SESAME: A New Tool for Life Cycle and Economic Assessment of Technology Pathways

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MITEI External Advisory Board Meeting
Cambridge, MA
October 24th, 2019

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Towards meeting the dual challenges of increasing energy supply while reducing GHG emissions, the need to understand the suite of available technology pathways and how they integrate into the energy system has become critical

Is there a role for natural gas?

What is the best strategy to decarbonize industry?

What is the impact of reduced methane leakages?

How to account for geologic/regional differences?

How much energy storage is needed for a reliable power grid?

Batteries or other technologies?

Cost of carbon?

How far can electrification go towards decarbonization?

H_2 for hard to electrify sectors?

Demand side response?

What does the energy system need for deep decarbonization?

Can algae biofuel be a viable liquid fuel?

What does the energy system need for deep decarbonization?

Emission reduction vs cost?

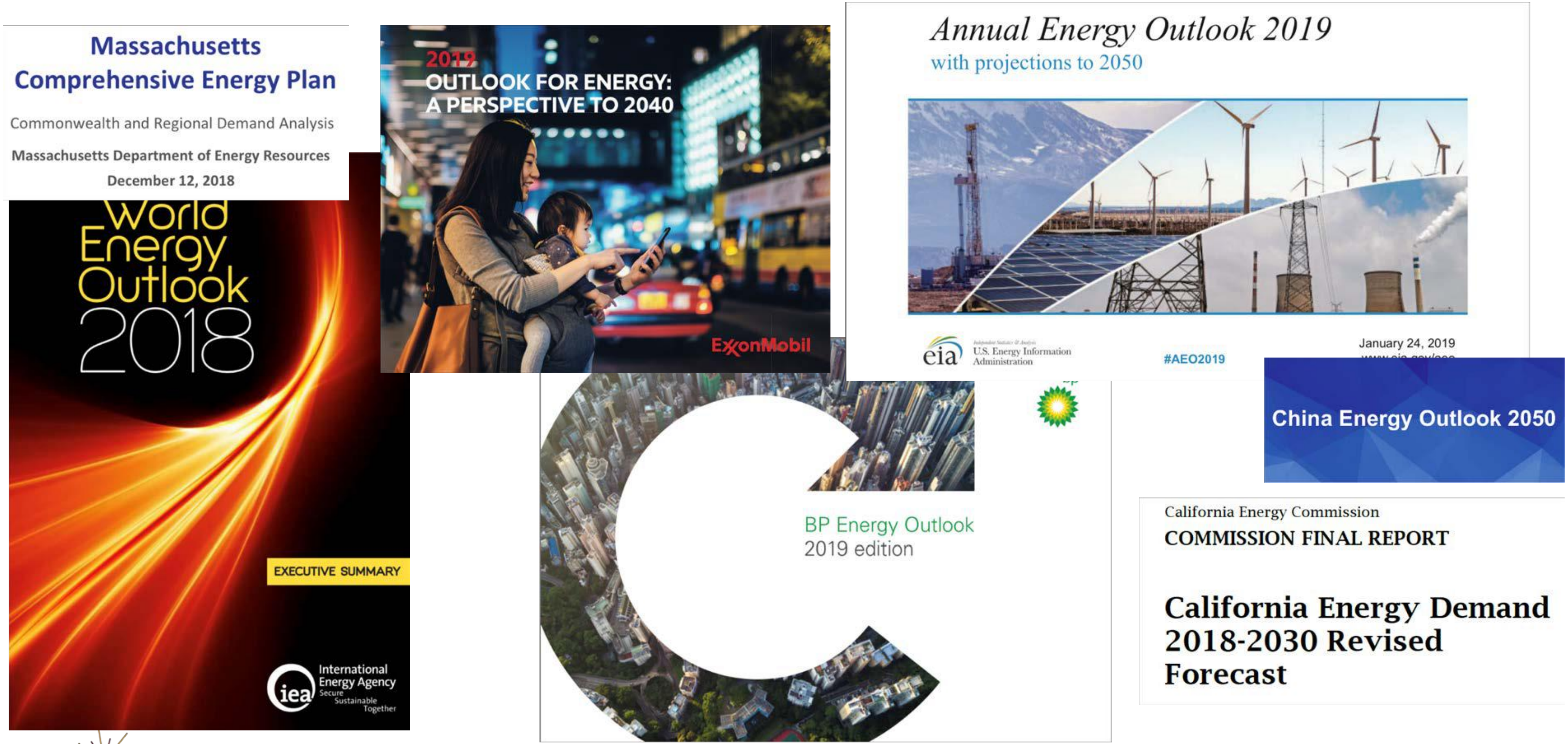
Do we need negative emission technologies?

Infrastructure requirement for different scenarios?

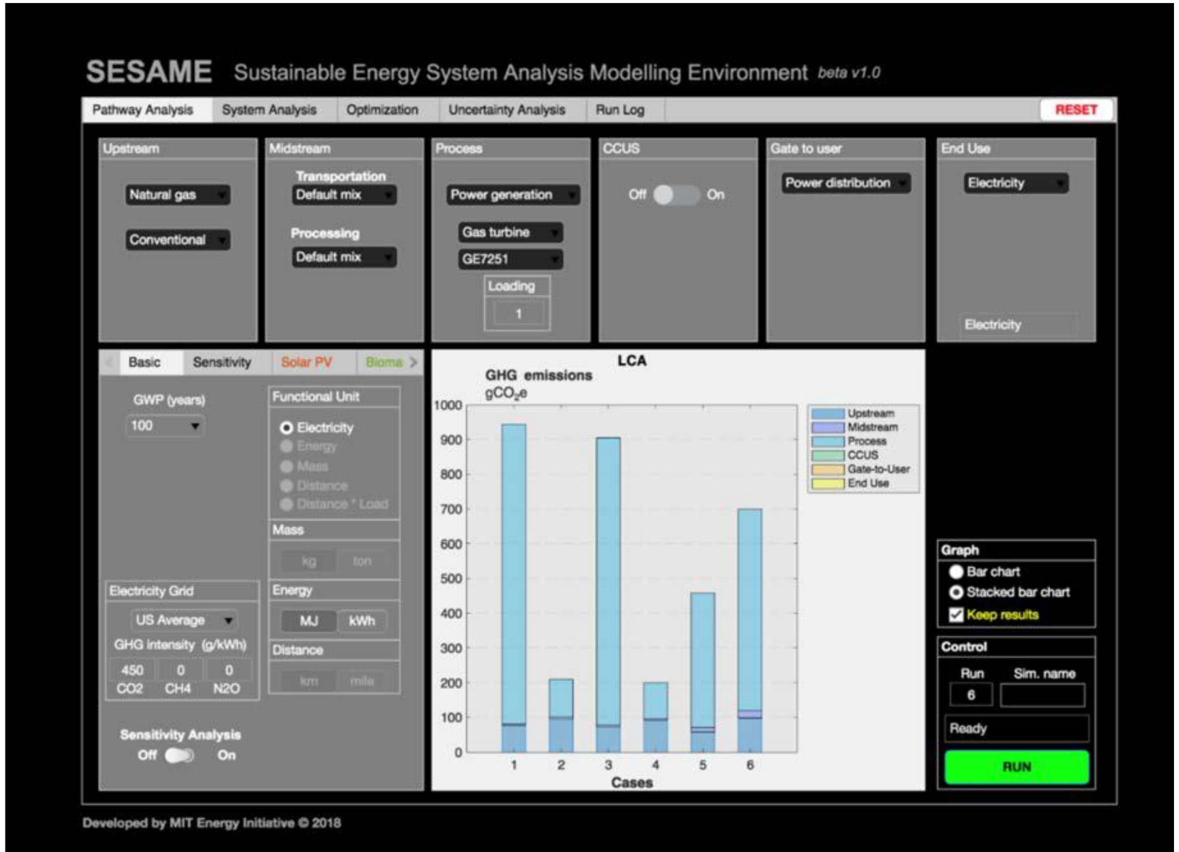
Carbon capture and sequestration: friend or foe?

How can we make existing assets more efficient?

