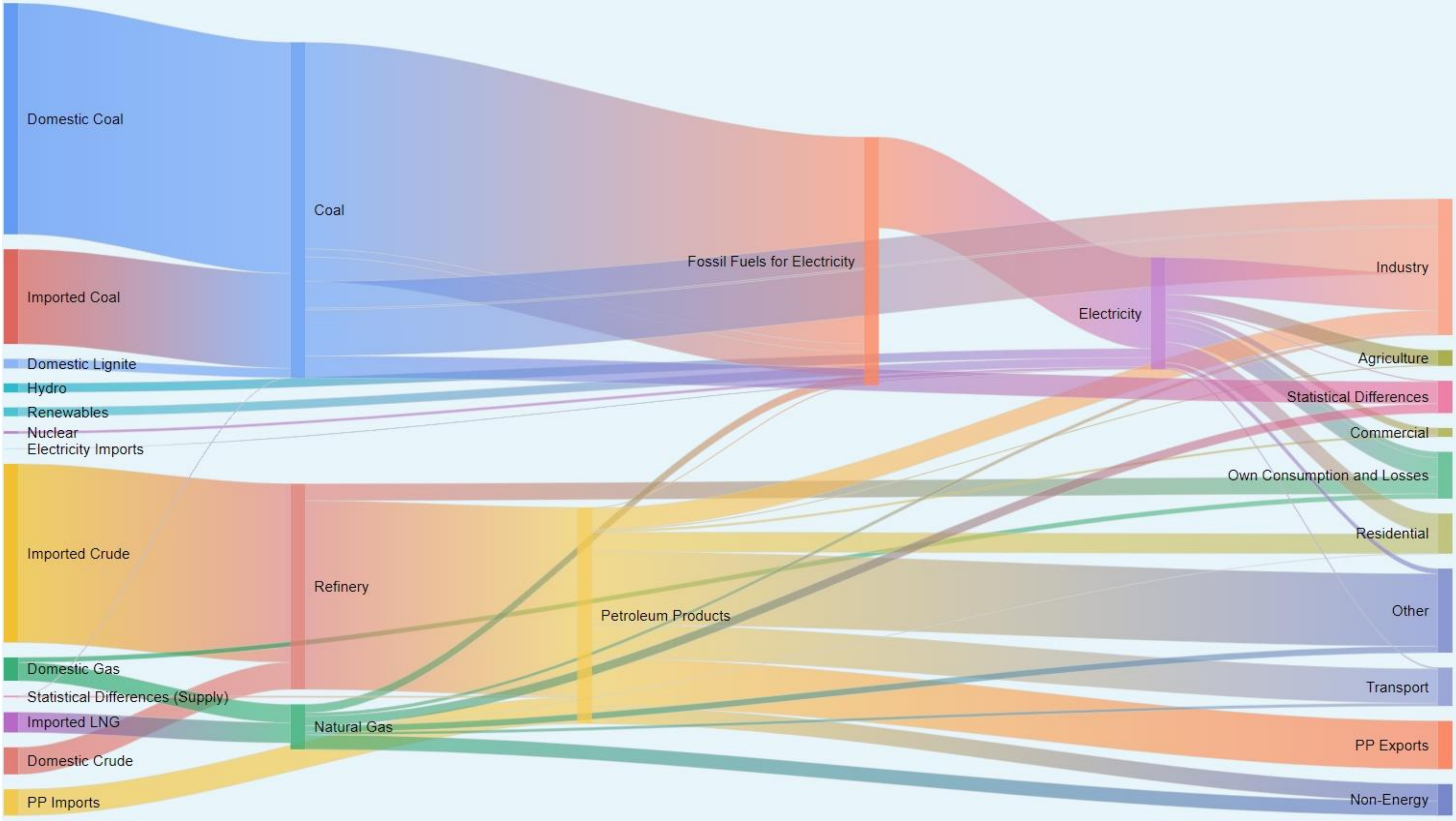
Electricity isn't all energy



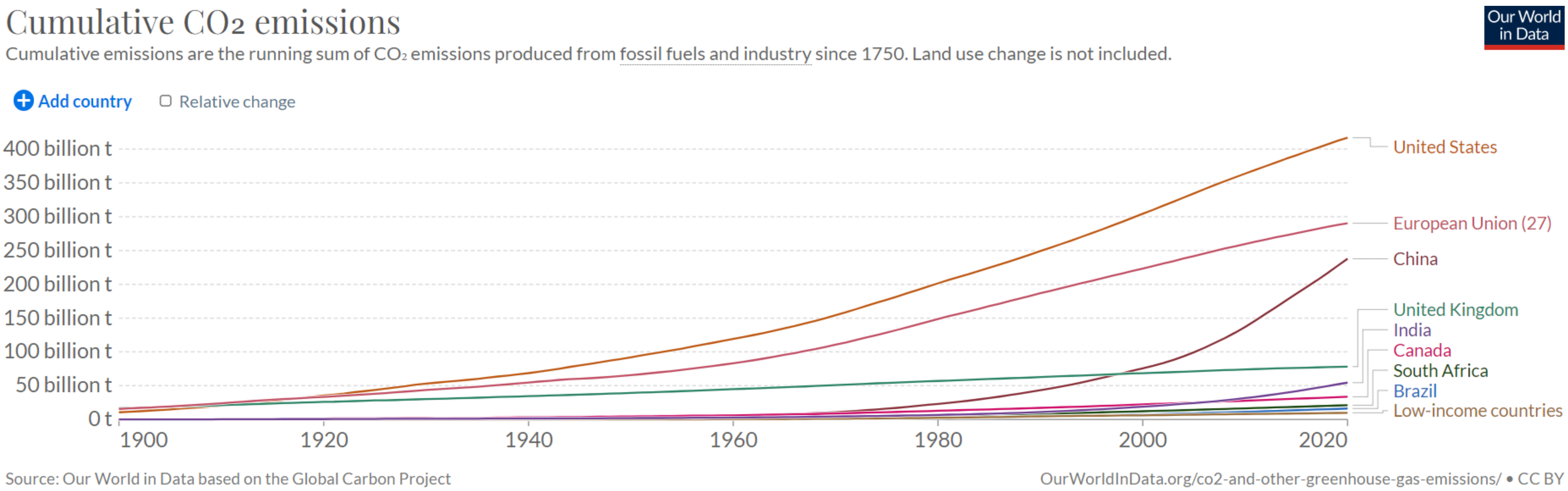
Source: NITI Aayog (EDM)

Total energy:

Primary Energy: 733.6 MTOE

End-use" 410.3

- **Sad Reality: 1.5°C rise was always tough**
- **But we have to remember the causes**



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- **India's "high" coal use in context**

