GOING BEYOND MWH

Marginal Emission Rate and Its Application in Voluntary Clean Energy Investments

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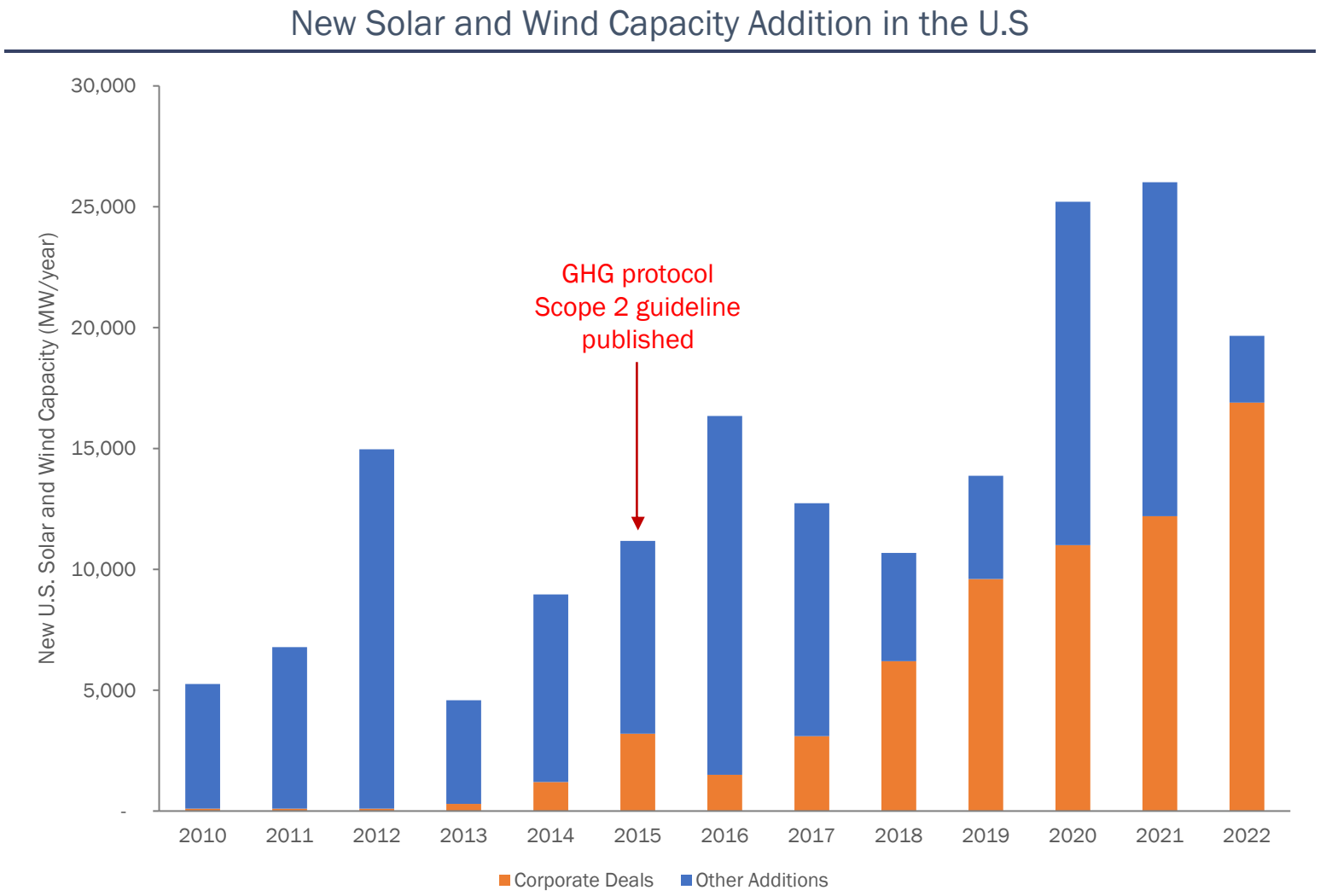
Voluntary Procurement

& the GHG Protocol Scope 2 Guidelines

Voluntary procurement added 40% of RE additions in the past decade



Data source: EIA 860, CEBA deal tracker

- Over the past decade, U.S. power grid added ~150 GW of new solar and wind capacity
- Corporate voluntary procurement account for about **40%** (65 GW) of that addition.
  - *48% of Fortune 500 companies committed to carbon neutral by 2050*

GHG protocol incentivizes procuring MWh of REC

- GHGP scope 2 guideline allows corporation to use a combination of
  - *MWh matching via vPPAs and/or unbundled RECs, &*
  - *Average emission rate*

  to track their emission

- Example 1:
  - *U.S. based company with 100 GWh of load, and 100 GWh of RECs*

    Emission : 100 GWh – 100 GWh = 0 net load, 0 emission
- Example 2:
  - *U.S. based company with 100 GWh of load, and 50 GWh of RECs*

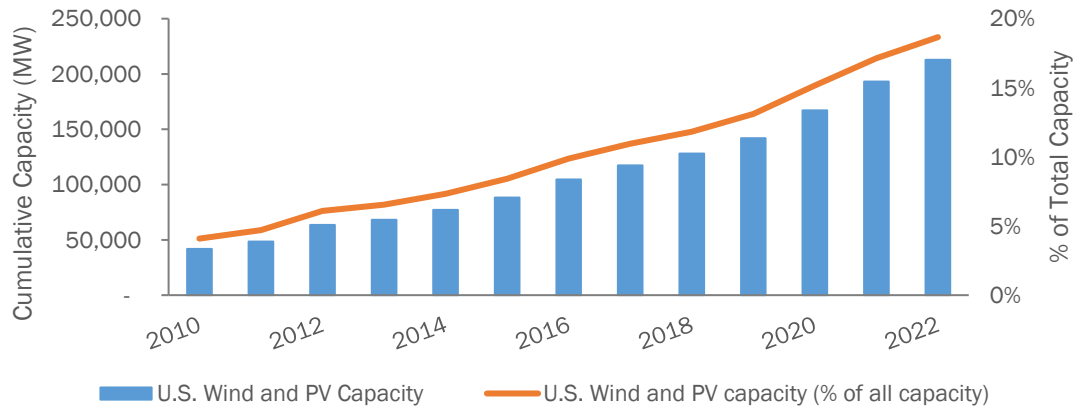
    Emission : (100GWh – 50 GWh) x 855 lbs. CO_2/MWh[1] = 42 million lbs. CO_2