Pressing need to capture the changing dynamics of energy transition in evaluating plausible energy futures, pathways and options considering environmental and economic elements



We have developed SESAME to understand the impact of all relevant technological, operational, temporal and geospatial variables to the evolving energy system



Sustainable Energy Systems Analysis Modeling Environment

- Exploration of system level interactions
- Cross sector comparisons
- Representing market dynamics, technology adoption and usage
- Incorporation of bespoke process simulation capabilities for in-depth analysis
- Investigation of intra- and inter- pathway trade-offs
- Assessment of impacts arising from standard vs. best practices
- Quantification of geographical dependencies
- Pathway-level and systems-level analysis
- Integration of high-resolution data

EM-Phase 1: LCA of mature technologies

EM-Phase 2: TEA of mature technologies

EM-Phase 3: LCA & TEA of emerging technologies

IEA-GOT: Beyond GHG and region expansion

The modular structure of our platform allows the analysis of a very large number of conventional and novel pathways – More than 1000 energy pathways are embedded in the framework capturing ~90% of energy-related emissions

UPSTREAM

Fossil

- Natural gas
  - Conventional
  - Shale gas
  - Tight gas
  - Coal bed
- Oil
  - Conventional
  - Tight oil
  - Oil sands
  - Oil shale
- Coal
  - Bituminous
  - Sub-bituminous
  - Lignite

Renewable

- Biomass
  - Corn
  - Corn stover
  - Cellulosic bolt-on
  - Forest residue
  - Biogas
- Solar
  - Photovoltaics
  - CSP*
- Wind
- Hydro
- Wave & Tidal
- Geothermal

Other

- Ore, chemicals, etc.

MIDSTREAM

Gas

- Compression
- Separation
- Liquefaction
- Pipeline, Tank, Ship
- Flare

Liquid

- Separation
- Pipeline, Rail, Ship, Truck

Solid

- Drying
- Crushing / Milling
- Truck, Ship, Rail
- Uranium ore transportation

PROCESS

Heat & Power

- Sub-critical
- Super-critical
- Gas turbine
- Combined cycle
- IGCC**
- Steam generation
- Combustion
- Nuclear

Industrial

- Refinery
  - Gasoline
  - Diesel
- Biorefinery
  - Ethanol (Fermentation)
- Gasification

Production Processes for:

- CNG, LNG
- Dimethyl ether
- Methanol
- Polyethylene
- H_2
  - Steam methane Reforming
  - Partial Oxidation
  - Auto Thermal Reforming
  - Electrolysis
- Iron & Steel
- Cement

CCUS***

CO_2 separation

- Absorption
- Adsorption
- Oxy-combustion

CO_2 compression

CO_2 Utilization

- Enhanced Oil Recovery
- Solvent
- Chemical production

CO_2 Storage

- Aquifer
- Unmineable beds
- Enhanced Oil Recovery

GATE TO USER

Power

- Transmission lines
- Distribution lines

Heat

- Steam

Gas

- Filling stations
- Pipeline, Tank, Ship

Liquid

- Pipeline, Rail, Ship, Truck

Advanced Storage

- Flow batteries
- Pumped hydro
- Molten salt
- Li-ion

Solid

- Truck, Ship, Rail

END USE

Products

- Electricity
- Heat
- Liquid Products
  - Gasoline
  - Diesel
  - Ethanol
  - Methanol
  - Dimethyl ether
  - Liquefied natural gas
  - LPG
- Gaseous Products
  - Compressed NG
  - Hydrogen
- Solid Products
  - Cement
  - Iron & Steel
  - Polyethylene

End Users

Residential

- Solar thermal
- Advanced lighting
- Cont. commissioning
- Advanced control

Transportation

- HDV
- LDV Technologies
  - ICEV
  - Hybrid
  - EV
  - FCV
- Engine efficiency

Industrial

- Efficiency
- Process enhancement & intensification

*Concentrated Solar Power, **Integrated Gasification Combined Cycle, ***Carbon Capture, Utilization & Storage

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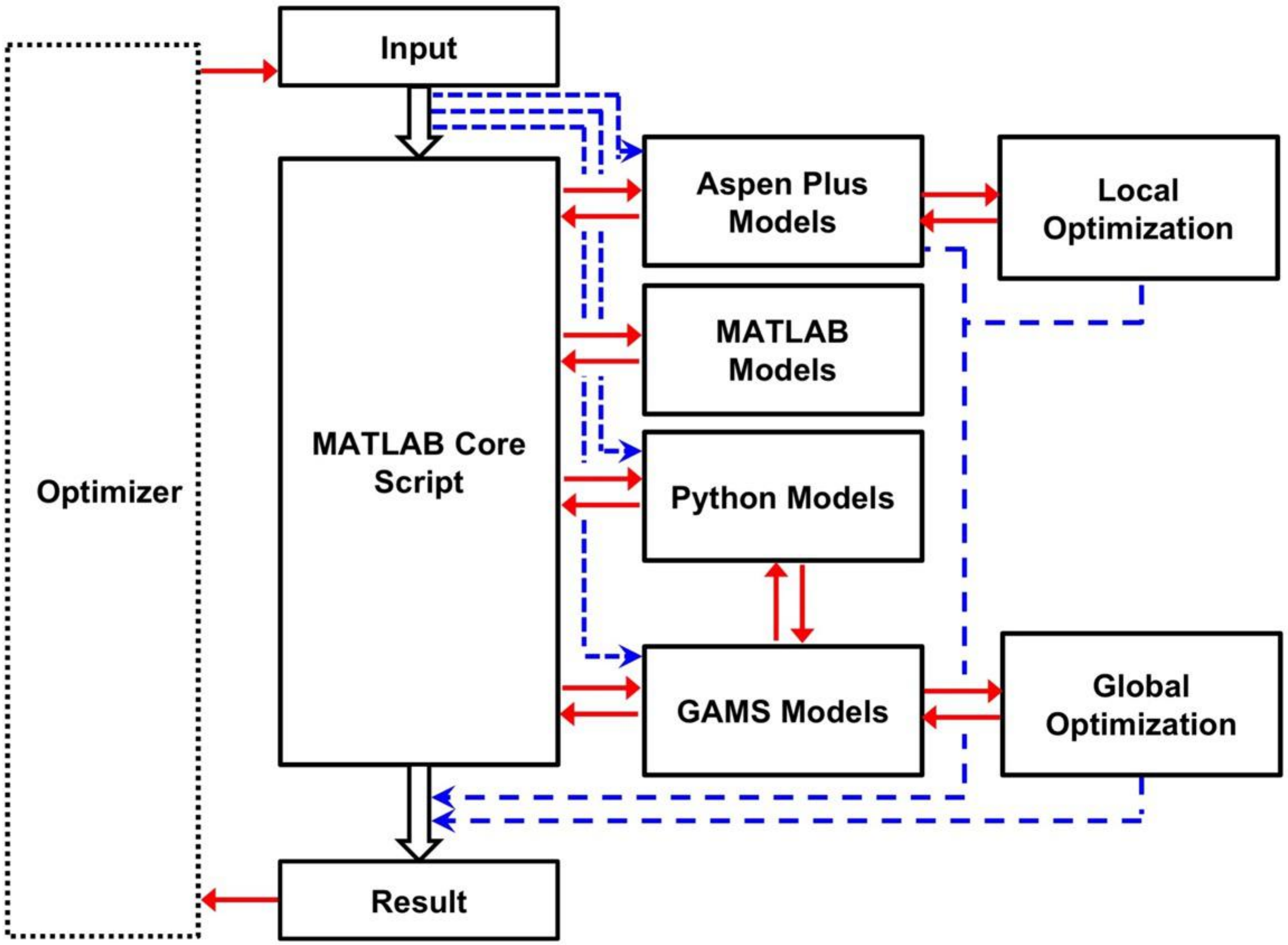
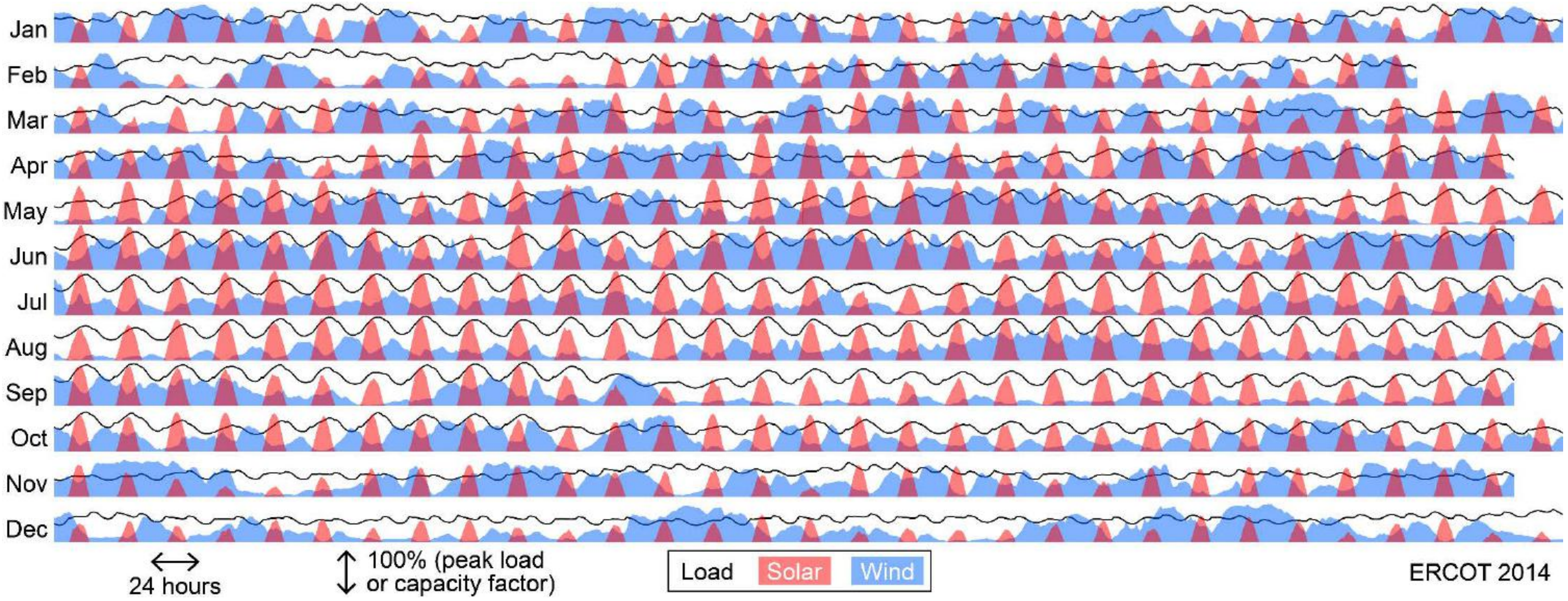
Modeling environment of SESAME allows integration of other tools and models to include state-of-the-art information