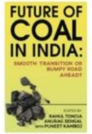

Table 1.1: Global snapshot of coal, 2019: Top 10 Producers / Consumers

	Production (million tonnes [MT])	Consumption (MT)	Per capita coal consumption (kg)	Estimated average calorific value (kcal/kg)	Converted per capita coal energy consumption (GJ)	Share of primary energy from coal
China	3,846	3,936	2,826	4,958	59	57.6%
India	756	966	714	4,021	12	47.7%
United States	640	507	1,553	5,340	35	12.0%
Germany	134	244	2,941	2,257	28	17.5%
Russia	440	174	1,202	4,991	25	12.2%
South Africa	254	161	2,789	5,655	66	70.6%
Indonesia	610	138	516	5,894	13	38.2%
Poland	112	115	6,284	3,975	105	44.7%
Kazakhstan	115	93	2,442	4,307	44	53.9%
Australia	507	69	2,751	6,199	71	27.8%
Colombia	82	9	180	6,871	5	13.4%
Rest of world	632	1,937	505	3,678	8	12.4%
Total World	8,129	7,658	1,009	4,925	21	27.0%

Source: Coal and Energy data from BP Statistical Review of World Energy 2020. Consumption data in tonnes calculated from energy (exajoules as listed via respective conversion as per production data, which was listed in both energy and tonnes). Population data taken from UN.[2] Only Indian consumption data are as per Ministry of Coal FY2018-19 official data.

Calorific values are calculated estimates, with uncertainty due to variance in the breakdown of imported coal by calorific value. A low share of primary energy from coal suggests high carbon emissions from other sources but specific alternatives to coal vary by country.

Per capita natural gas/yr.
[thousand CUF]

Russia	107.2
USA	84.9
UK	38.6
Germany	35.3
Japan	34.1
Nigeria	3.7
India	1.3

source: Worldometer data

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- China offers some insights
- **Both cleanest and dirtiest country energy-wise**

China is the global leader in the **mass production** of low carbon energy technologies

Solar Panels:	From 1% to 66% (2001-2018)
Wind Turbines:	1/3 of global supply (2018)
Electric Vehicles:	53% of global sales (2018)
Lithium-ion Batteries:	69% of global production (76% by 2025)
Nuclear Reactors:	From 45 to 88 plants by 2030

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- **For India, short term action matters**
- **Most critical will be the power sector**
  - Electricity is the most growth (and ~half of present emissions) – but luckily easiest to decarbonize
  - There are several metrics that aren't the same:
    - Energy ≠ Capacity ≠ Peak Demand ≠ Real-Time balancing
  - Power Grid realities:
    - India has built up a temporary *capacity* surplus thanks to doubling coal capacity FY11-FY16
    - Most growth is RE = Variable RE (VRE) – without storage
      - Storage costs are still VERY high and projected to be so through 2030
    - Most modelling is on energy basis, or a few grid balancing studies (incl. CSEP, plus CEA, NREL, LBL, TERI, and state-level like Prayas, CSTEP).
      - There is enormous uncertainty on load and demand profiles (by time of day) – but we can start with energy as the key *exogenous* factor for planning
  - By ~2027 (+/-), the present surplus will exhaust, and Variable RE won't suffice
    - Will need firm power, maybe storage
    - More transmission
    - Grid re-design

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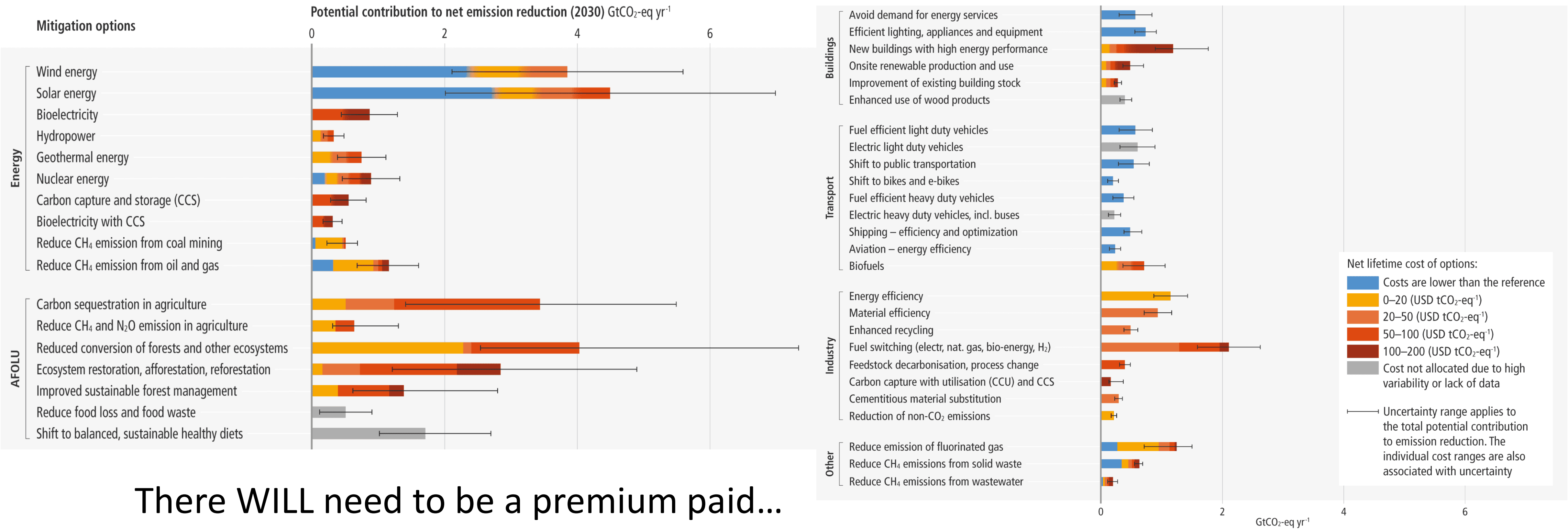
• IPCC's AR6 Mitigation Report (SPM.Fig7)

Many options available now in all sectors are estimated to offer substantial potential to reduce net emissions by 2030. Relative potentials and costs will vary across countries and in the longer term compared to 2030.



There WILL need to be a premium paid…
…and even then is it enough?

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What does “NET” Mean

- Is it really zero?
- Or reliant on “offsets”?
  - Carbon neutral LNG tanker for sale…
- Most models rely on lots of –ve emissions (land-based, Direct Air Capture, etc.)
  - This is tricky
    - Required for things like cement
    - But kicks the can down the road

Metrics for emissions

- Scope 1
  - Your own usage of fossil fuels or GHG
- Scope 2
  - Adds electricity you use but generated offsite
- Scope 3
  - Adds supply chain emissions

- Many companies are tasked (e.g., SEBI) for Scope 1 & 2 – 3 is very hard to do
  - Survey Based
  - Input-Output model based

Kochi Airport: "World's first 100% solar airport"

- It has lots of solar panels – but no storage
- It "banks" power via the utility
- This has implications
    - Costs (mainly borne by the DisCom aka consumers)
    - Emissions

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What is Green Power?

