Technology and Policy Leapfrogs in energy systems

Dr. Amol Phadke
Scientist and Group Leader
International Energy Studies Group
Lawrence Berkeley National Laboratory
June 2017 ELP

Introduction to Lawrence Berkeley National Laboratory

Managed by the University of California for
the United States Department of Energy

Lawrence Berkeley National Laboratory

13 — Nobel Prizes
13 — National Medal of Science recipients
4,200 — Employees
200 — Site acreage

- **Dedicated to solving the most pressing scientific problems facing humankind**
  - Basic science for a secure energy future
  - Science of living systems to improve the environment and energy supply
  - Understanding and control of matter and energy in the universe
  - Translation to applied energy programs
- **Build and safely operate world-class scientific facilities**
- **Train the next generation of scientists and engineers**

International Energy Analysis Department

Key Research Areas

Long-Term Energy Modeling

Smart & Resilient Cities & Urban Infrastructure

Energy Market Policies

Clean Power & Smart Grid Integration

Electricity Access

Green & Energy Efficient Industry

High Performance Buildings & Products

Low Emission & Efficient Transportation

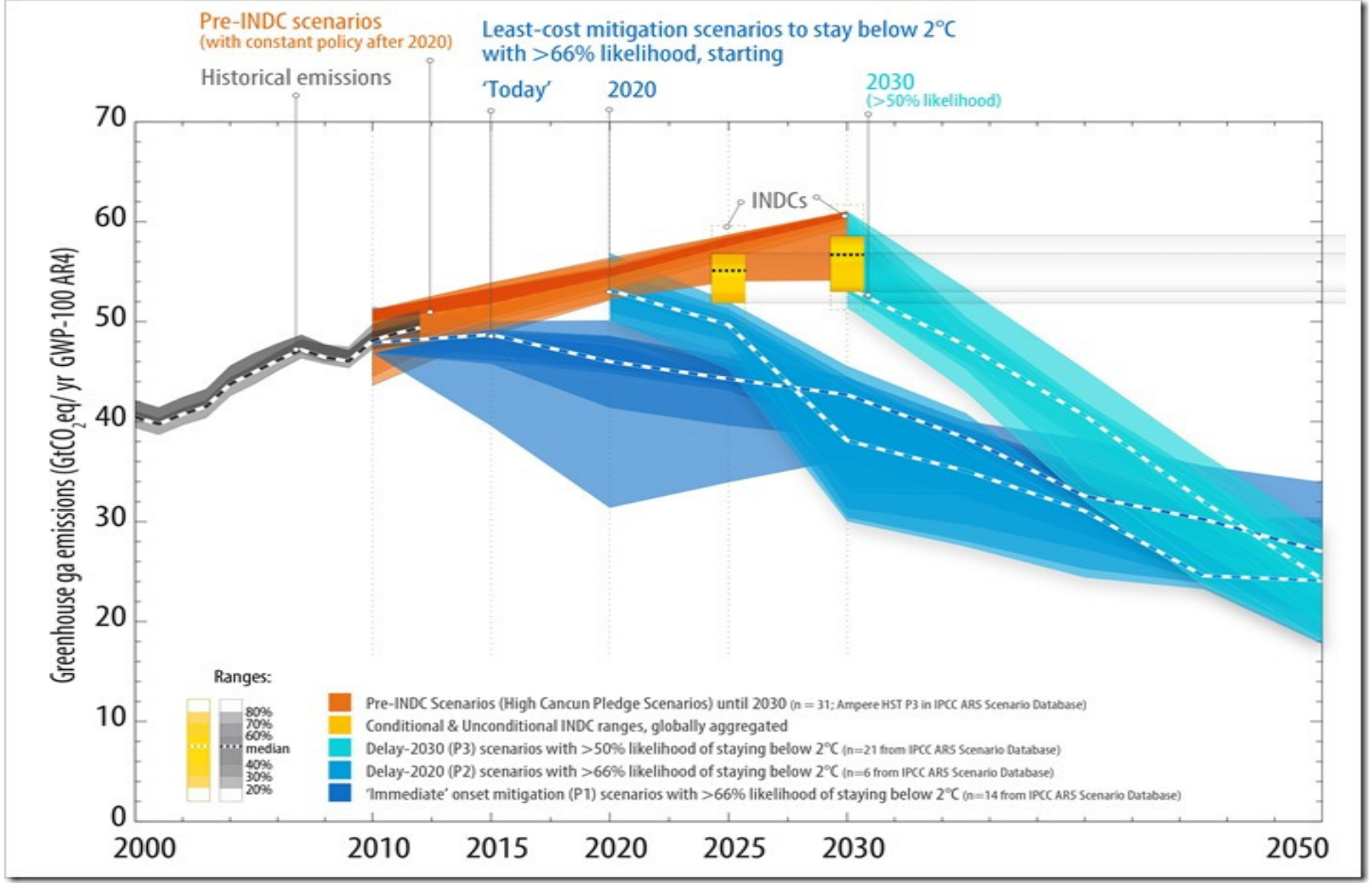
Outline of the session

A. Introductions: Broad overview of energy - environment challenges

B. Leapfrog opportunities

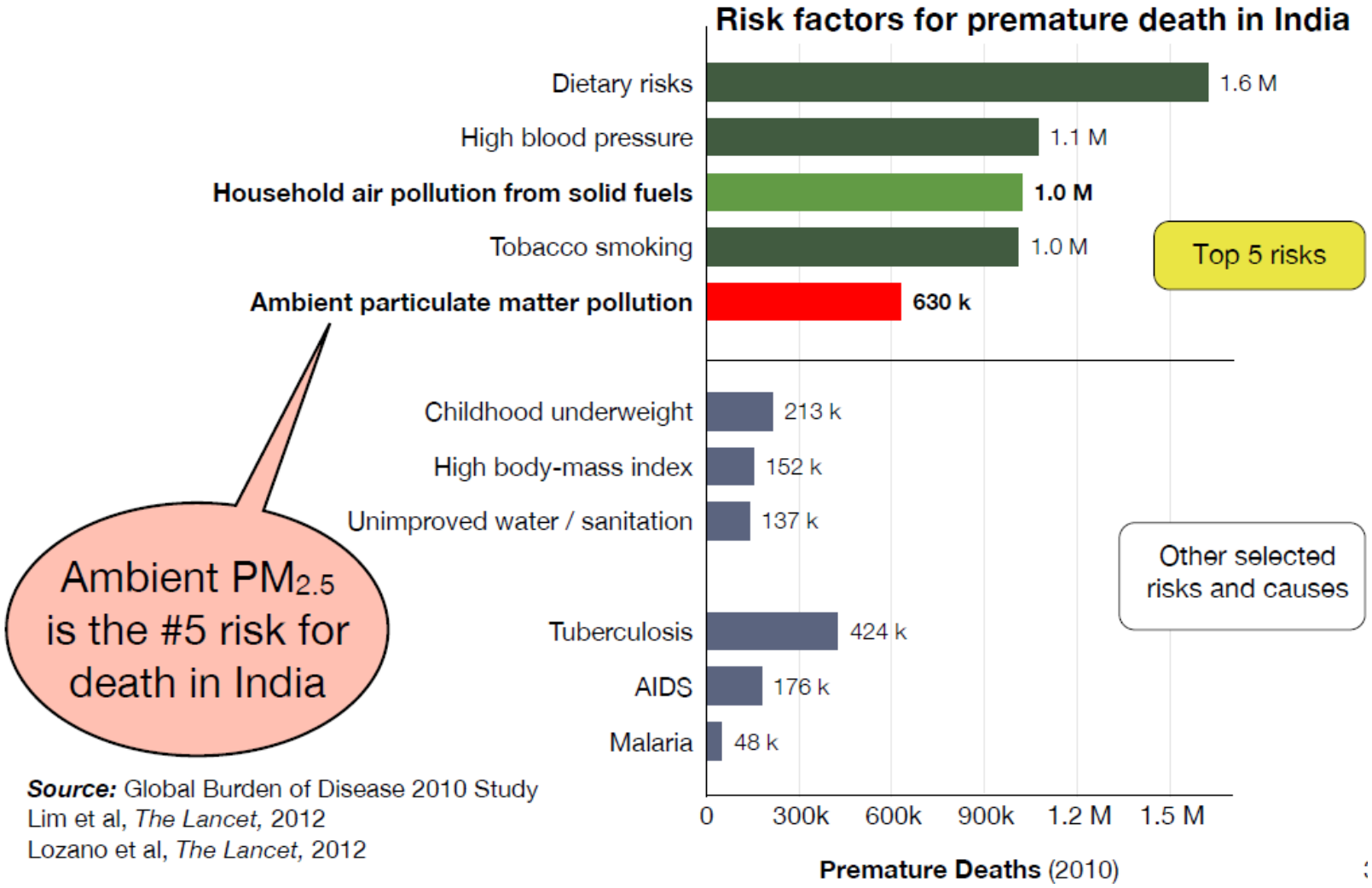
1. Super efficiency and electricity access
2. Electrification of transport
3. Sustainable space cooling
4. Cool roofs
5. Cost effective RE power

- Group discussion and presentations



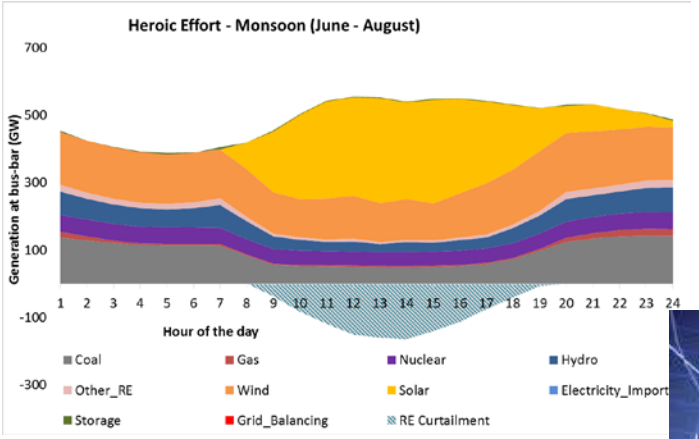
Climate challenge overview

Air pollution challenge in context



Source: Global Burden of Disease 2010 Study
Lim et al, *The Lancet*, 2012
Lozano et al, *The Lancet*, 2012