By executing the analysis using a modular framework we can establish a basis for the accurate assessment of the life cycle implications arising from complex system-level restructuring

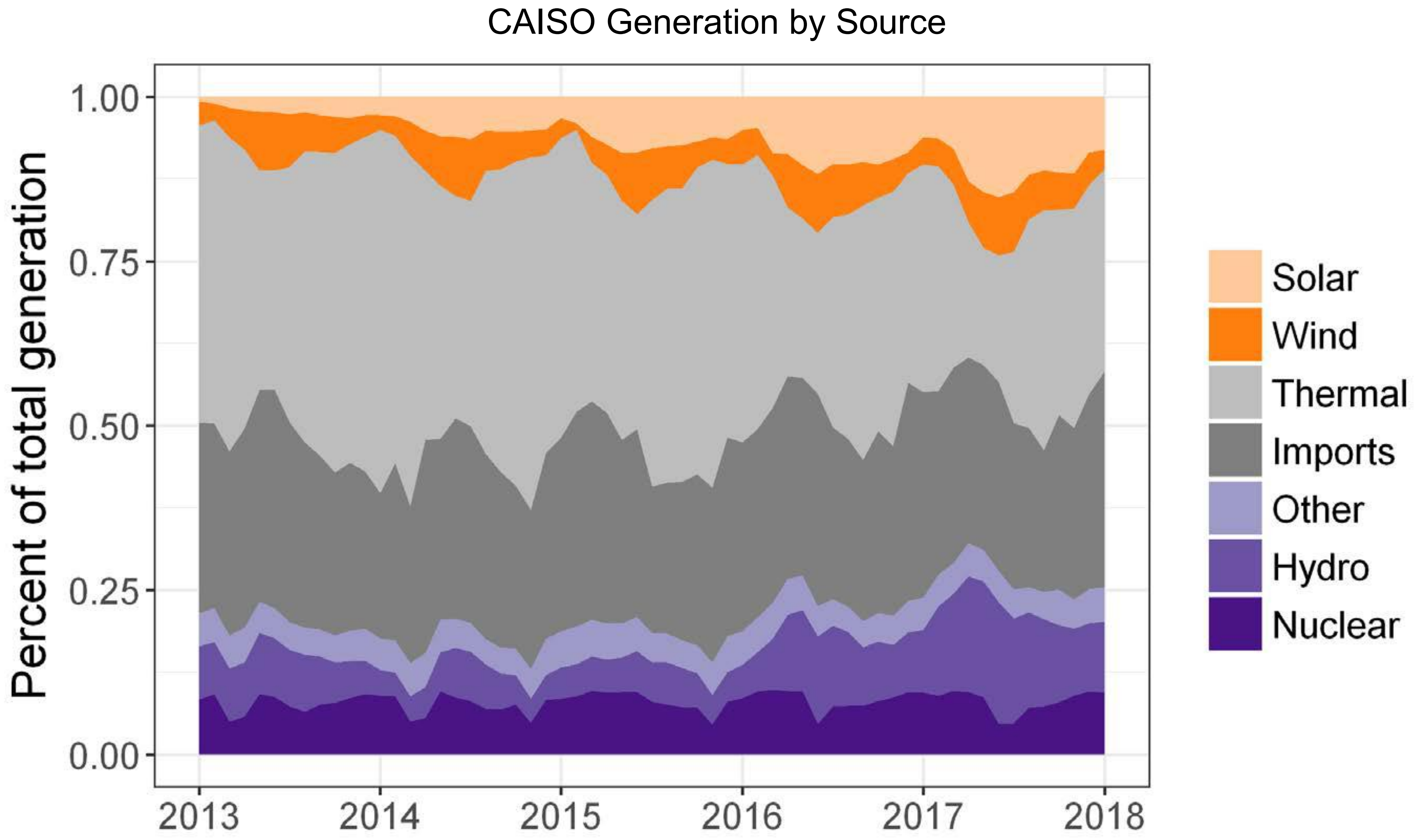
Daily variability of wind and solar resource in Texas relative to load in 2014



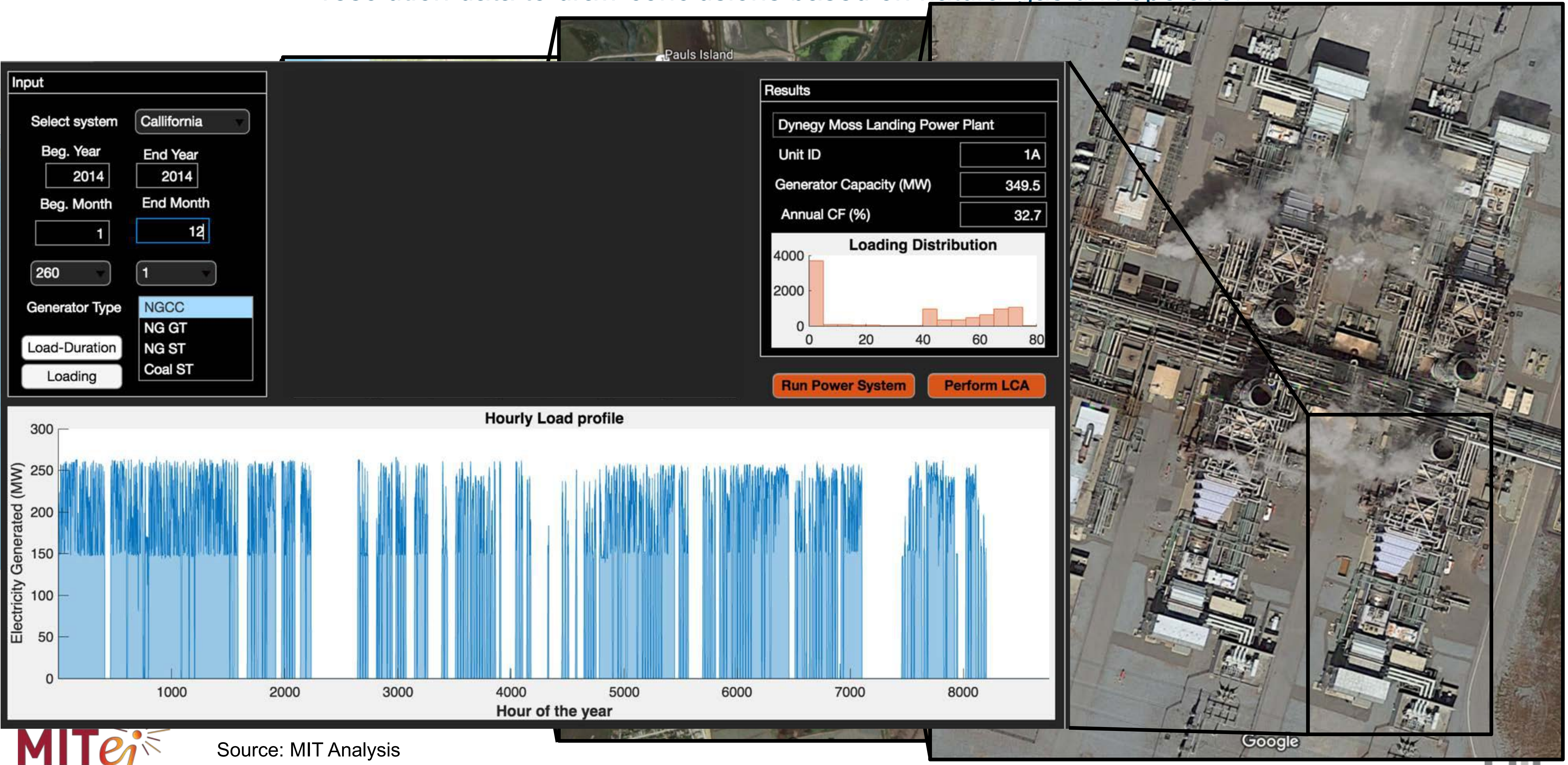
Source: MIT Analysis, NSRDB, ERCOT, P. Brown

Example Analysis 1: Electric Power System

Solar generation in CAISO grew by 14 percentage points (from 3 to 17 percent of total generation) between 2013 and 2018 – What are the consequences and implications of this expansion for existing dispatchable generation?