- Global and Indian norms are still evolving
- Ministry has clarified 2 kg-CO_2/kg H as the threshold for “green” – but many details are TBD
- BUT Indian Green Hydrogen norms allow for 30 days banking
  - At night it will use coal
  - The theory is this will be offsetting coal in the day via surplus solar…but is that additive?

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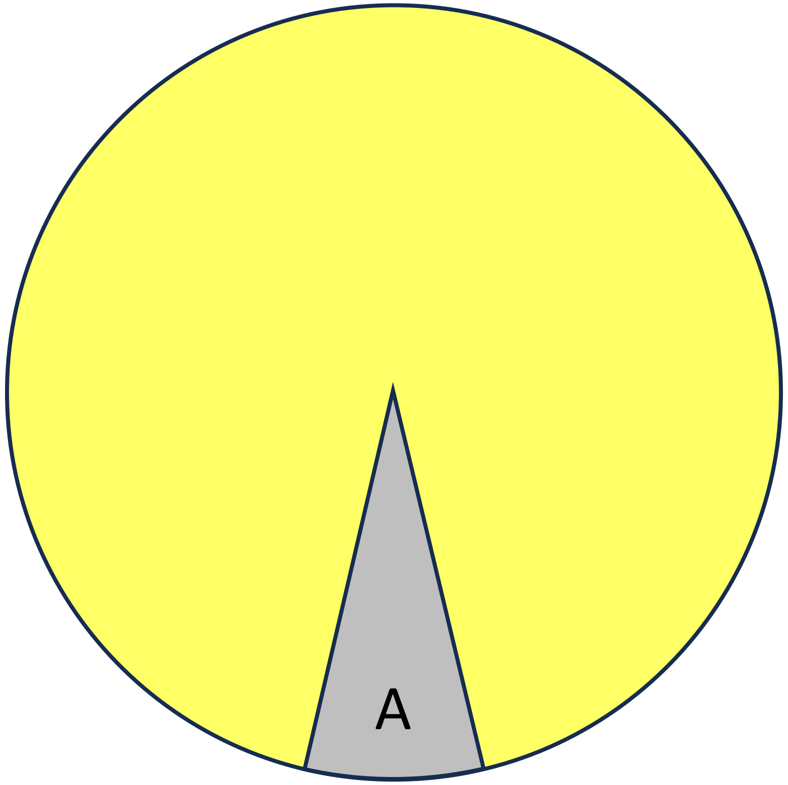
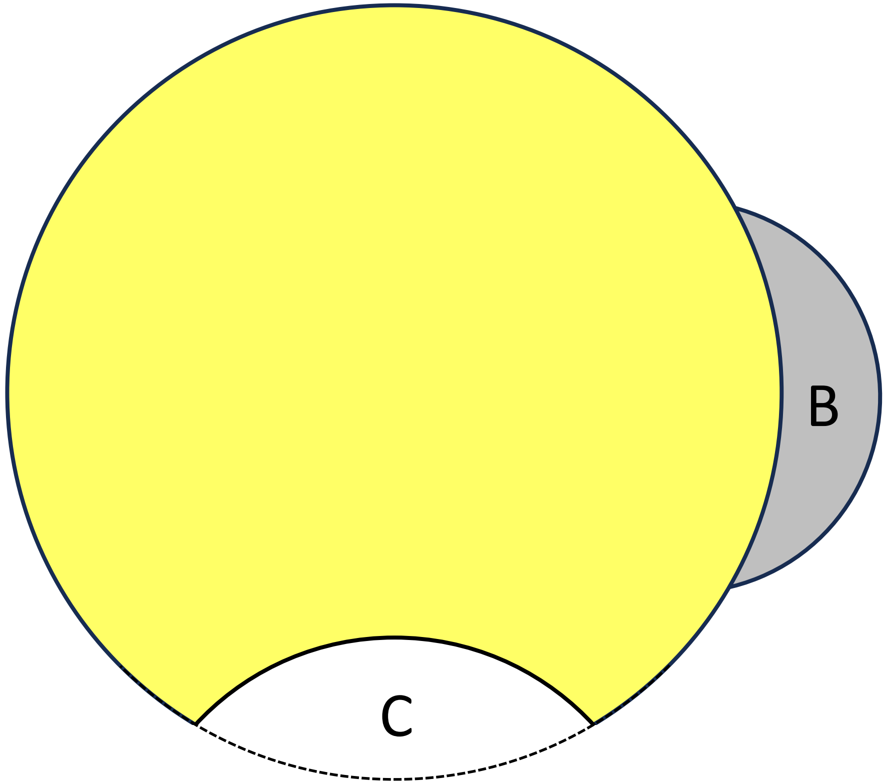
What are the marginal emissions?

- In the SHORT RUN, it's almost always fossil fuels
  - Grid *as existing*
  - Hydro is rain limited
  - This applies until we reach curtailment levels of RE
- BUT, in the long run, we'll have a different grid
  - We need to align Green Supply with demand
    (let's ignore MoP's recent Green Tariff directive)

Two types of (lifecycle) emissions accounting



Attributional
(A)



Consequential
(B – C)

Source: NASEM

Problems with Kochi airport type model (incl. for Green Hydrogen)

- Displacing coal through over-supply of RE only applies when we do not have surplus RE (in parts of the day)
- RE growth is mostly solar, which is relatively quite coincident (e.g., 5 MT Green H is more than a third of planned solar growth through 2030)
- RE is being built anyways – how much is truly additional?
- The extra RE needs to displace coal 1:1, and have coincident consumption
- Both sets of users (primary and extra like mid-day) cannot BOTH be green
    - Consequential may appear zero, <u>but attributional is not</u>
- The economics of banking are very challenging (e.g., to the utility)
    - Not all power is the same
    - They don't have enough "spare" capacity in the evening to return banked power at 5 MT Green H scale (forget green capacity)
- More RE in coincident parts of the day would impact grid pricing signals
- Storage is very expensive – but over-sized blending can help quite a bit (over 50% CUF)
- Others outside India may drive definitions of "green" – impacts exports

Table 1: Hydrogen production from various techniques and corresponding emissions

			Electrolysis with RE	Electrolysis with electricity from the grid (average)			USA IRA thresholds for PTC	
	Grey H (Directly from natural gas)	Blue H (Natural gas with carbon capture)	Green H (Pure RE supply)	US	Germany	India	Limit for full benefit	Maximum limit for partial support (sliding scale)
Avg. Electricity Emissions ($g\text{-}CO_2/kWh$)	Not applicable	Not applicable	0	424	336	708		
H-production Emissions ($kg\text{-}CO_2/kg\text{-}H$)	~10	3–7	0	19.9	15.8	33.3	< 0.45	< 4

Global criteria (ambitions) for Green Power

- Additionality
  - Else green is a zero-sum game
- Deliverability (US IRA Section 45V just clarified this as geographic limits)
  - Note in India that “free” ISTS is still a cost to others
- Hourly matching
  - US analysis for the grid shows this is close enough to dedicated in terms of benefits

This matches Europe that wants to avoid *direct* or *indirect* use of fossil fuels

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Where is the stable RE?