How a Future Without Coal and Oil can be Achieved – Big picture



RE based Power

Electrified transport

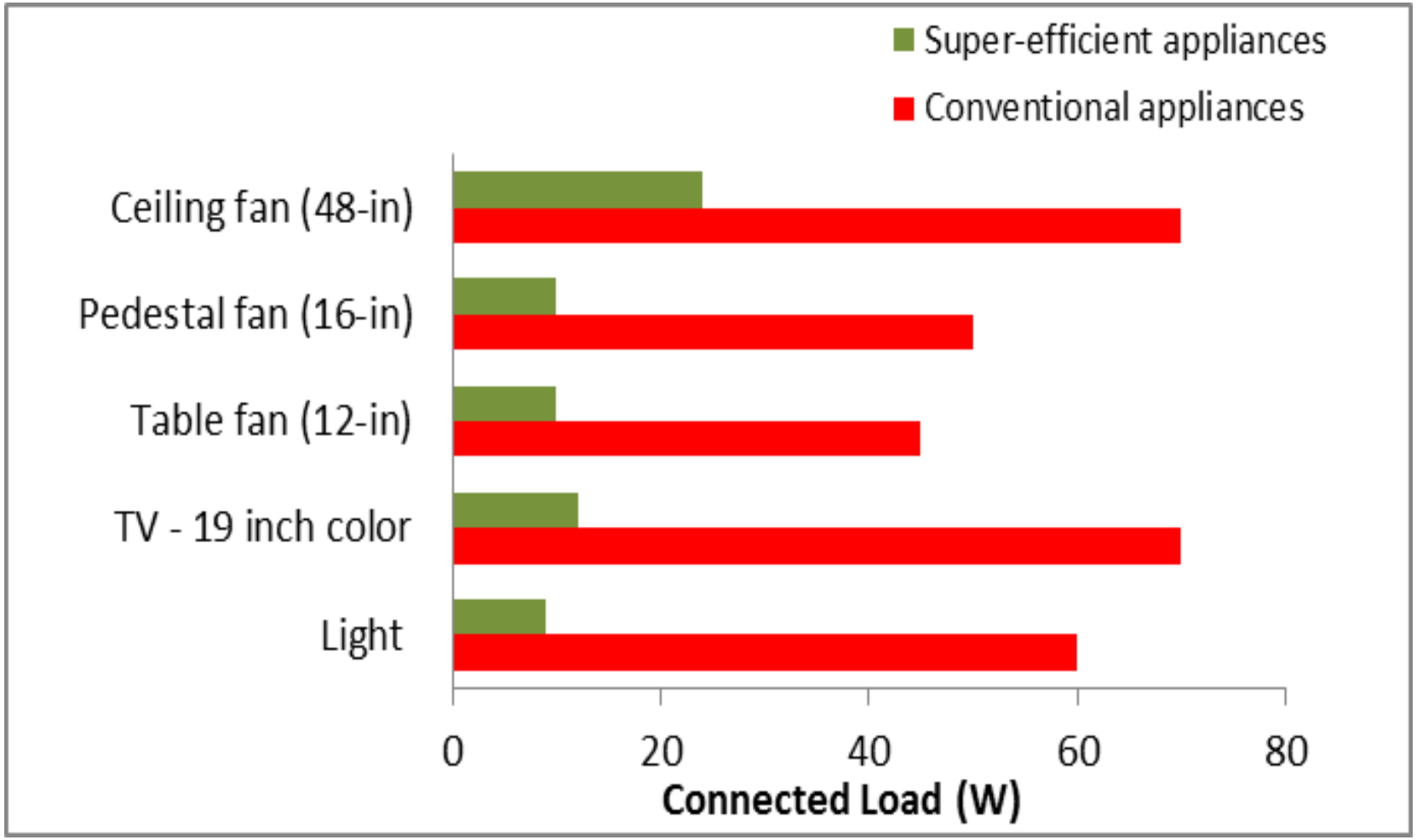
Integrated markets

Smart and innovative storage

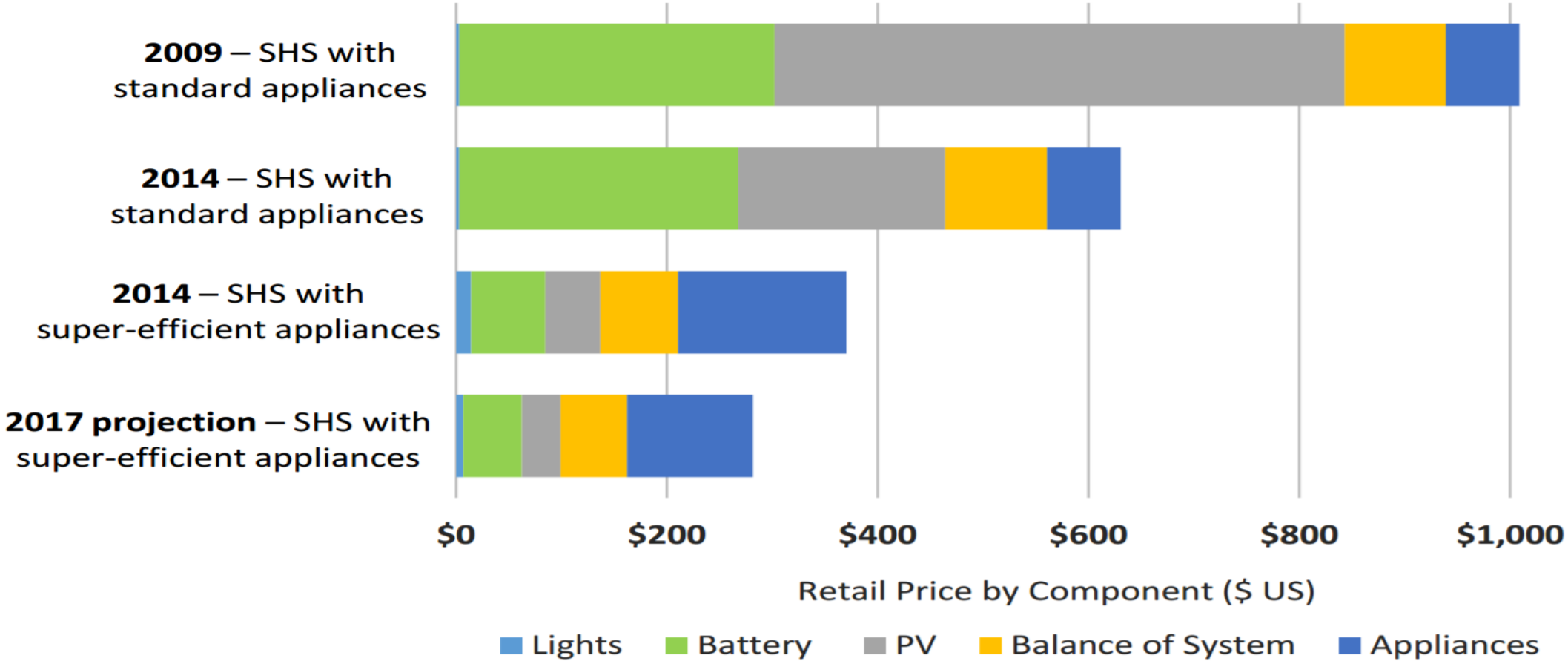
Smart and super efficient demand

1. Super Efficiency to enable electricity access

Super EE can reduce consumption up to 80%



Super-efficient appliances can reduce total cost of providing off-grid

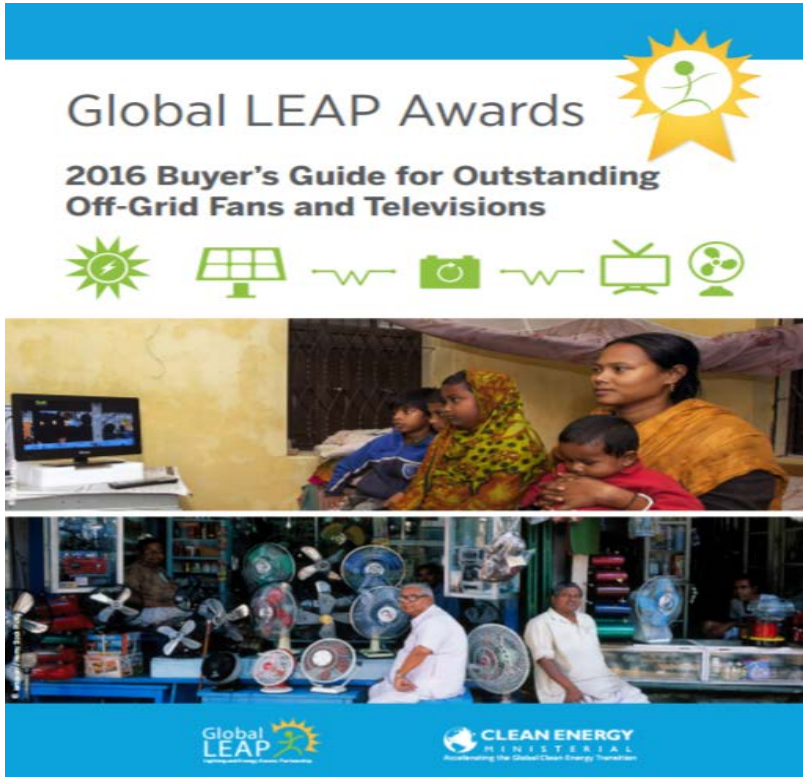


Phadke, A., A. Jacobson, W. Y. Park, G. R. Lee, P. Alstone, and A. Khare, 2015. *Powering a Home with Just 25 Watts of Solar PV: Super-Efficient Appliances Can Enable Expanded Off-Grid Energy Service using Small Solar Power Systems.* Berkeley, CA: Lawrence Berkeley National Laboratory.

Global LEAP Awards

Global LEAP Awards

- Outstanding Off-Grid LED Room Lighting Appliance (2013-14)
- Outstanding Off-Grid Televisions (2013-14 / 2015-16 / 2016-17)
- Outstanding Off-Grid Fans (2015-16 / 2016-17)
- Outstanding Off-Grid Refrigerators (2016-17)



2015-16
LED 23.6"
Rated power input 15 W
Tested power input 10.8 W (in on mode)

2015-16

Eco Air 16"

Rated power input 9 W

Tested power input 9 W (at max speed)

Test air delivery 41 (m^3/min)

2015-16
48" DC Ceiling Fan
Rated power input 35 W
Tested power input 24 W (at max speed)
Test air delivery 147 (m^3/min)

- Daily Energy Use: 125 Wh
- One 40 Wp PV
- One 70 Ah lead-acid battery, 3 days of autonomy (backup)

Home A:
One 25 Watt Light Bulb for 5 hrs/day (125Wh)

Home B:
- 2 LED lights for 5 hrs/day (40Wh)
- 1 LED-LCD TV for 4 hours (50Wh)
- 1 Table Fan for 4 hours (24Wh)
- 1 Radio (5Wh)
- 1 Mobile Phone Charger (5Wh)