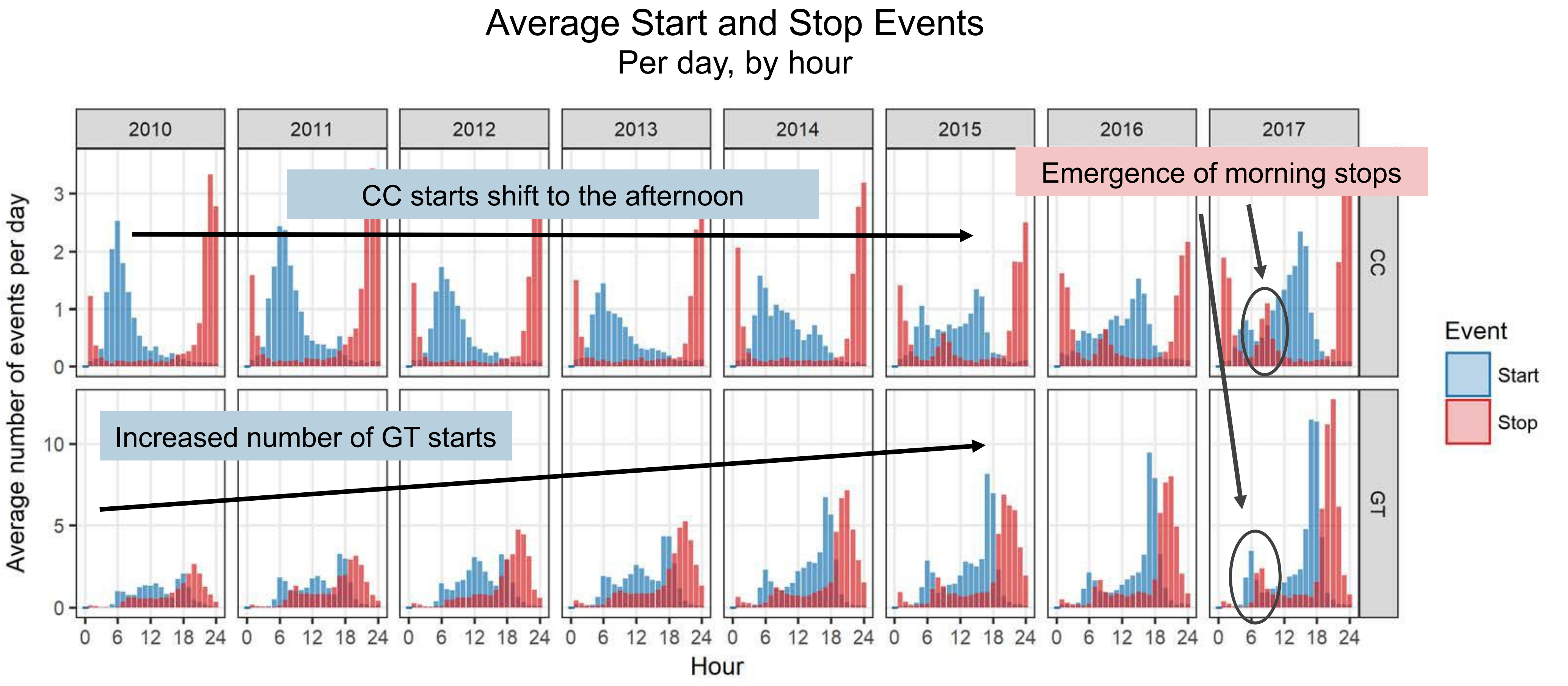


Exploring dynamic power system responses to expanding renewable generation – Using high-resolution data to draw conclusions based on natural gas unit operation



Source: MIT Analysis

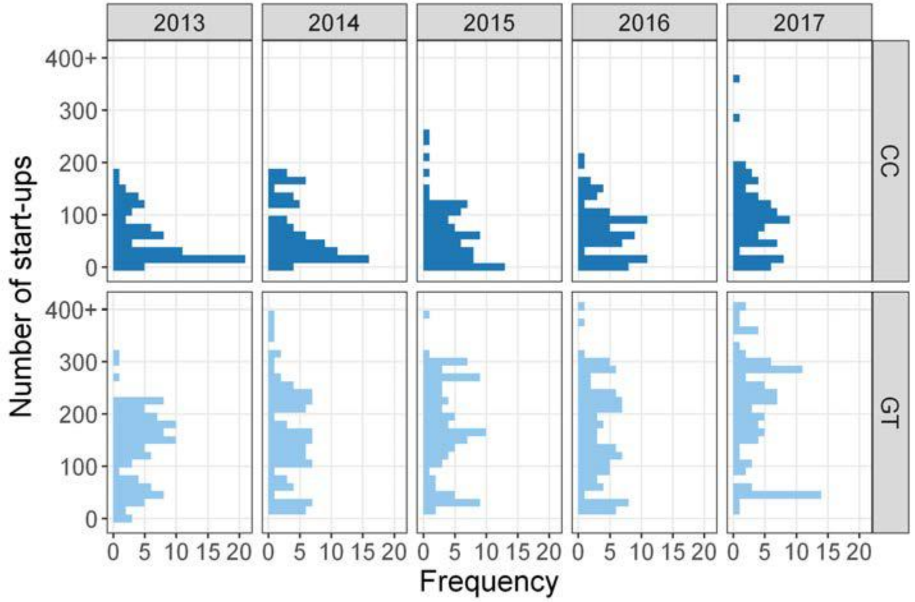
Observed trends in system-wide operating events – An increase in solar generation shifts the net load curve drastically, we examine the generation side of this outcome.

