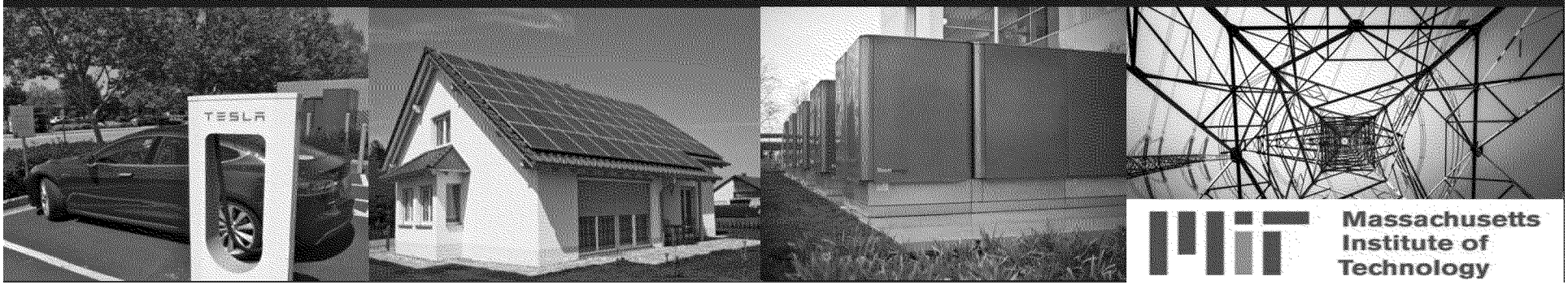
POWER SYSTEM PLANNING WITH DISTRIBUTED ENERGY RESOURCES

NEW TRADEOFFS, METHODS AND INSIGHTS

Jesse D. Jenkins

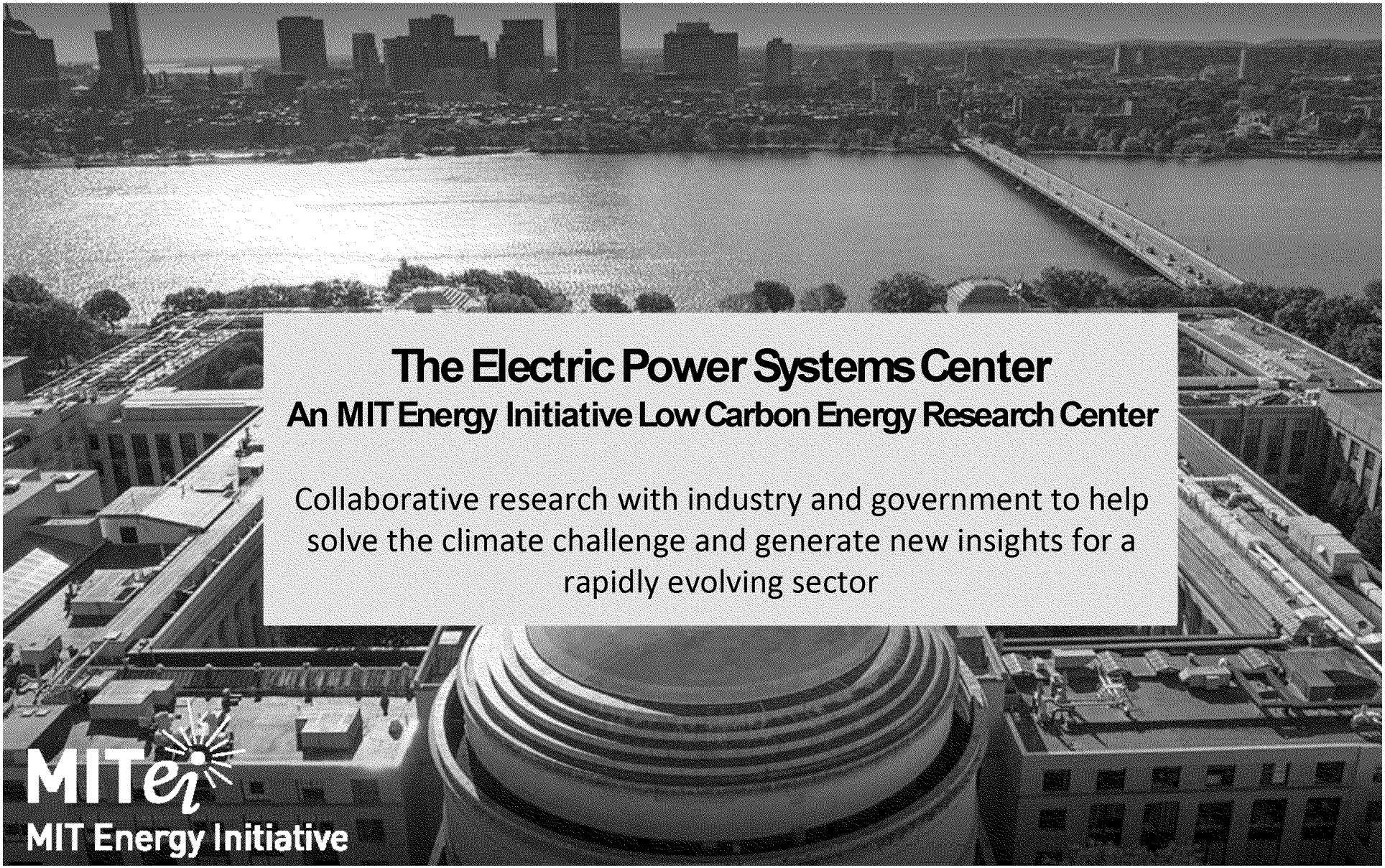
EPRI 36th Seminar on Fuels, Power Markets, and Resource Planning

November 8th, 2017 — Washington, DC



Massachusetts Institute of Technology

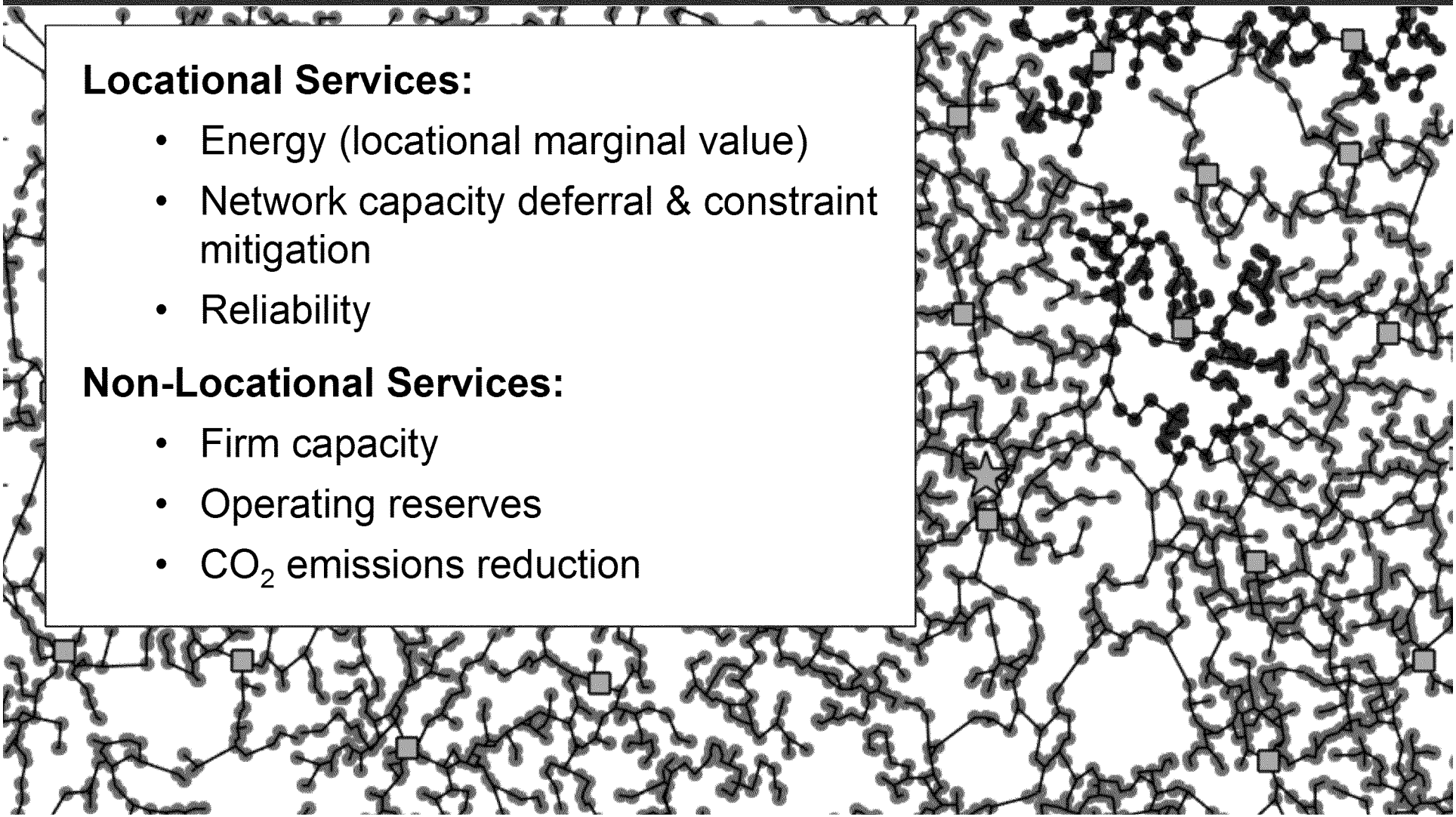

MITei
MIT Energy Initiative
UTILITY OF THE FUTURE
An MIT Energy Initiative response to an industry in transition
In collaboration with IIT-Comillas
Full report available at:
http://energy.mit.edu/uof


The Electric Power Systems Center
An MIT Energy Initiative Low Carbon Energy Research Center
Collaborative research with industry and government to help solve the climate challenge and generate new insights for a rapidly evolving sector
MITei
MIT Energy Initiative

Part 1:

NEW TRADEOFFS AND CHALLENGES FOR POWER SYSTEM PLANNING

LOCATION, LOCATION, LOCATION!



Locational Services:

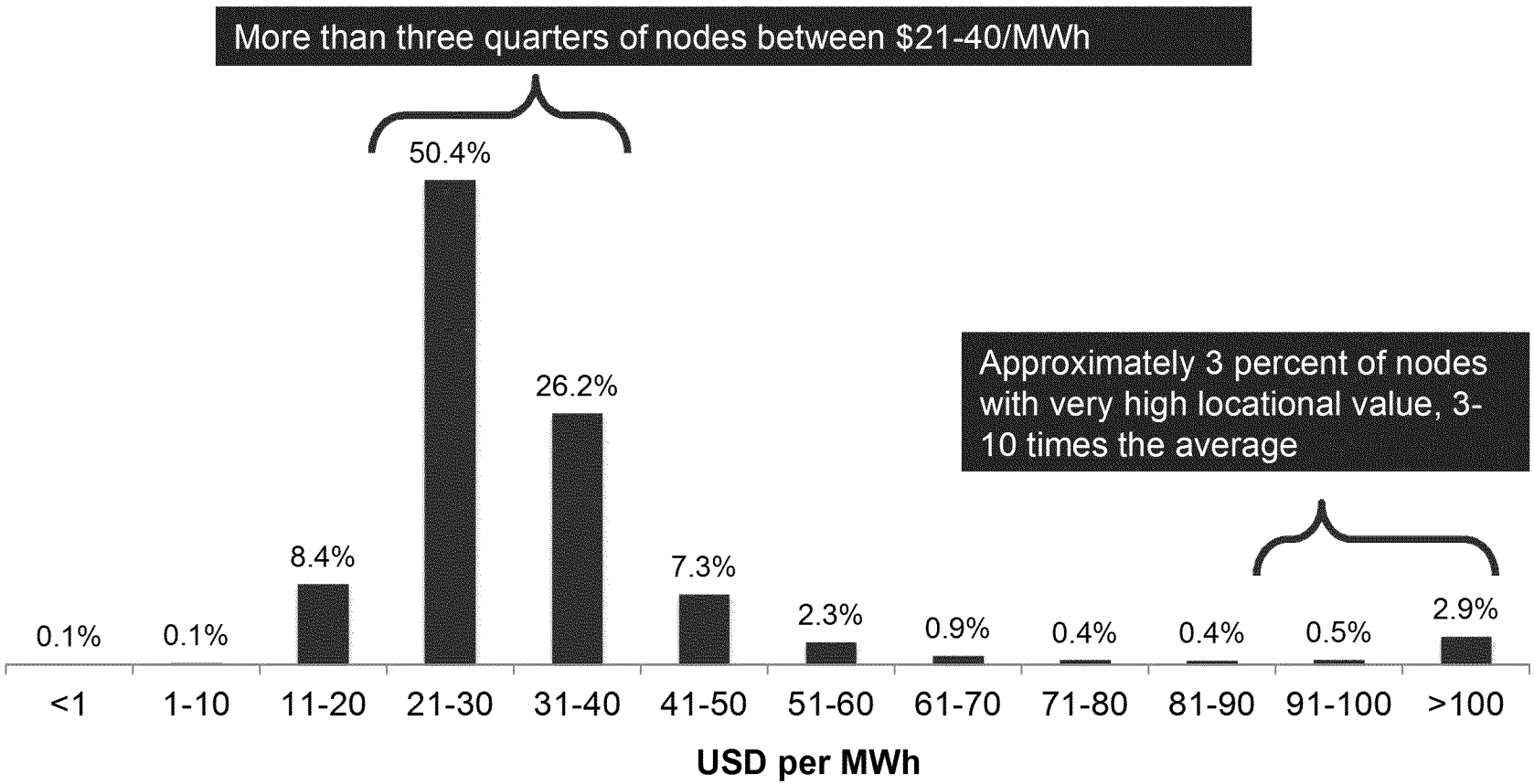
- Energy (locational marginal value)
- Network capacity deferral & constraint mitigation
- Reliability

Non-Locational Services:

- Firm capacity
- Operating reserves
- CO_2 emissions reduction

1. LOCATIONAL VALUE VARIES DRAMATICALLY

Distribution of 2015 annual average nodal LMPs in PJM

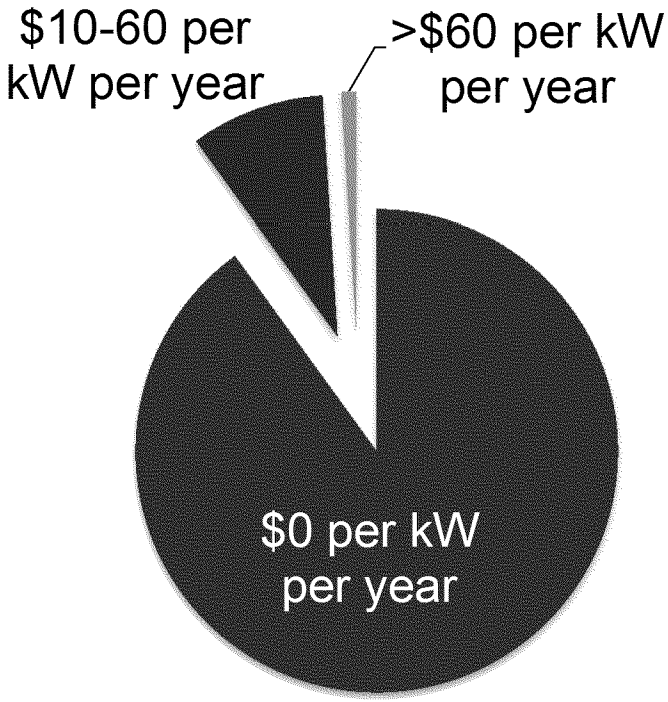


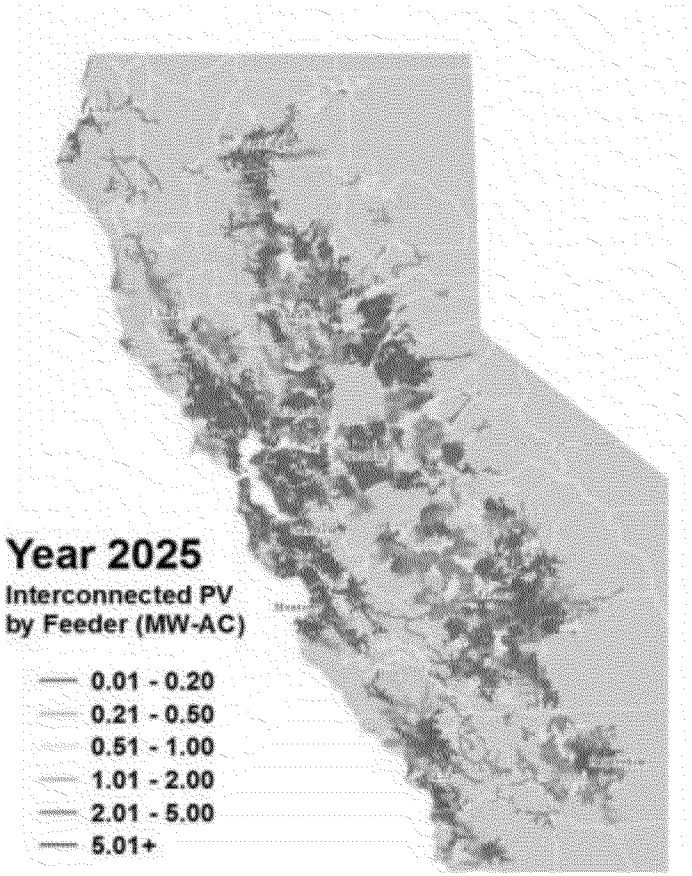
See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

