POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Using air conditioners to increase the wholesale market value of solar PV electricity-2040 scenarios for India

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What motivates our research?

A future with high shares of solar PV in many power systems is inevitable if global warming is to be limited to well beyond 2 ° C and SDGs are to be met.

Economic value of solar PV electricity declines with increasing share in the system mainly due to the mismatch between solar generation and demand.

The decline in economic value has serious implications for the achievement of high solar shares as it affects the competitiveness of solar investments and total power system costs.

What motivates our research?

A future with large-scale deployment of air conditioners is also inevitable with increasing income, population and global warming.

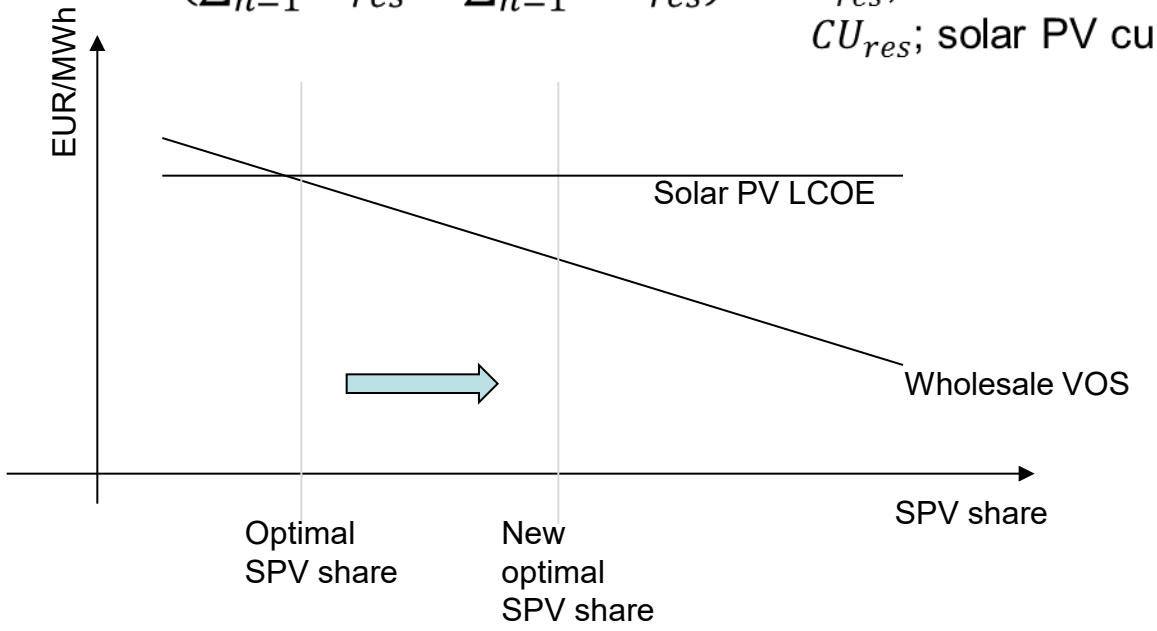
Due to its unique daily and seasonal profiles, air conditioning load increases system peak load, which will require massive investments in additional generation and network capacity.

But AC load is very flexible due to its inherent thermal characteristics, which could help improve the mismatch between solar generation and demand.

The decline in the economic value of solar PV electricity (VOS)

$$Solar\ market\ value = \frac{\sum_{h=1}^{8760} P_h\, G_{res}}{\left(\sum_{h=1}^{8760} G_{res} + \sum_{h=1}^{8760} CU_{res}\right)}$$

P_h; wholesale price (USD/MWh)
G_{res}; solar PV feed-in (MWh)
CU_{res}; solar PV curtailment (MWh)



How to move towards the new optimal share?

Mitigating the decline in the economic value of solar PV electricity (VOS)