- Hydrogen electrolyzer economics (CUF) depend heavily on RE PLF
- RTC bids are misleading (more on this later)
  - Most solutions today are based on blending/oversizing
  - Limited storage (some bids are NIL)
  - Pure storage RTC is very expensive
- Indian wind is inferior to W. Europe
  - New offshore has faced a meltdown recently
- 70% CUF is considered good – may impact electrolyzer technology choices
- Blending wind+solar WITH oversizing appears cost-effective

Figure 6: CUF of a wind-solar hybrid and oversized RE system

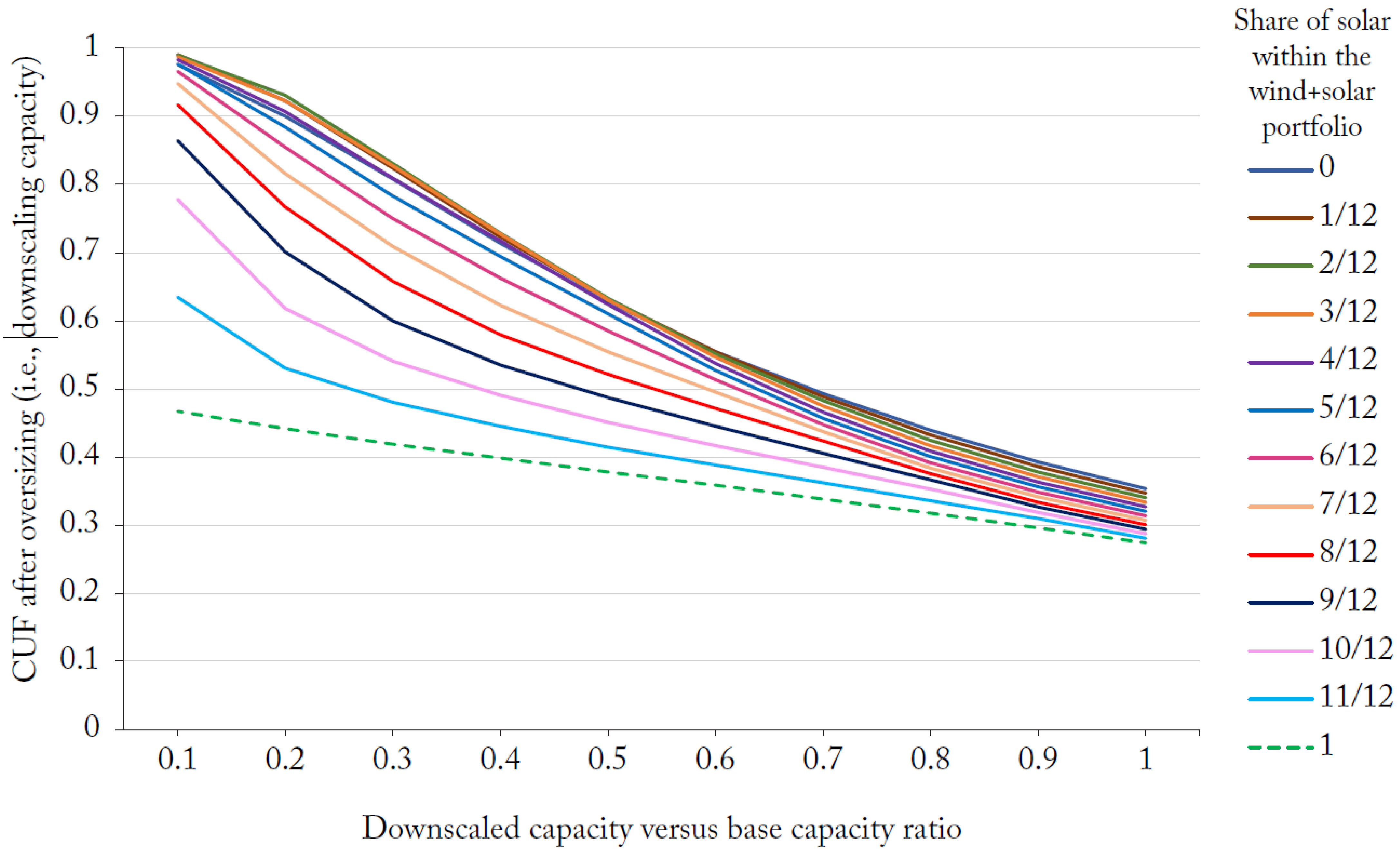


Figure 7: RE curtailment (excess output) based on downscaled nameplate capacity

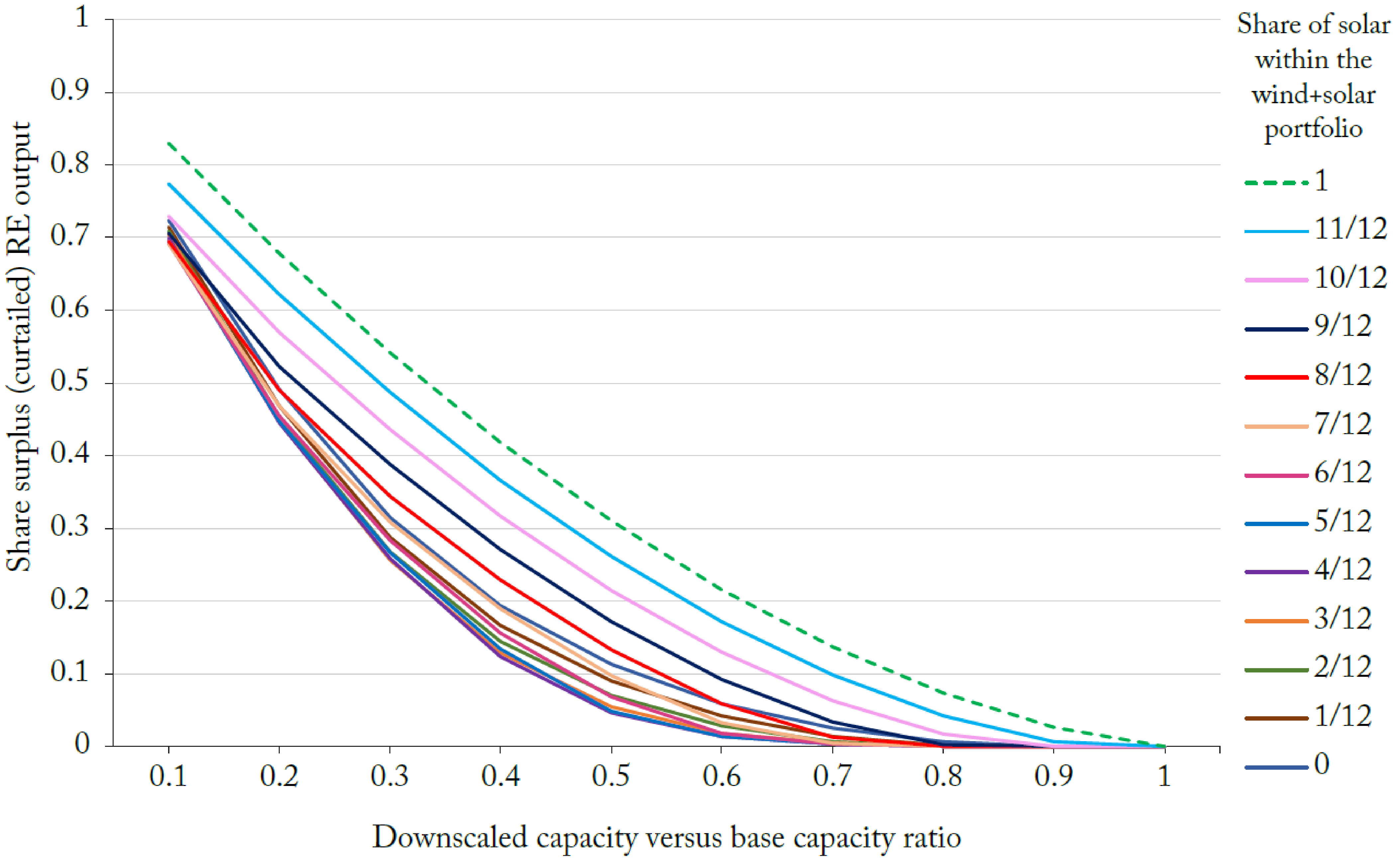


Figure 8: Frontier of RE costs versus CUF for various combinations of solar and wind and oversizing

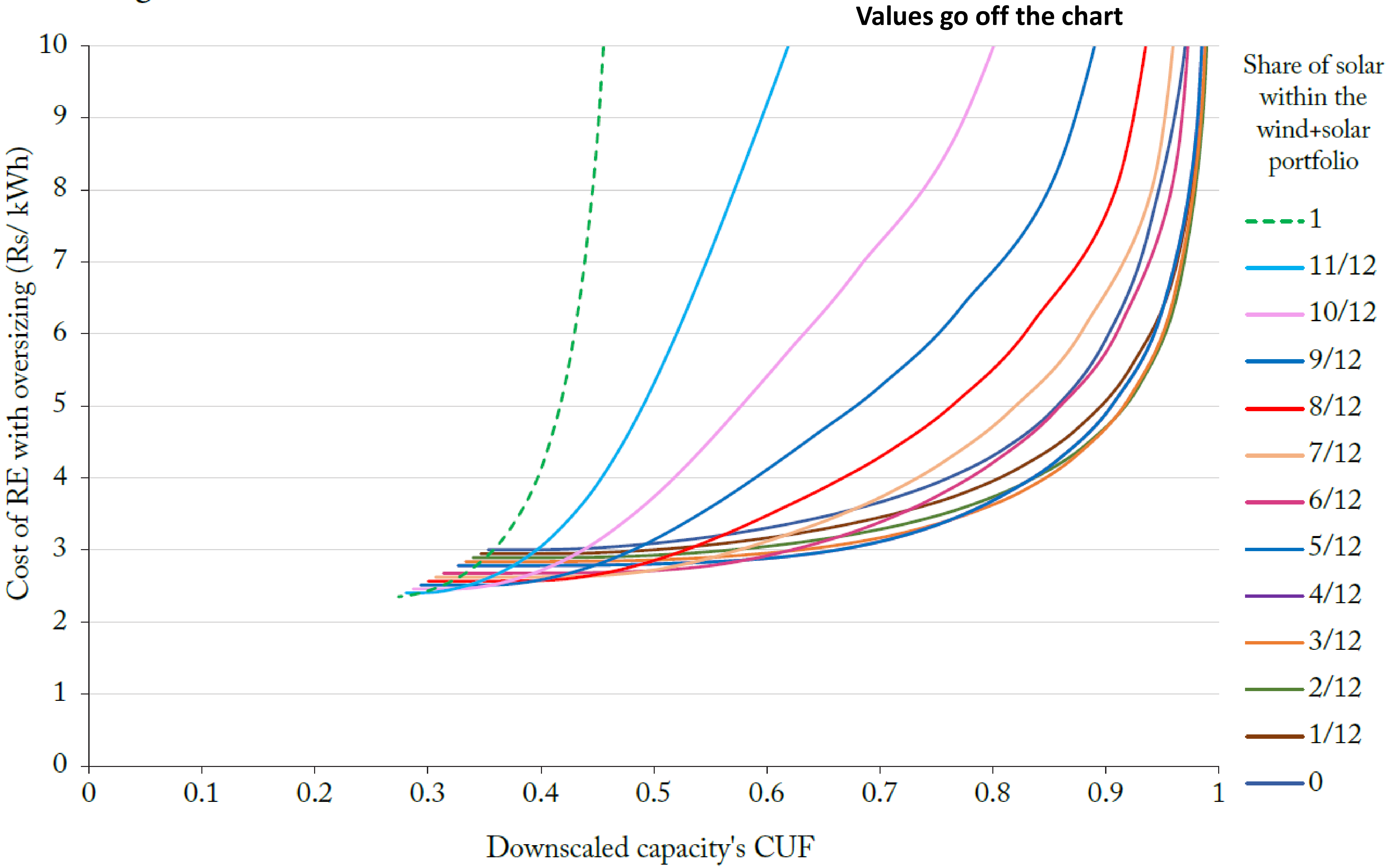
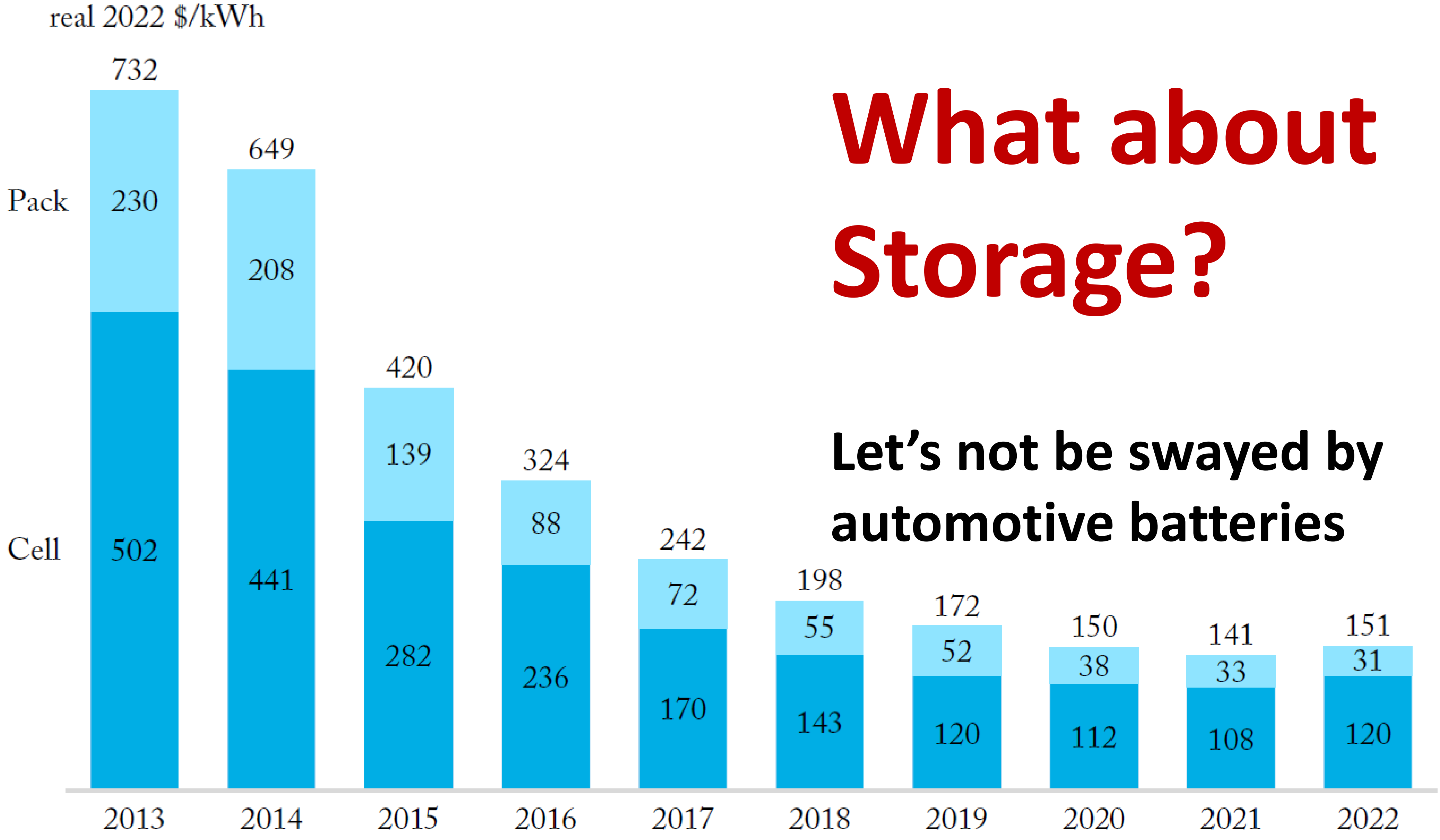