1. LOCATIONAL VALUE VARIES DRAMATICALLY

Network capacity benefits of distributed solar PV in California

(Cohen, Kauzmann & Callaway, 2016)

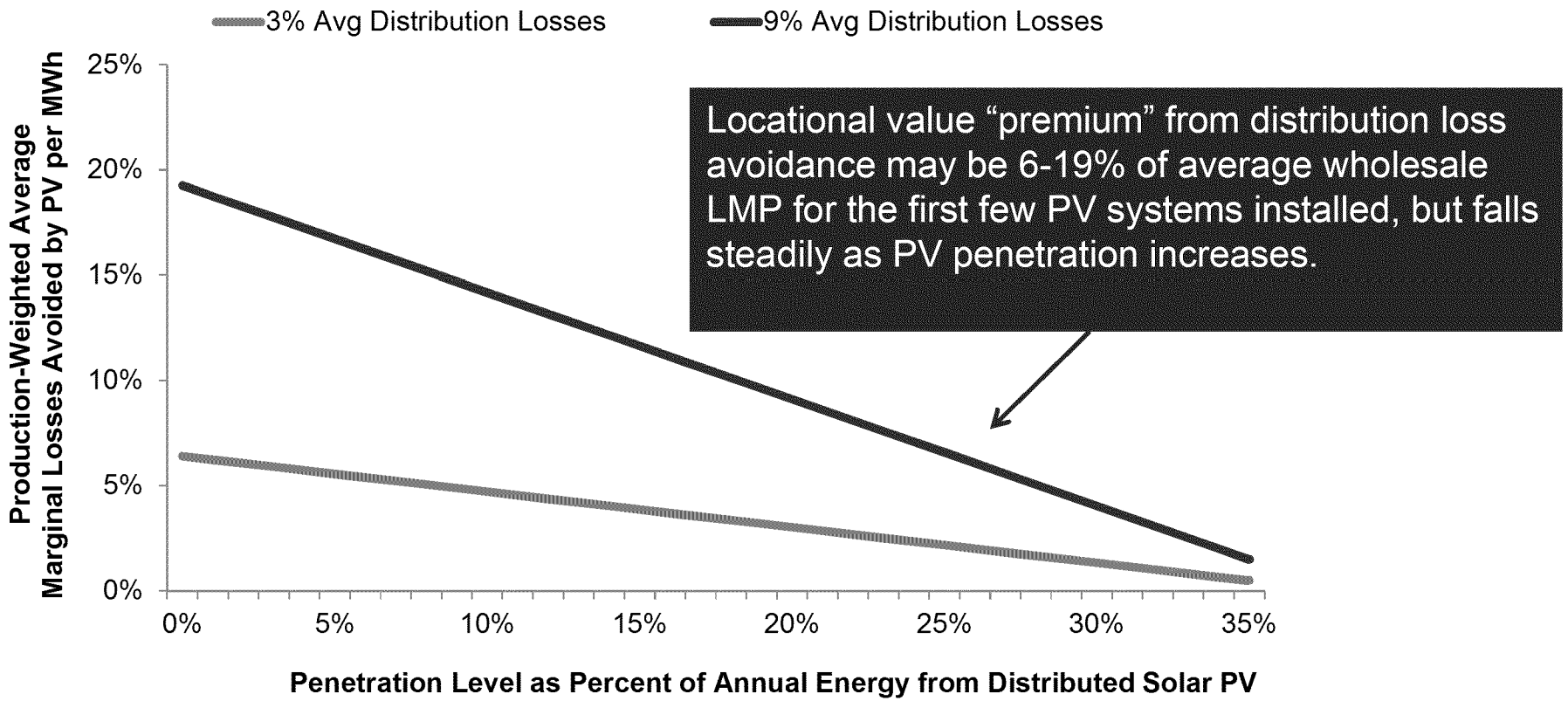




See: M.A. Cohen, P.A. Kauzmann, D.S. Callaway, Effects of distributed PV generation on California's distribution system, part 2: Economic analysis, Solar Energy, Volume 128, 2016, 139–152

2. MARGINAL LOCATIONAL VALUE DECLINES

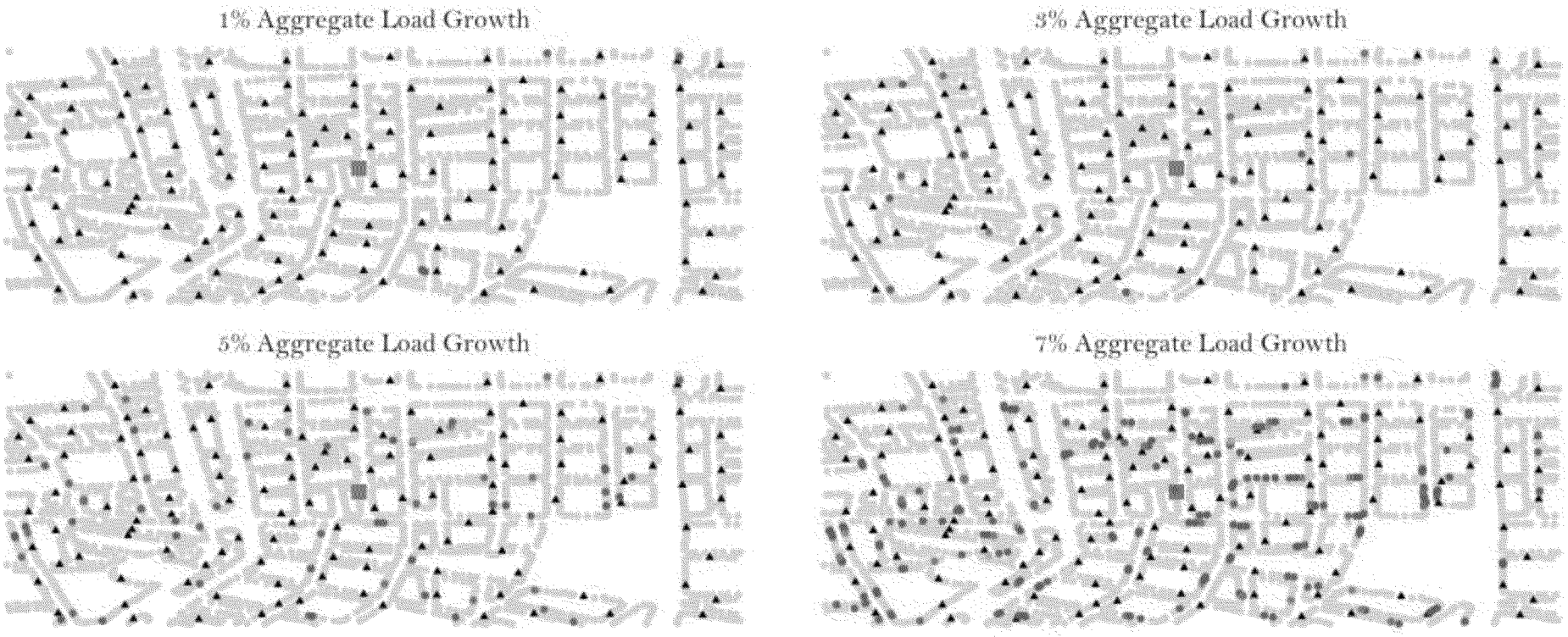
Marginal value of distribution network losses avoided by distributed solar PV as penetration increases (Texas ERCOT Example)



See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

2. MARGINAL LOCATIONAL VALUE DECLINES

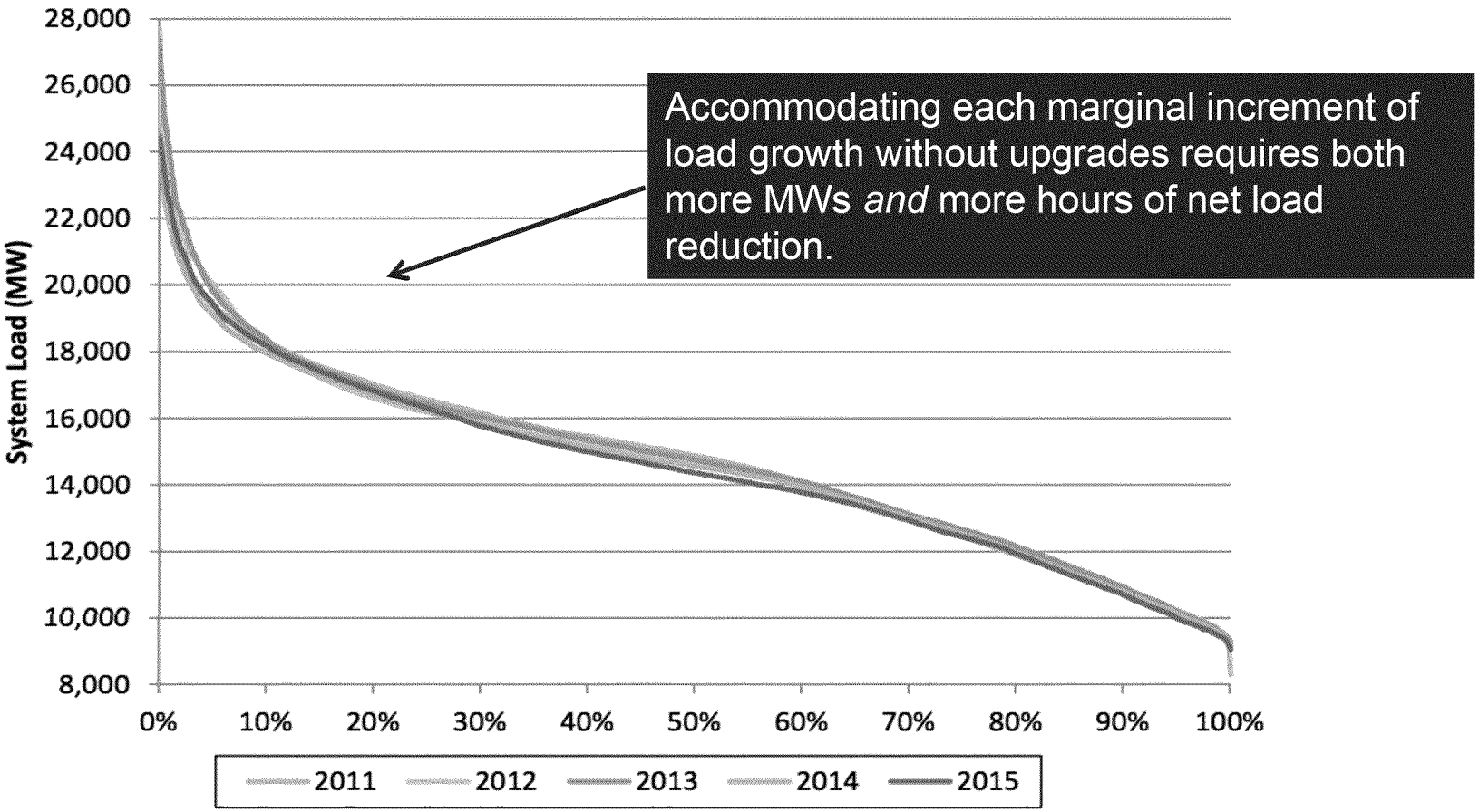
Distribution of load curtailment/self-generation necessary to accommodate load growth without network reinforcement – European urban network case



Source: Jenkins, Luke & Vargara, forthcoming

2. MARGINAL LOCATIONAL VALUE DECLINES

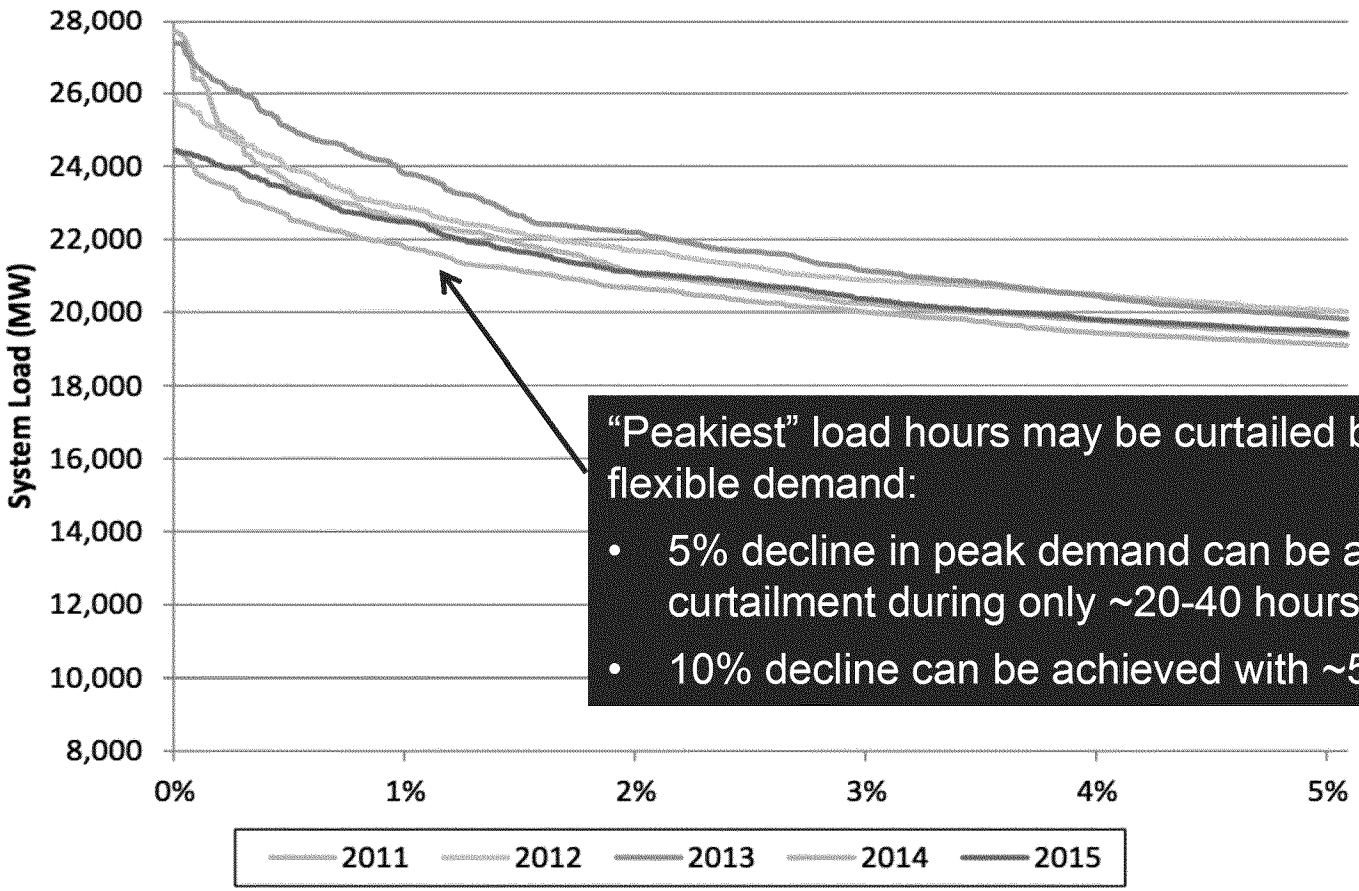
Load duration curve for ISO New England, 2011-2015, all hours.