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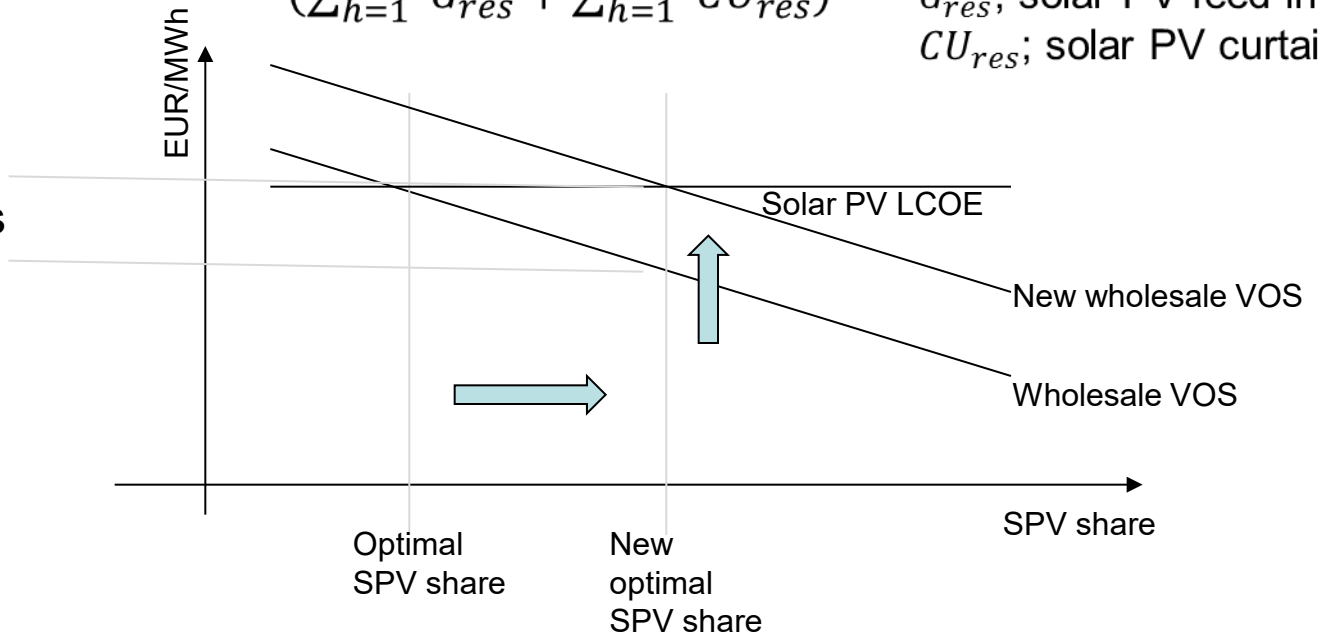
Air conditioners can help



But how?

Demand-side management (DSM) from air conditioners with cool thermal energy storage

- **We examine two DSM measures with different**
  - **maximum DSM durations,**
  - **efficiencies and**
  - **costs**
- **Mechanical precooling of the building thermal mass using programmable thermostats here called in short, Precooling, and chilled water storage (CWS).**
- **CTES enables the shifting in time of the electricity consumption of air conditioners from times of low or no solar generation to times of high solar generation.**

Our 2040 DSM technology and cost assumptions

	Precooling	CWS	Unit
Load shifting costs	1	1	USD/MWh
Overnight investment costs	30,000	100,000	USD/MW
Annual fixed costs	-	-	USD/MW
Interest rate	7	7	%
Technical lifetime	10	10	Years
Efficiency	70	90	%
DSM maximum duration	4	8	Hours
DSM recovery time	1	1	Hours
Maximum installable capacity	350,000	350,000	MW

DIETER Model (investment and economic dispatch)

- DIETER is an open source power sector model developed by researchers at DIW Berlin.

- Minimizes total system costs (maximizes welfare) over 8760 hours of a full year ensuring that power generation equals price-inelastic demand at all times.

- System costs comprise annualized investment costs and fixed costs as well as variable costs of conventional generators (e.g. fuel and CO2 costs), renewables and DSM.

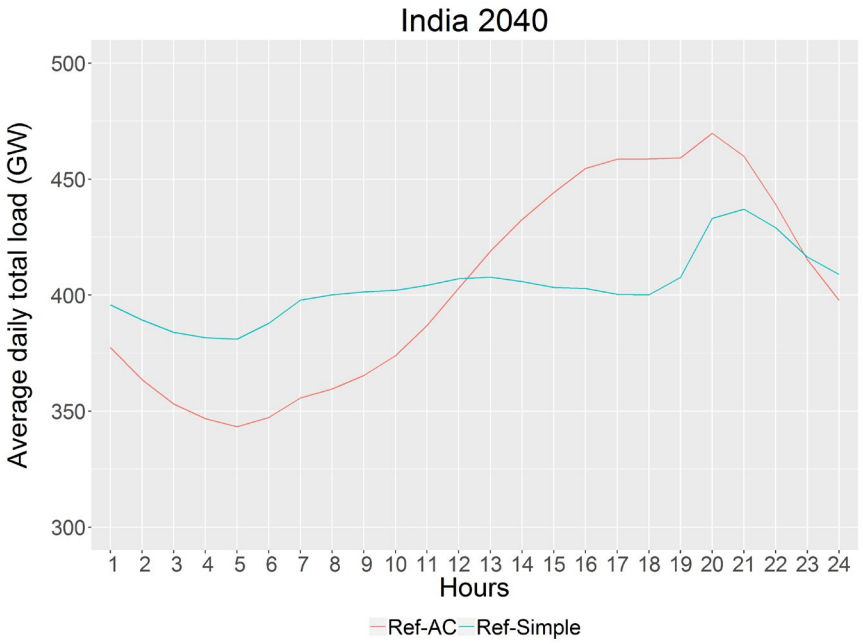
- Inflexibility of conventional generators are captured using load change costs.