New guidance is needed for an evolved grid

Locational Marginal Emission Rate

RECs are not the same

U.S. solar and wind capacity

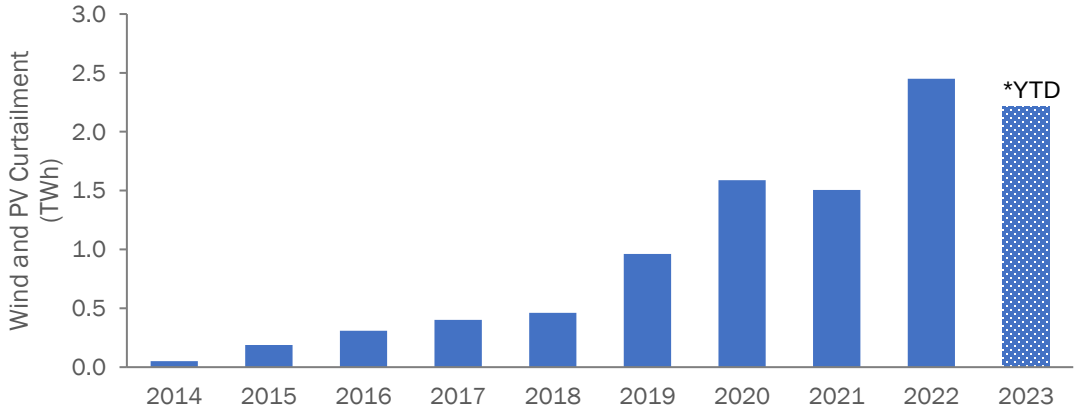


- GHGP kickstarted corporate voluntary procurement and added significant renewable capacity to the grid
  - *RECs do not distinguish projects'*
    - Location, and
    - generation profile
  - *RECs and average emission do not reflect physics of grid emission*

ERCOT 2022 Curtailment Stats

Wind Curtailment:	PV (utility) Curtailment
5%	9%
~5,600 GWh	~2,400 GWh

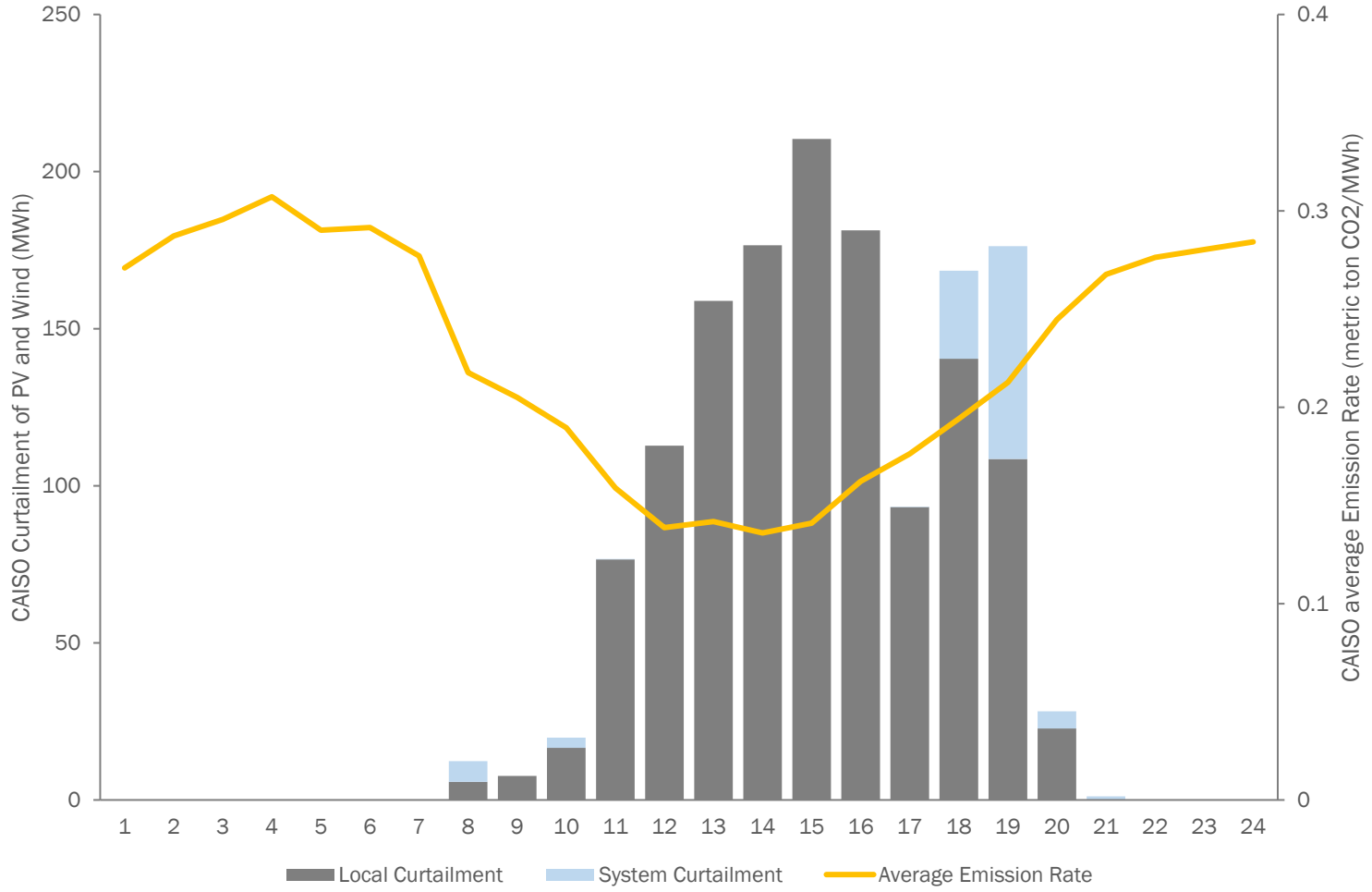
CAISO Curtailment of Solar and Wind



Source: BTU Analytics, ERCOT, CAISO

Average emission rate does not provide sufficient information

CAISO emission rate and renewable curtailment (June 30th , 2023)



- Average emission rate suggest
  - *Shift load to mid-day*
  - *Increase zero-emission generation in the morning and later afternoon*
- Curtailment data shows more intricate detail
  - *Mid-day curtailment is local: not all area sees low emission*
  - *High curtailment at late afternoon: more zero-emission gen has no impact*