Source: ISO New England (2015), "ISO New England's Internal Market Monitor 2015 Annual Markets Report."

3. COMPETITION BETWEEN RESOURCES

Load duration curve for ISO New England, 2011-2015, top 5% hours



"Peakiest" load hours may be curtailed by price responsive or flexible demand:

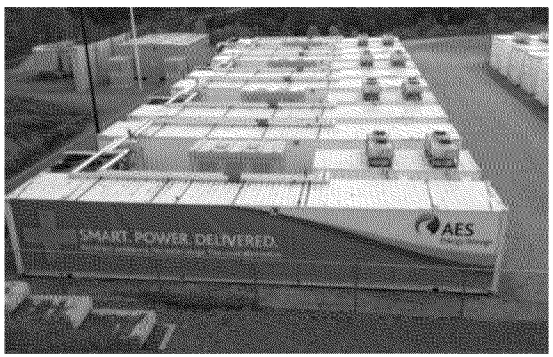
- 5% decline in peak demand can be achieved via curtailment during only ~20-40 hours of the year.
- 10% decline can be achieved with ~50-100 hours.

Source: ISO New England (2015), "ISO New England's Internal Market Monitor 2015 Annual Markets Report."

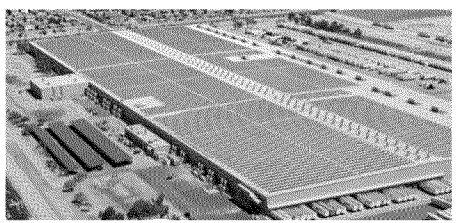
4. ECONOMIES OF SCALE STILL MATTER

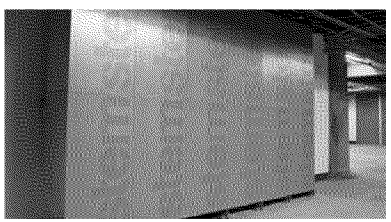
Economies of unit scale vs locational value

Utility Scale

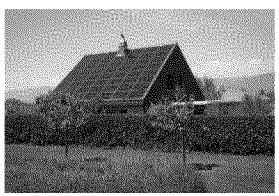


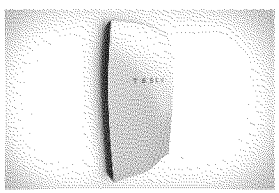
C&I Scale





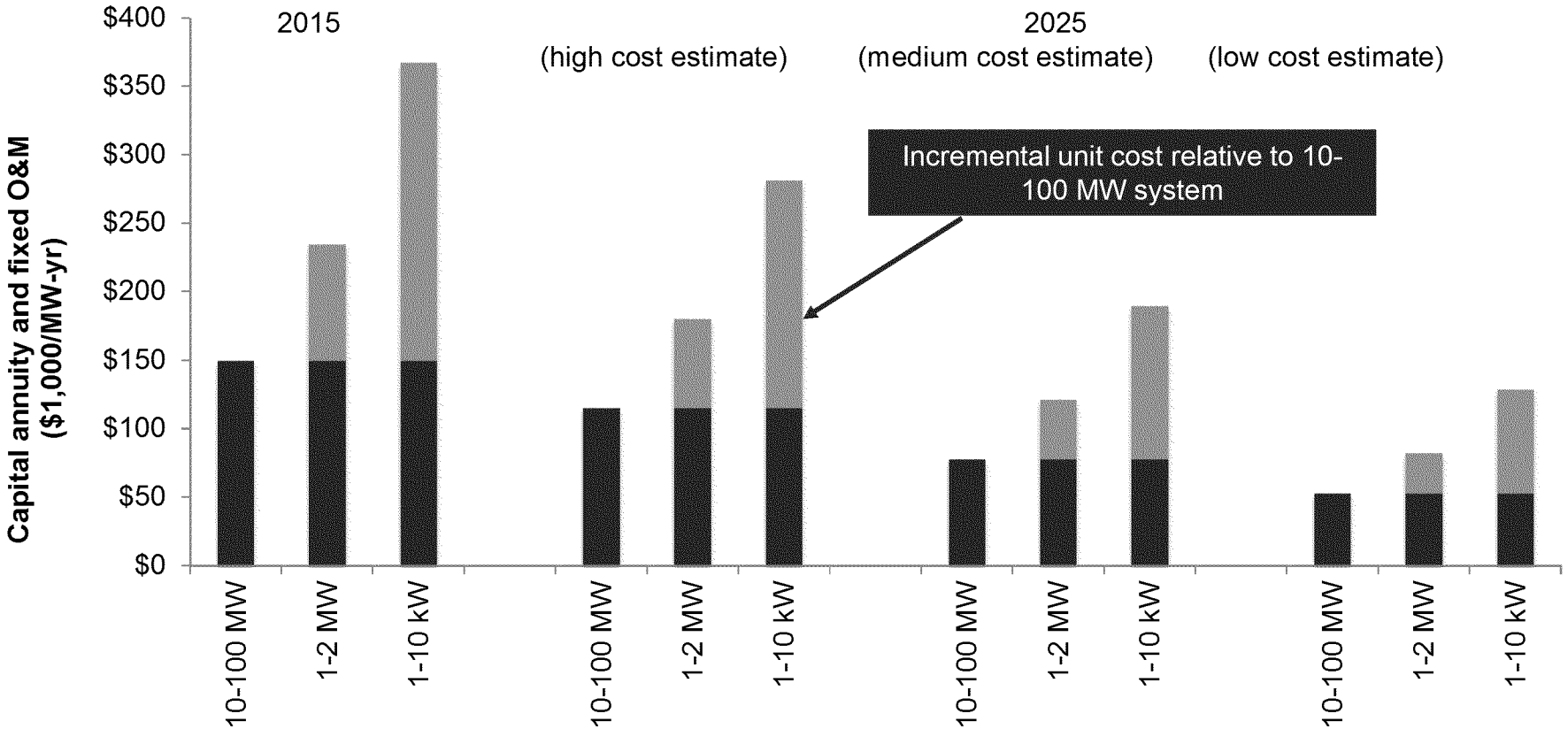
Residential Scale





4. ECONOMIES OF SCALE STILL MATTER: SOLAR PV

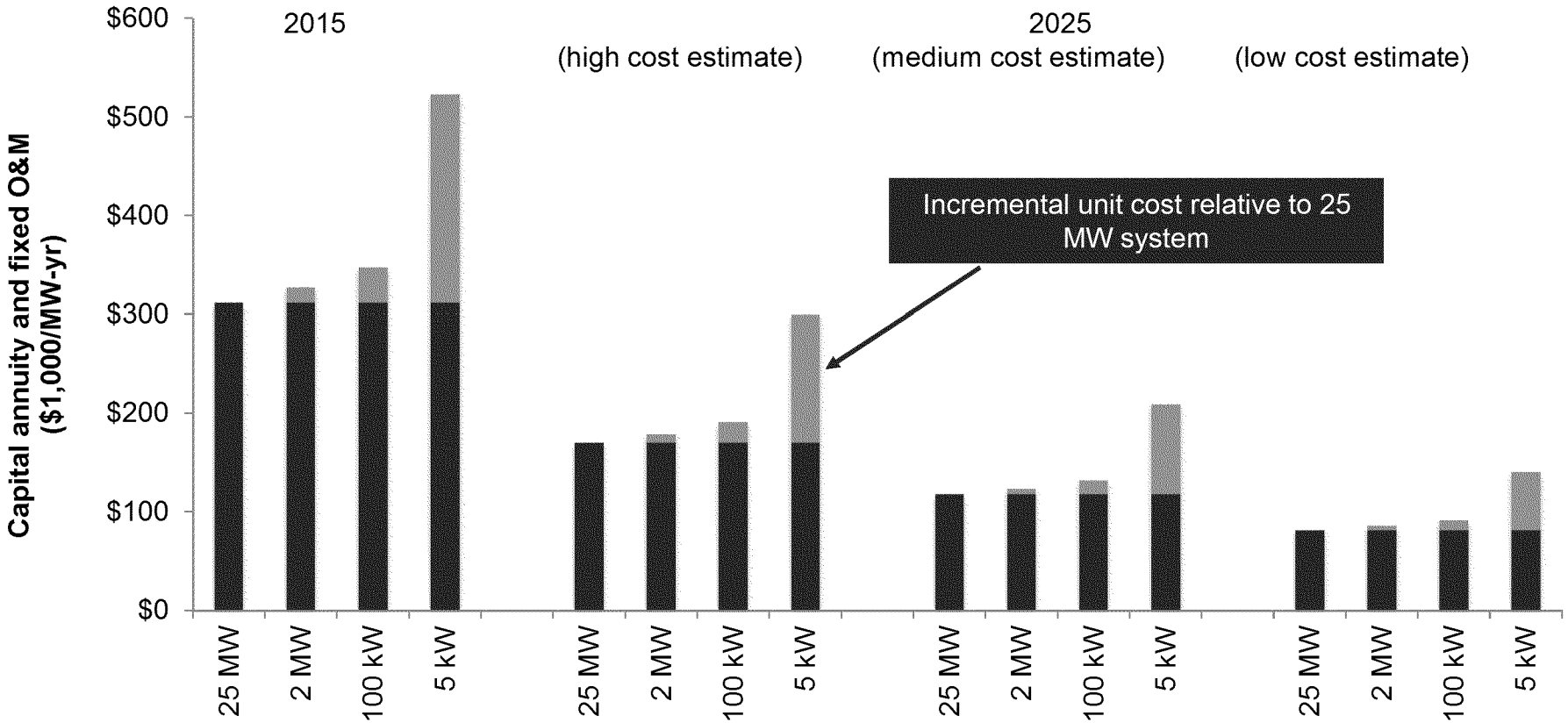
Estimated economies of unit scale for fixed-tilt U.S. solar PV systems: Annual cost of ownership in 2015 and projected for 2025



See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

4. ECONOMIES OF SCALE STILL MATTER: ENERGY STORAGE

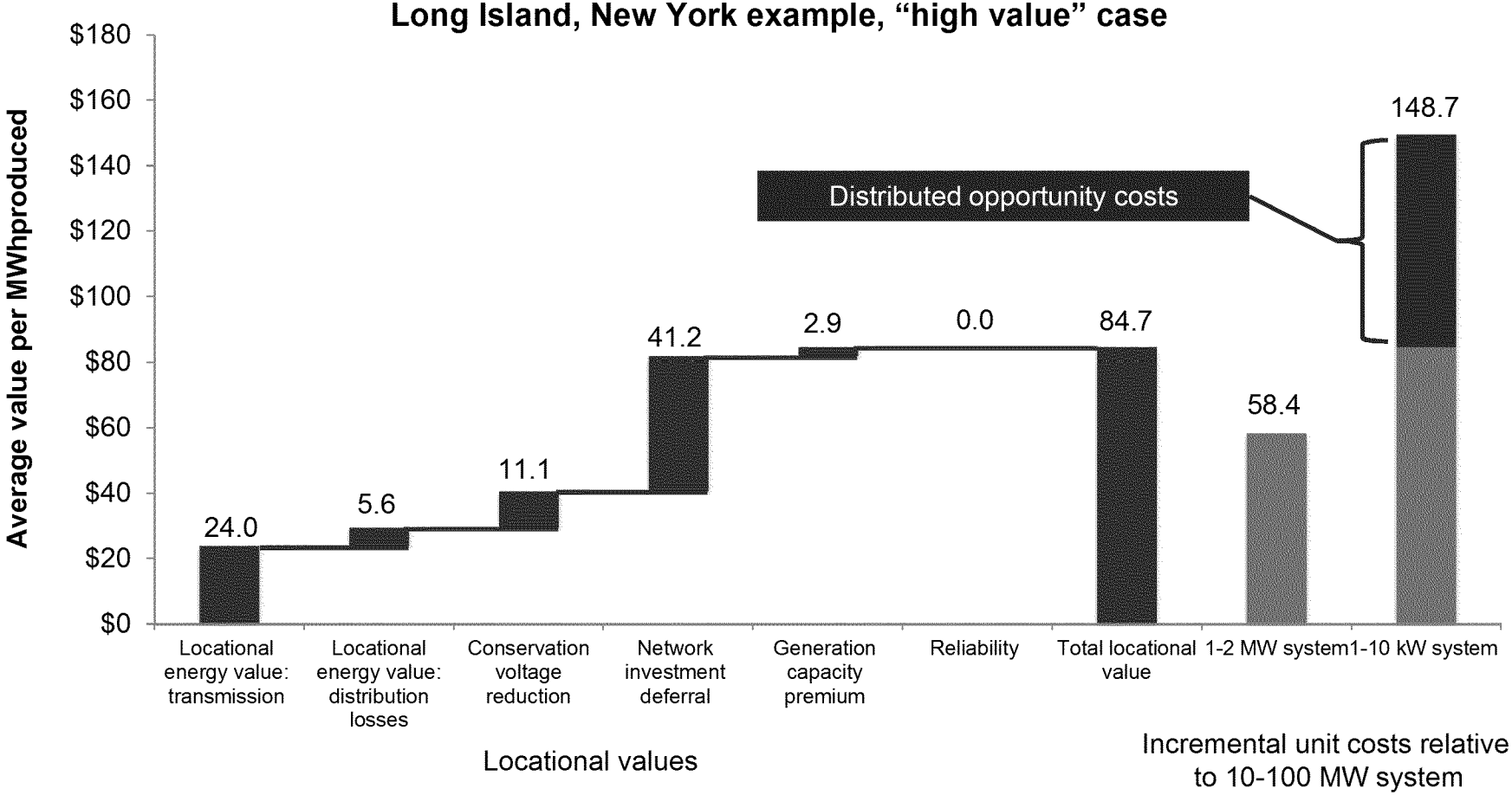
Estimated economies of unit scale for Li-ion energy storage systems (1:2 power to energy ratio): Annual cost of ownership in 2015 and projected for 2025