The 5th Clean Energy Ministerial
Seoul, May 12-13, 2014

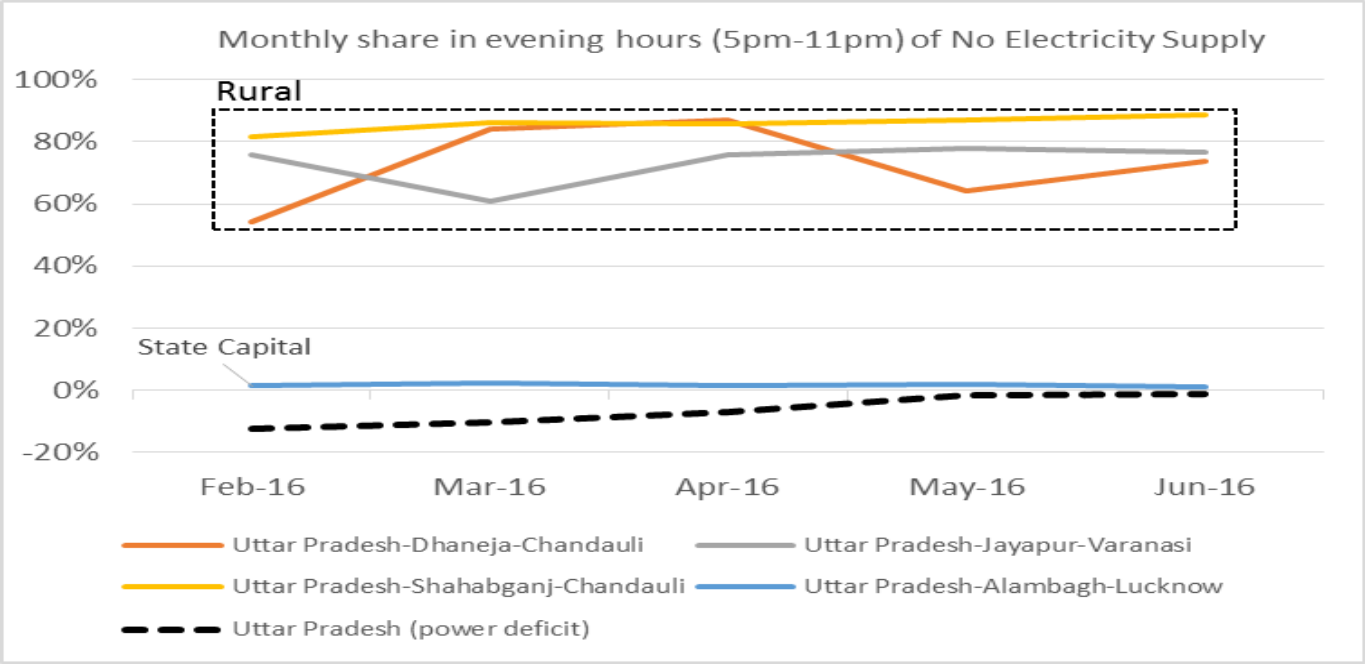
Super-Efficient Appliances Can Enhance Utility Finances Significantly

- Rural residential tariffs are highly subsidized

- With ambitious electrification program, such subsidy burden may increase significantly and worsen utilities' financial condition

- For example, Uttar Pradesh
  - Average Cost of Supply = Rs 6.4/kWh
  - Average Rural BPL Tariff = Rs 1.7/kWh
  - Avg Subsidy Requirement = Rs 4.7/kWh
  - Total State Subsidy to Utilities in 2015 = Rs 9,803 Cr/yr (~37% of revenue; mostly for residential consumption)
  - Unelectrified Rural households = 15 million
  - Additional Subsidy Requirement = Rs. 8,751 Cr/yr

SE system with battery back up can increase willingness to pay



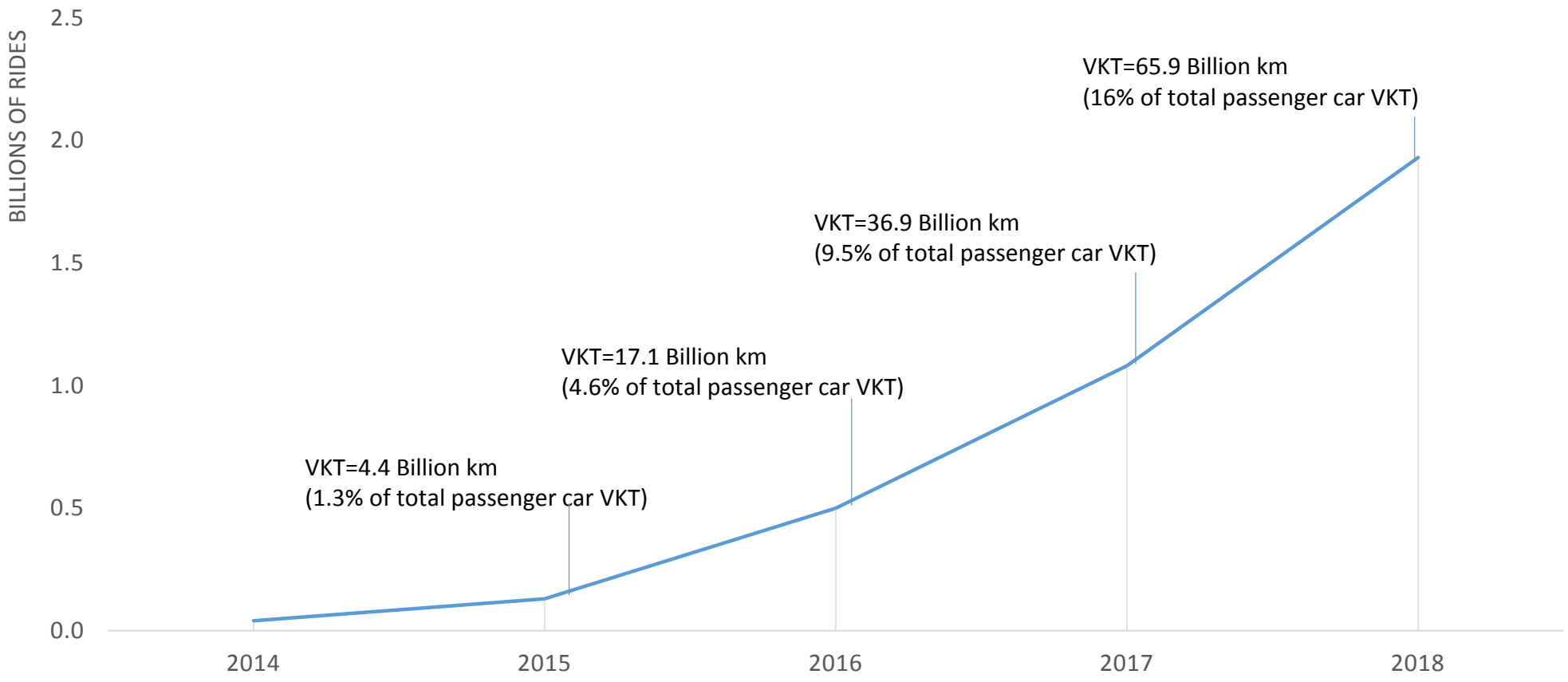
- Due to subsidized rural tariffs and range of governance challenges, utilities have little incentive to supply reliable power
- Poor quality of supply leads to low willingness to pay
- SE system with battery back-up can enhance reliability without 24/7 grid supply, which may lead to higher willingness to pay

2. Electrification of Transport - EV Opportunities

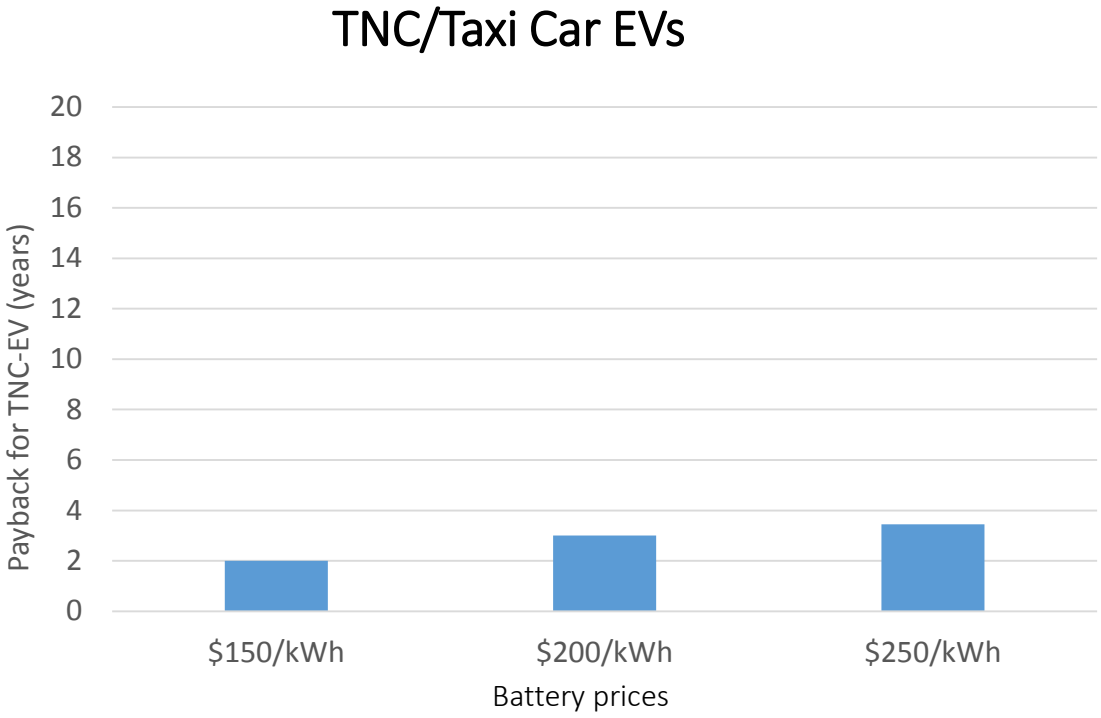
EV Battery Pack Prices dropping faster than expected

- ***"The battery cell cost in our 2016 Bolt is an industry-leading $145/kWh"***
  - ***General Motors CEO, implies pack cost of $175/kWh***
- ***"The cost of the battery in a Model S is less than a quarter of the cost of the car"***
  - ***JB Straubel, Tesla CTO in 2013***
  - ***This implies a cost of $238/kWh in 2013***
- ***"Our battery cost is below $190/kWh"***
  - ***Jeff Evanson, Tesla VP of Investor Relations, early 2016***
- ***"We have achieved 35% battery pack cost reduction in Gigafactory 1 for the Model 3"***
  - ***Elon Musk, 2017; this implies cost below $125/kWh***

TNC (Uber, Ola etc) ridership is growing rapidly in India, China, US, others ??