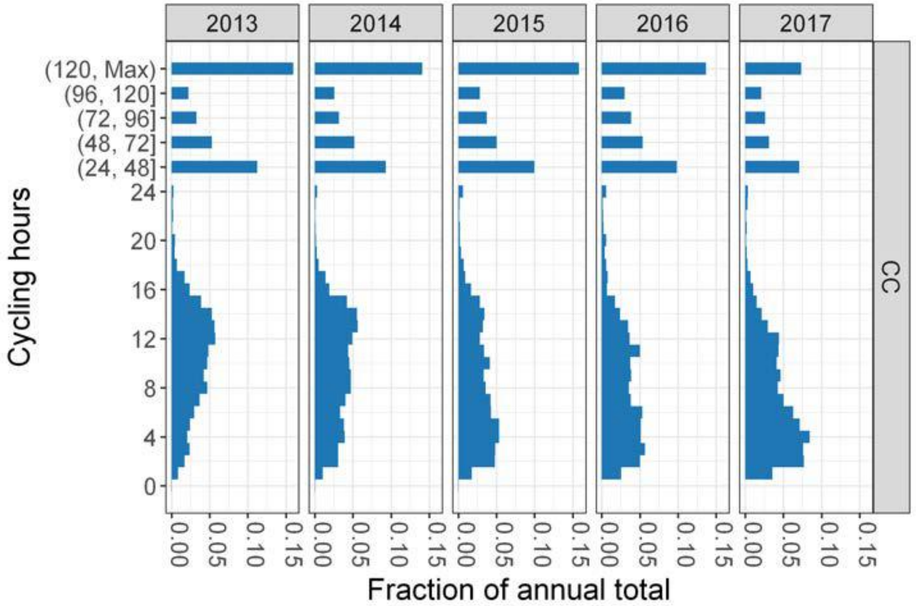


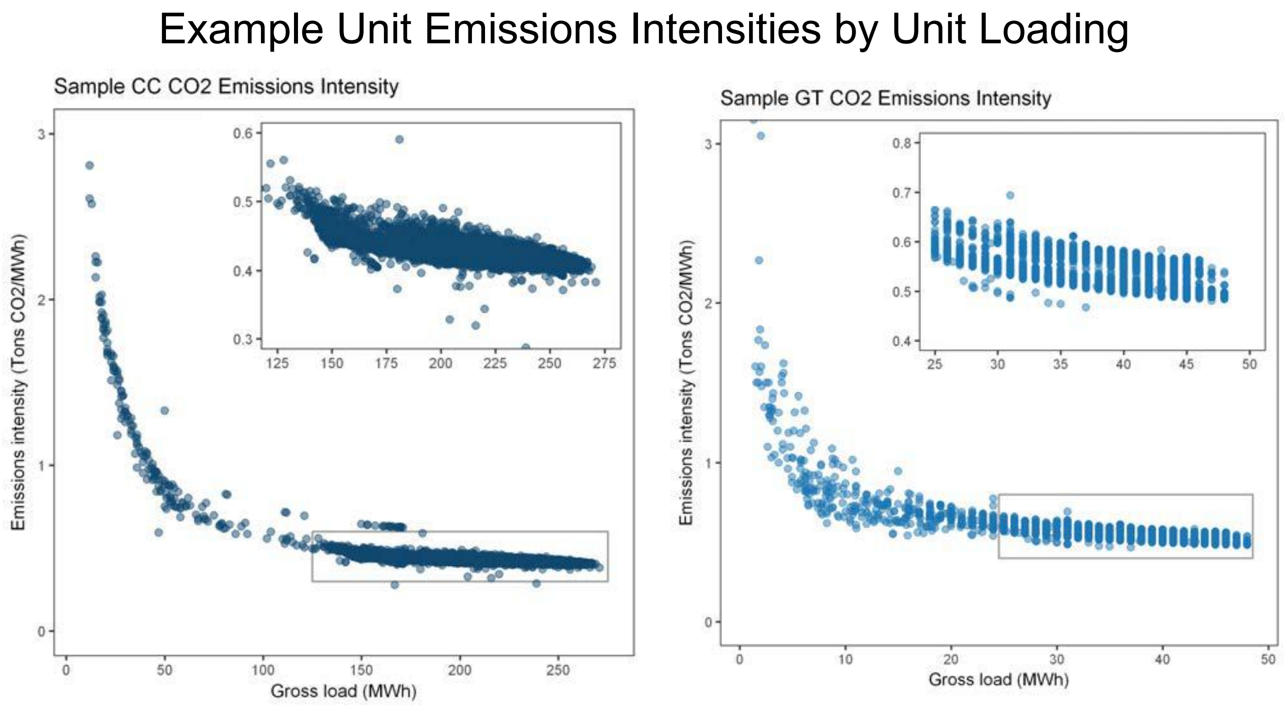
Hourly operation data are used to **identify individual start and stop events**

Source: EPA CEMS and MITEI analysis

Changes in residual load alter unit firing and cycling duration – Trends in CC and GT unit operating behavior indicate shifts in unit start and stop times as well as shorter CC cycling periods.



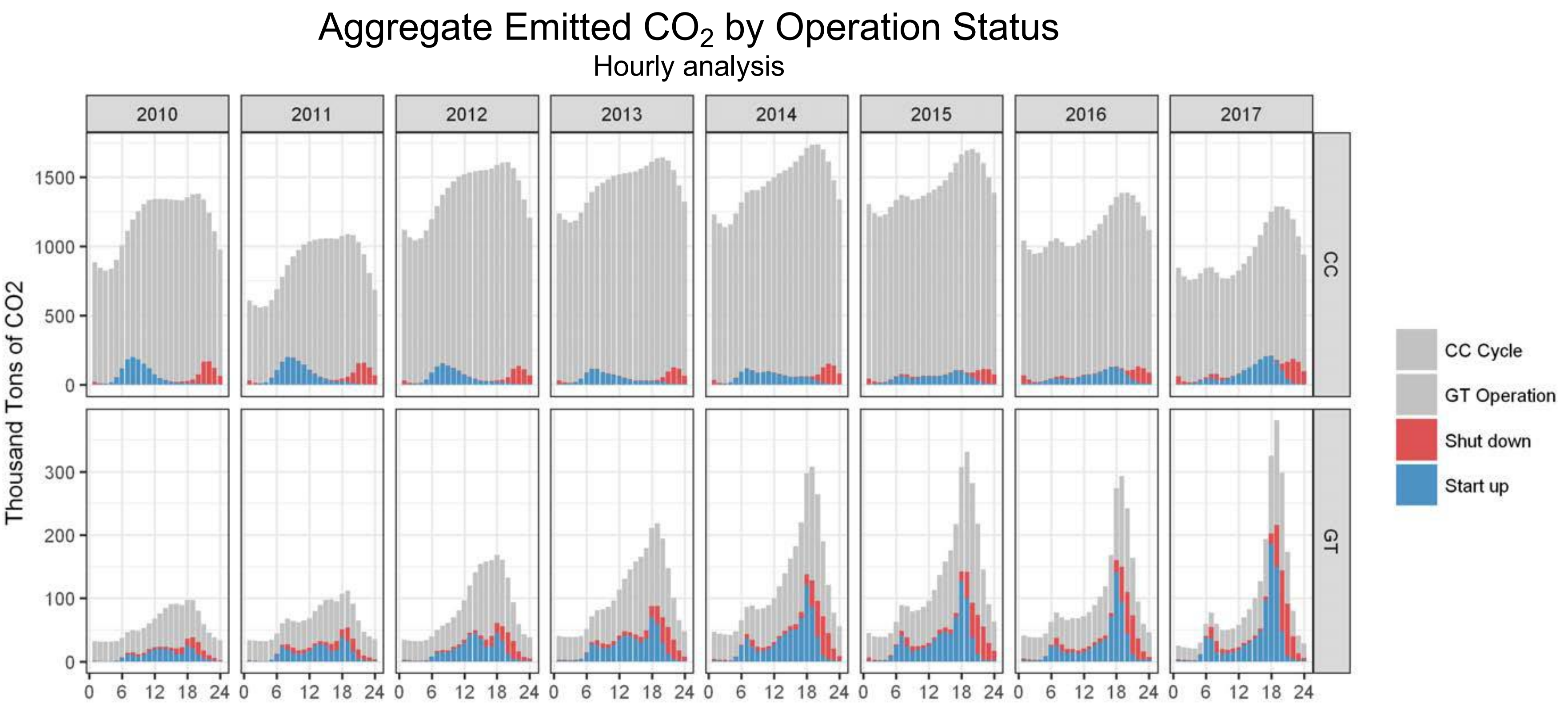


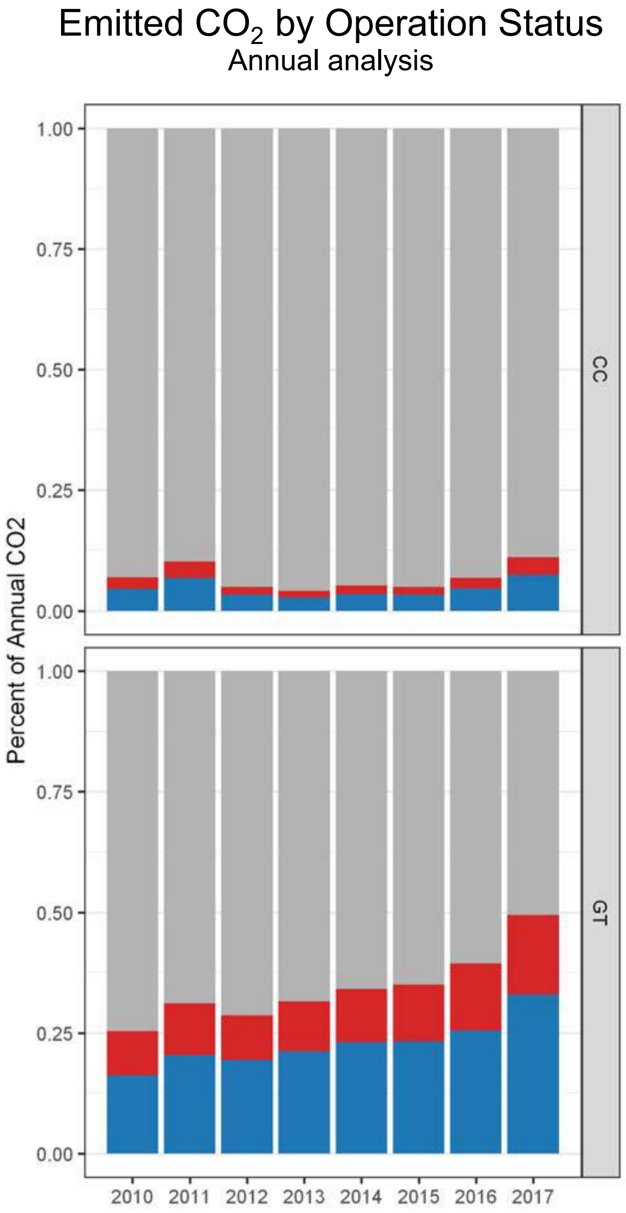


Analysis of start and stop events indicates:

- **Increased number of starts** for both CC and GT units
- Shift in **timing of start events** (especially for CC)
- Emergence of **morning start/stop routine**
- **Shorter cycling durations** for CC units

Emission consequences of operation at part-load levels – Dynamic operation alters total CO_2 emissions and the ratio of emissions during these part-load periods.