See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

5. BE WARY OF DISTRIBUTED OPPORTUNITY COSTS

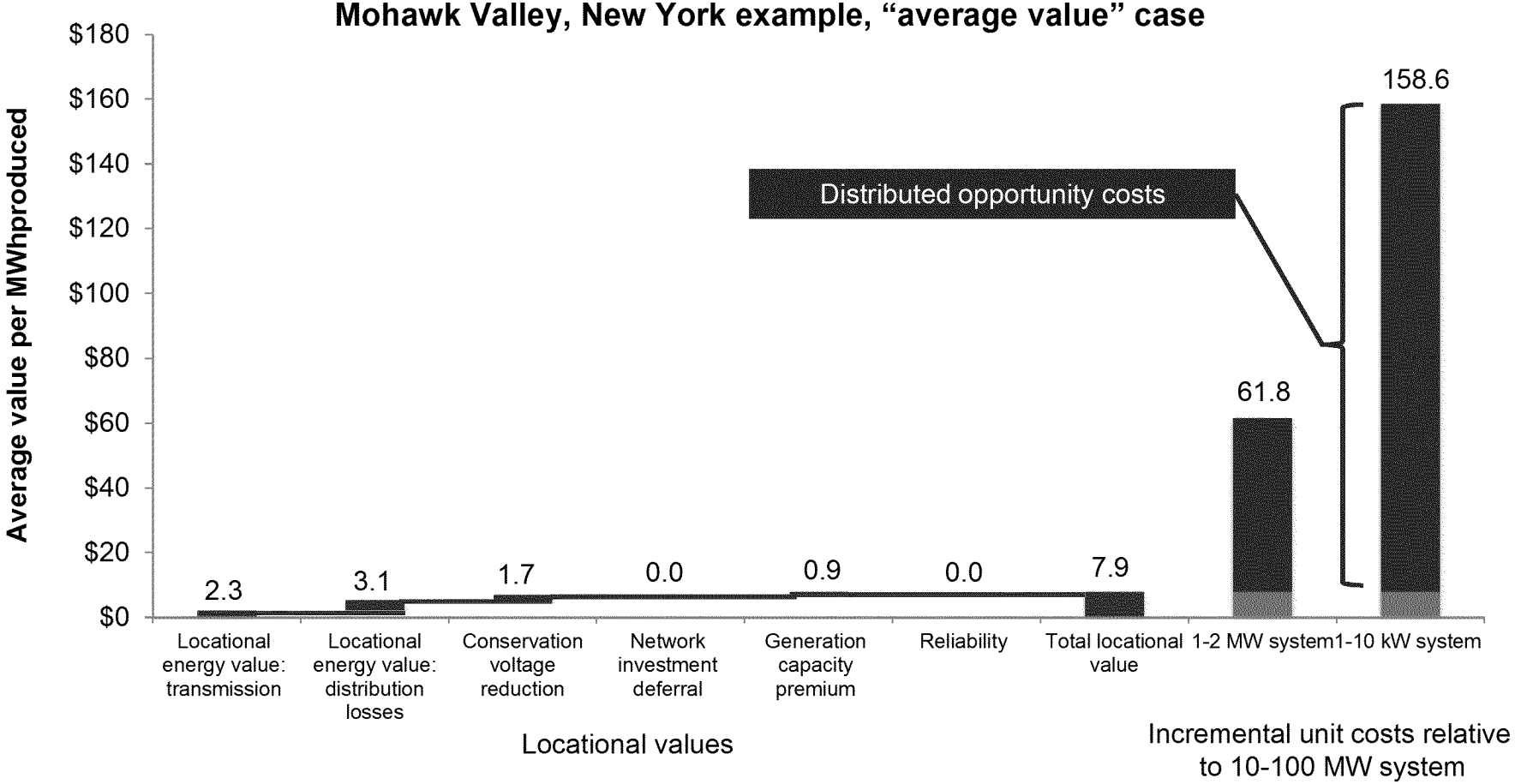
Comparison of locational value and incremental unit costs for solar PV systems: Long Island, New York example, "high value" case



See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

5. BE WARY OF DISTRIBUTED OPPORTUNITY COSTS

Comparison of locational value and incremental unit costs for solar PV systems: Mohawk Valley, New York example, "average value" case



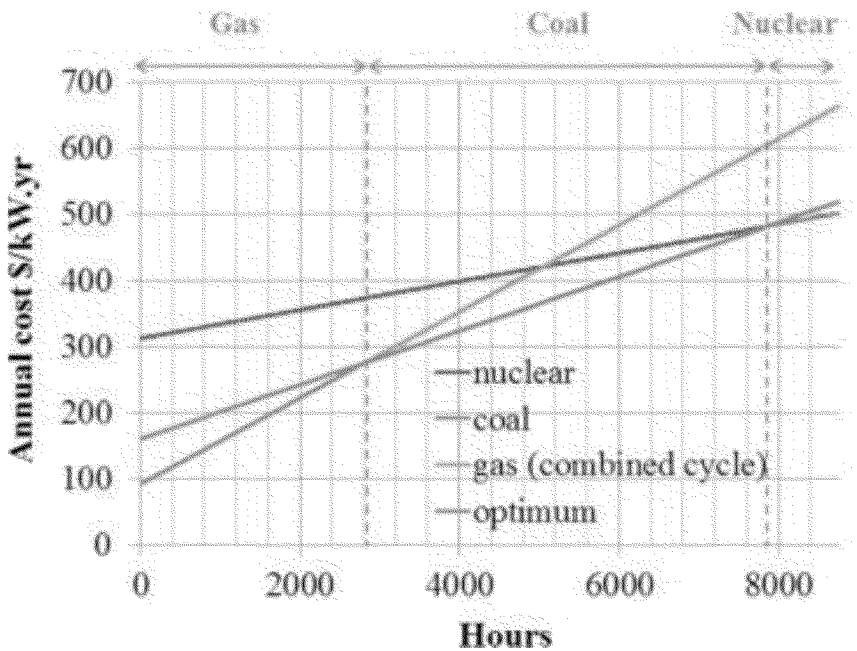
See: Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

Part 2:

NEW COMPUTATIONAL TOOLS FOR SYSTEM PLANNING WITH DERS

PUSHING THE BOUNDARIES OF CAPACITY PLANNING

Load Duration and Screening Curve Based Methods

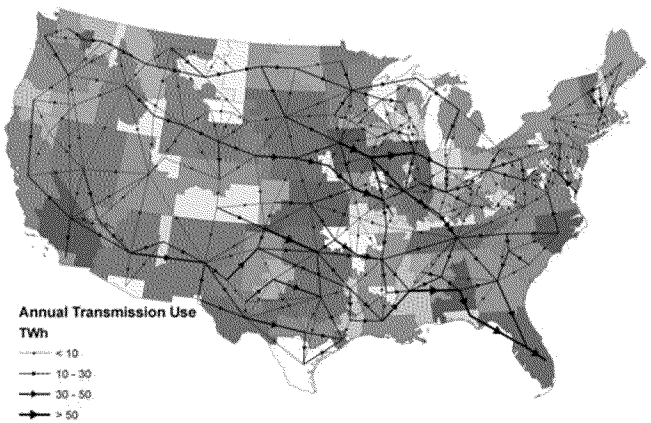


PUSHING THE BOUNDARIES OF CAPACITY PLANNING

Load Duration and Screening Curve Based Methods

Incorporating Flexibility

Incorporating Networks

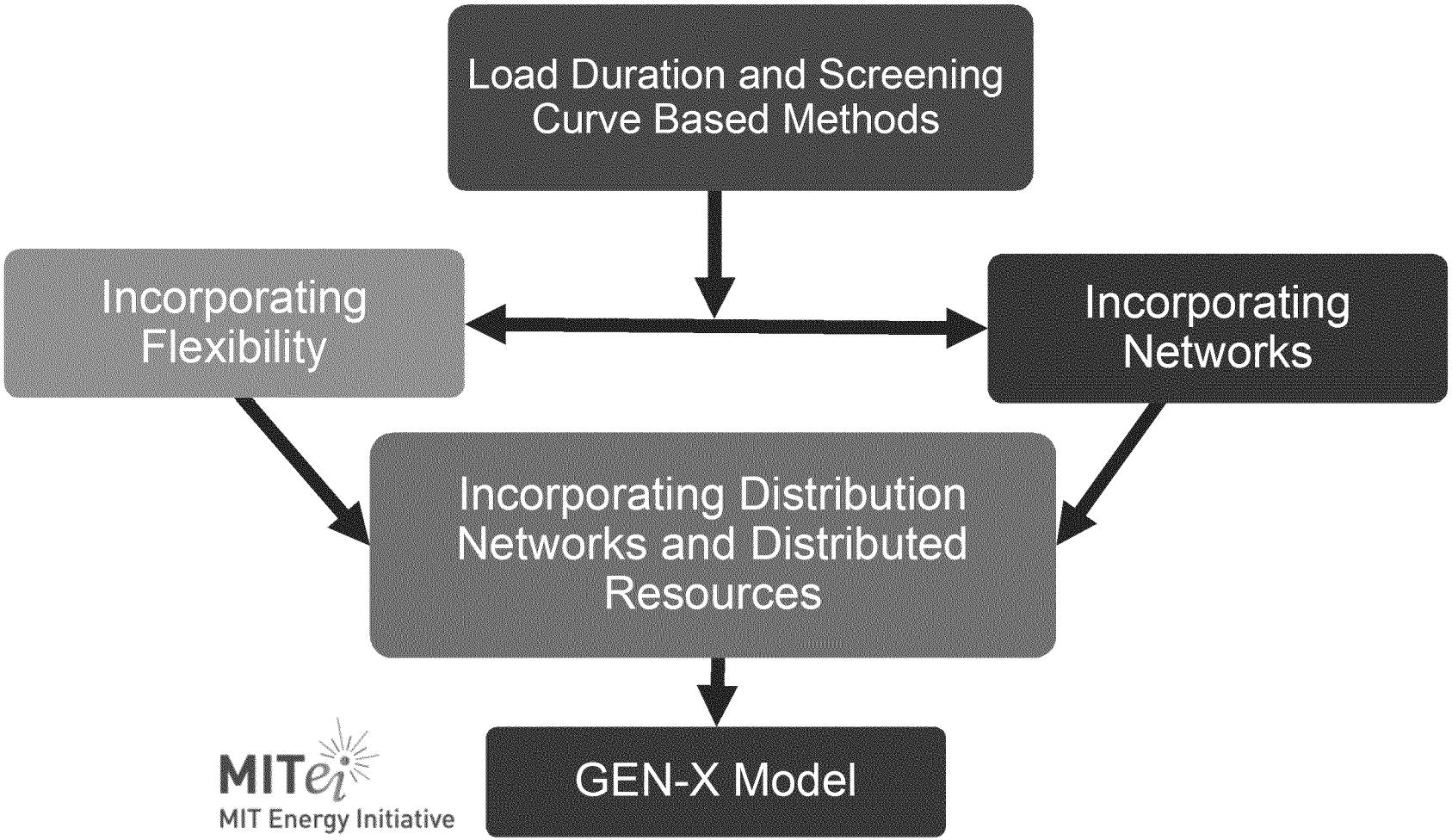


MITei MIT Energy Initiative

Integer Clustering (Palmintier)
Time Domain Reduction (de Sisternes)

NREL NATIONAL RENEWABLE ENERGY LABORATORY REEDS Model

PUSHING THE BOUNDARIES OF CAPACITY PLANNING



THE GEN-X MODEL

Minimize:

(1) Sum of investment, fixed O&M and network reinforcement costs;

(2) Sum of variable O&M and fuel costs per hour;

(3) Sum of cost (or value) of other services provided by DERs (e.g. voltage regulation, back-up power);

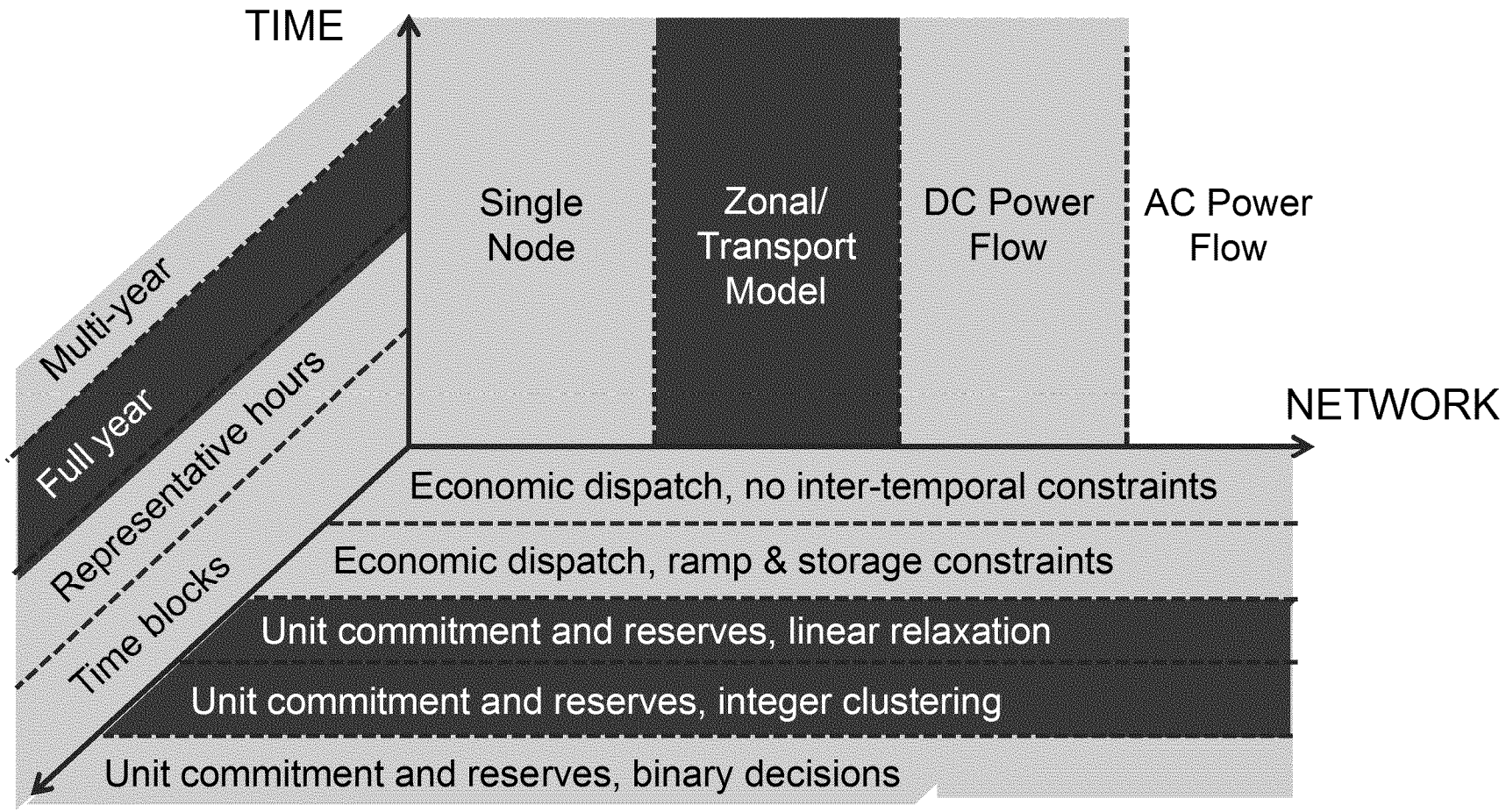
(4) Sum of cost of curtailed demand and unmet operating reserves for each hour

Subject to…

- Operational constraints on thermal generators, dispatchable renewables, energy storage, deferrable (schedulable) demand, and demand curtailment (price-responsive demand)
- Network power flow constraints