DIETER Model (investment and economic dispatch)

- It is assumed to be a partial equilibrium model of the wholesale electricity market focusing both on supply and demand sides.

- Wholesale electricity price is the shadow price of demand (marginal cost of increasing demand). In other words, it is the price in an energy-only market with scarcity pricing.

2040 demand-side scenario - a highly air-conditioned Indian power system



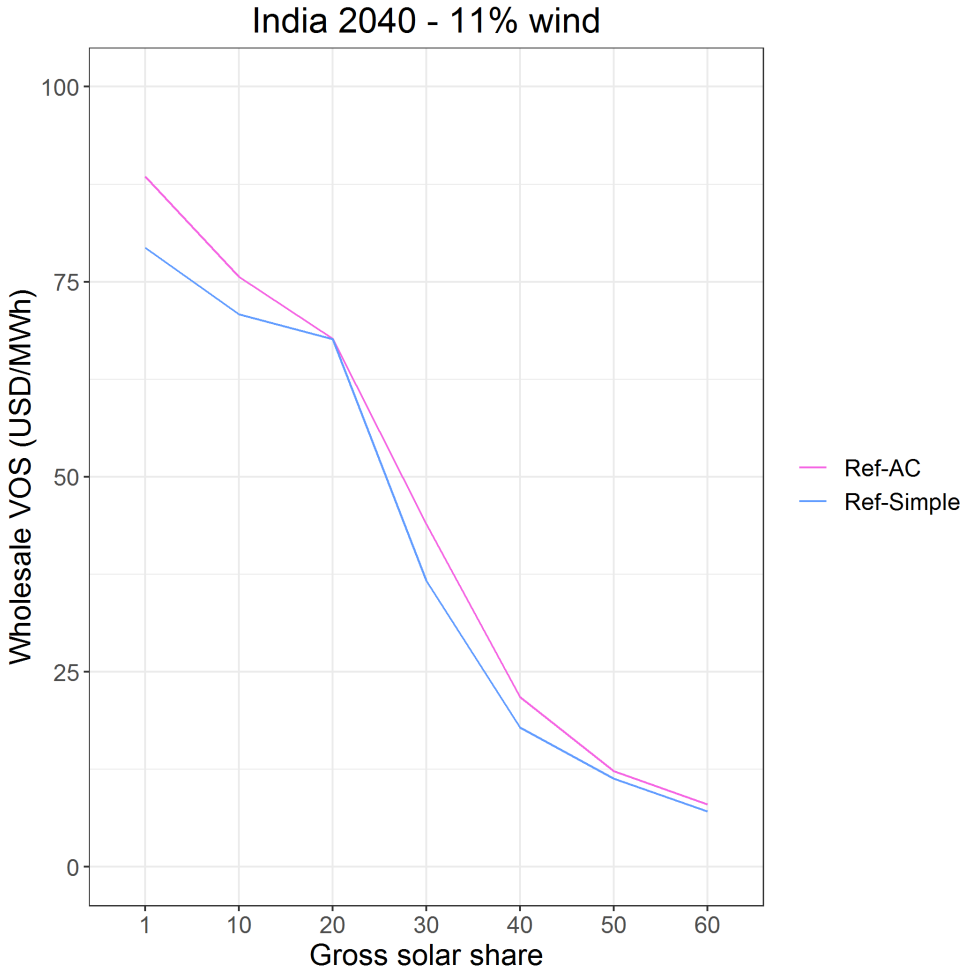
	Ref-Simple	*Ref-AC*	Unit
Total AC load		807	TWh
Total load	3535	3535	TWh
Load factor (%)	84	67	%
Peak load (GW)	482	606	GW
Average load (GW)	403	403	GW
Minimum load (GW)	305	259	GW
Peak coincident AC load (GW)		350	GW
Peak non-coincident AC load (GW)		350	GW
Time of total peak load	8:00 PM	5:00 PM	
Month of peak load	October	May	