Source: CAISO, managing oversupply

Emission on the grid is time and location sensitive, same as LMP

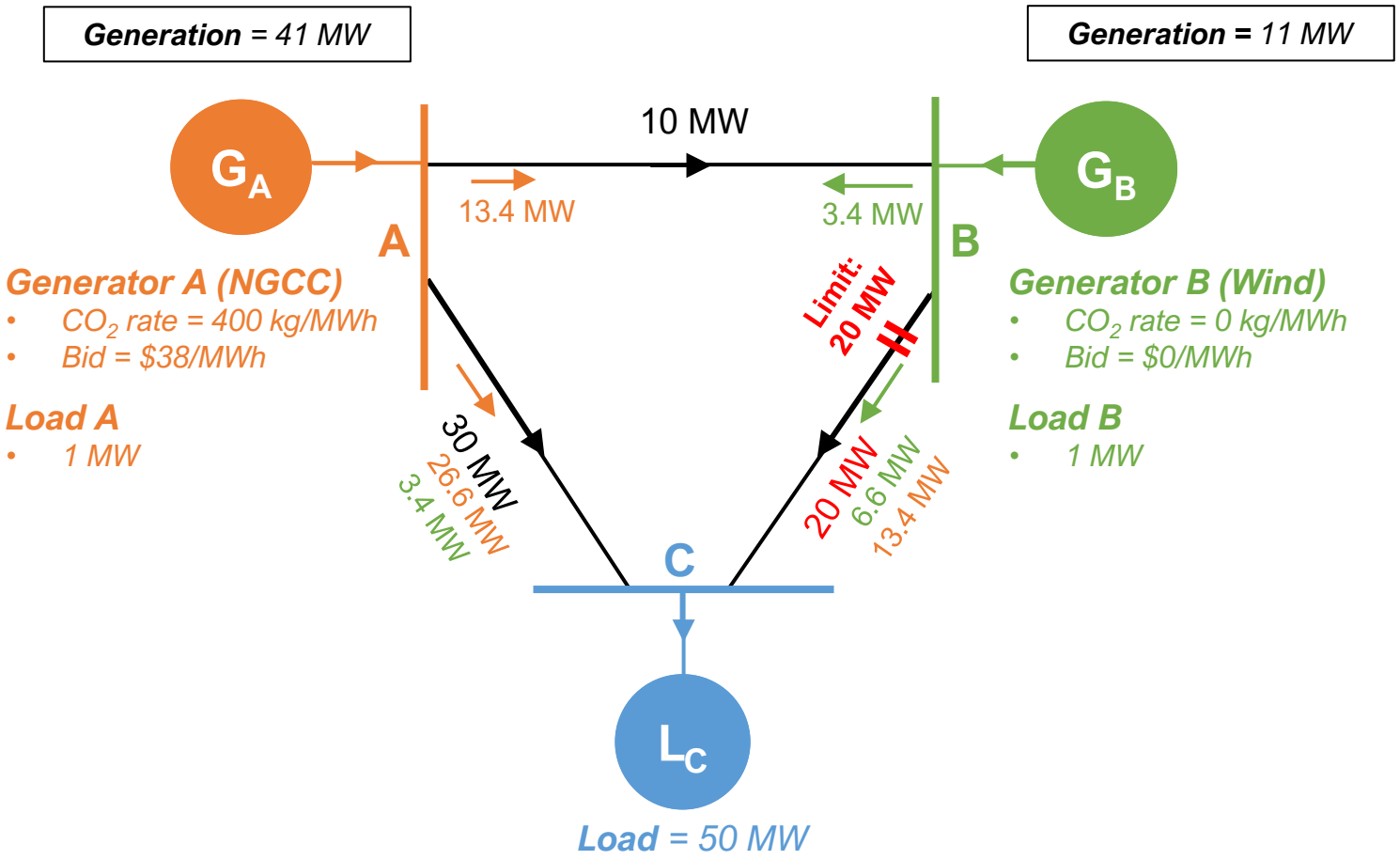
- Incremental change of energy injection/withdrawal changes system dispatch
  - *Cost impact = Locational Marginal Price (LMP)*
  - *Emission impact = Locational Marginal Emission Rate (LMER)*
- Locational marginal emission rate (**LMER**) can be calculated for every node on the grid at a given time

$$MER_{node} = \frac{\Delta(CO_2)_{system}}{\Delta(Demand)_{node}}$$

Change in system CO_2 emissions for an incremental MW of load at
1. given location; and
2. given time

LMER reflect nodal impact on emission

LMER calculation for a sample system



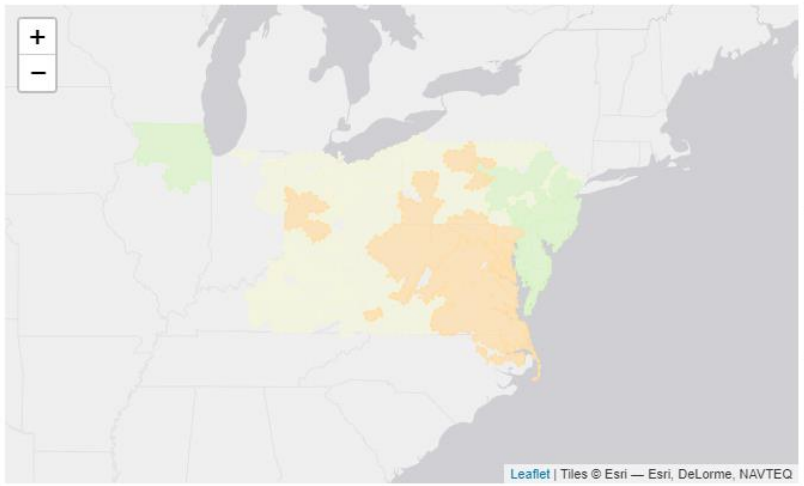
- Total cost = 38*41
  - *$1,558*
  - *$29.96/MWh*
- Total emission = 41 *400
  - *16,400 kg-CO_2*
  - *315.4 kg-CO_2/MWh*

Increase 1 MW load at C requires
Decrease generation at B by 1 MW
Increase generation at A by 2 MW