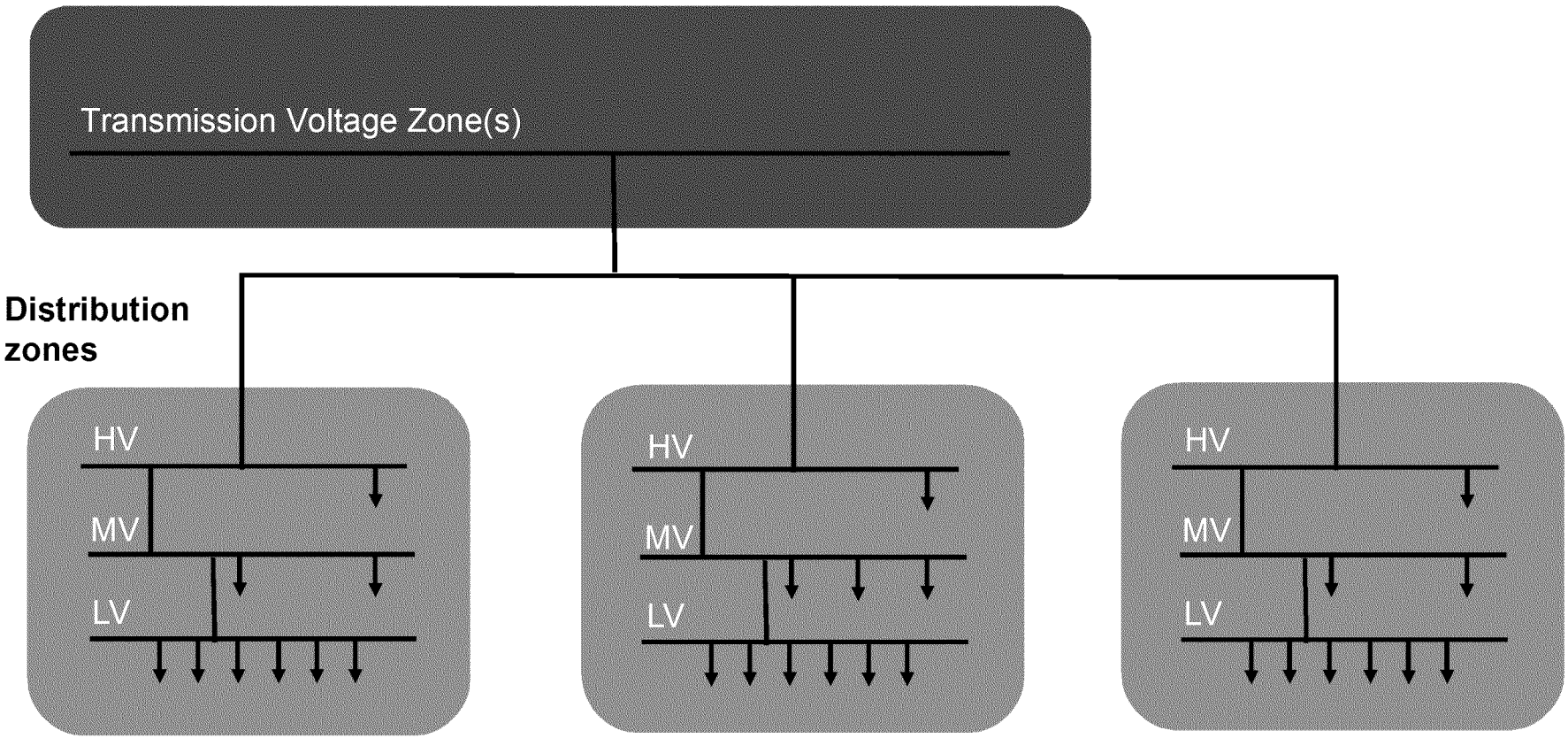
Jenkins & Sepulveda (2017) - http://bit.ly/GenXModel

WRESTLING WITH DIMENSIONALITY



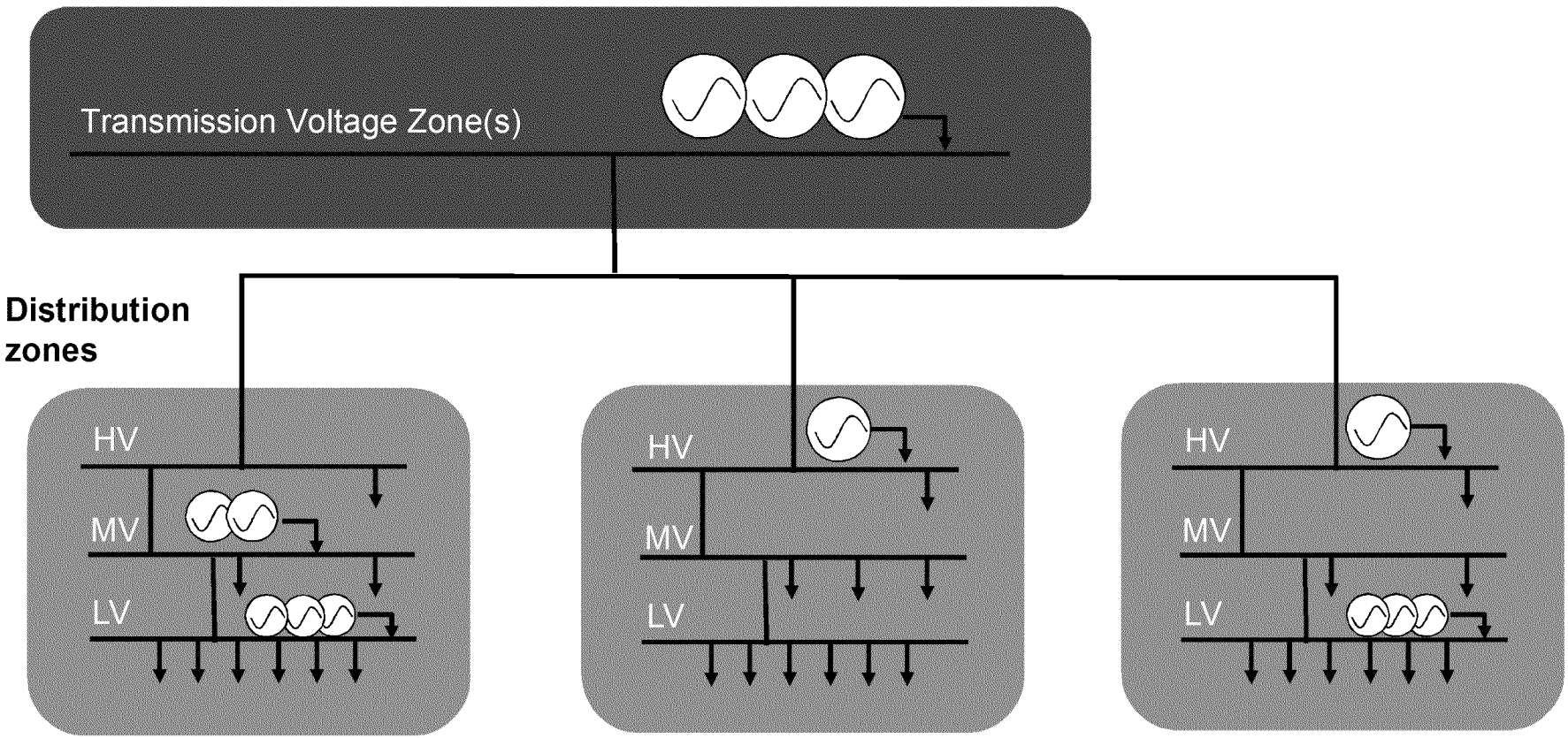
CAPACITY PLANNING WITH DISTRIBUTED RESOURCES

Multi-zonal structure with multiple distribution voltage zones and voltage levels



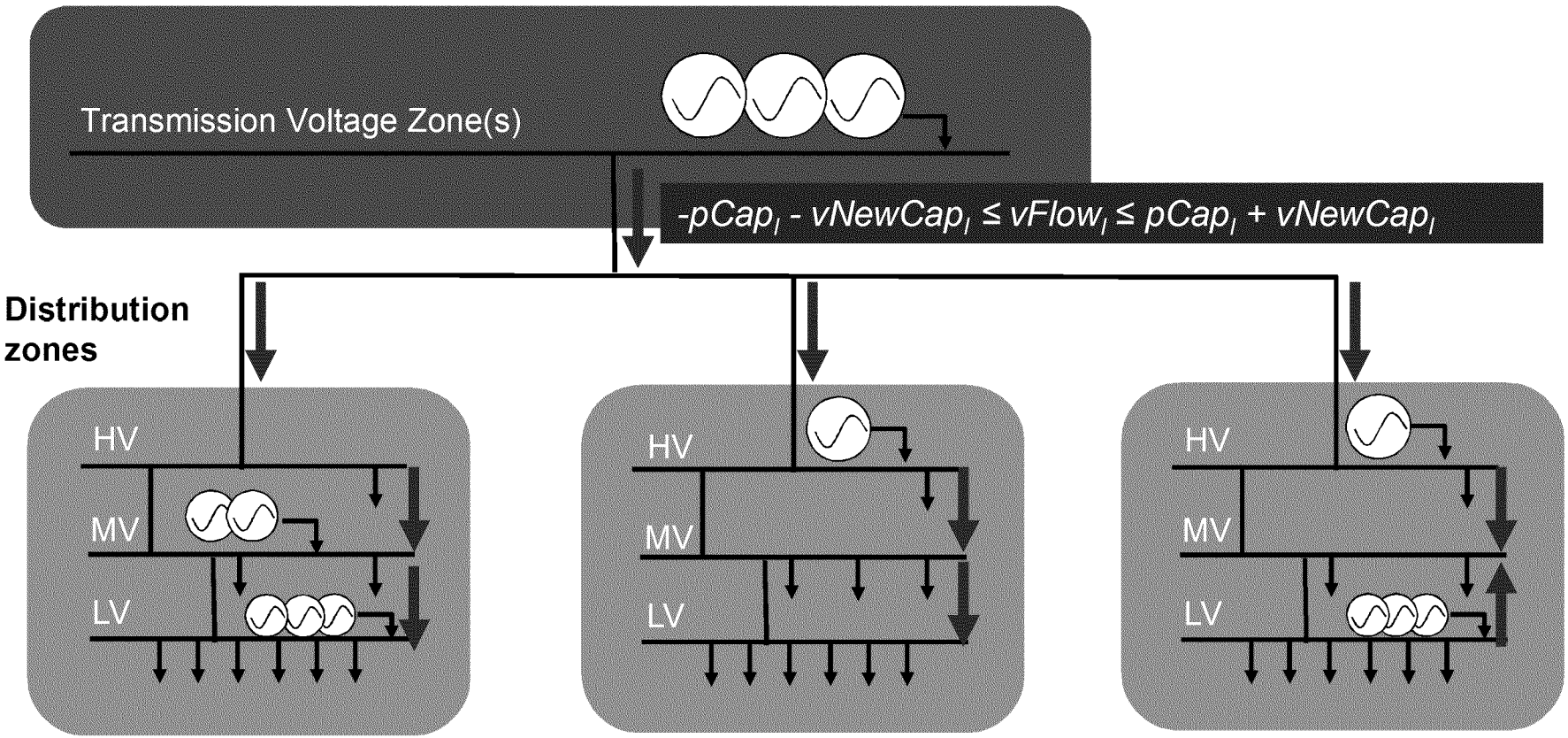
CAPTURING DERS AND ECONOMIES OF UNIT SCALE

Siting of resources possible at multiple locations and multiple scales (unit costs)



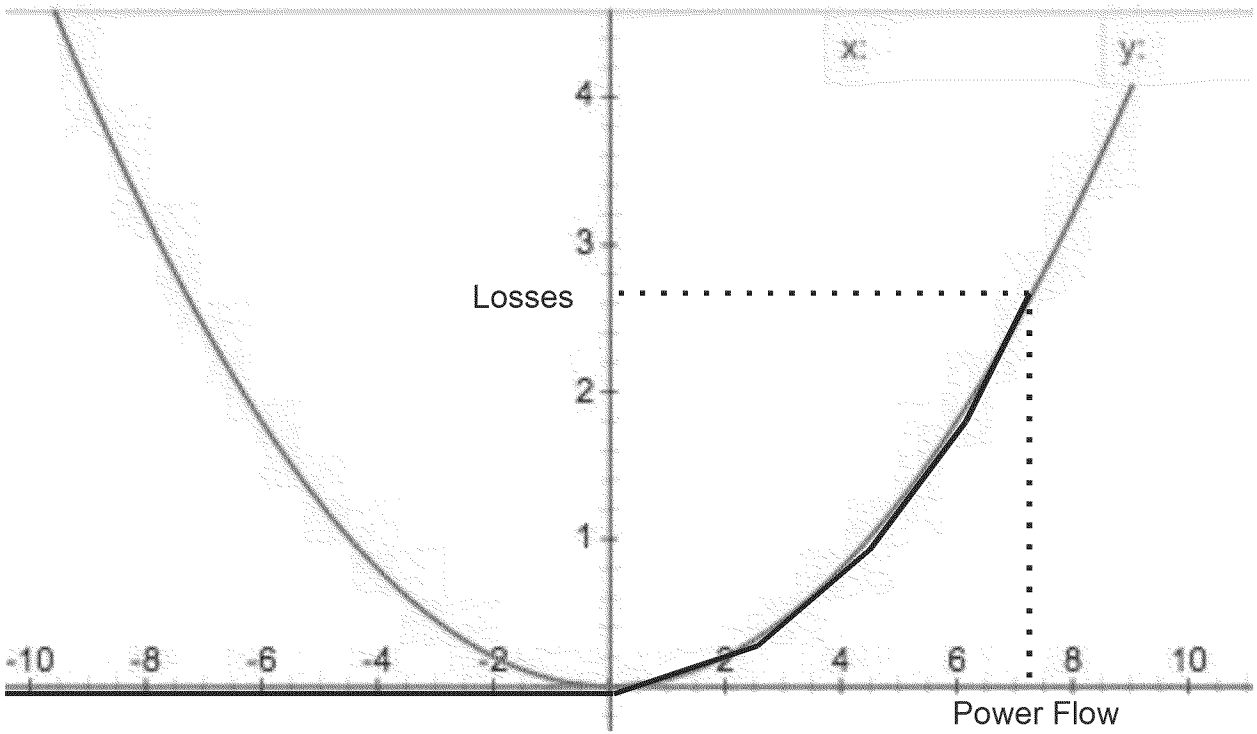
LOCATIONAL VALUE: TRANSMISSION CONGESTION/EXPANSION

Multizonal “pipeline” flow model w/constraints between zones & network expansion



LOCATIONAL VALUE: TRANSMISSION NETWORK LOSSES

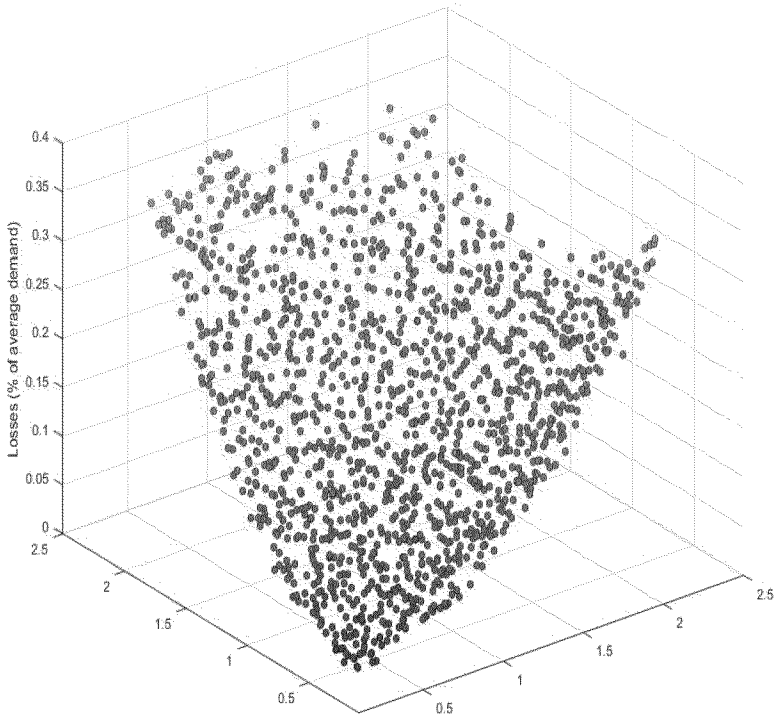
Transmission losses are segment-wise interpolation of losses as a quadratic function of power flows.
(Based on Zhang, Hu, & Song 2013 and Fitiwi et al., 2016)