Figure 9: Volume-weighted average lithium-ion battery pack and cell price split, 2013–2022



What about Storage?

Let's not be swayed by automotive batteries

Source: BloombergNEF (2022).

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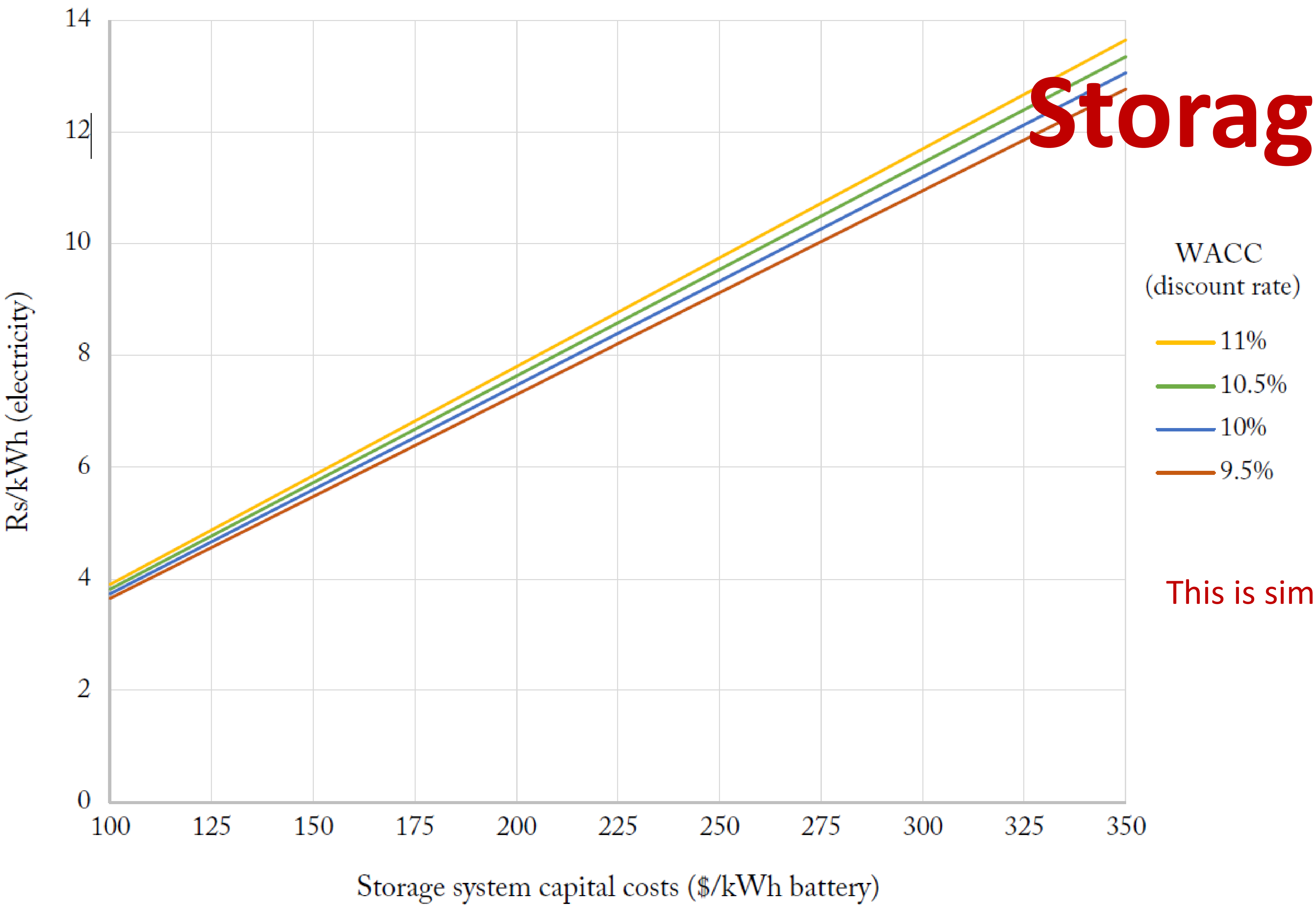
Storage costs

Figure 11: Cost of storage per unit electricity



This is simple LCOE, assuming high

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Simplified Economics of Green H

- 1 kg of Green H requires about 47 kWh of electricity
  - This is forward-looking = 71% efficiency
- If this costs *just* Rs 3/kWh, that's still over Rs 140/kg just for energy
  - Realistic costs are higher for 2030, more so when we factor in transmission needs
- Plus we have to pay for the electrolyzer
- H Storage and transport is also expensive
- How are we taxing (or not taxing) H?