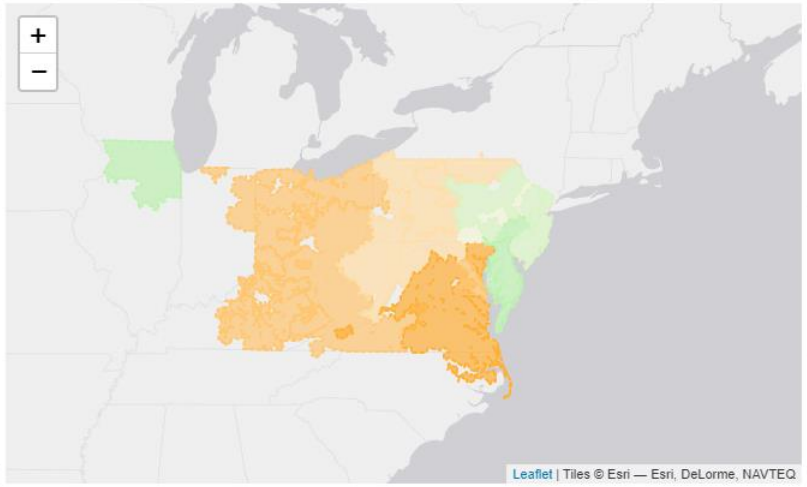
Node	LMP ($/MWh)	LMER (kg-CO_2/MWh)	Avg Emission (kg-CO_2/MWh)
A	38	400	315.4
B	0	0	
C	76	800	

PJM LMER shows significant locational difference

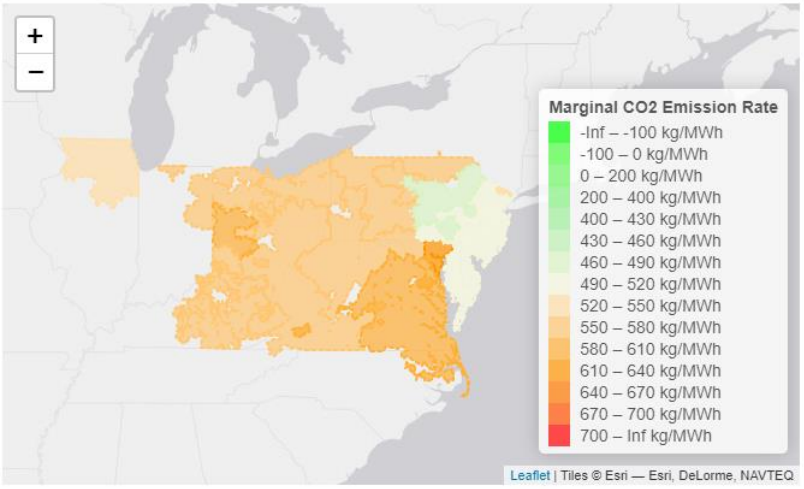
Winter 23 (Jan ~ Feb)

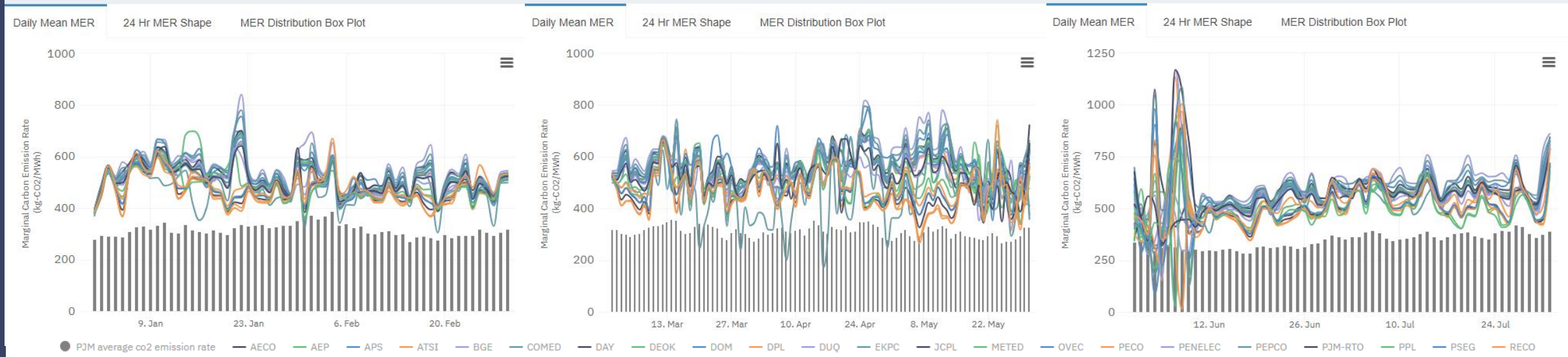


Spring 23 (Mar ~ May)



Summer 23* (June ~ Jul 31st)





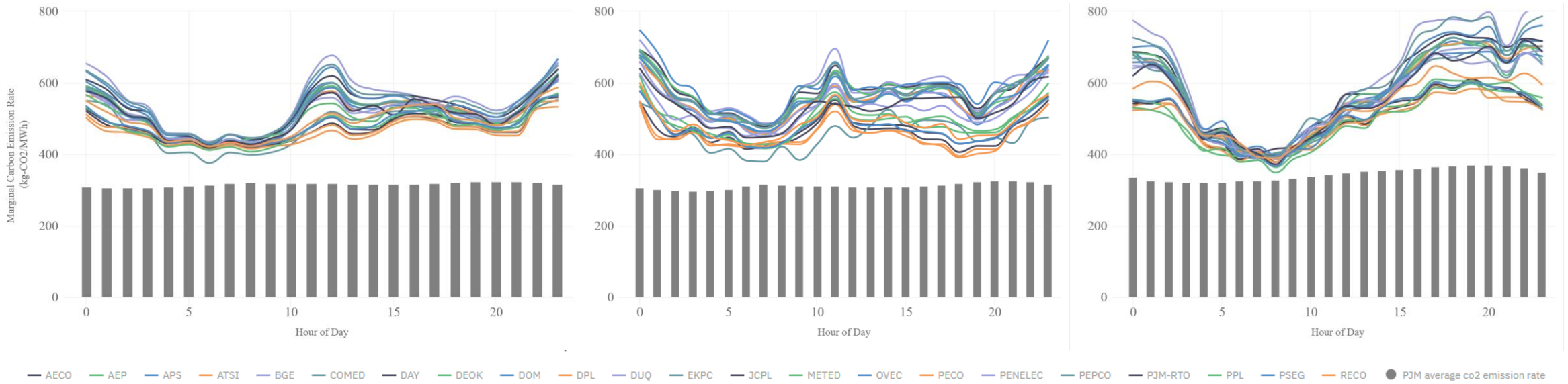
Source: PJM data miner

PJM LMER exhibits material hour by hour variation

Winter 23 (Jan ~ Feb)