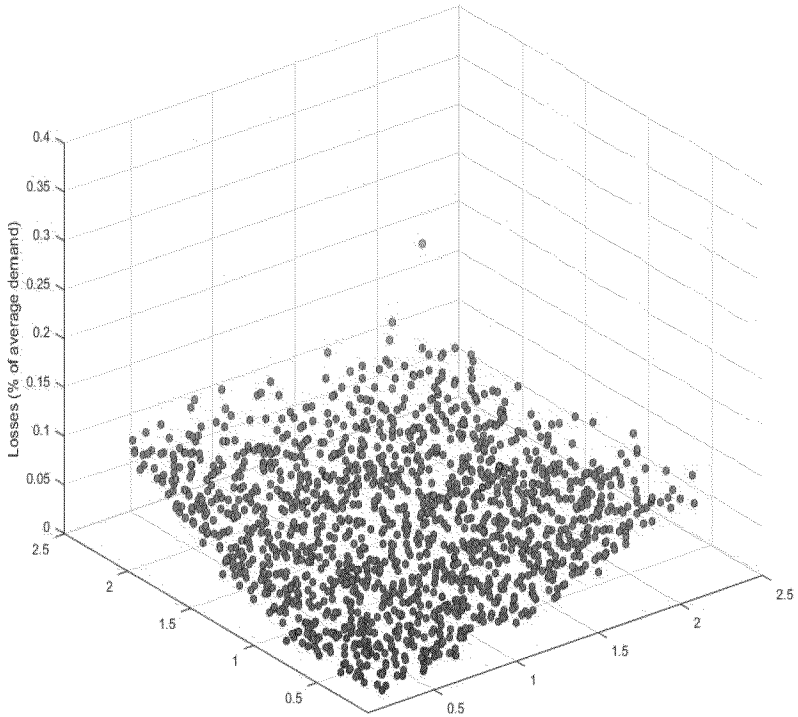
LOCATIONAL VALUE: DISTRIBUTION NETWORK LOSSES

Distribution losses as a function of injections and withdrawals within each voltage level: Semi-urban European network results

Variation in low voltage



Variation in medium voltage

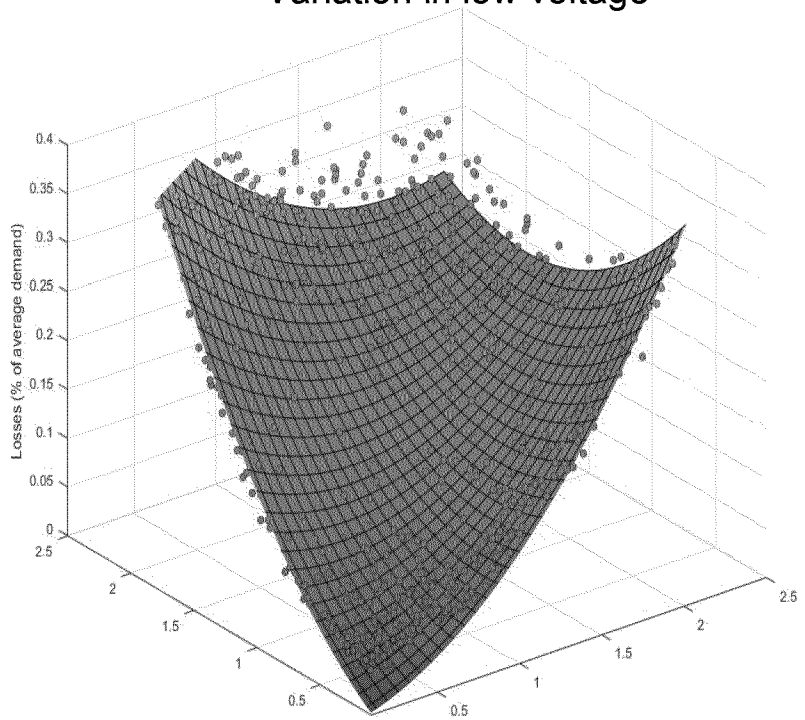


(Jenkins, Luke, & Vergara forthcoming)

LOCATIONAL VALUE: DISTRIBUTION NETWORK LOSSES

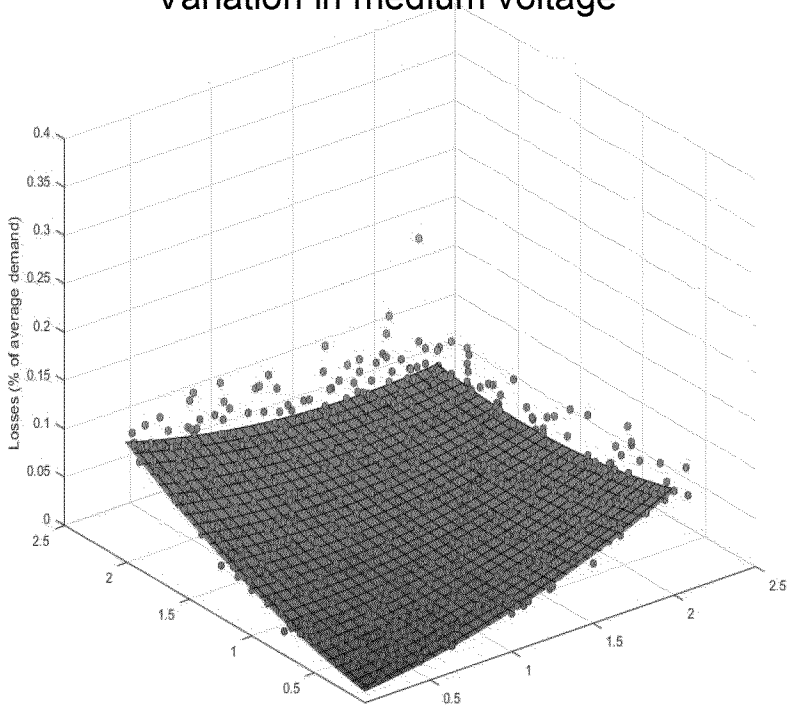
Distribution losses as a function of injections and withdrawals within each voltage level: Semi-urban European network results

Variation in low voltage



$$\text{losses} = -357.1 + 0.4 \times (\text{net withdrawals})^2 + 36.0 \times (\text{peak withdrawals}) + 16.2 \times (\text{peak injections})$$

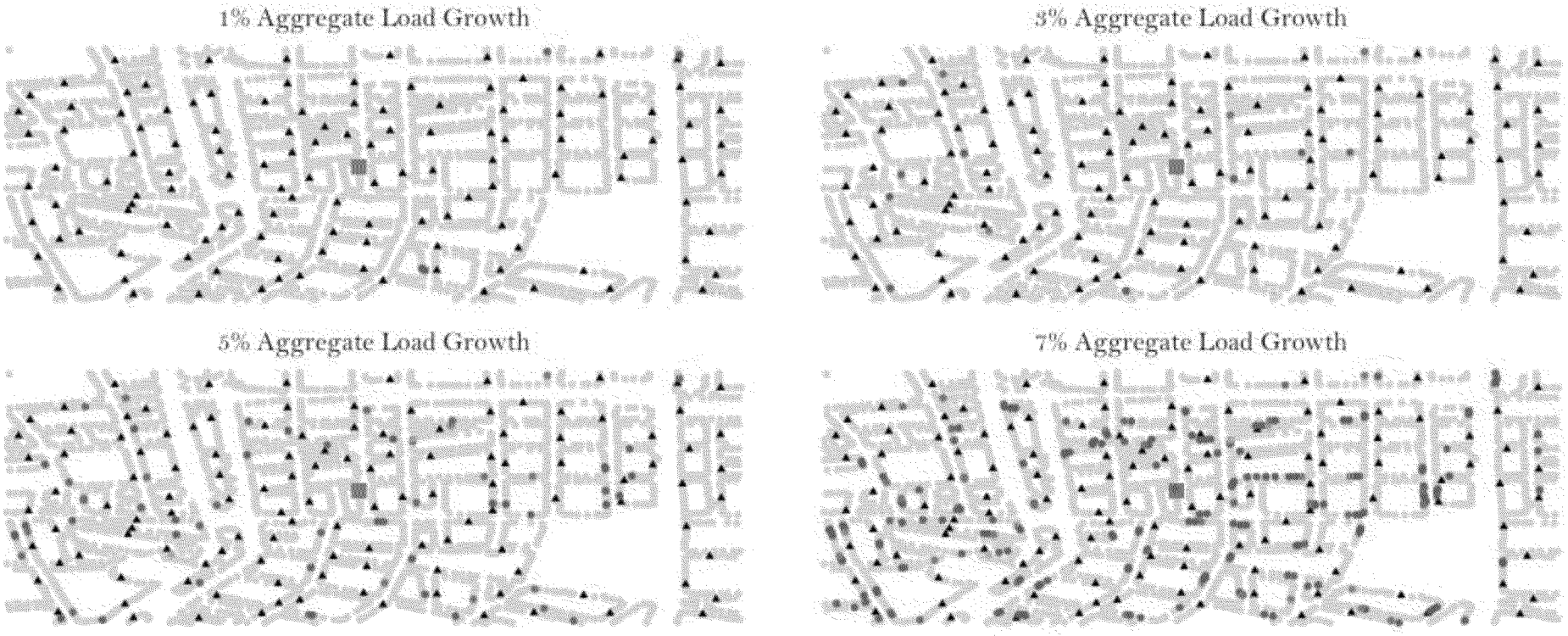
Variation in medium voltage



$$\text{losses} = 170.1 + 0.1 \times (\text{net withdrawals})^2 + 8.8 \times (\text{peak withdrawals}) + 6.1 \times (\text{peak injections})$$

LOCATIONAL VALUE: DISTRIBUTION NETWORK CAPACITY

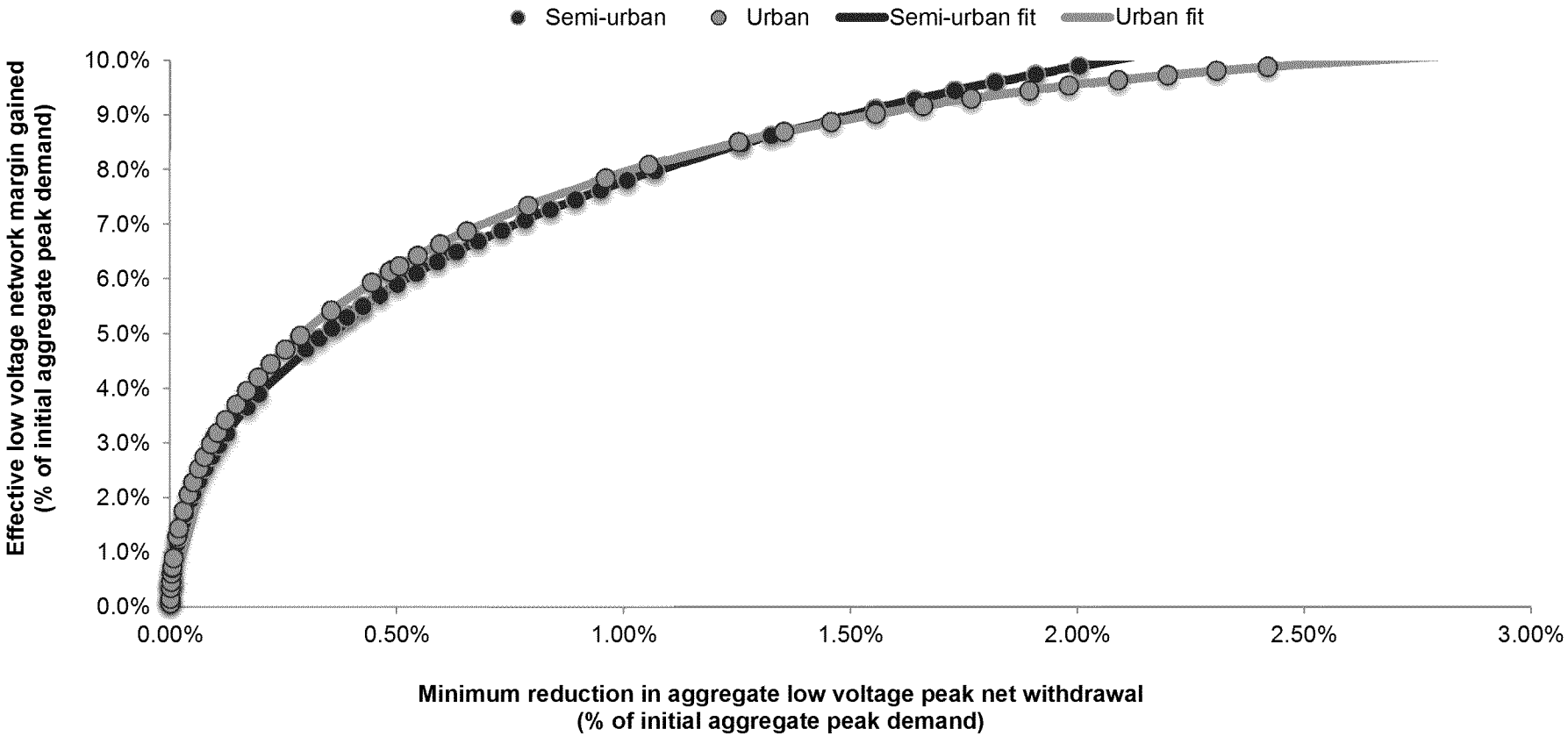
Distribution of load curtailment/self-generation necessary to accommodate load growth without network reinforcement – European urban network case



Source: Jenkins, Luke & Vargara, forthcoming

LOCATIONAL VALUE: DISTRIBUTION NETWORK CAPACITY

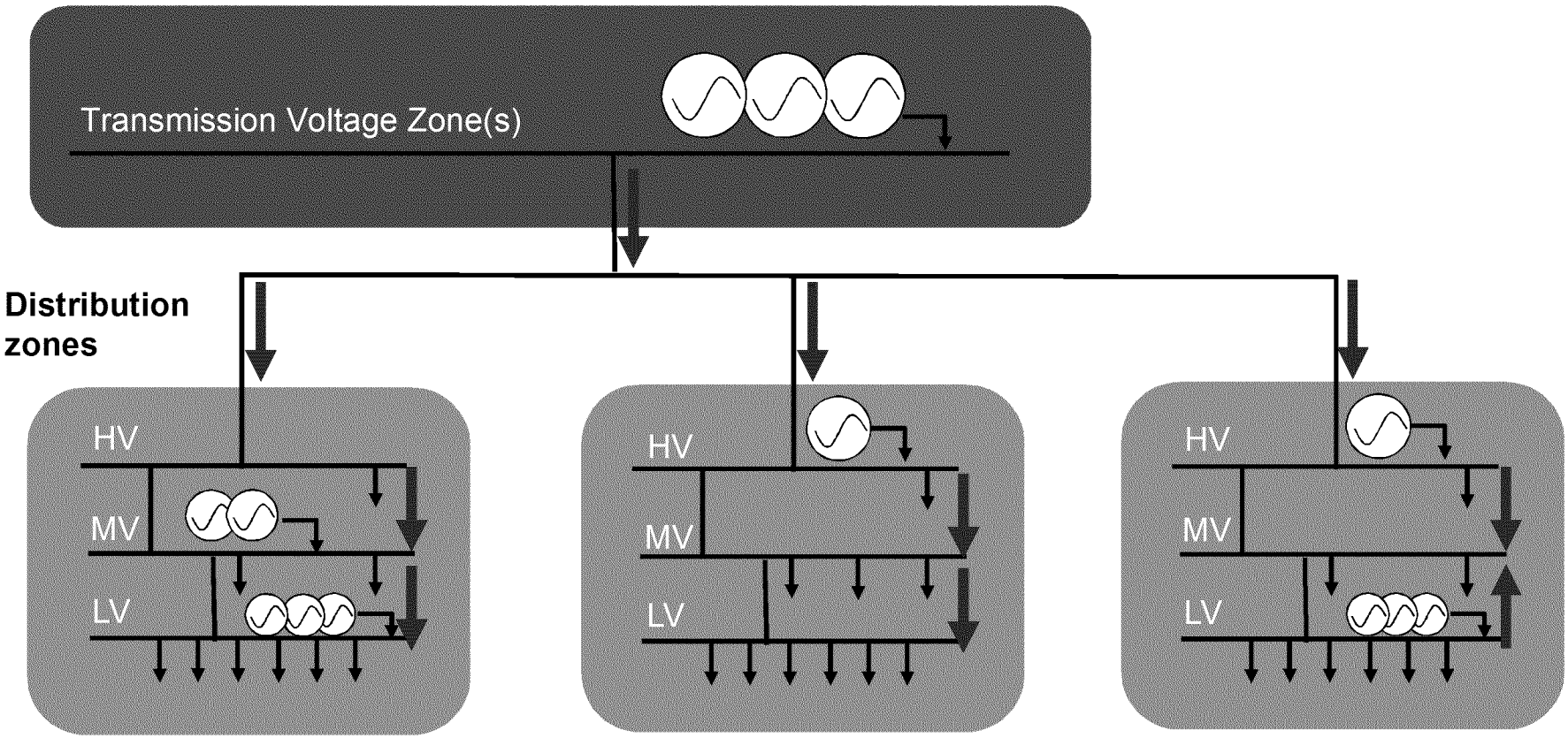
Potential for DERs to substitute for distribution network upgrades in representative European distribution networks - low voltage distribution example