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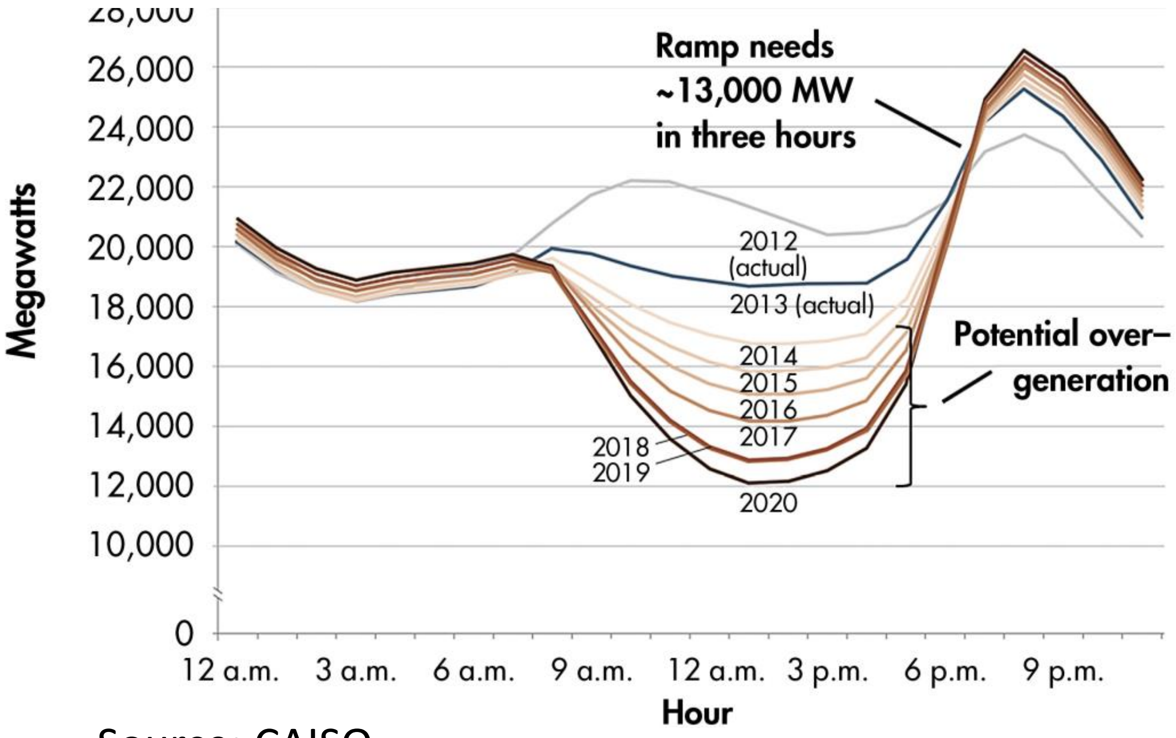
Power Sector has a path forward…high RE

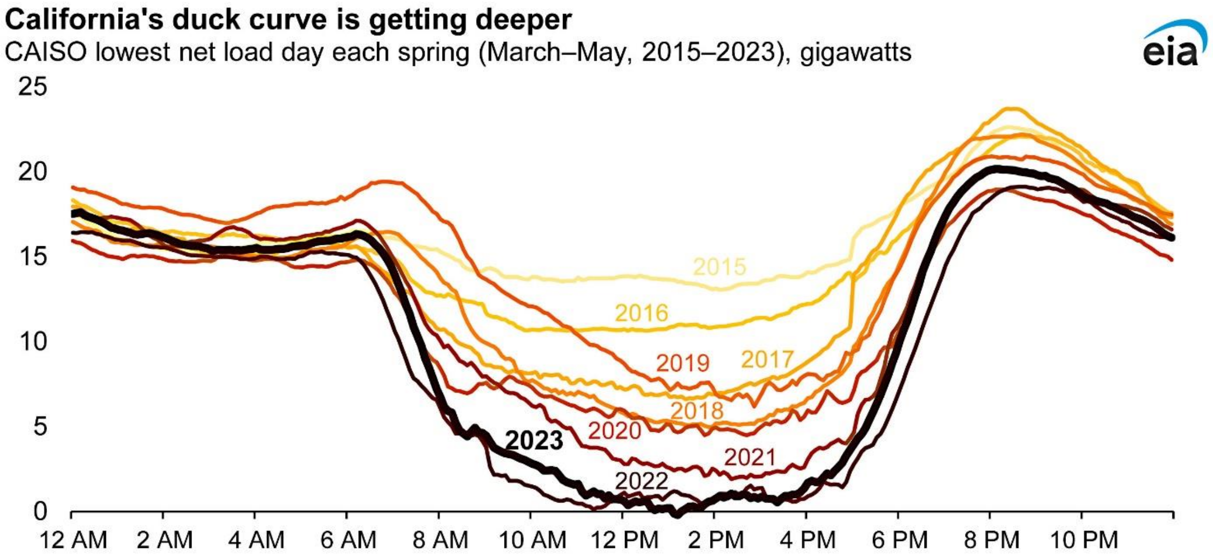
- VRE (no storage) can do a lot more
- Curtailment (limited) isn't a problem
  - The problem is the (evening) peak (net demand peak)
- ToD (time of day) is the biggest change in the power sector we'll have to embrace

Duck curves: Net Demand (aka Net Load)

Original Duck Curve was based on high solar



Source: CAISO



Reality has been deeper and wider

India will have greater challenges due to coal (part load aka flex operation limits)