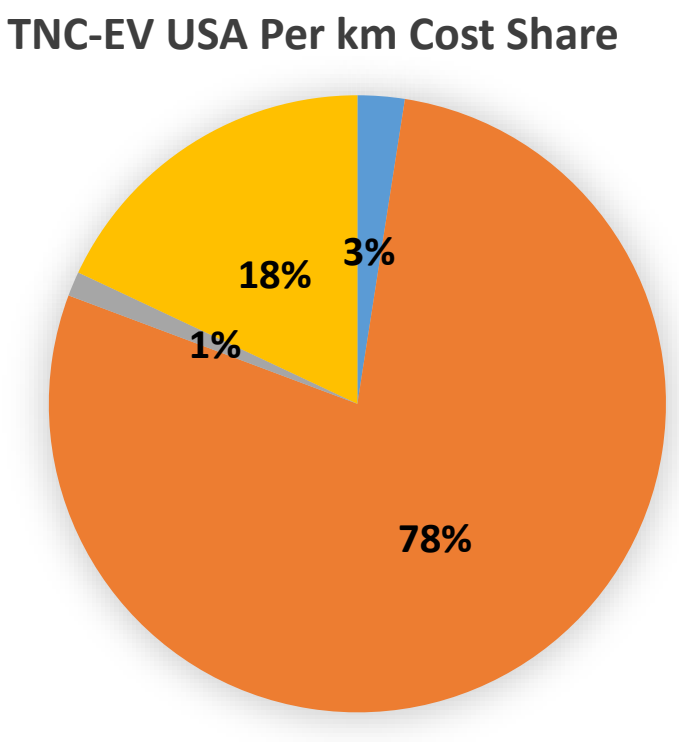


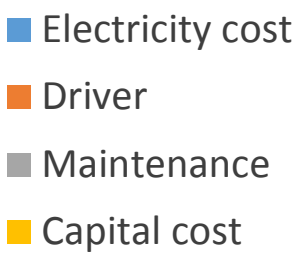
TNC/Taxi EVs make a compelling business case

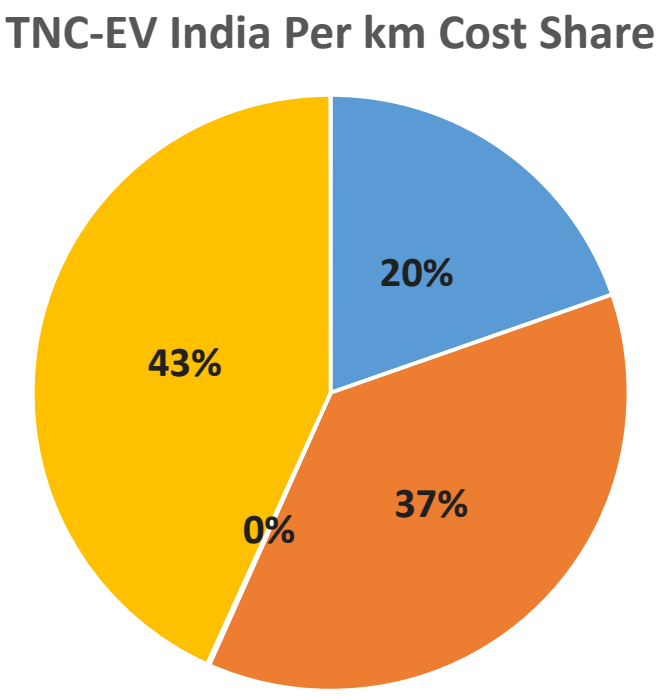


Simple payback period for TNC/Taxi EVs is ~2-3 years even under conservative battery price assumptions

Electrification should precede automation in India

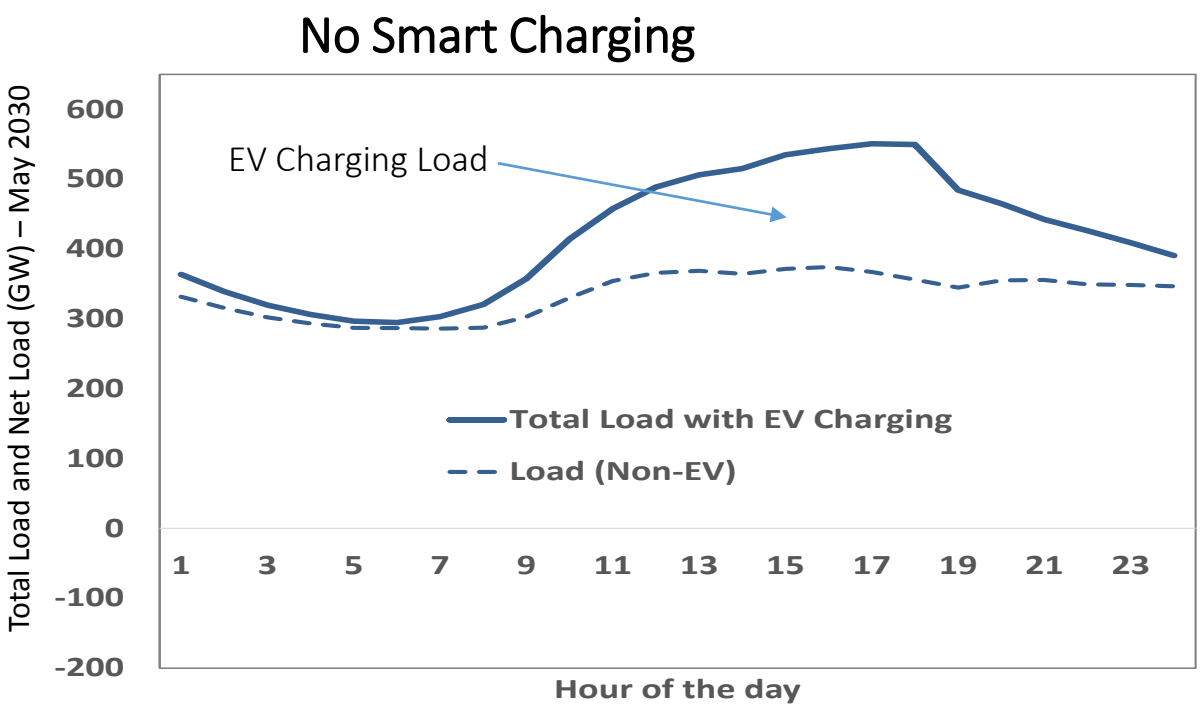


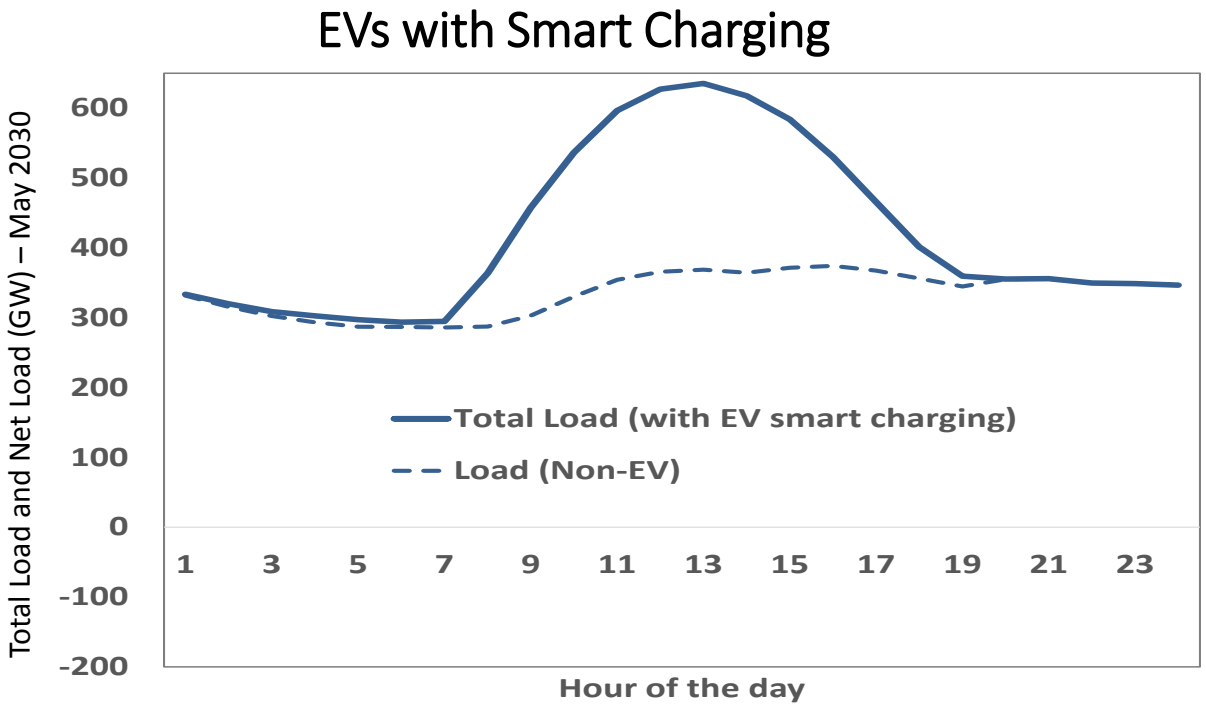




With smart charging and fast DC chargers, most of the EV charging demand can be shifted during the day in order to avoid RE curtailment

Total Load with EV Charging (May 2030)

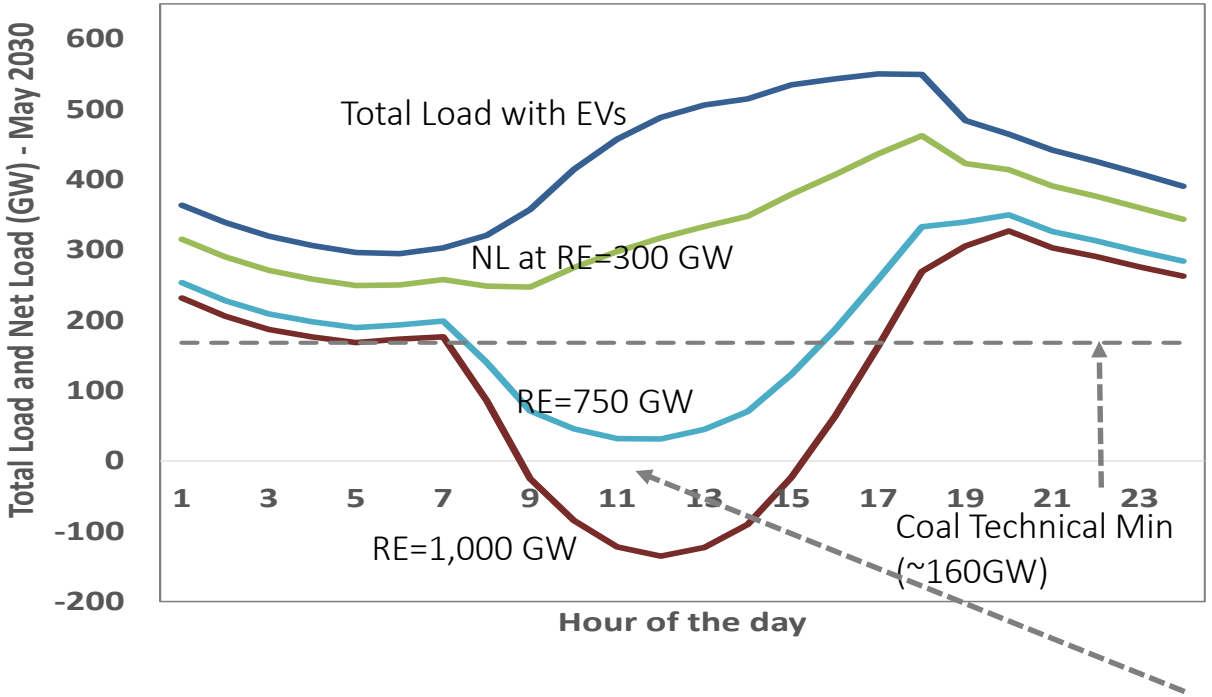




EVs Can Enable Cost-effective RE Grid Integration

Duck Curves (Net Load) in India (May 2030)