2040 supply-side scenario – optimized expansion – quasi GREENFIELD

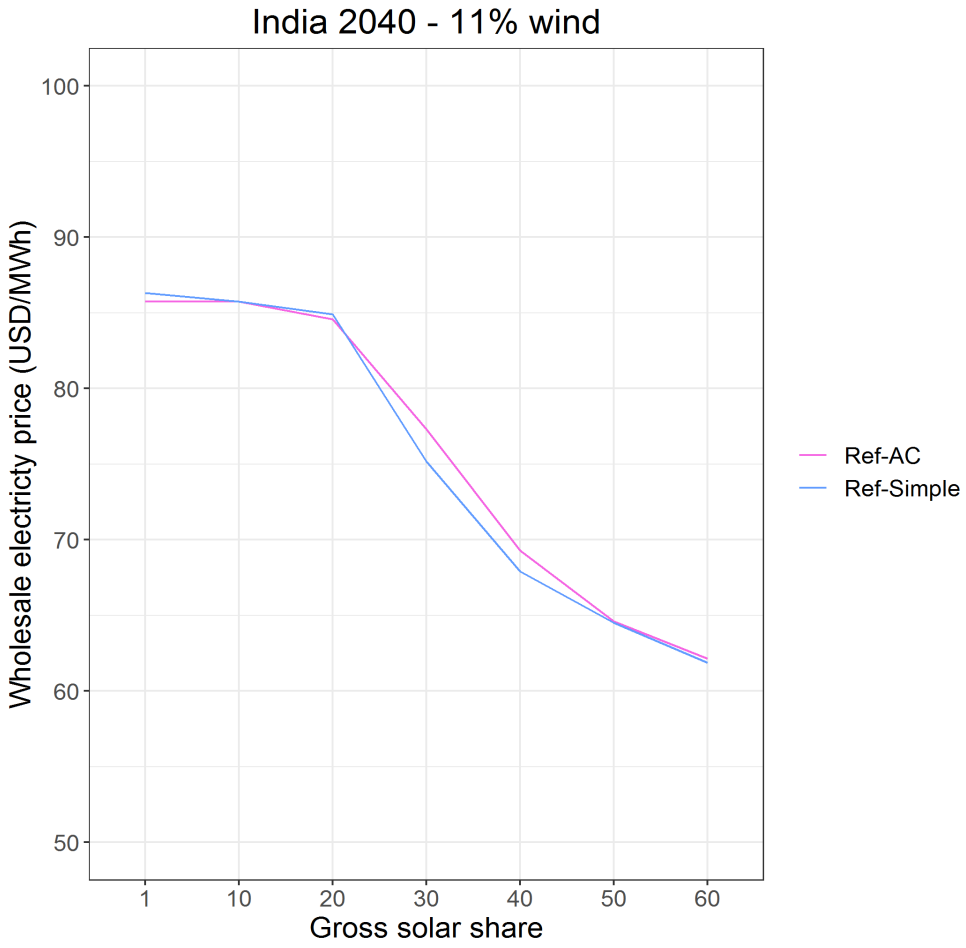
- **A CO2 price of 50 USD per ton is in place.**
- **Wind meets 11 % of total load.**
- **Only ~150 GW of coal is in the system.**
- **No more than ~50 GW of nuclear can be built.**

	Nuclear	Hard coal	CCGT	OCGT	Unit
Efficiency	34.3	43	58	45.7	%
Carbon content	0	0.354	0.202	0.202	t/MWh
Overnight investment costs	5,500,000	1,580,000	700,000	400,000	USD/MW
Annual fixed costs	140,000	55,000	25,000	20,000	USD/MW
Variable O&M costs		-	-		USD/MWh
Load change costs up and d	50	30	20	15	USD/MW
Technical lifetime	40	35	25	25	years
Interest rate	7	7	7	7	%
Maximum capacity factor	85	85	85	85	%
Maximum load change for reserves	4	6	8	15	% of capacity per minute

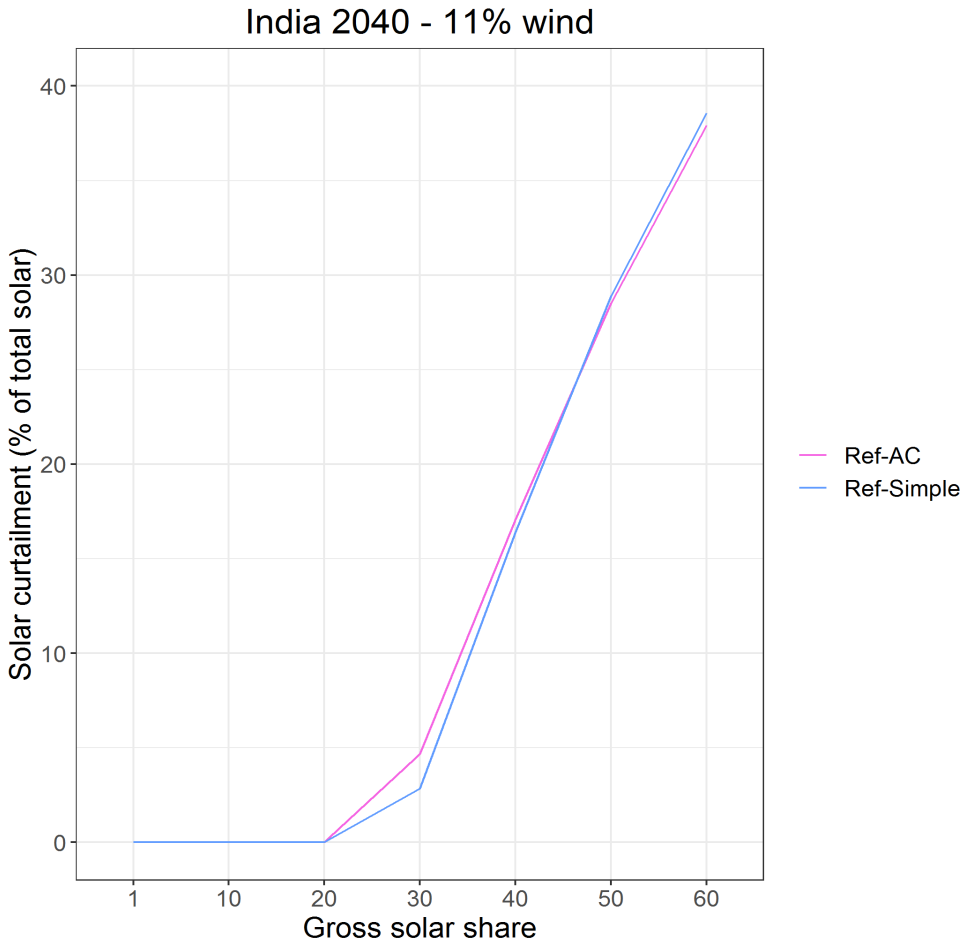
Wholesale VOS declines with increasing solar PV share