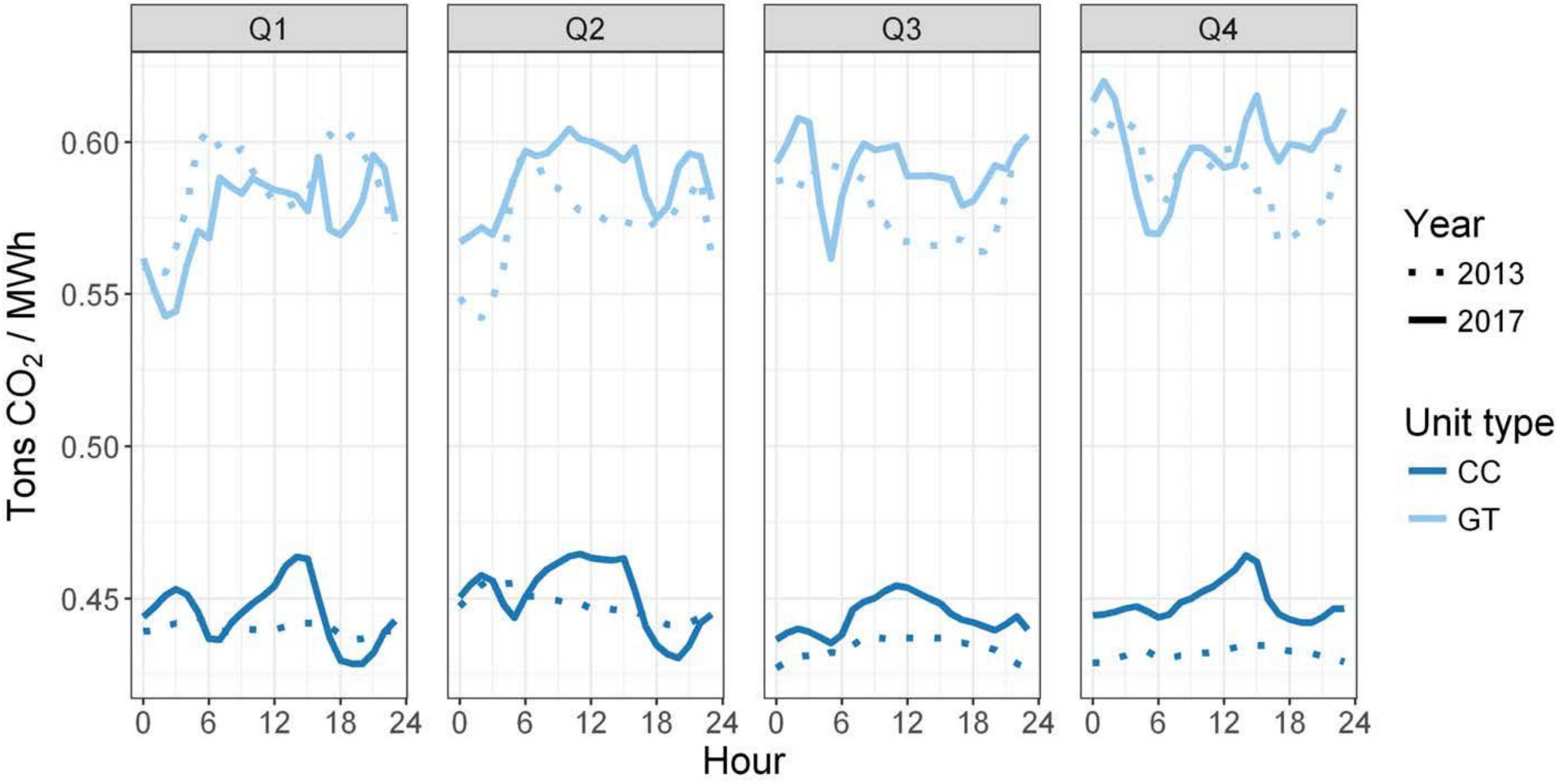




- CO_2 patterns follow gross generation trends
- Ratio of CO_2 from start-ups to CO_2 from operation increases over time
- Findings highlight the importance of understanding system-level operation trends with unit-level data

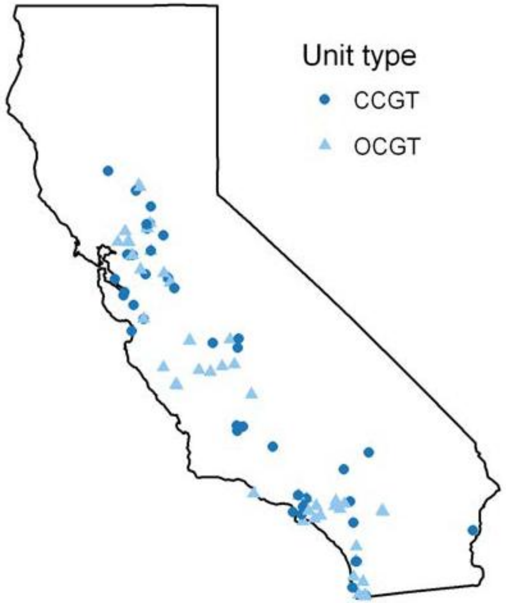
Source: EPA CEMS and MITEI analysis

The hourly variation of emission intensity of natural gas power generation units in California

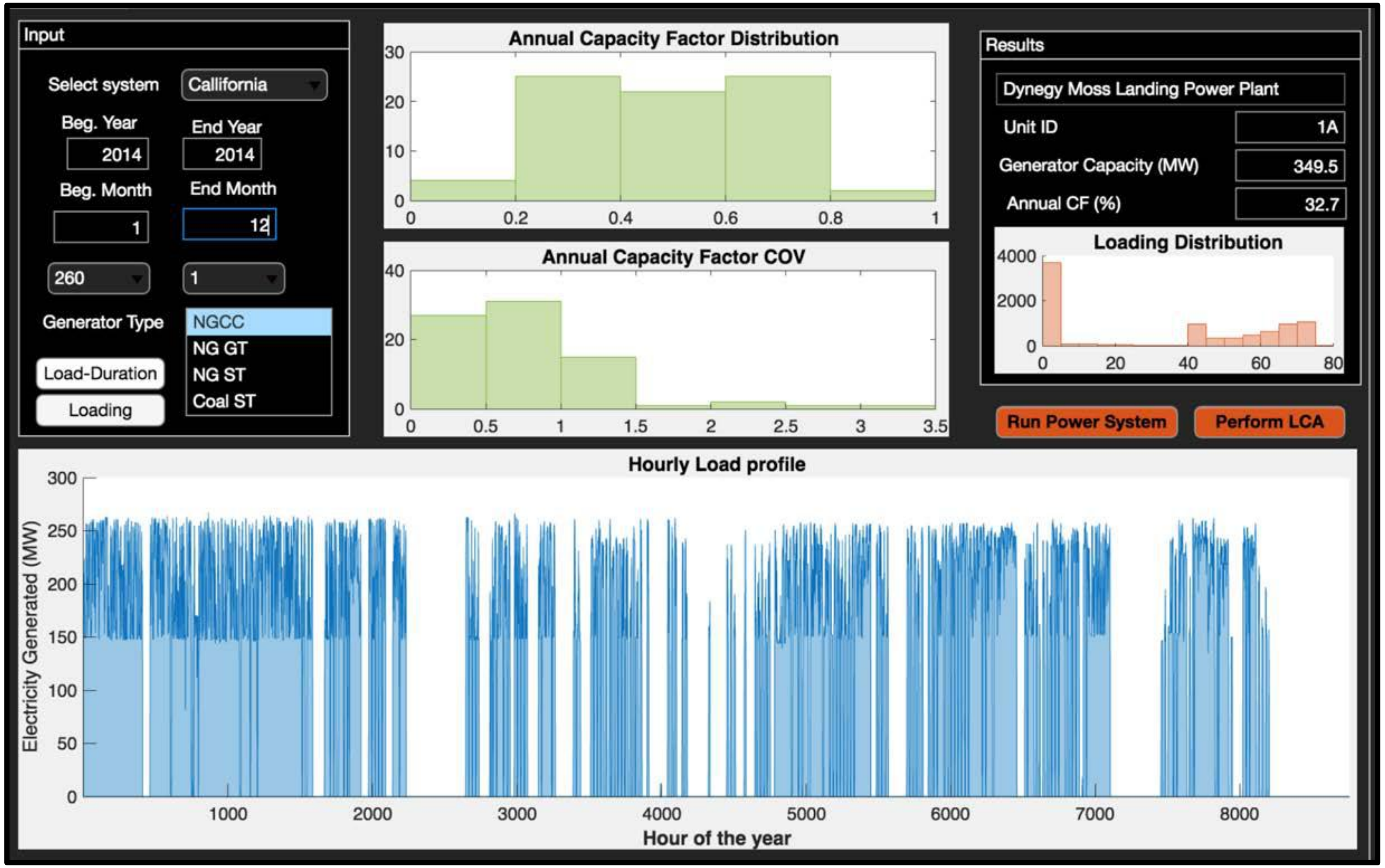


Other implications for available technology pathways?