Spring 23 (Mar ~ May)

Summer 23* (June ~ Jul 31st)



Source: PJM data miner

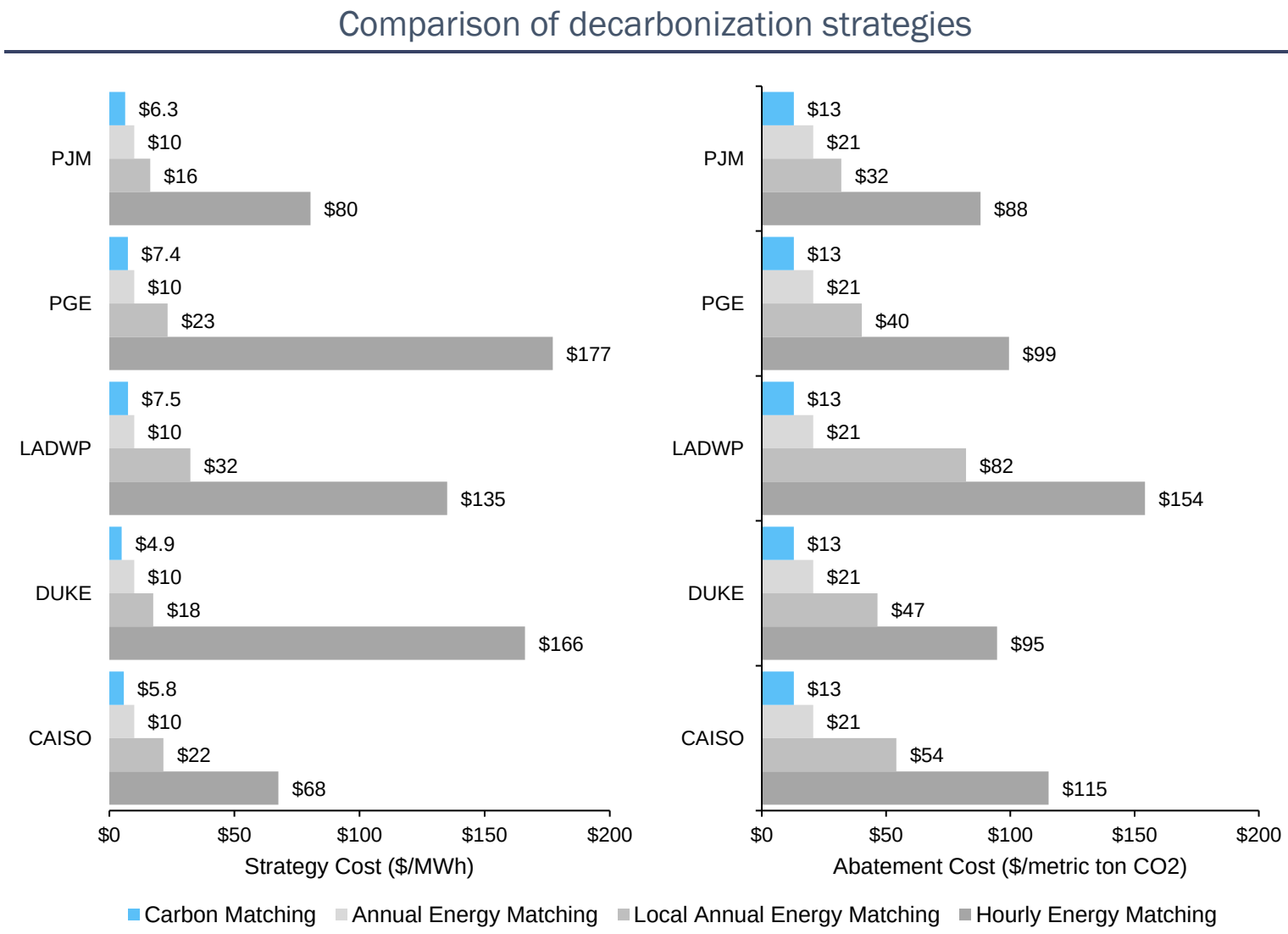
Going Beyond MWh

How LMER can advance grid decarbonization

Going beyond MWh

- LMER can help buyers optimize site selection and maximize amount of carbon displaced per $ invested in clean energy projects
- LMER can provide signal for load/DER and storage to
- LMER can assign carbon impact to transmission assets, therefore allow corporate sustainability capital to take part