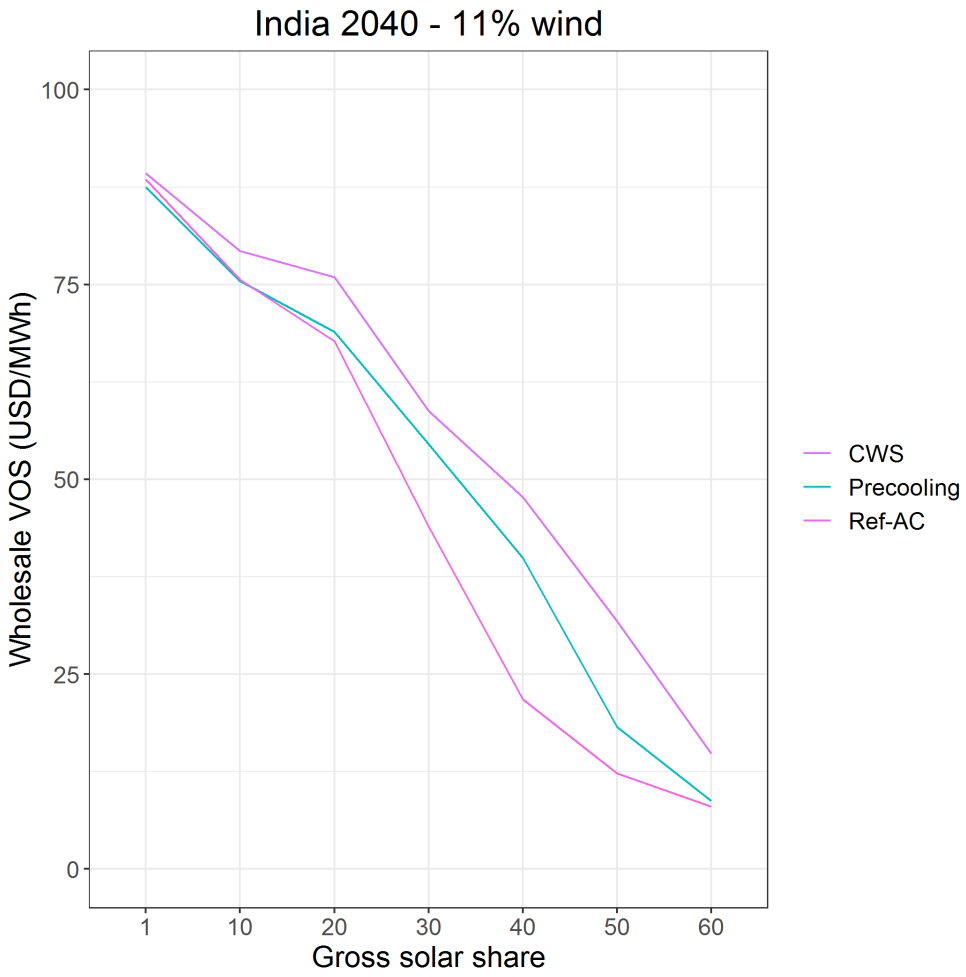
One reason is suppressed solar-coincident electricity prices and the resulting lower average electricity prices.