Natural gas fleet currently provides balancing capacity but to meet decarbonization targets continued use requires deployment of CCS – Low capacity factor and operational variations will be challenging with current CC technologies.

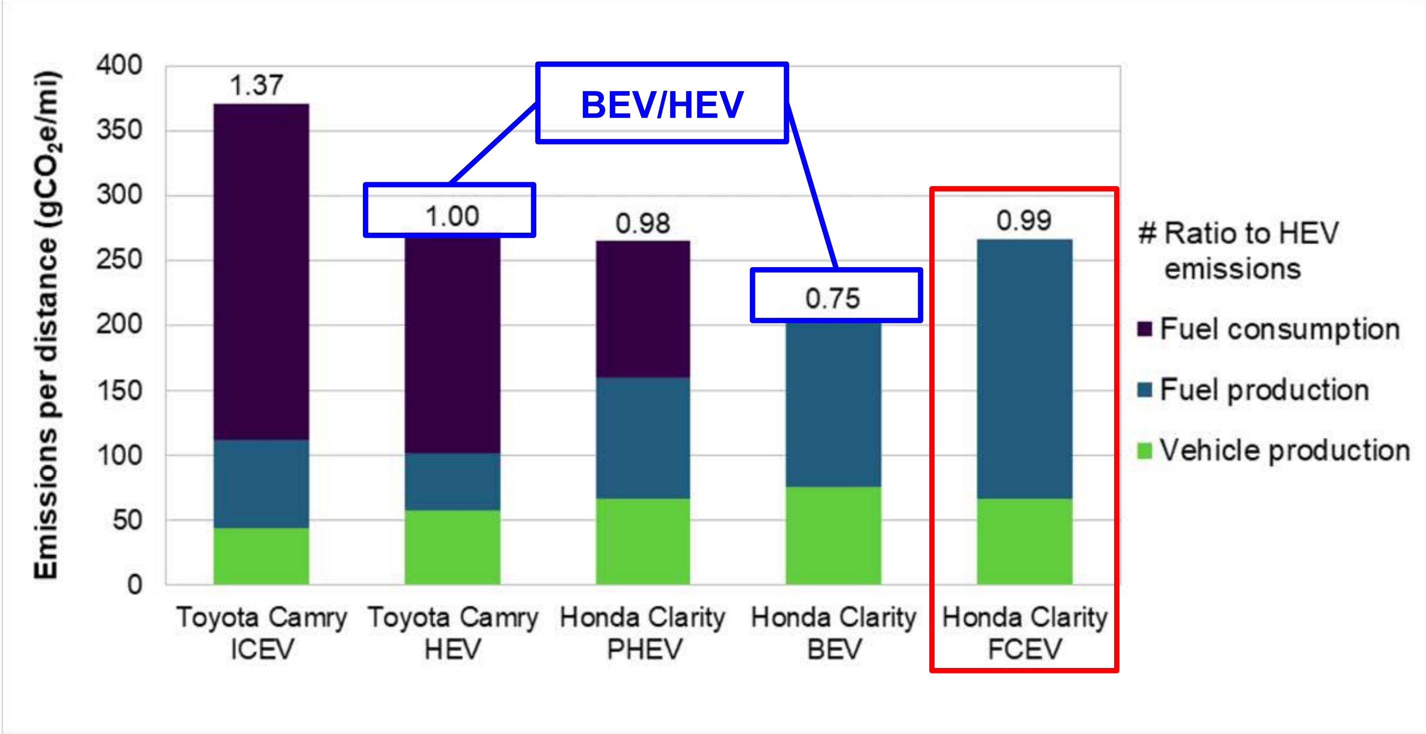


Geographic Distribution of CAISO NG Units in Sample



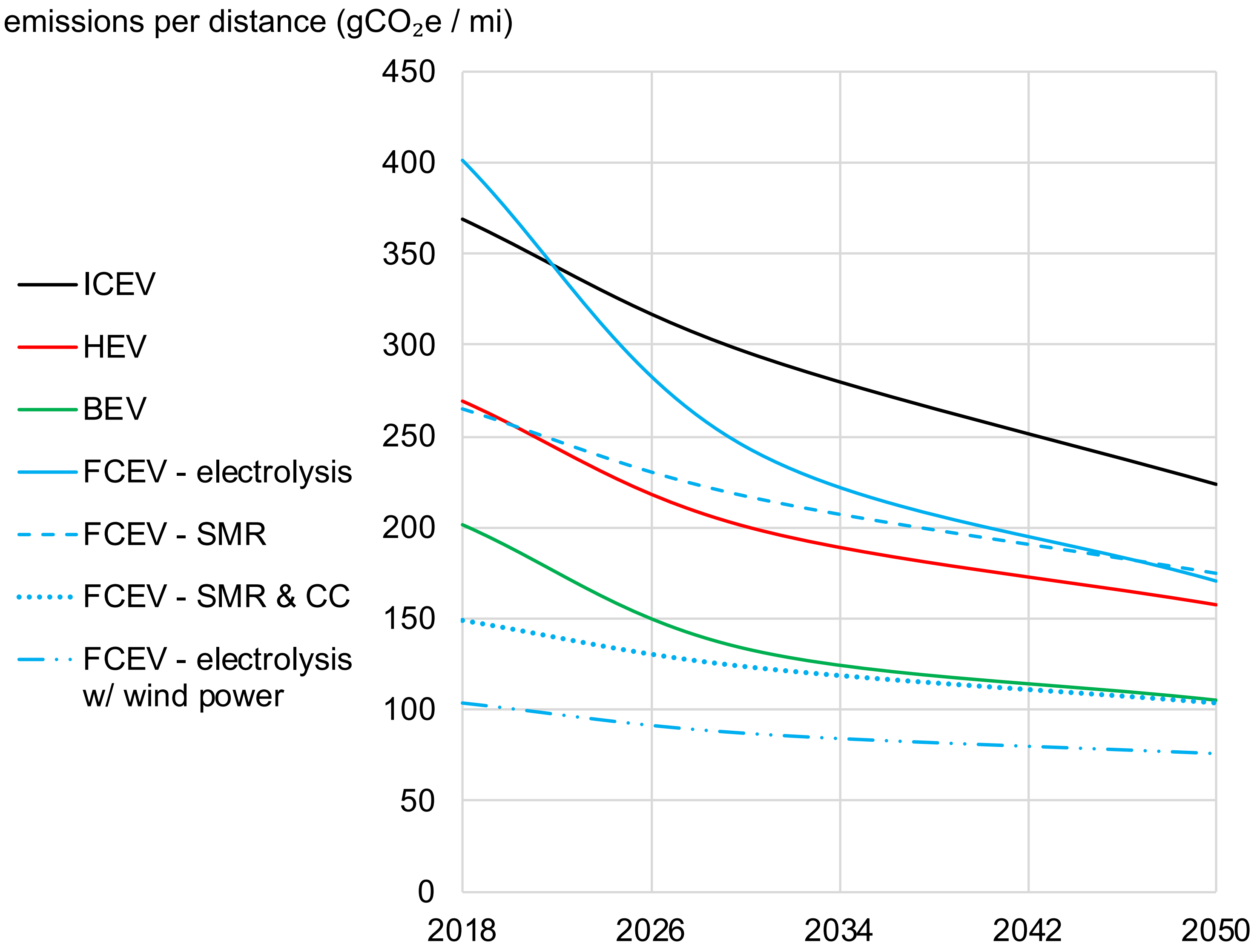
Example Analysis 2: Transportation

GHG Emissions for Vehicles with Different Powertrains *from MoF Study*



1. BEV emissions per mile are about 55% of comparable ICEVs.
2. HEV, PHEV and FCEVs emissions are all similar and fall between ICEV and BEV emissions.
3. BEV emissions are based on the average carbon-intensity of U.S. electricity
4. FCEV emissions are based on hydrogen from steam methane reforming