See: Jenkins, Luke & Vergara forthcoming and Pérez-Arriaga et al. 2016. *The Utility of the Future: an MIT Energy Initiative response to an industry in transition*. Cambridge, MA: Massachusetts Institute of Technology. http://energy.mit.edu/research/utility-future-study/

A NEW MODEL FOR NEW OPPORTUNITIES & TRADEOFFS

GEN-X: a new electricity resource capacity expansion planning model that captures key tradeoffs between locational value and economies of unit scale



GEN-X APPLICATIONS

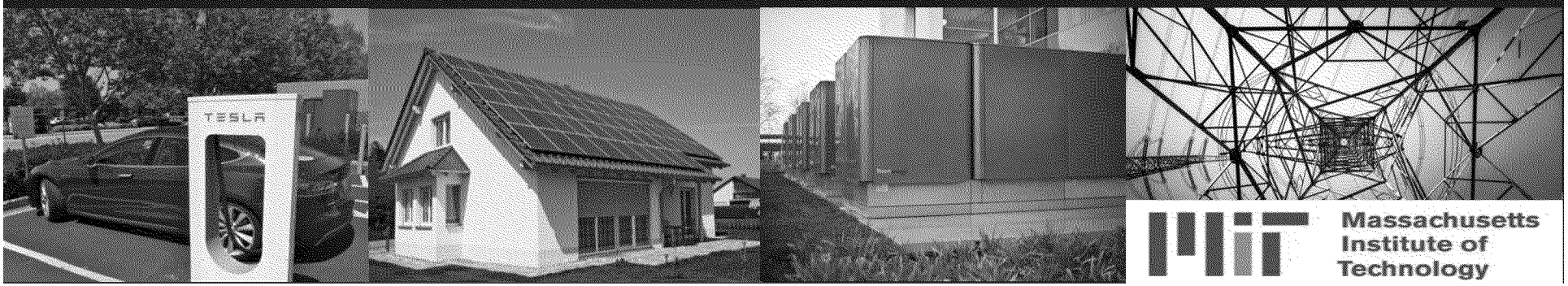
1. • Evaluate economically optimal portfolio of conventional and distributed energy resources to meet projected load growth and policy constraints, as well as implications for network reinforcements
2. • Analyze economics of distributed energy resources and understand how novel resources deliver value and affect operation of power systems
3. • Evaluate optimal scale of solar PV, energy storage devices, fuel cells, etc. (e.g. economies of scale vs. locational benefits tradeoffs)
4. • Evaluating and benchmarking policy and regulation
5. • Electricity utility integrated resource planning with distributed energy resources

Jesse D. Jenkins

PhD candidate, Institute for Data, Systems & Society
Research assistant, MIT Energy Initiative Electric Power Systems Center
Massachusetts Institute of Technology

jessedj@mit.edu | Linkedn.com/in/jessedjenkins

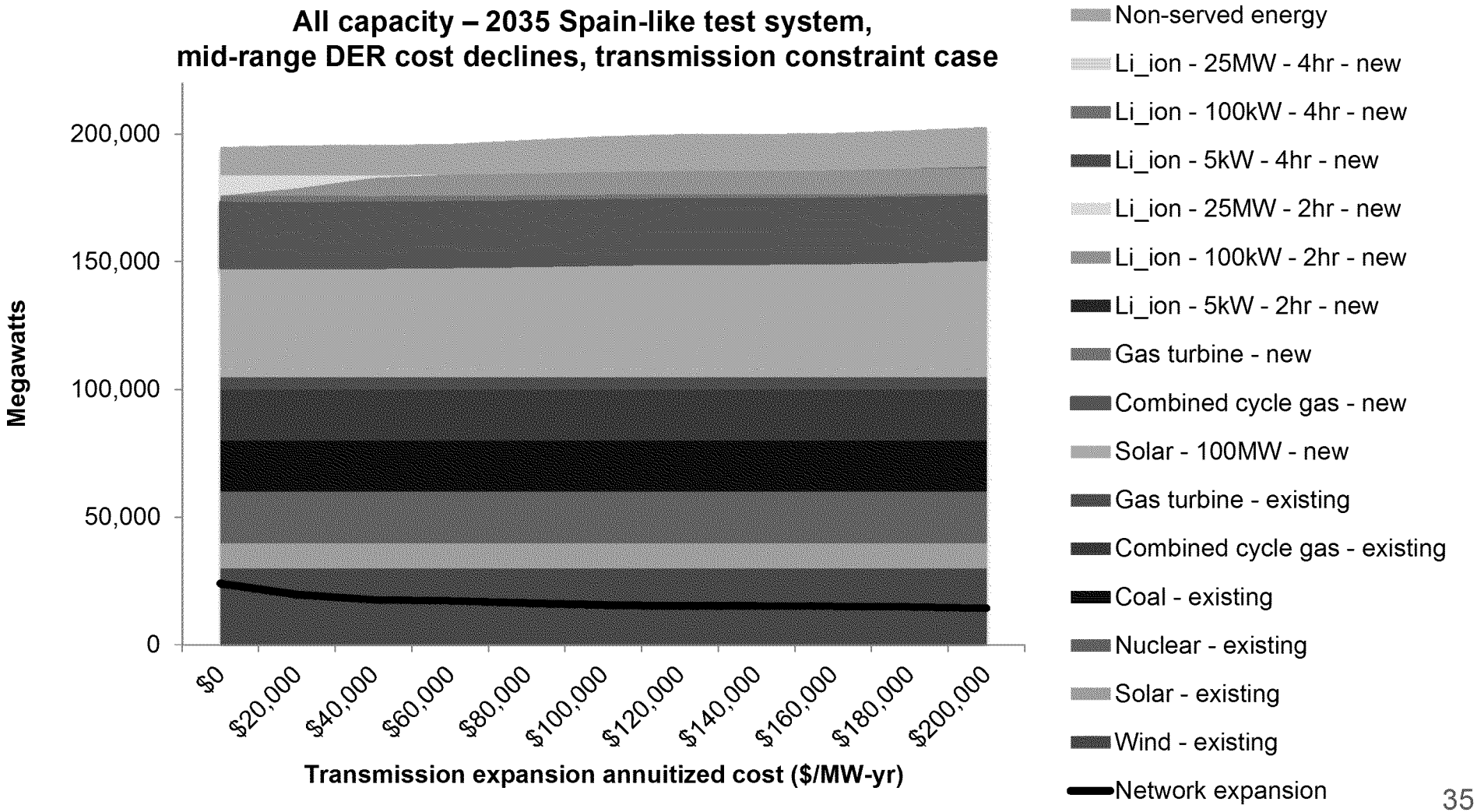
Questions



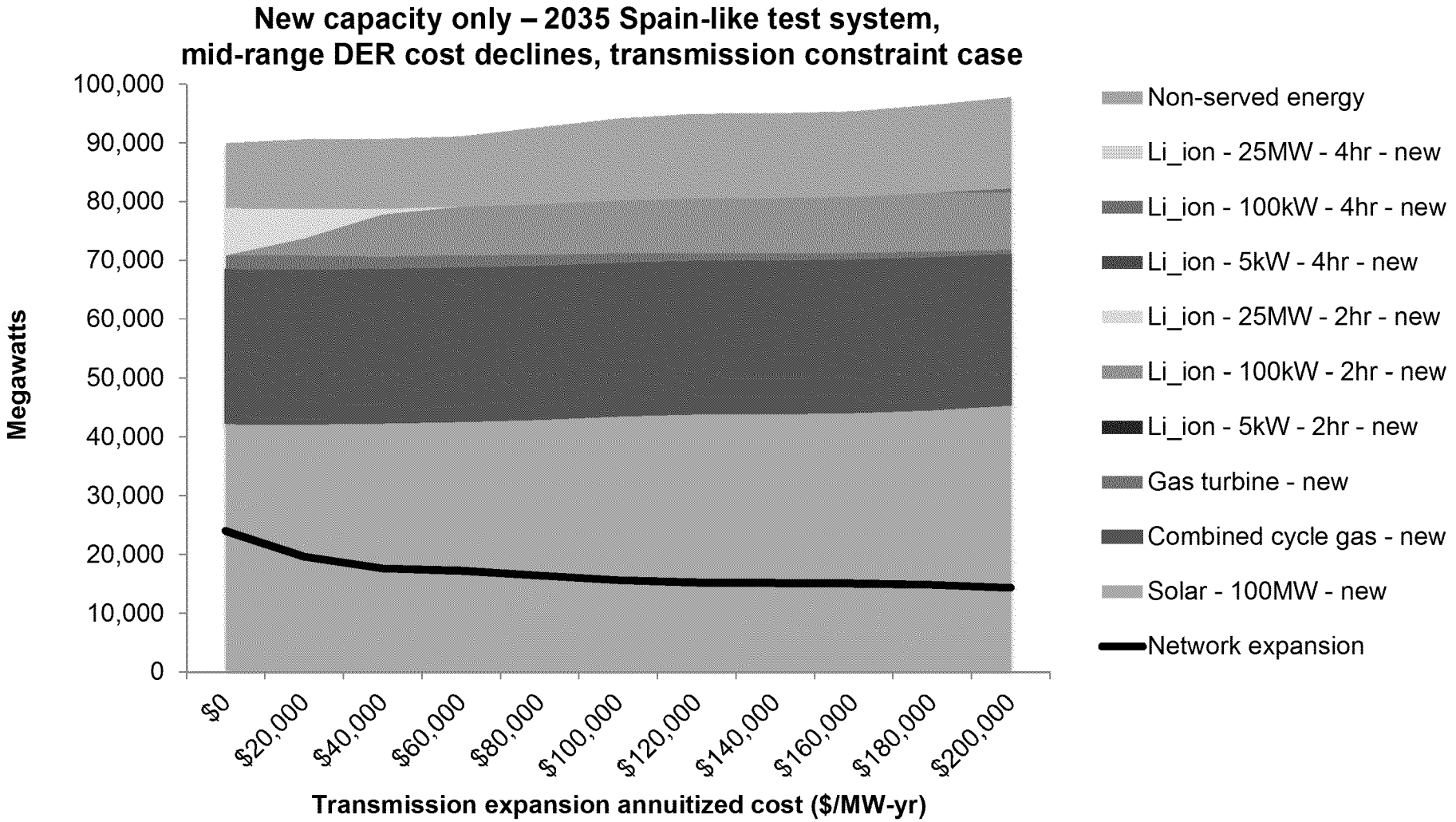
APPENDIX:

A CASE STUDY OF ENERGY STORAGE AND TRANMISSION DEFERRAL

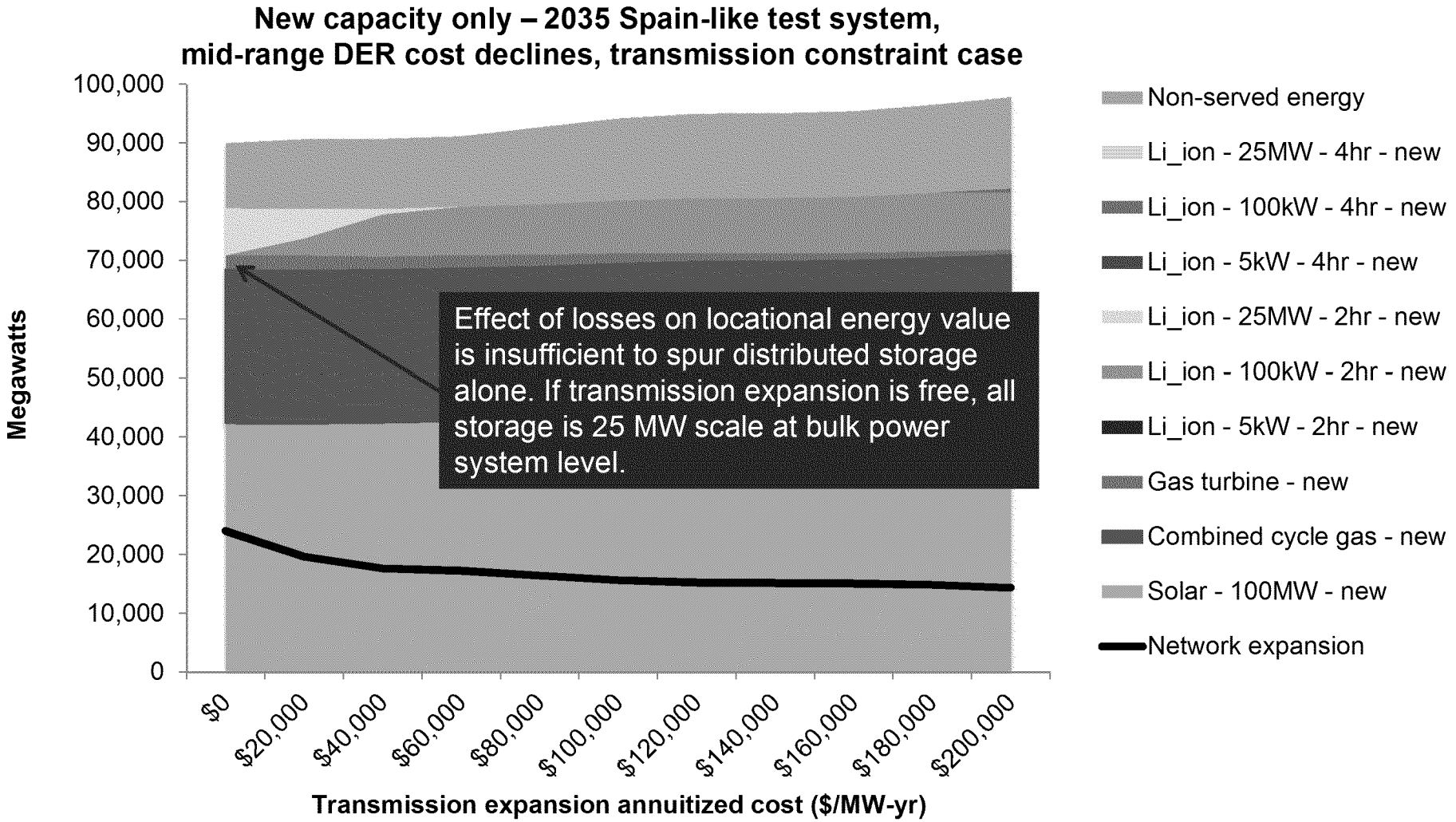
TRANSMISSION EXPANSION AND STORAGE CASE STUDY