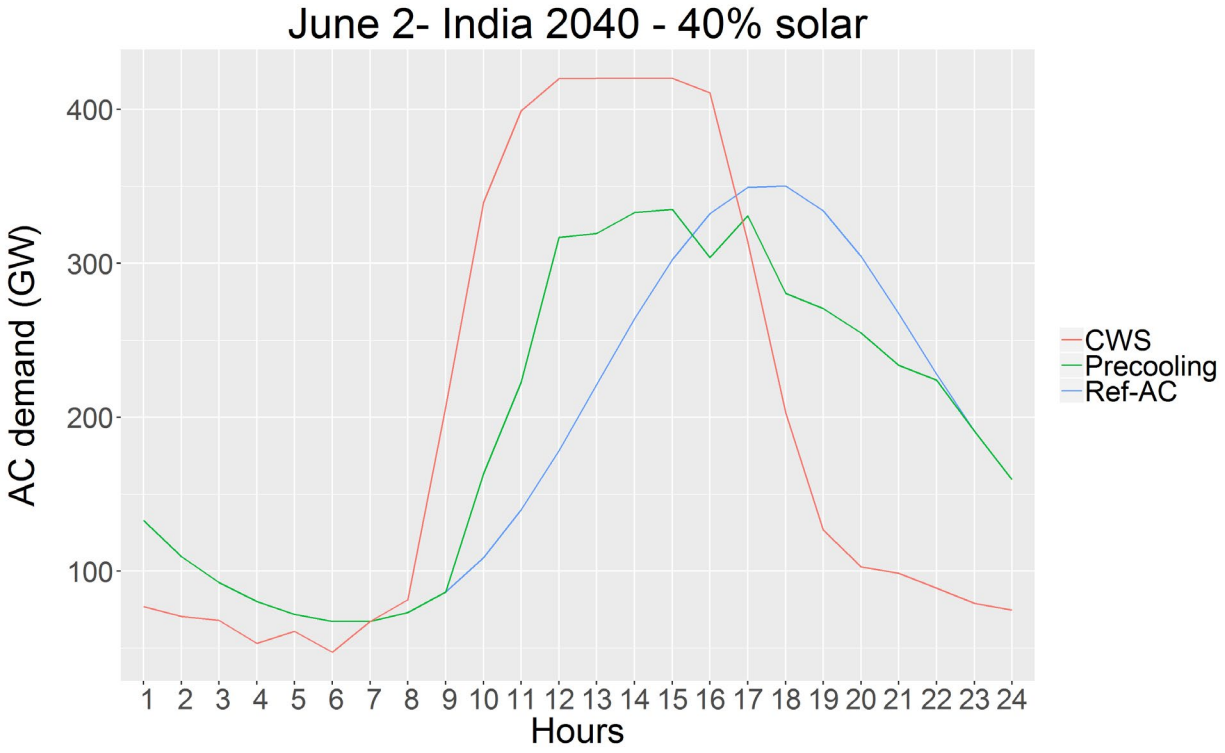
Another reason is that a larger share of solar generation gets no revenues at all because it is curtailed.



Precooling and CWS increase the wholesale VOS.