With EVs – No Smart Charging

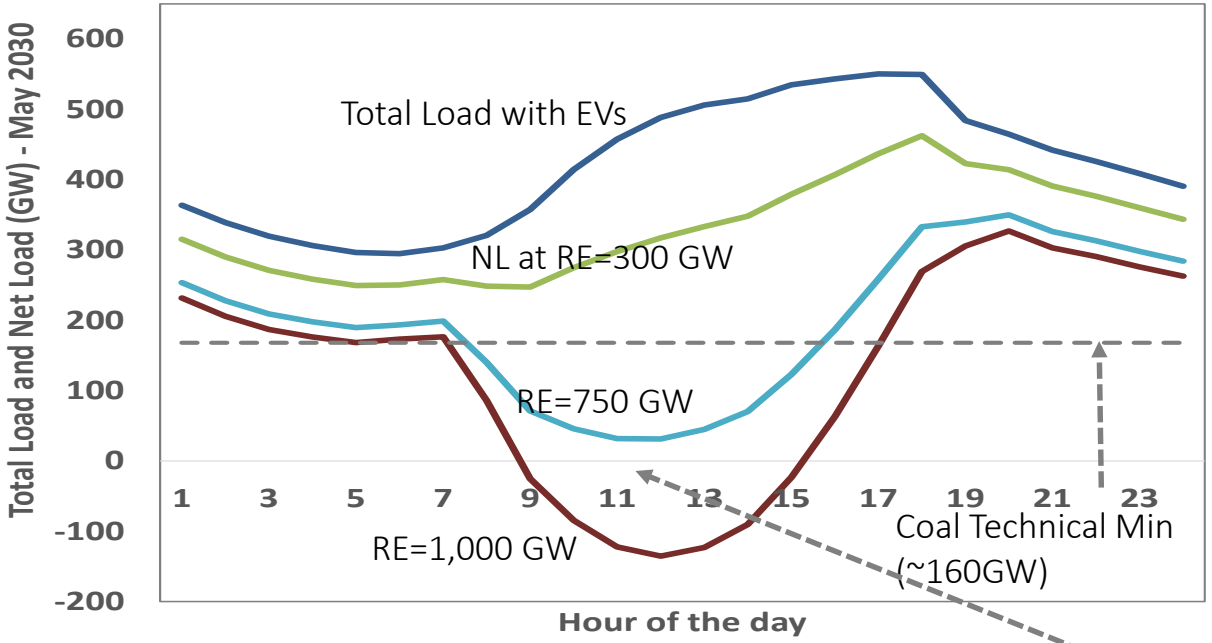


Area under the minimum generation line indicated curtailment (or need for additional DR)

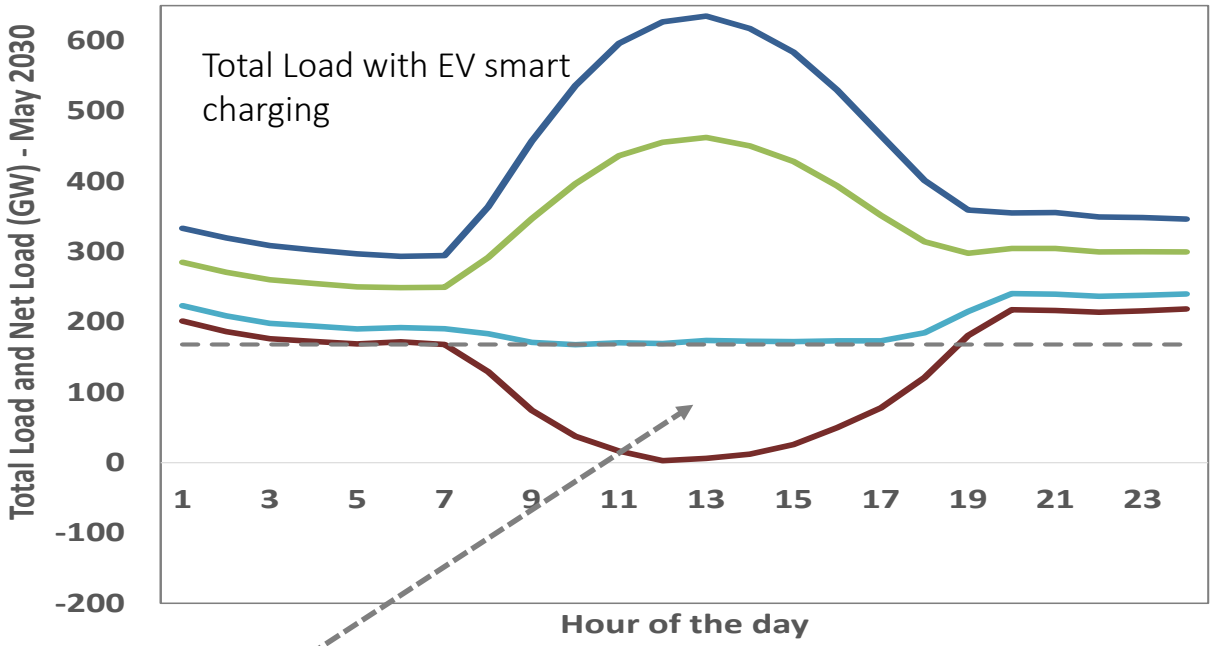
EVs Can Enable Cost-effective RE Grid Integration

Duck Curves (Net Load) in India (May 2030)

With EVs – No Smart Charging

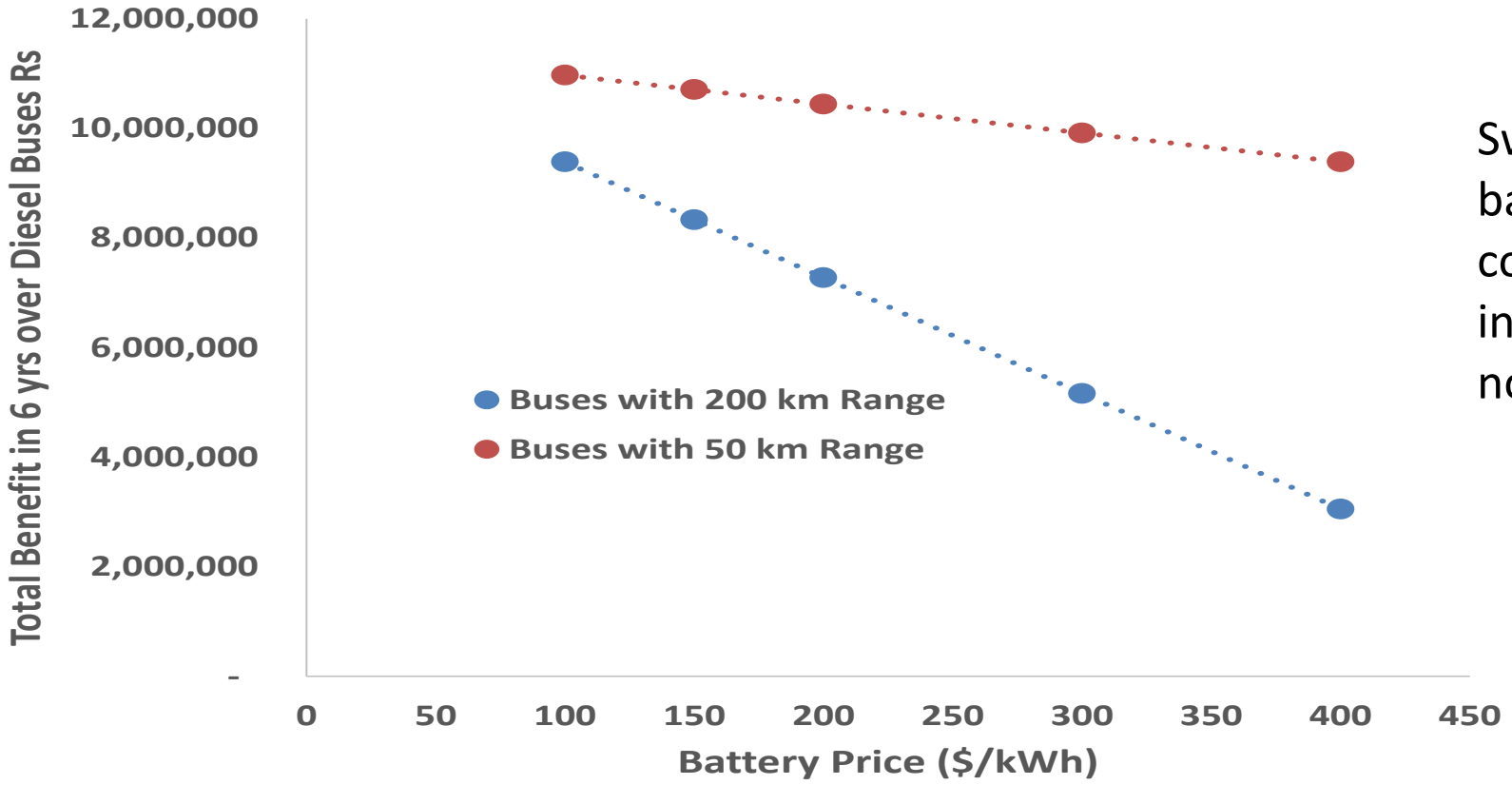


EVs with Smart Charging



Area under the minimum generation line indicated curtailment (or need for additional DR)

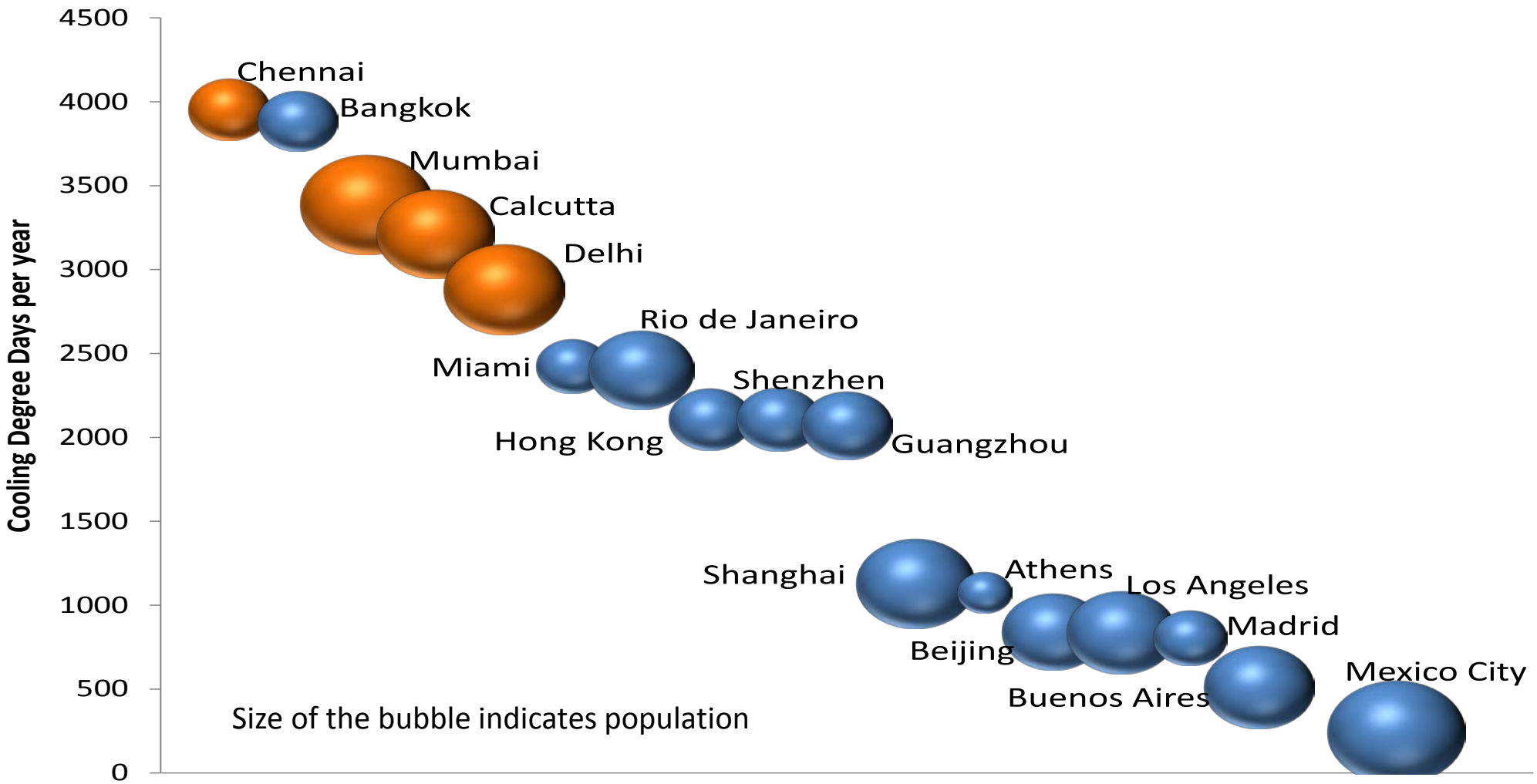
Longer range buses are becoming very competitive