LMER can maximize carbon impact of RE investments

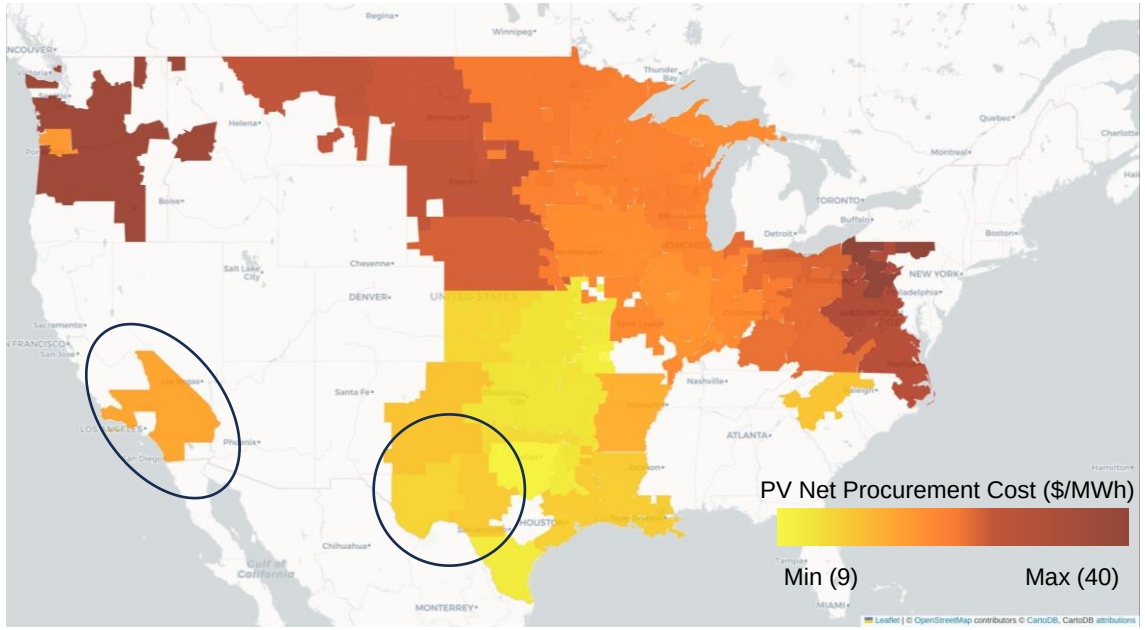


- Translate MWh into carbon impact
- Avoid local matching constraint
  - *Expensive*
- Target areas and projects that have the maximum carbon displacement
  - *Low abatement cost*
  - *High carbon ROI*

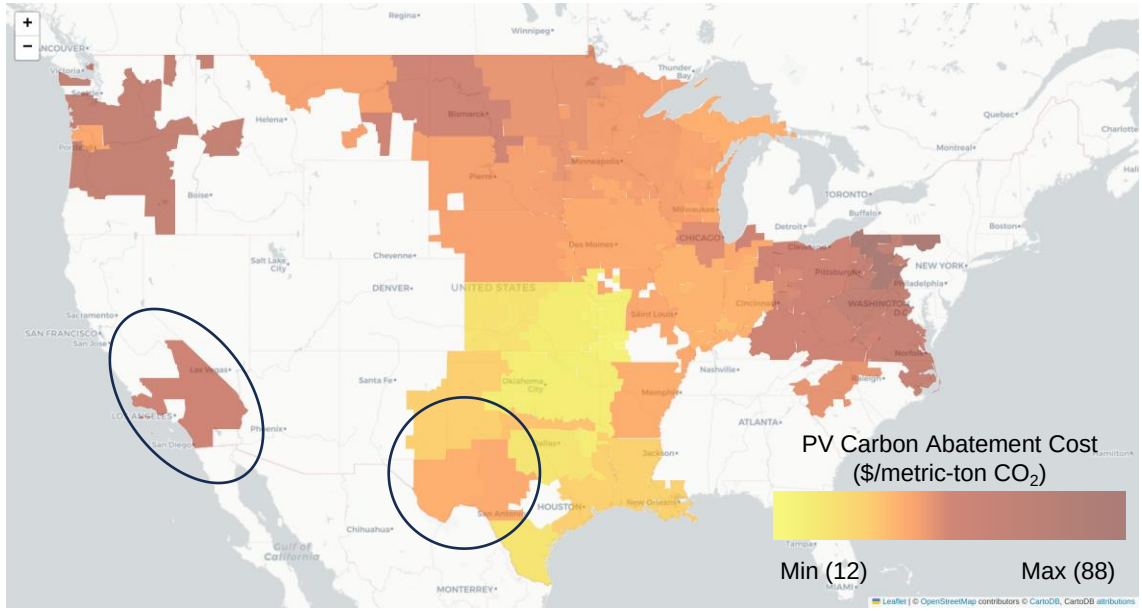
Source: TCR Path to Carbon Neutrality White Paper, June 2023

LMER tracks carbon impact

PV Net Procurement Cost ($/MWh)



PV Carbon Abatement Cost ($/'000 kg-$CO_2$)



- LMER reflect transmission congestion and local gen mix
  - *CAISO: reasonable PPA, but low displacement potential*
  - *ERCOT: low PPA, frequent congestion*

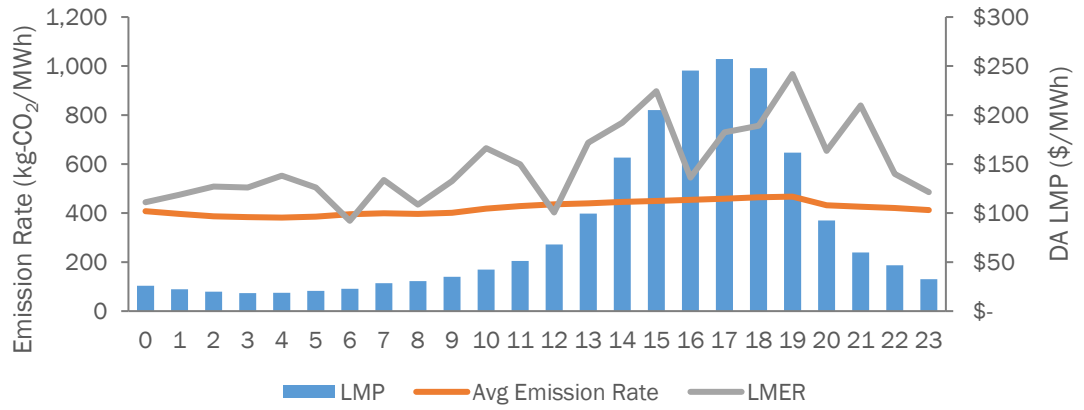
Source: TCR Path to Carbon Neutrality White Paper, June 2023

Emissions First Partnership

LMER provides signal for DR and storage to reduce emission

- Most demand response and storage assets are used for revenue generation /peak reduction with little regard for carbon emission
  - *A retrospective study found that 80% of ERCOT's utility battery projects were carbon positive*[1]
- LMER can provide better signal for DE and ES to reduce carbon emission
  - *Direct emission signal*
  - *More pronounced variation than average emission = encourages more cycling*

PSEG LMP and emission rates (2023 JUL 27th)[2]



Sample 10MW/40MWh battery performance

	Emission Footprint ($kg\text{-}CO_2$)	Energy Revenue ($)	Carbon Abatement Cost ($/kg-$CO_2$)
Revenue Maximizing	- 8,585	$ 8,777	$ - 1.02
Emission minimizing using average emission	- 5,779	$ - 6,947	$ 1.2
Emission minimizing using LMER	**- 19,444**	$ 1,333	$ - 0.07

Source: 1. Tierra Climate White Paper, Aug 2023; 2. PJM data miner

Energy Storage Solutions Consortium (ESSC)