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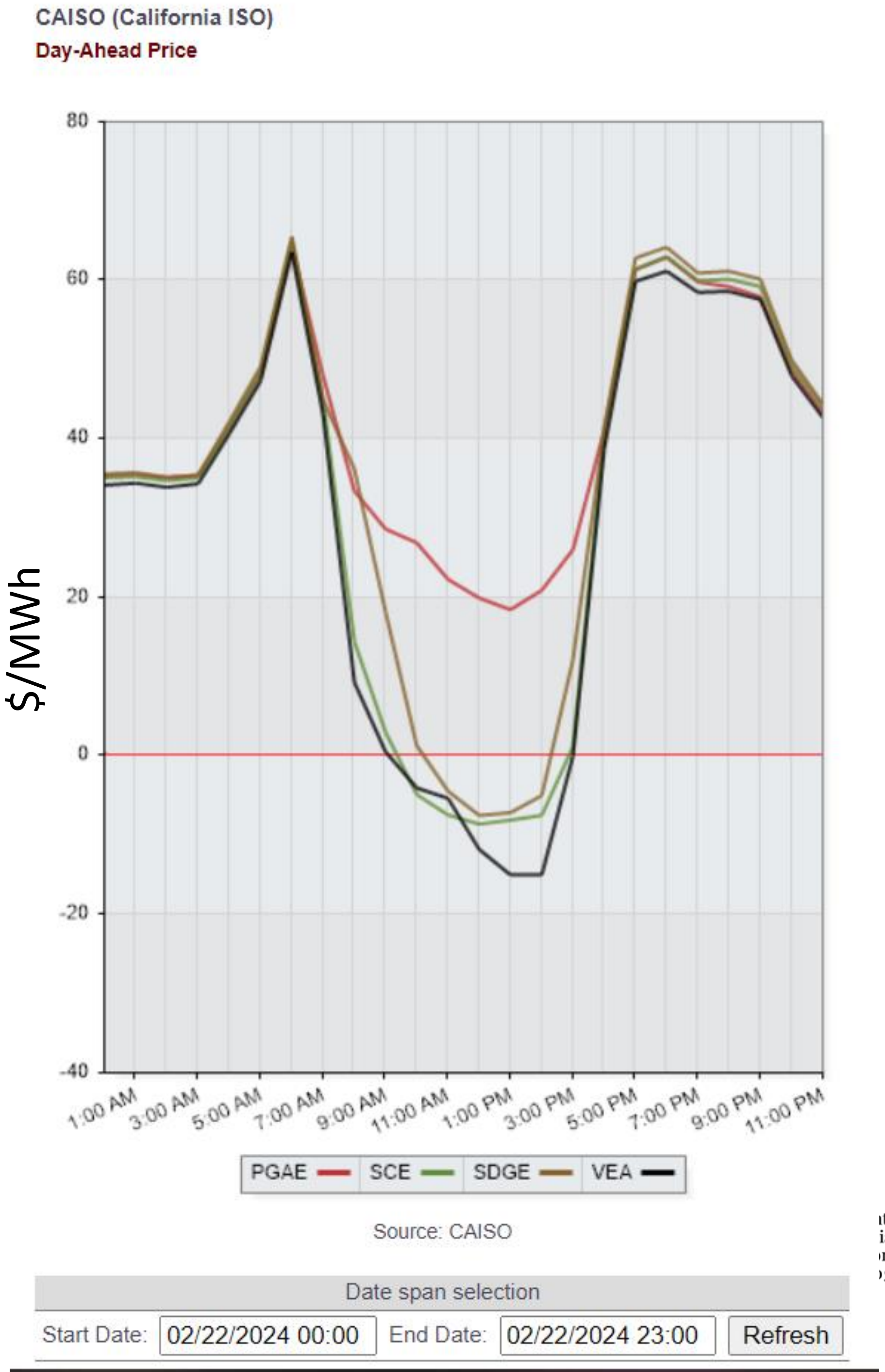
Cost, Price, and Value are NOT the same

The DisCom bears the brunt of net-metering

- We WILL have a combination of surplus mid-day *and* challenges in the evening

California Duck Curve becomes price hit



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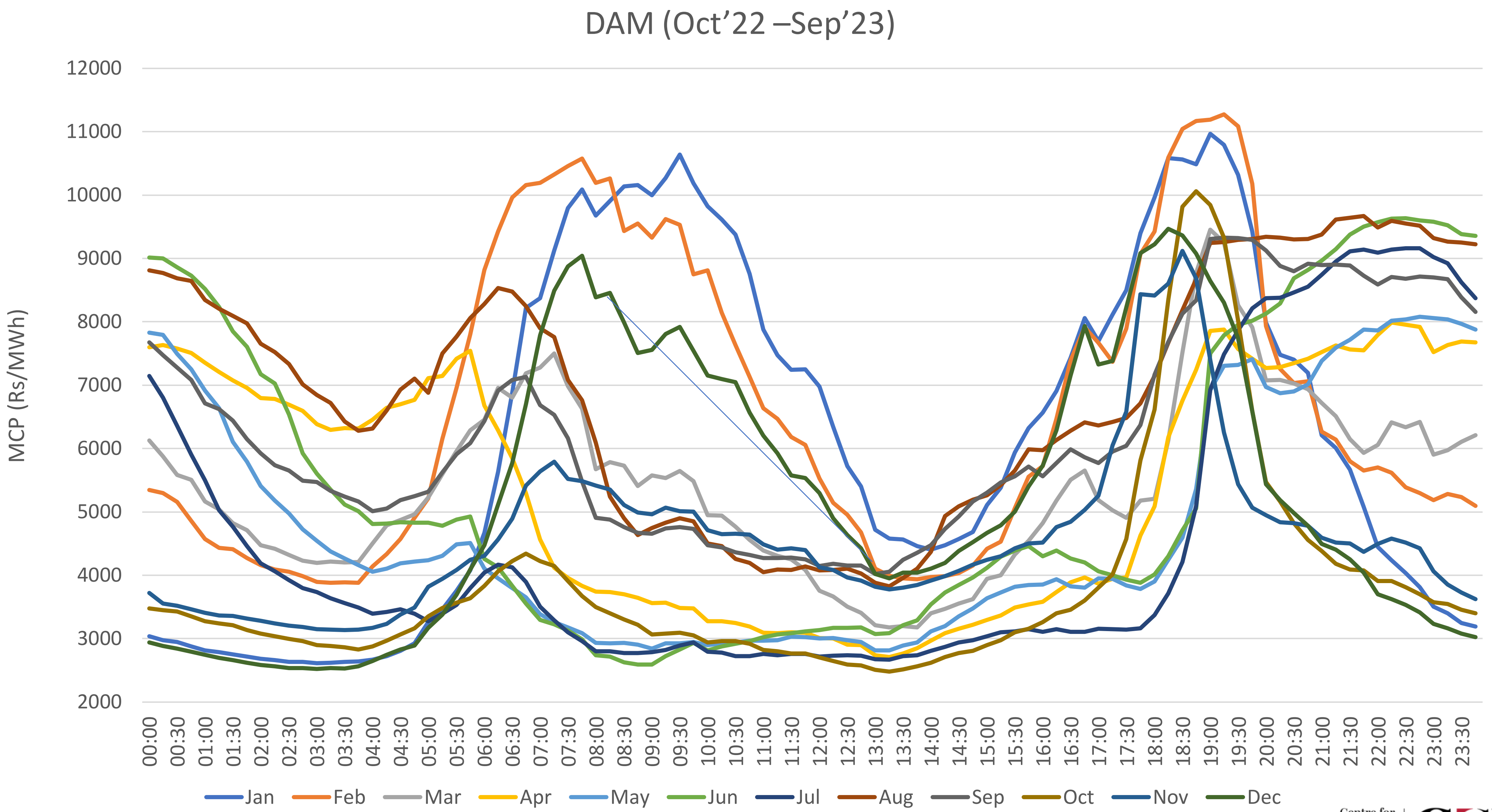

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Way forward links to timeframes

- Green H = longer term
- Power sector – plateau coal before worrying about ending it
  - Needs to be cleaner, more flexible
- Scaling up is a big challenge
  - We're not adding enough for 2030…but 2070 is more than double requirements per annum
- Stop using LCOE as a measure – need portfolio (system) pricing
  - Solar is cheap LCOE, but wind has higher system value

THANK YOU

[More information via publications at www.csep.org](http://www.csep.org)