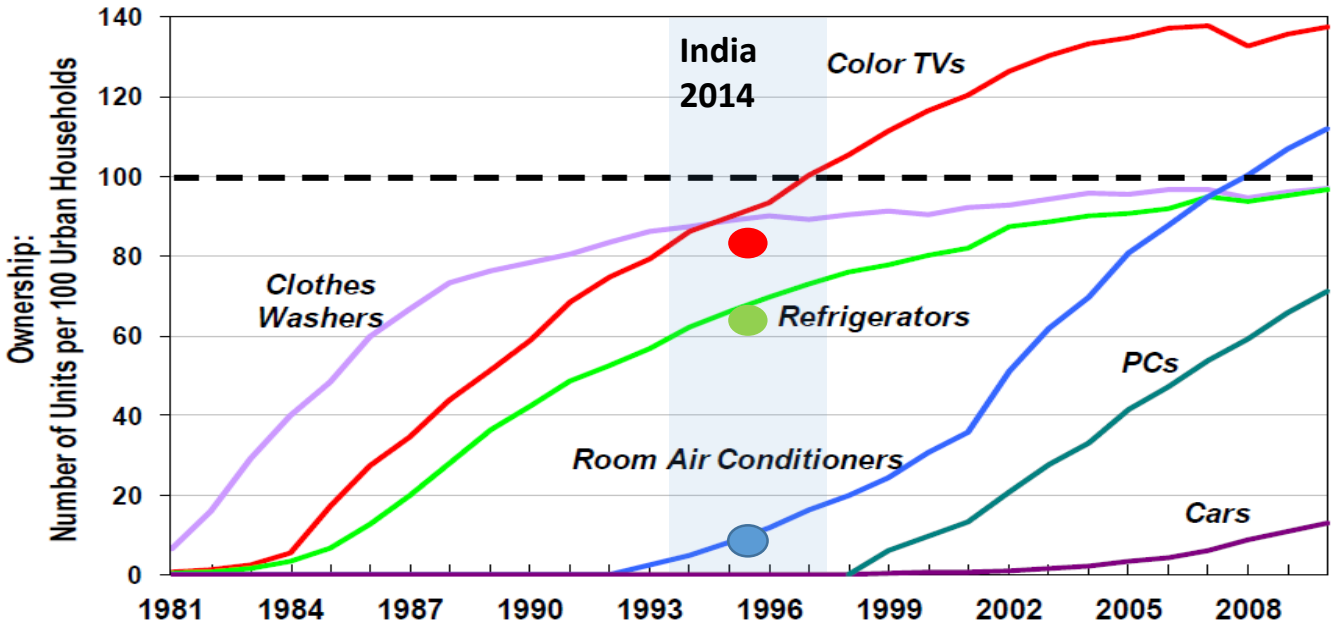
Swapping stations for heavy batteries require high capital cost (> Rs. 60 lakh without including batteries). That cost is not accounted for here.

Room ACs Can Add ~140GW to Peak Load by 2030: Potential for Energy Saving and Demand Response

Compared to other regions, climate in India has higher cooling requirements



Room AC demand: Huge Increase Expected by 2030-2040



Appliance Penetration in Urban China

Rising incomes made the AC sales in urban China jump rapidly

Source: Zhou et al (2012)

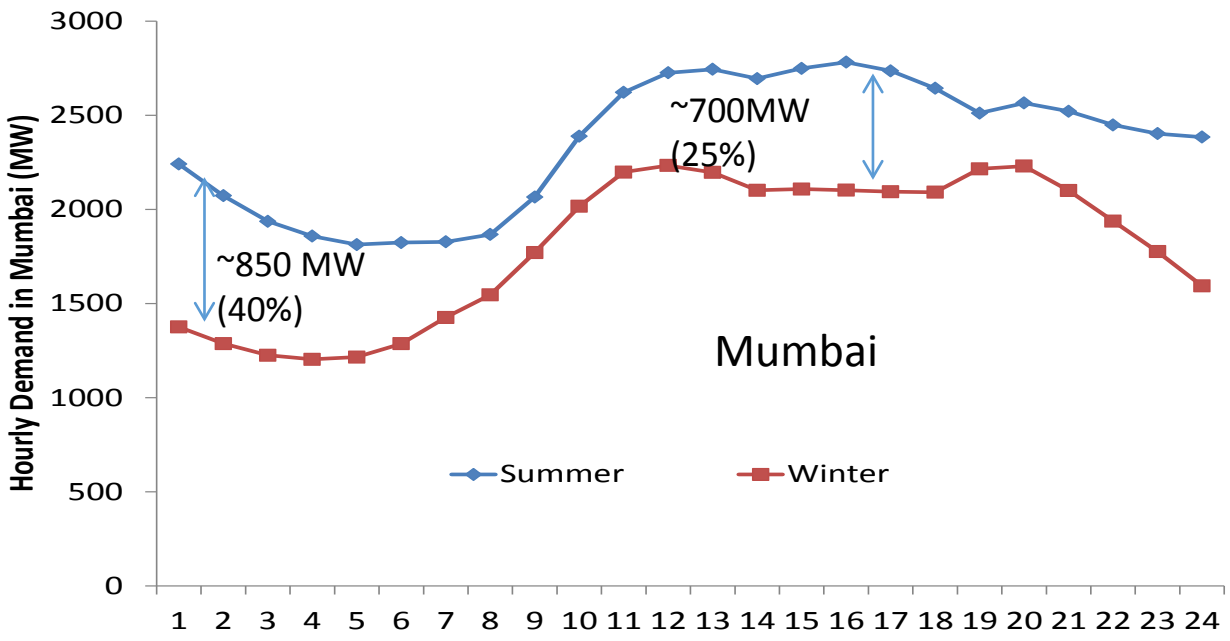
Although current penetration in India is low, room AC sales are growing at 15-20% p.a. for the last several years

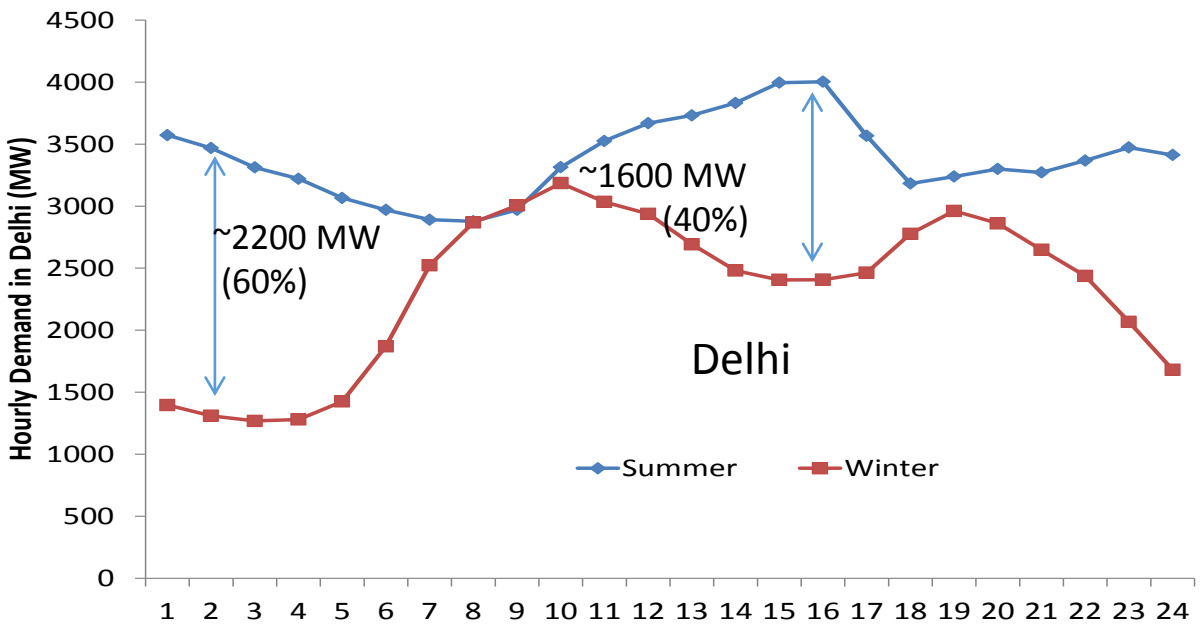
Room AC prices have fallen by 60% in the last decade

Current Room AC penetration is ~ 5%; could increase to more than 70% in the next 20 to 30 years

Space cooling contributes significantly to the peak demand in Indian cities

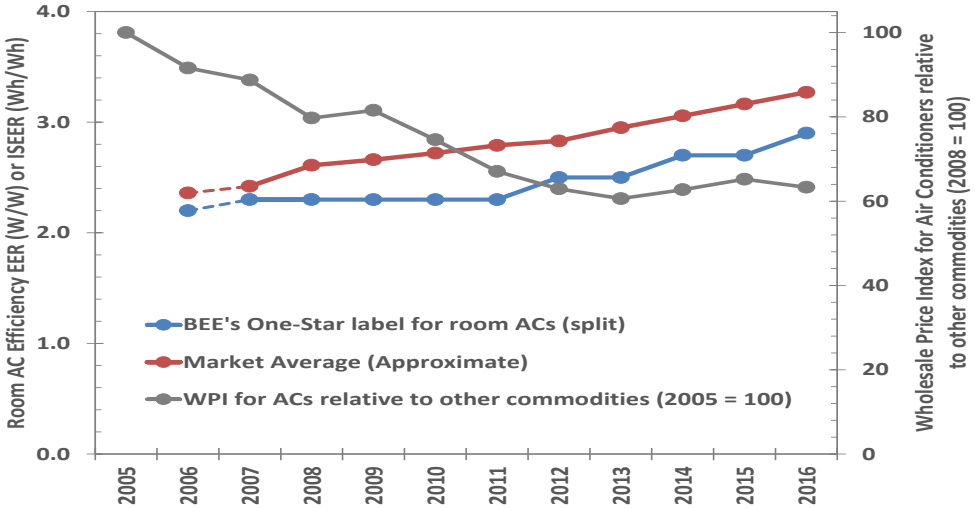
Load Curves on a Summer and Winter Day (Average) in Mumbai and Delhi