Meta

REsurety

BROAD REACH POWER

tierra CLIMATE

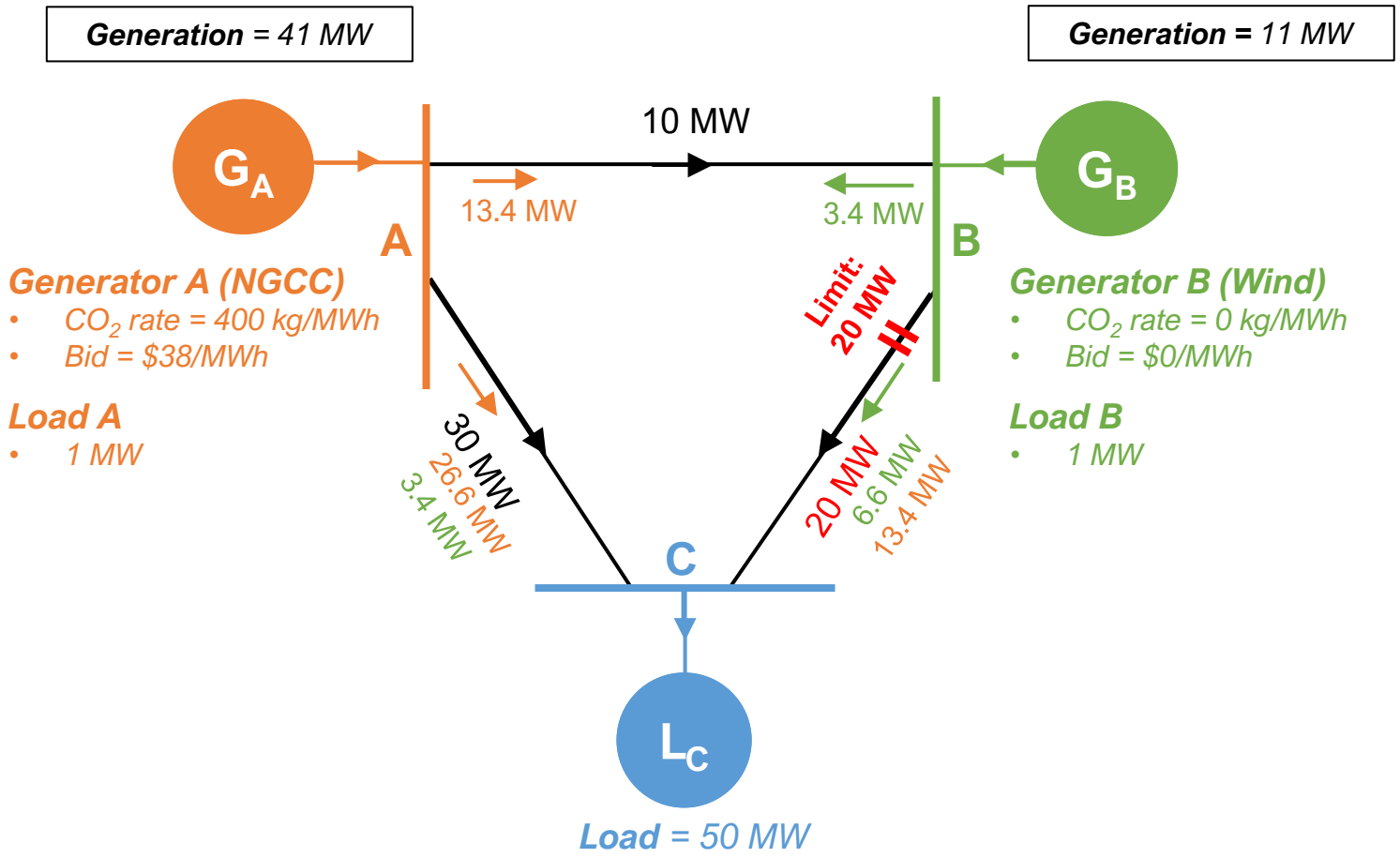
Transmission is key to energy transition, but…

- Transmission has received virtually no attention in corporate voluntary CE procurement
  - *It does not produce RECs*
  - *No way to account for emission benefit of transmission assets*

- A greener grid will not happen unless we improve transmission, we need:
  - *New lines*
  - *Grid Enhancing Technologies*

LMER reflect nodal impact on emission

LMER calculation for a sample system



- Increasing line B-C limit by 1MW would reduce system emission by
  - *1,200 kg*