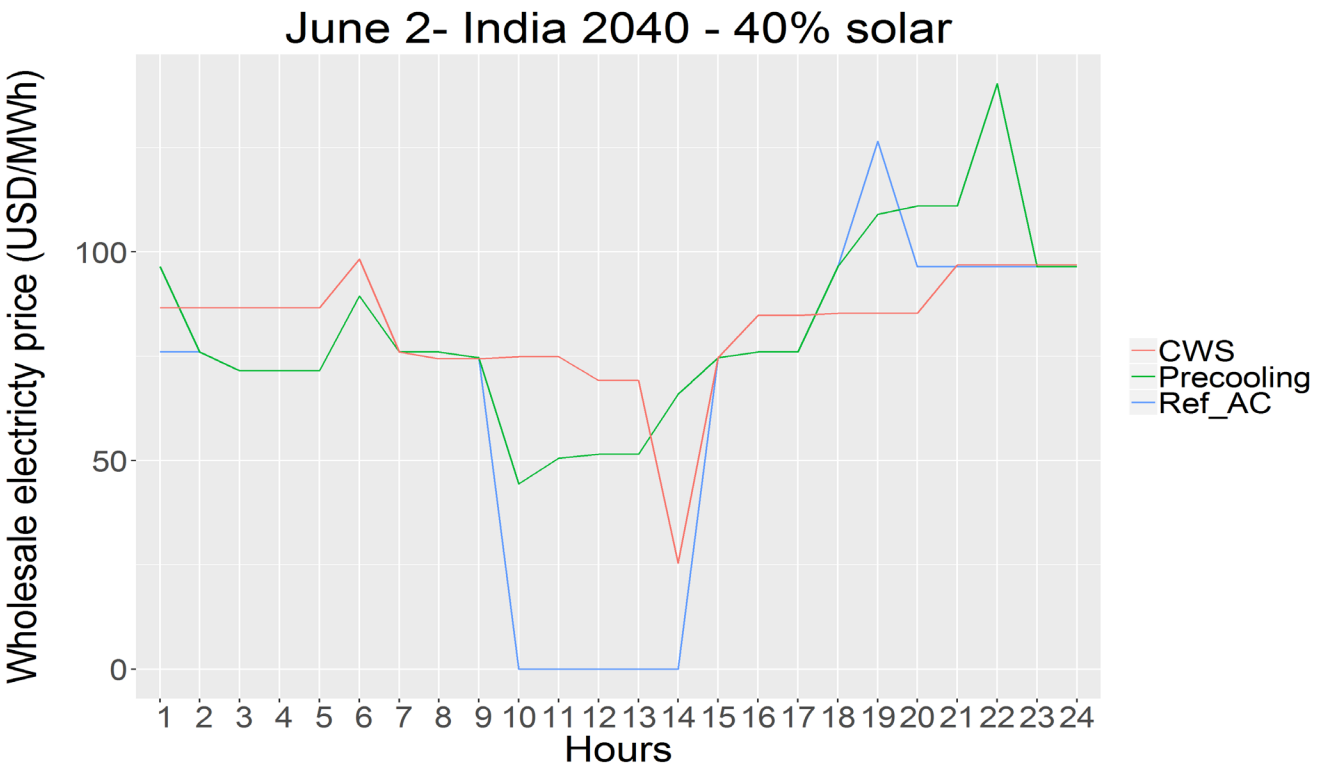


By improving the matching of AC demand and solar generation profiles.



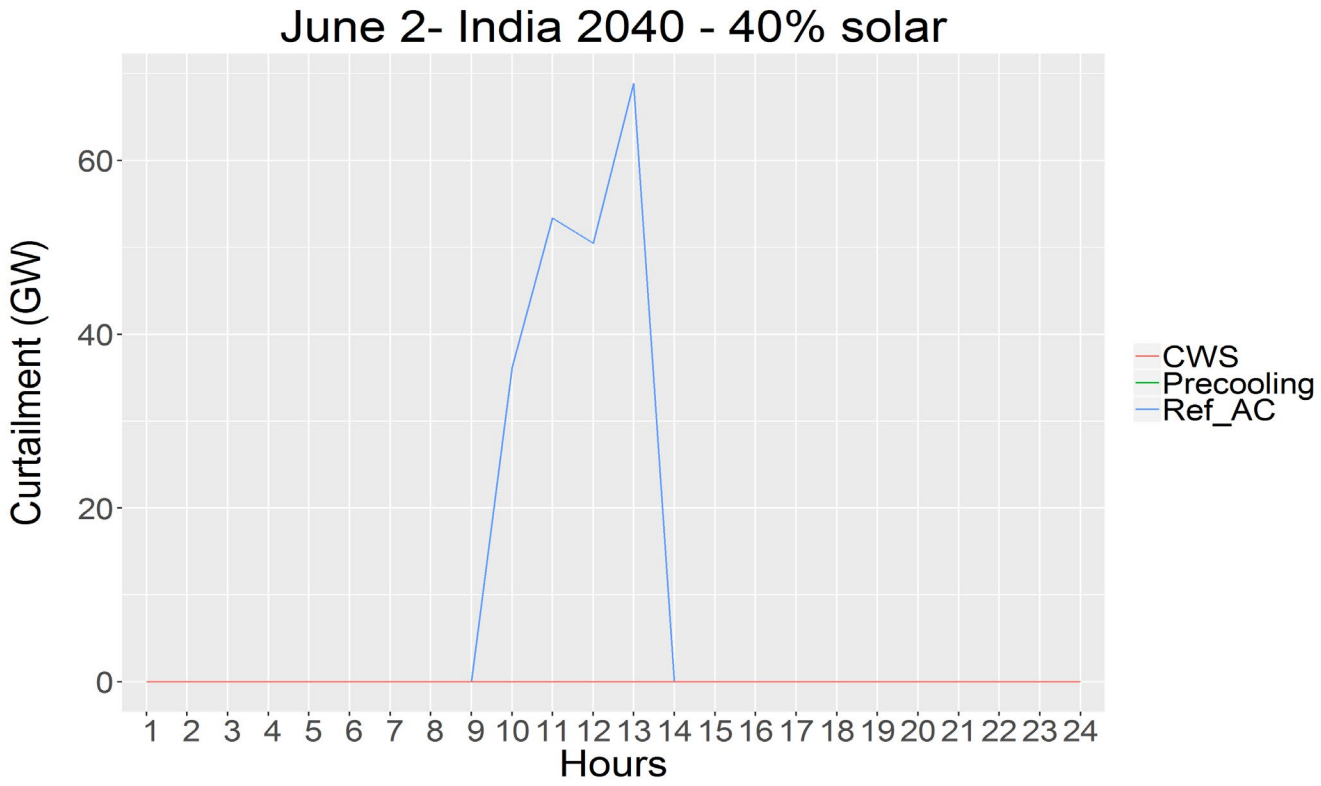
June 2, which is the day with the highest AC demand.