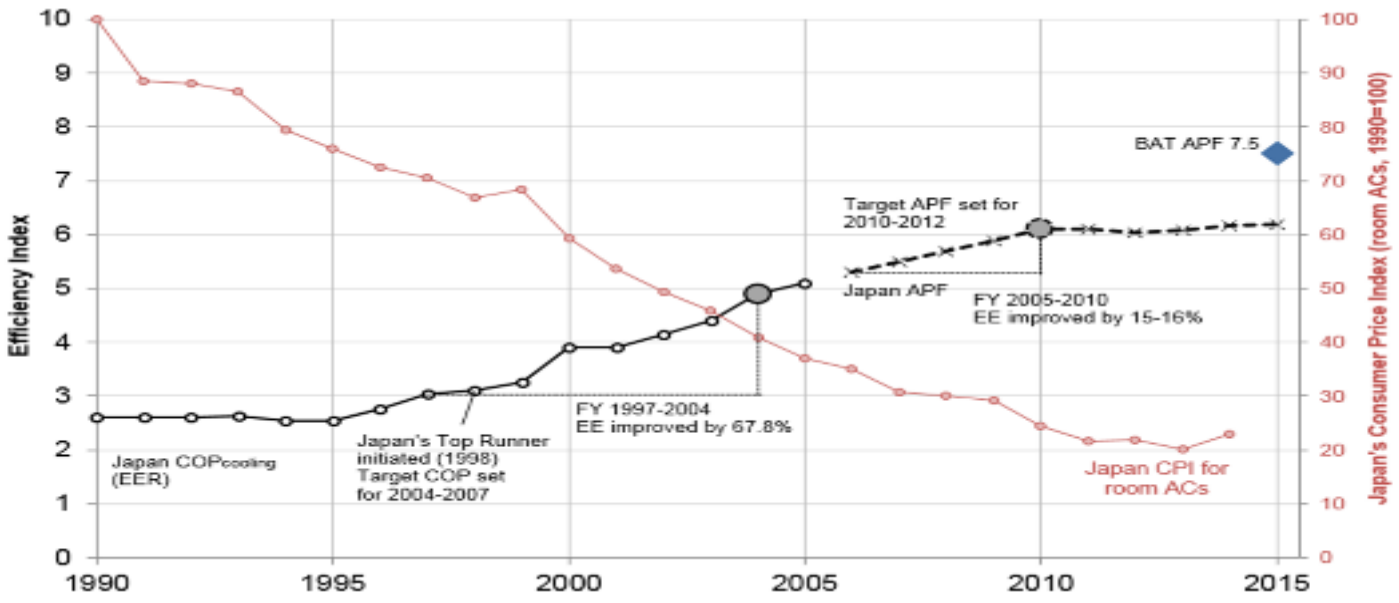
Room AC Efficiency and Policies in India

- Bureau of Energy Efficiency's (BEE) labeling program has a 5-star rating system
  - For appliances with mandatory labeling, 1-star serves as the Minimum Energy Performance Standard (MEPS)
  - Currently, labels are mandatory for fixed speed room ACs and voluntary for variable speed room ACs
  - Starting 2018, fixed and variable speed categories would be merged with mandatory labels for all room ACs



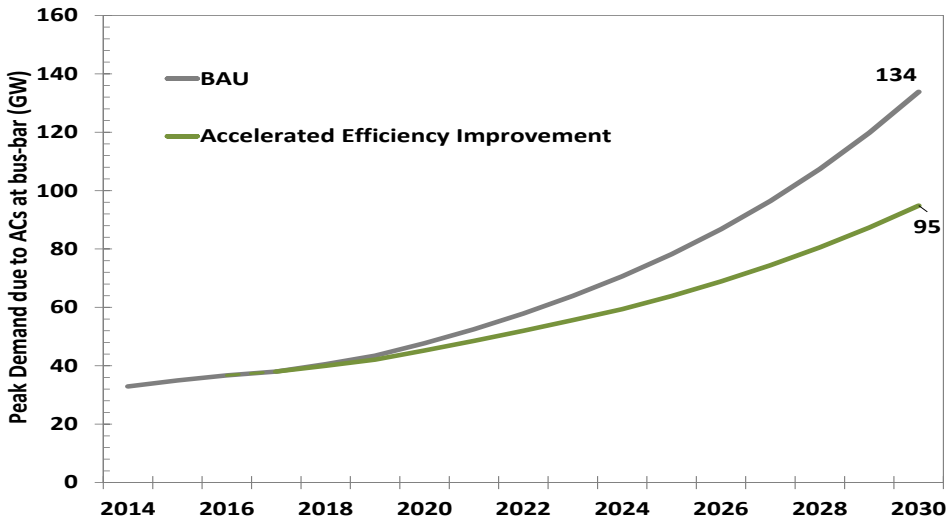
- Room AC Efficiency has been improving while costs continue to decline
  - Room AC star labels have been ratcheted up by one star equivalent every two years
  - Between 2006 and 2016, room AC MEPS has increased by 35% (~3% per year)
  - Market average efficiency, slightly higher than MEPS, has improved similarly
  - In the same period, inflation adjusted room AC prices (Wholesale Price Index) relative to the basket of all commodities, have fallen by over 35%

Accelerated Efficiency Improvement Driven by Policy: Japan's Top Runner Program

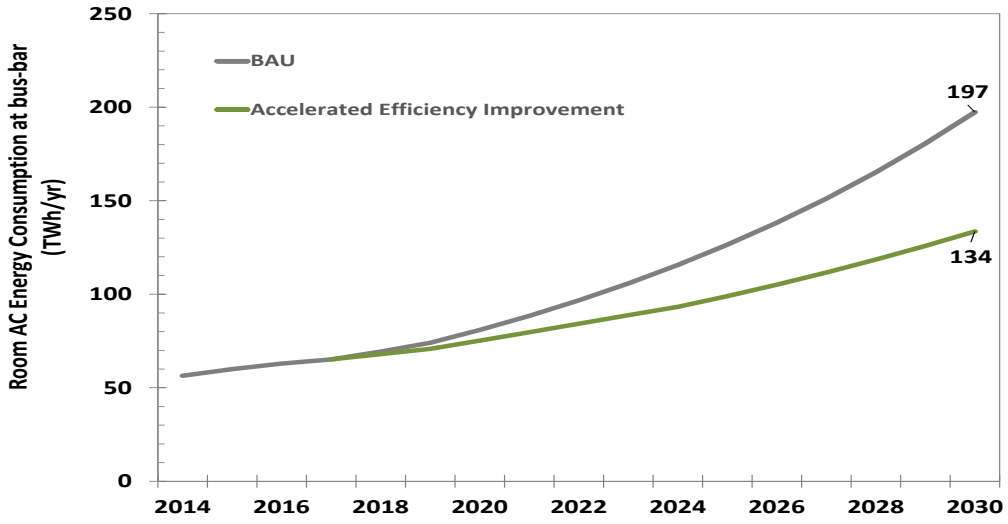


- Japan's Top Runner Program (1997) mandated a sales weighted average fleet COP of 5.3 (W/W) for small room ACs and 4.9 (W/W) for larger room ACs by 2004
  - This was ~60% more efficient than the market average efficiency in 1997
  - The target was determined by the COP of the most efficient AC model in the market
- Between 1995 and 2005, room AC efficiency in Japan improved by ~100% (from COP of 2.55 to 5.10 improving at a rate of 7.2% per year)
  - In the same period, inflation adjusted prices declined by over 80%
- Post-2009, consumer financial incentives (Eco-Point System) helped uptake of efficient ACs

Room AC Peak Load Can Be Reduced by 40GW Cost-Effectively



- In the BAU trajectory, by 2030, peak load due to room ACs would be about 134 GW at bus-bar
- **With accelerated efficiency improvement, peak load could be reduced by over 40GW**
  - This is equivalent to avoiding 80 large power plant units of 500MW each



- By 2030, under the accelerated efficiency improvement scenario, room AC consumption could be reduced by nearly 64 TWh/yr at bus-bar without compromising any cooling service
  - This is equivalent to the total energy generation from nearly 40 GW of solar PV capacity

Cool Roofs (or White roofs) can lower the buildings cooling energy consumption by ~20%

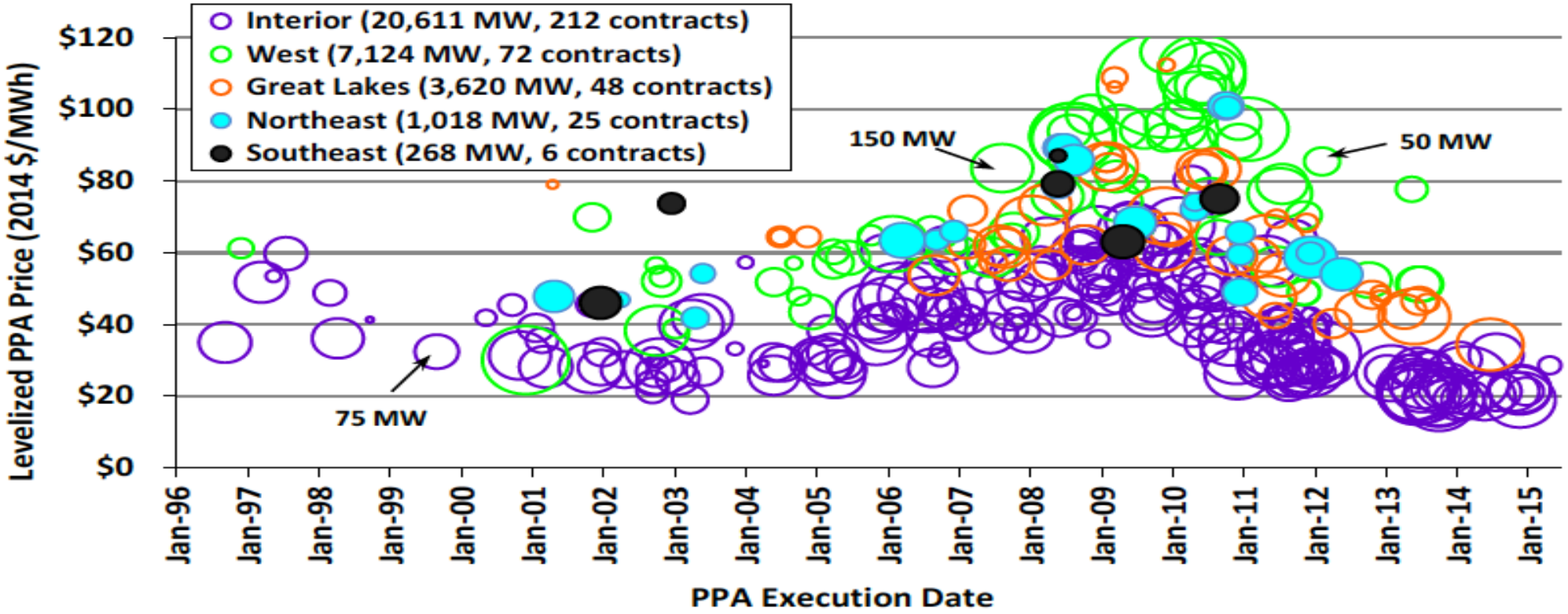
How rooftops of the two cities differ ?