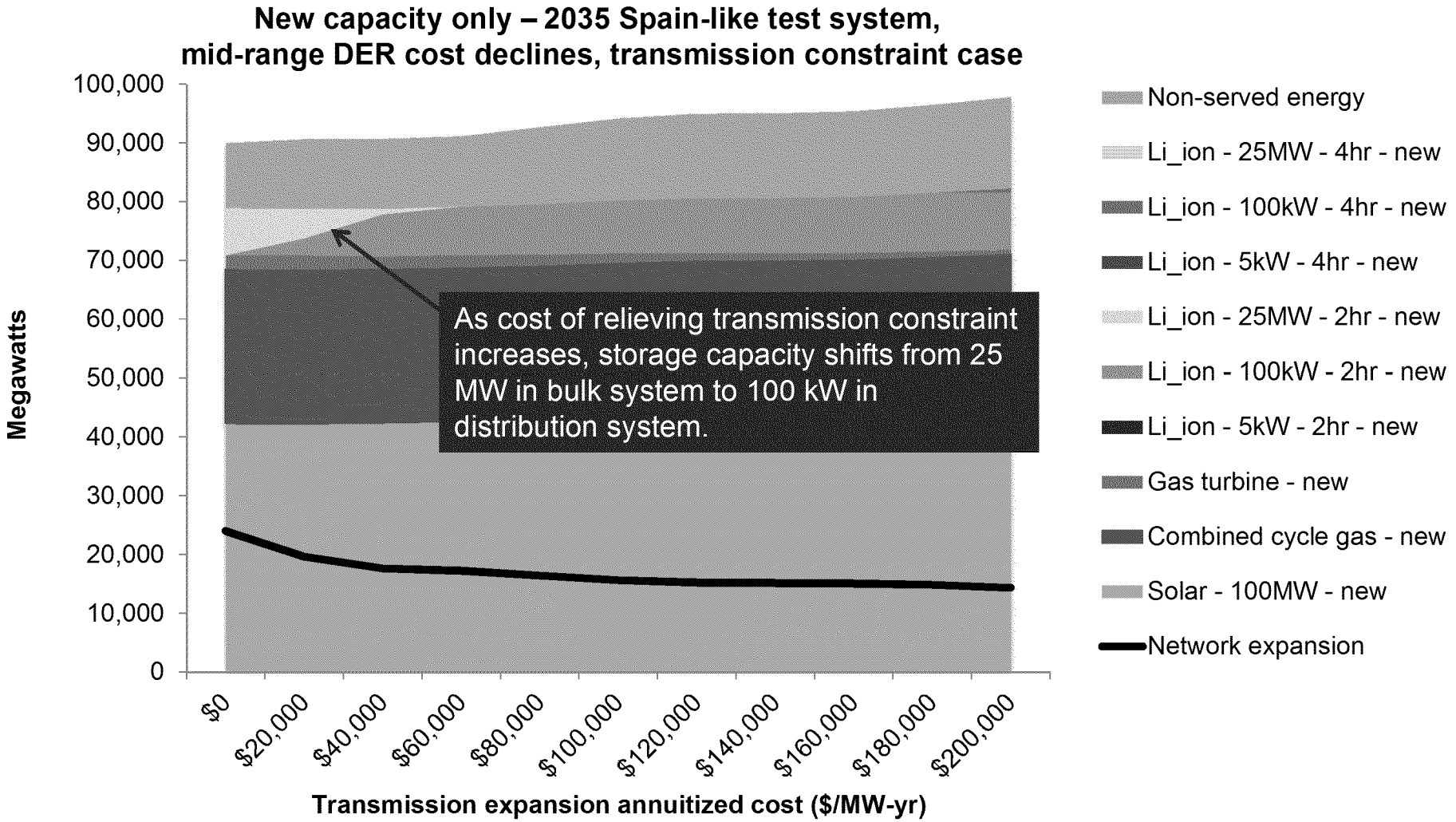
TRANSMISSION EXPANSION AND STORAGE CASE STUDY



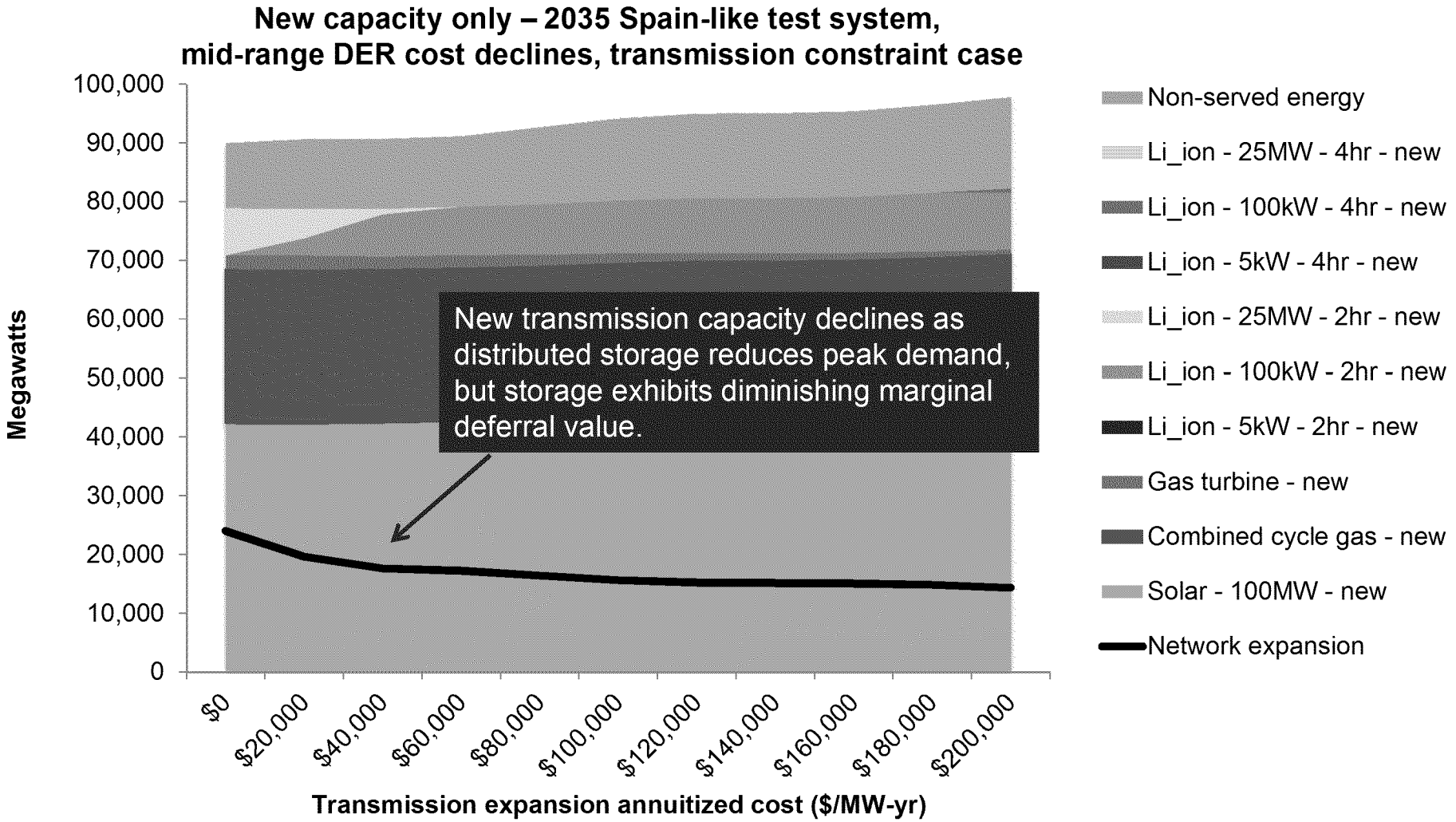
TRANSMISSION EXPANSION AND STORAGE CASE STUDY



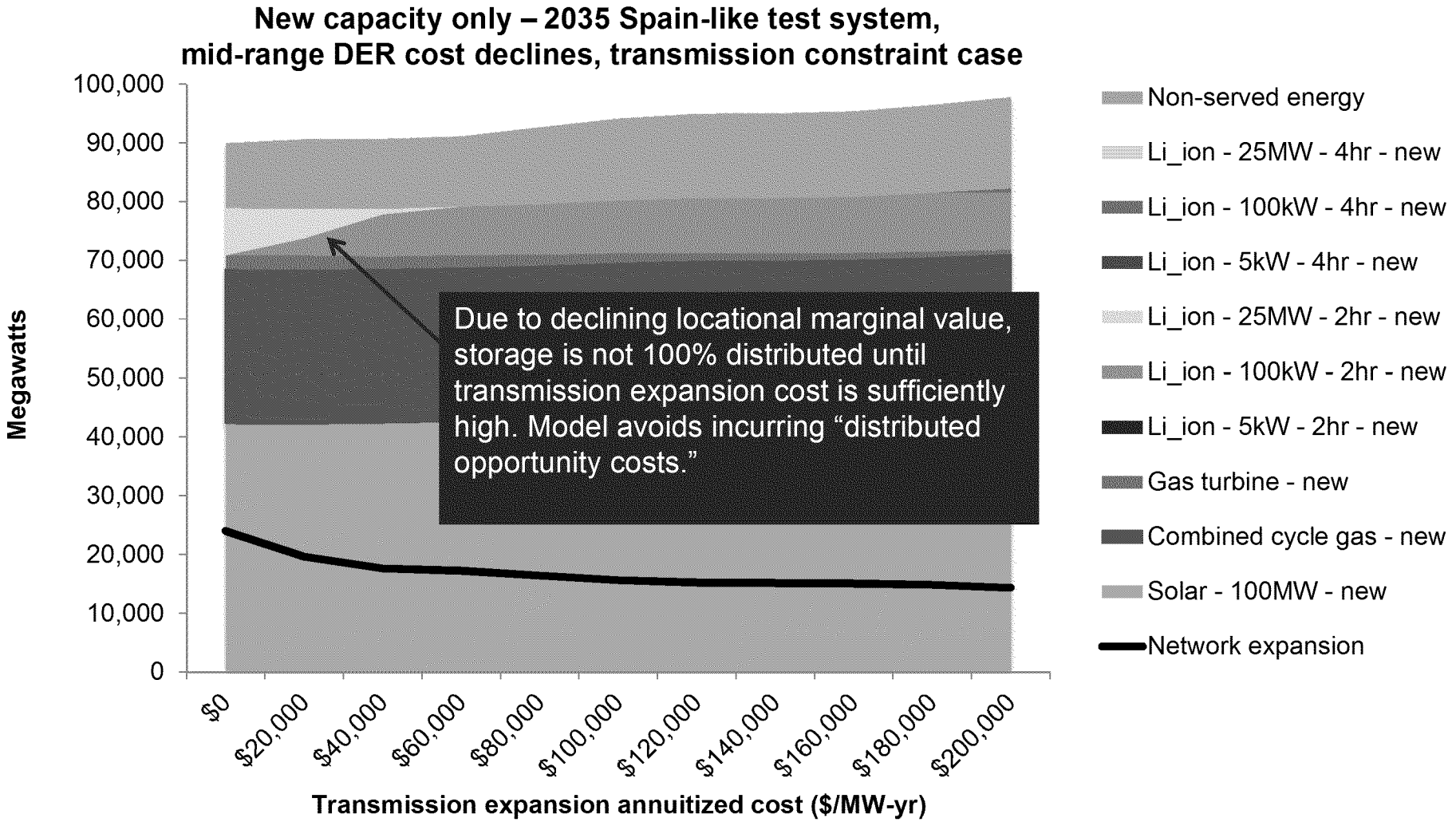
TRANSMISSION EXPANSION AND STORAGE CASE STUDY



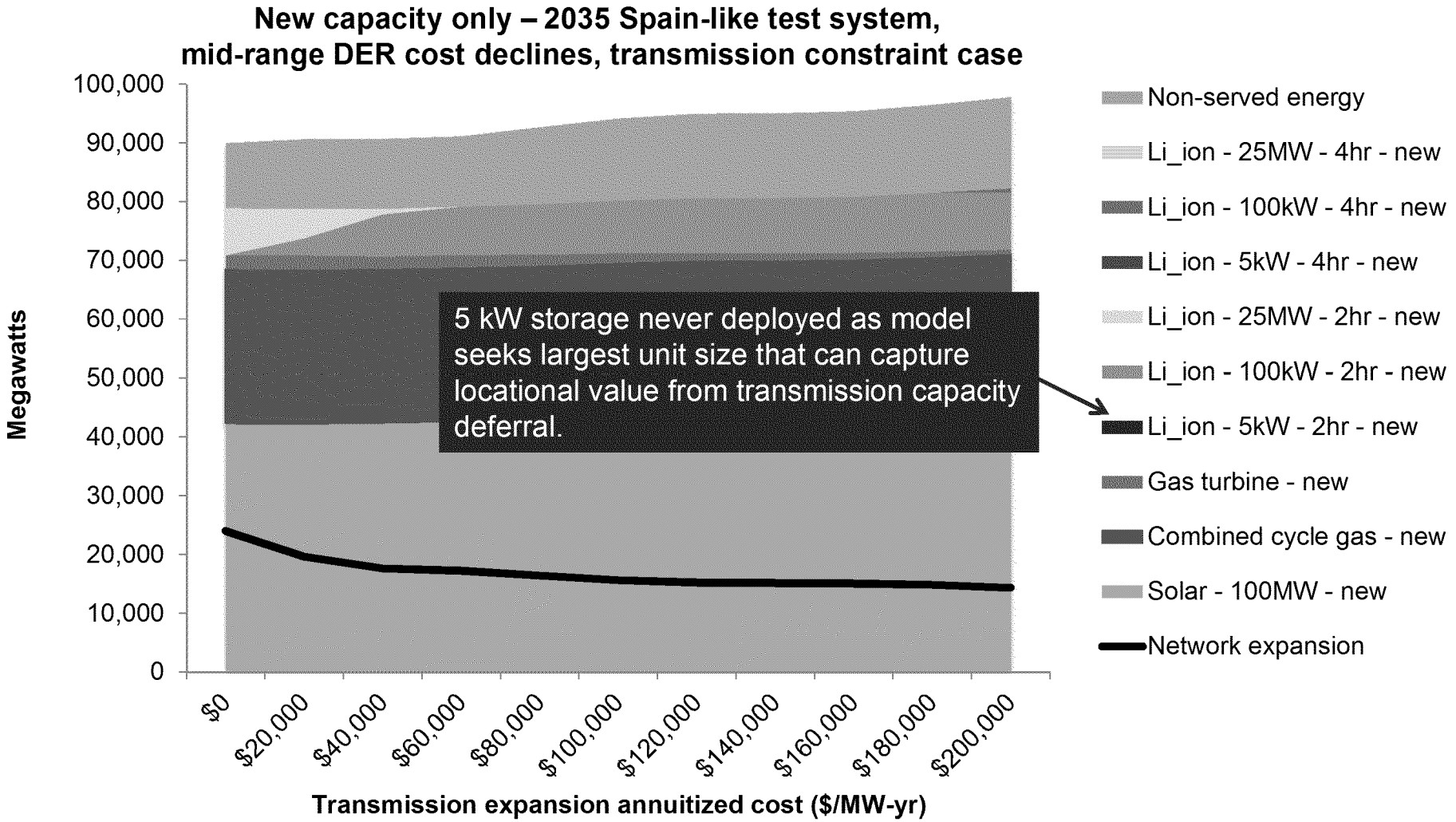
TRANSMISSION EXPANSION AND STORAGE CASE STUDY



TRANSMISSION EXPANSION AND STORAGE CASE STUDY



TRANSMISSION EXPANSION AND STORAGE CASE STUDY



TRANSMISSION EXPANSION AND STORAGE CASE STUDY