Which leads to higher solar-coincident electricity price



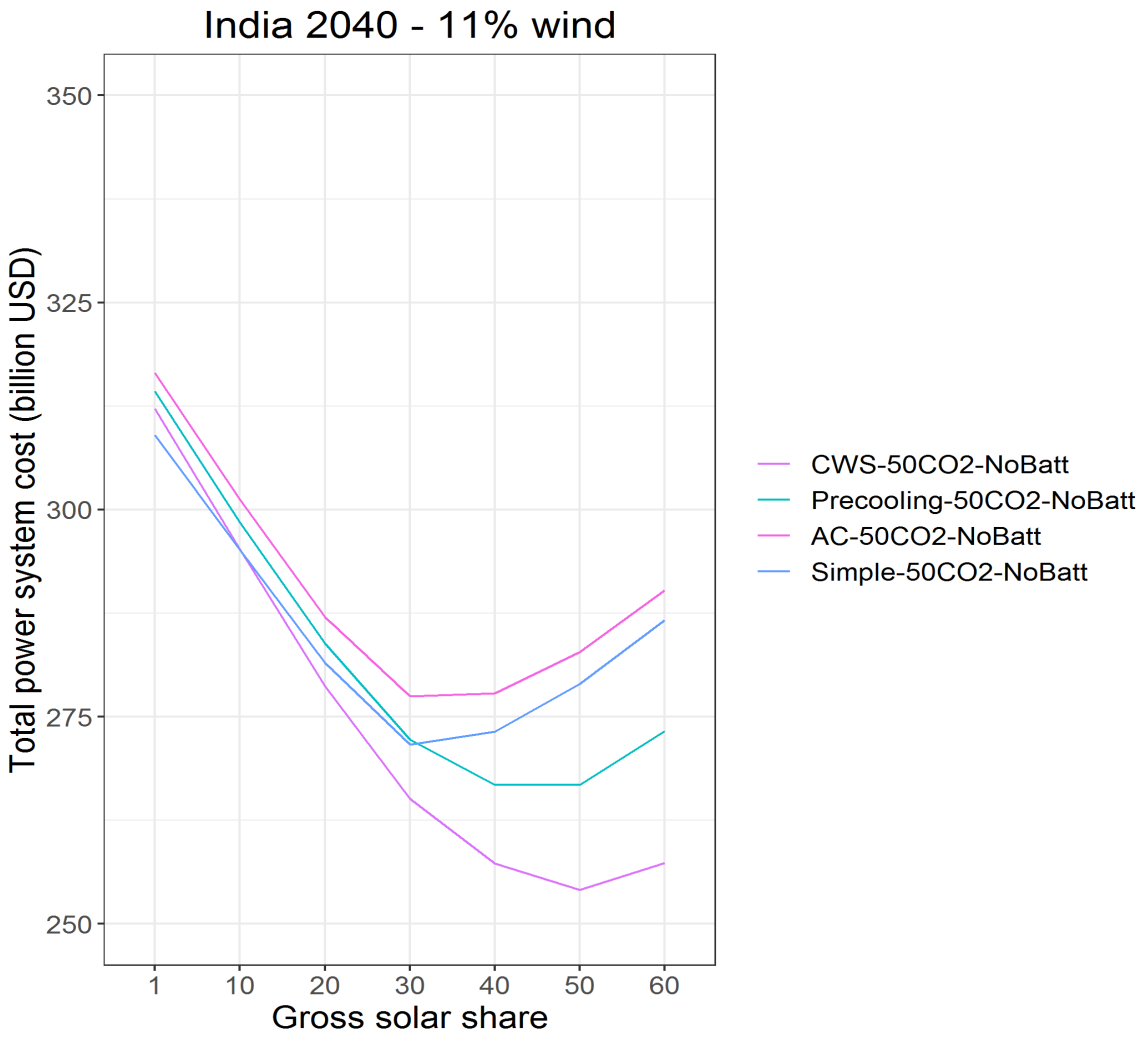
June 2, which is the day with the highest AC demand.

Which leads to higher solar-coincident electricity price and reduced curtailment.



June 2, which is the day with the highest AC demand.

Impact of DSM on optimal solar share



Conclusions

- **We examined the role of two DSM measures using air conditioners with CTES to mitigate the decline in the wholesale market value of solar.**

- **We found that the wholesale VOS declines from 89 USD per MWh at 1 % solar share to less than 10 USD per MWh at 60 % solar share in our Ref-AC scenario.**

- **Precooling and CWS increased the wholesale VOS up to 18 USD per MWh and 26 USD per MWh compared to our Ref-AC scenario respectively.**

- **DSM measures provided by distributed thermal energy storage could make solar PV investments cost-competitive at larger shares, which is key for the transition to a low-cost and low-carbon energy system.**

- **Indian policy makers, utility planners, regulators and system operators ought to consider DSM provided by distributed CTES as a key resource when planning and setting targets for large-scale solar PV deployment and peak load management.**

Thank you.