Node	LMP ($/MWh)	LMER (kg-CO_2/MWh)	Avg Emission (kg-CO_2/MWh)
A	38	400	315.4
B	0	0	
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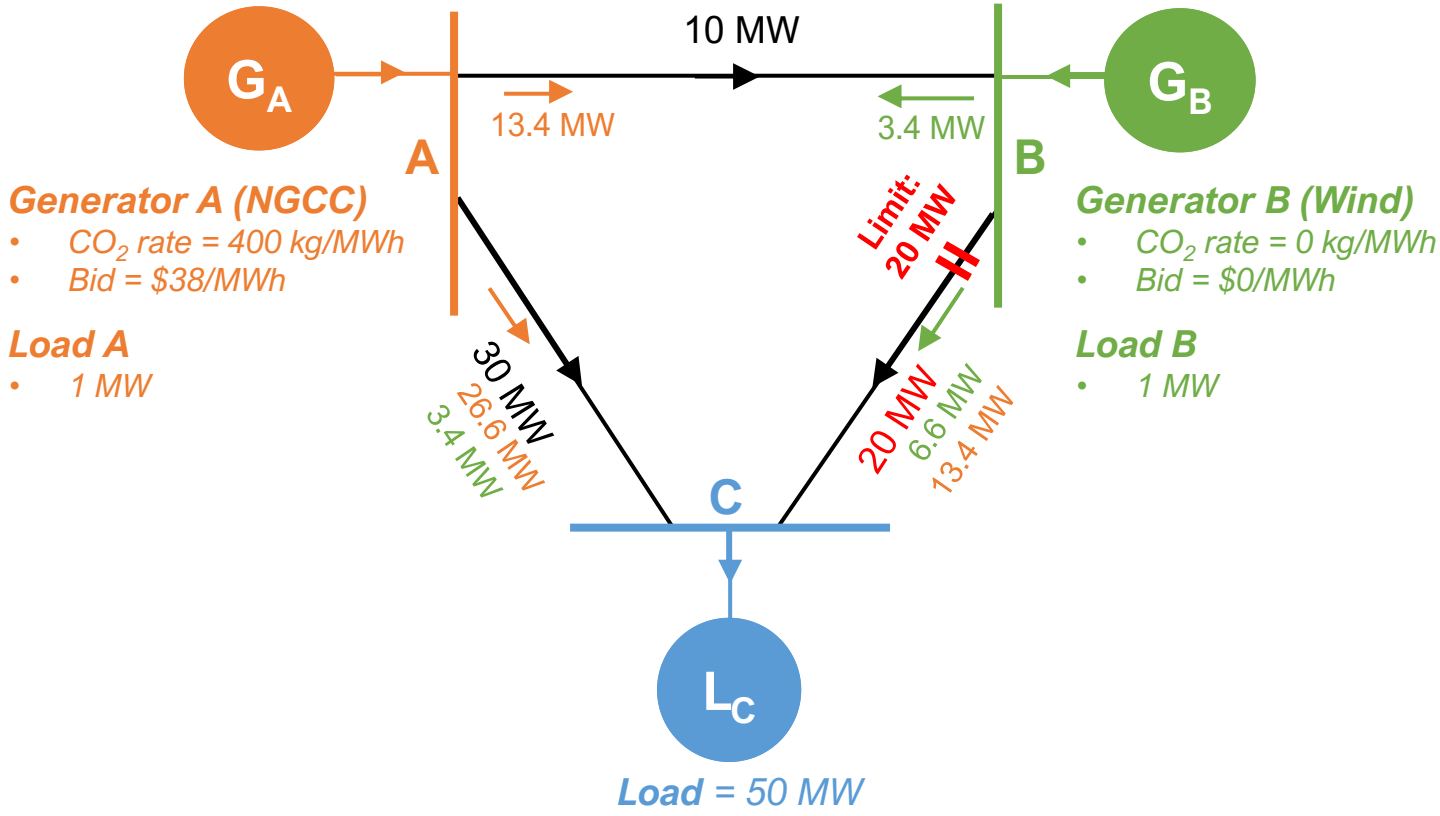
Increase 1 MW load at C requires
Decrease generation at B by 1 MW
Increase generation at A by 2 MW

LMER provides a way to allocate system emission to each asset on the network, including transmission assets

Average emission accounting

	Generation (MW)	Plant Emission Rate (kg-CO_2/MWh)	Scope 1 Emission (kg-CO_2)
Generator A	41	400	16,400
Generator B	11	0	0
Total Scope 1			**16,400**

	Load	Grid Avg Emission Rate (kg-CO_2/MWh)	Scope 2 Emission (kg-CO_2)
Load A	1	315.4	315
Load B	1	315.4	315
Load C	50	315.4	15,770
Total Scope 2			**16,400**



Recap

- LMER provides a transparent and reliable way to report granular emission date
  - *Nodal*
  - *Hourly/sub-hourly*

- LMER provides a new way to re-distribute system emission to every asset on the grid

- LMER provides the right information for advancing grid decarbonization:
  - *Improve renewable project selection for maximizing carbon displacement*
  - *Optimize demand response (DR) and energy storage (ES) operation to reduce emission*
  - *Provide carbon impact value for non-generation assets, especially transmission.*

THANK YOU

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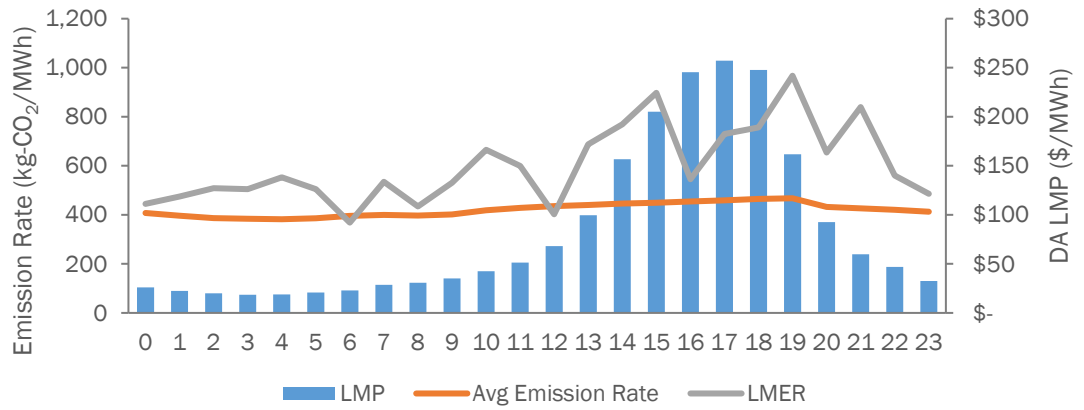
Simple optimization of 10MW/40MWh battery operation

PSEG LMP and emission rates (2023 JUL 27th)[2]



Simple Optimization Performance

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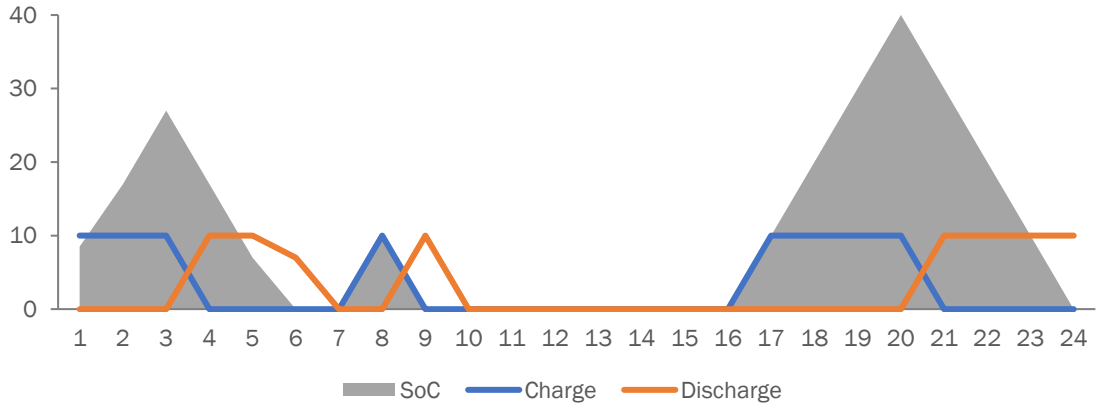
Emission Minimizing (Avg Emission)



Emission Minimizing (LMER)