Delhi

Jaisalmer

Cost effective RE – status and strategies

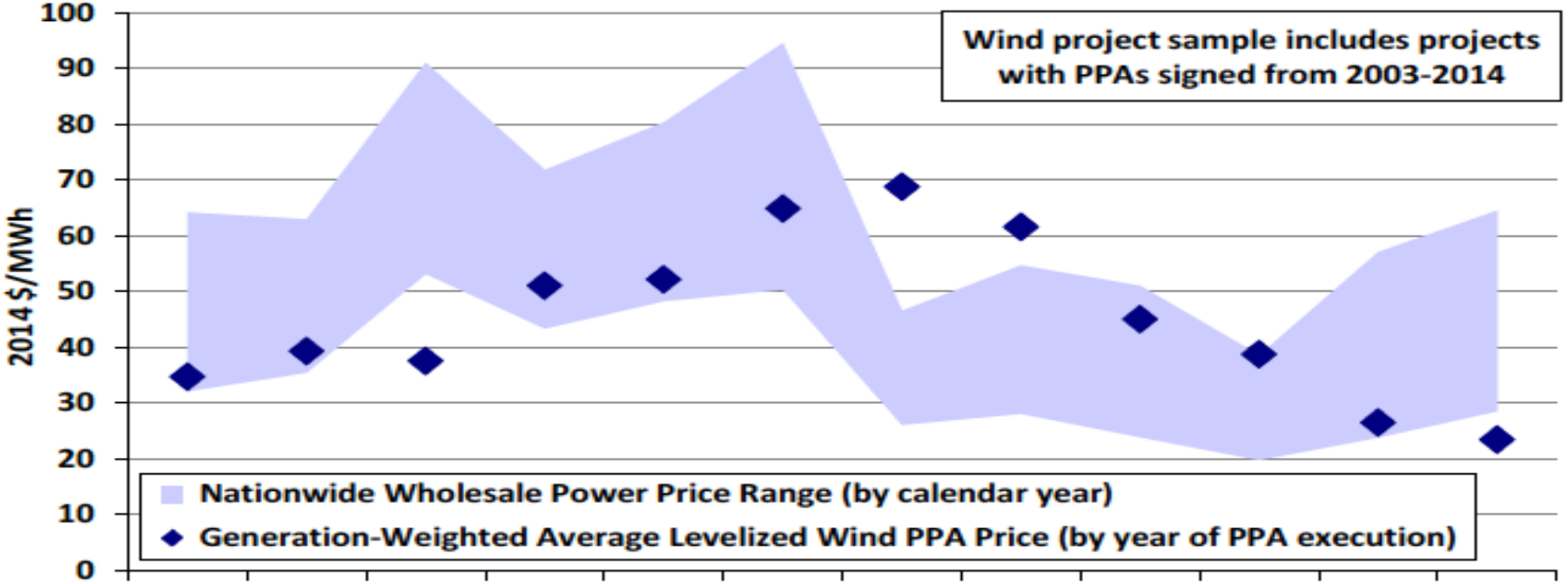
Wind PPA Prices Have Reached All-Time Lows, Dominated by Interior Region



All wind procured through competitive bidding – some utilities implement technology neutral competitive bidding where solar and wind compete

Source: Wiser & Bolinger, 2015 – LBNL

Relative Competitiveness of Wind Power Improved in 2014: Comparison to Wholesale Electricity Prices

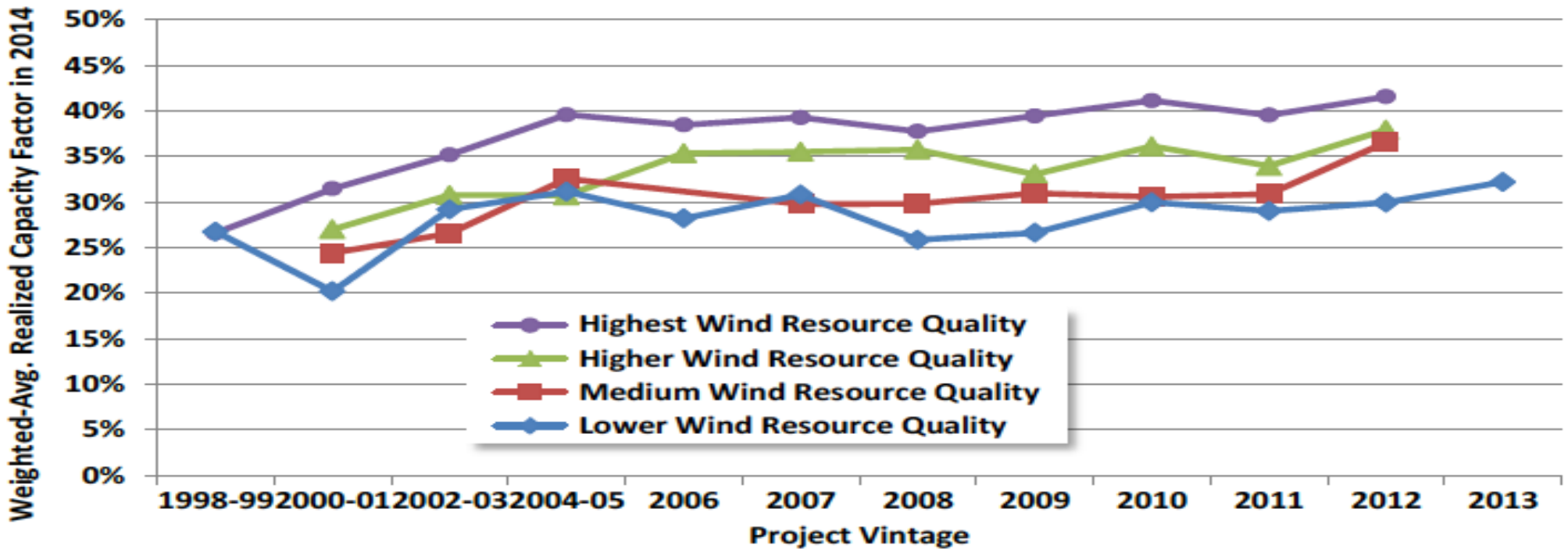


PPA year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Contracts:	9	13	17	30	26	39	49	48	42	14	26	13
MW:	570	547	1,643	2,311	1,781	3,465	4,048	4,642	4,572	985	3,674	1,768

- Wholesale price range reflects flat block of power across 23 pricing nodes across the U.S.

Source: Wiser & Bolinger, 2015 – LBNL

Controlling for Wind Resource Quality and Commercial Operation Date Demonstrates Impact of Turbine Evolution



Notwithstanding build-out of lower-quality wind resource sites, turbine design changes are driving capacity factors higher for projects located in given wind resource regimes

Source: Wiser & Bolinger, 2015 – LBNL

All time low solar PPA prices

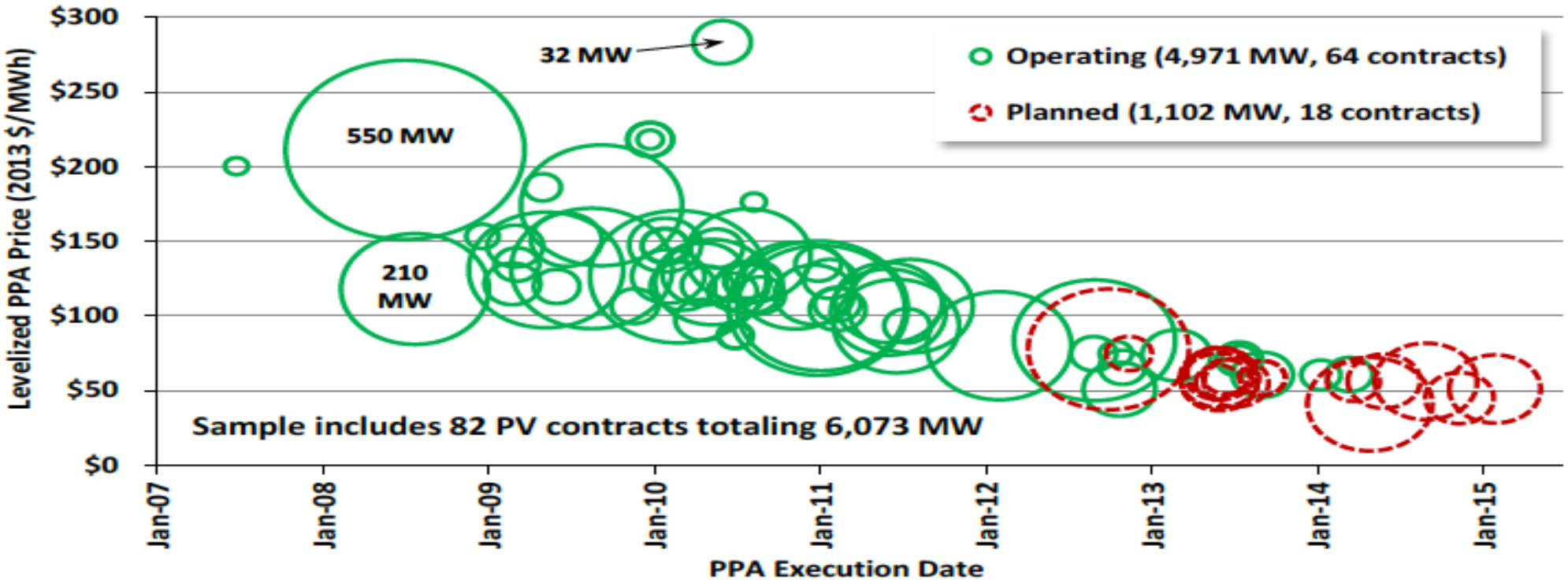


Figure 1. Levelized U.S. Utility-Scale PV PPA Prices by Operational Status and PPA Execution Date

Project Name	State	Project Capacity (MW_{AC})	Levelized PPA Price (2013 $/MWh)	PPA Execution Date & Term	Year Online	State Financial Incentives
Austin Energy/ Recurrent	TX	150	$41.0/MWh	5/2014 20 years	2016	None
Sandstone	AZ	45	$44.8/MWh	11/2014 21 years	2015	10-year PTC
Macho Springs	NM	50	$50.9/MWh	10/2012 20 years	2014	10-year PTC
River Bend	AL	80	$51.0/MWh	2/2015 20 years	2016	None

Bolinger and Weaver, 2015 - LBNL

Questions – feedback ??

For follow up

Amol Phadke – aaphadke@lbl.gov