FCEV GHGs with Hydrogen via Different Methods



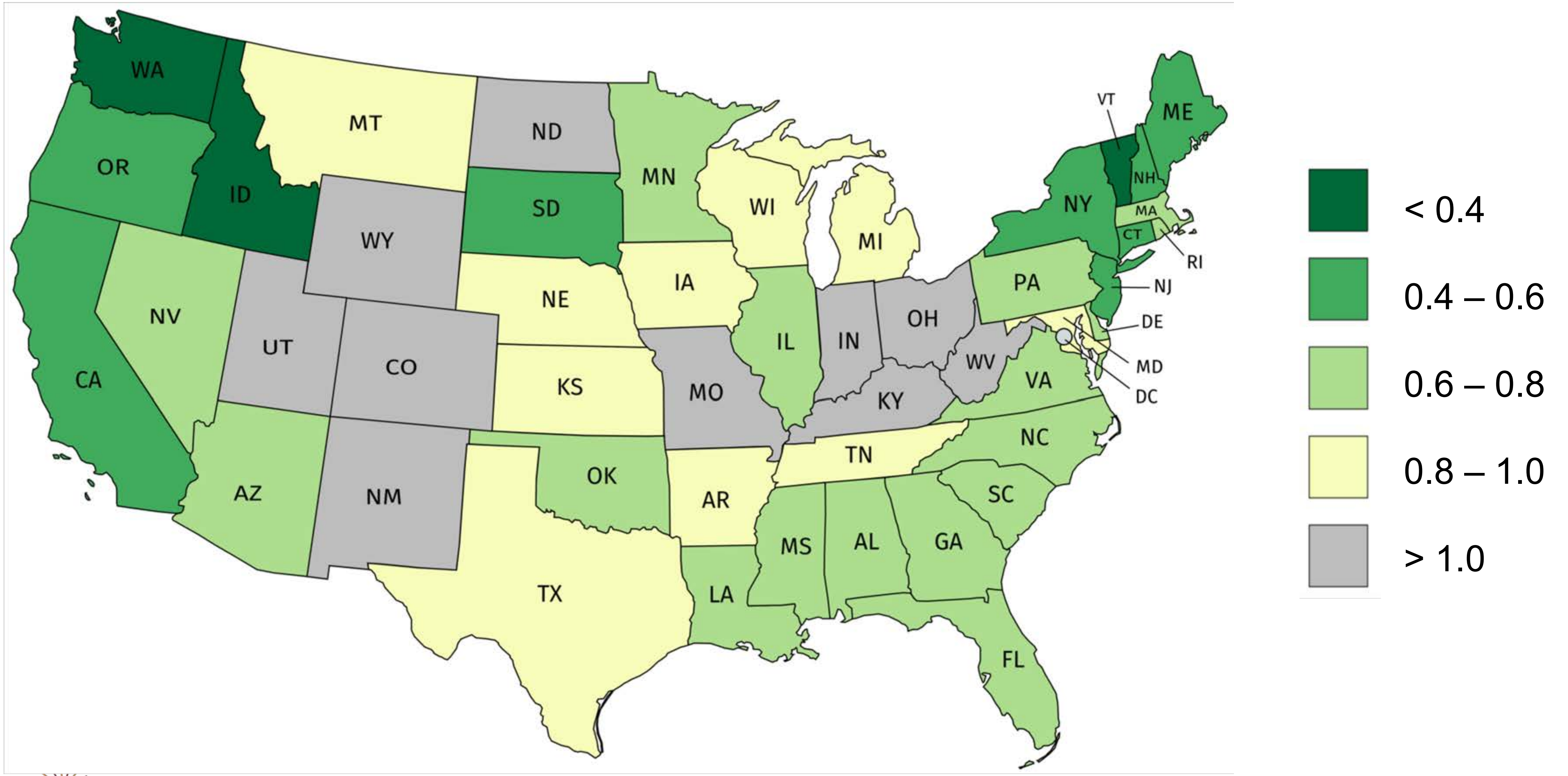
1. Electrolysis w/ wind is cleanest.

2. Compared to SMR, electrolysis w avg grid does not have carbon benefits for FCEVs, even with ~50% drop in grid carbon from 2018 to 2050.

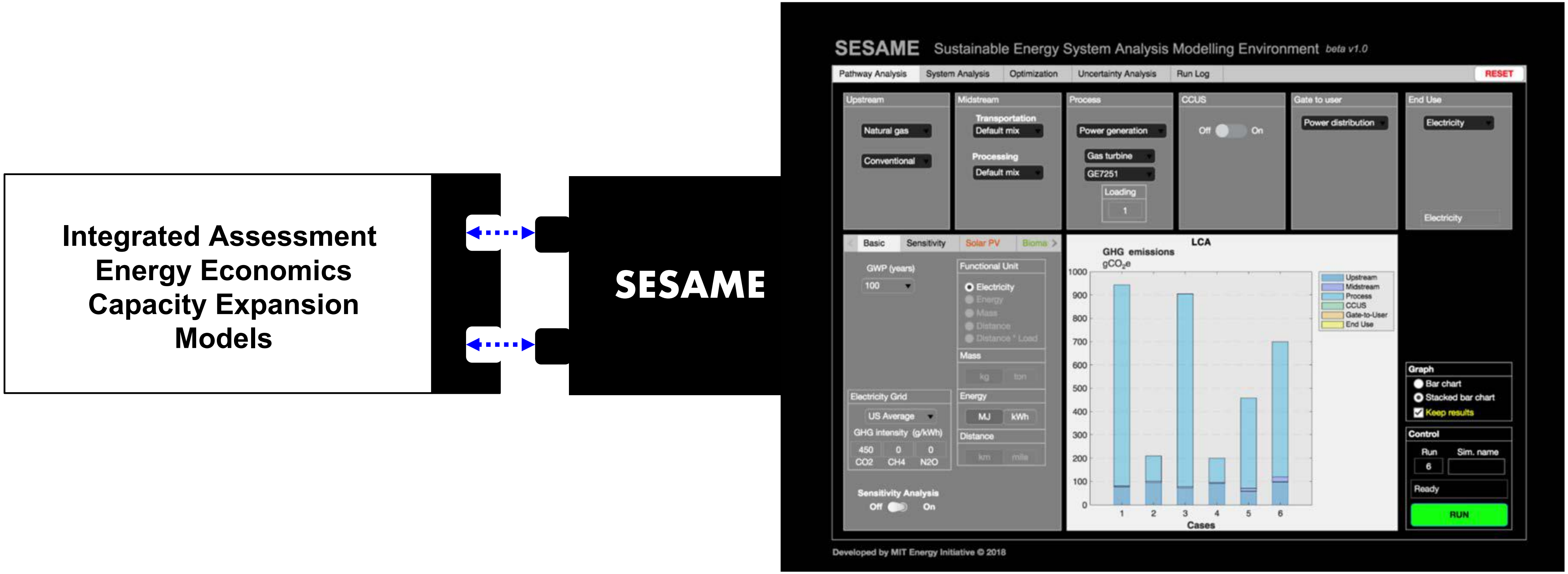
3. Adding carbon capture to SMR reduces FCEV emissions to similar level as BEVs.

Sources: MITEI Analysis I. Miller and E.Gençer, SESAME model

BEV / HEV GHG Emissions Ratio Across United States



A key focus for SESAME as a systems-level technology assessment tool is to provide insights on the feasibility, scalability, and emission reduction potential of various technology pathways as the energy system restructures

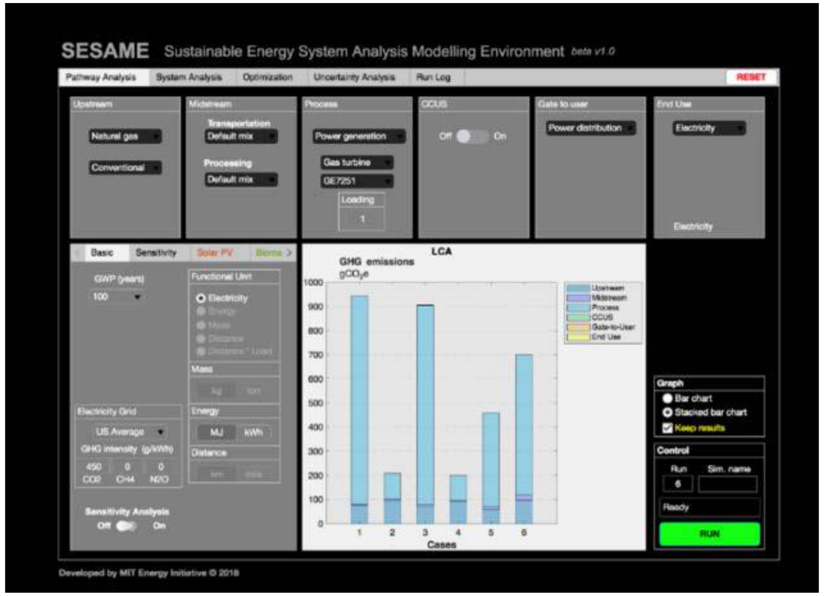


Key takeaways

- Understanding the evolving energy system requires new analytical methods and tools that allow exploration of system level interactions and perform cross sectoral comparisons.

- Impacts arising from standard vs. best practices can have a significant impact such as in California's natural gas fleet. Multi-level analysis with integrated process simulation capabilities can accurately predict these behaviors.

- The shift in energy system from isolated to integrated and from centralized to distributed is hard to characterize. High temporal and geospatial resolution is a must for any accurate analysis.



Thank you

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