Electricity market modeling in TIMES: A US illustration of key TIMES features

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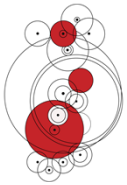
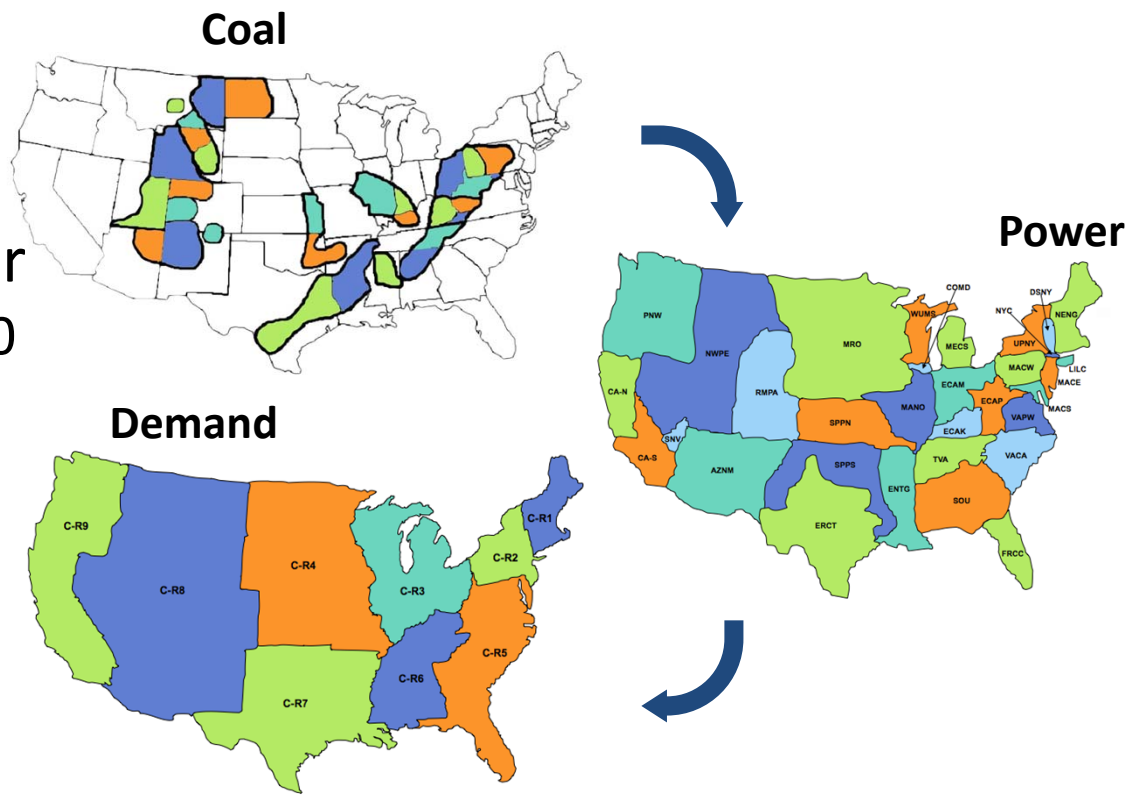


Outline

- FACETS model overview
- MATS-CES analysis
  - Modeling existing capacity, emissions and retrofits
  - Alternative foresight conditions
- 111d analysis
  - Modeling complex policies
  - Extracting insights from many scenarios

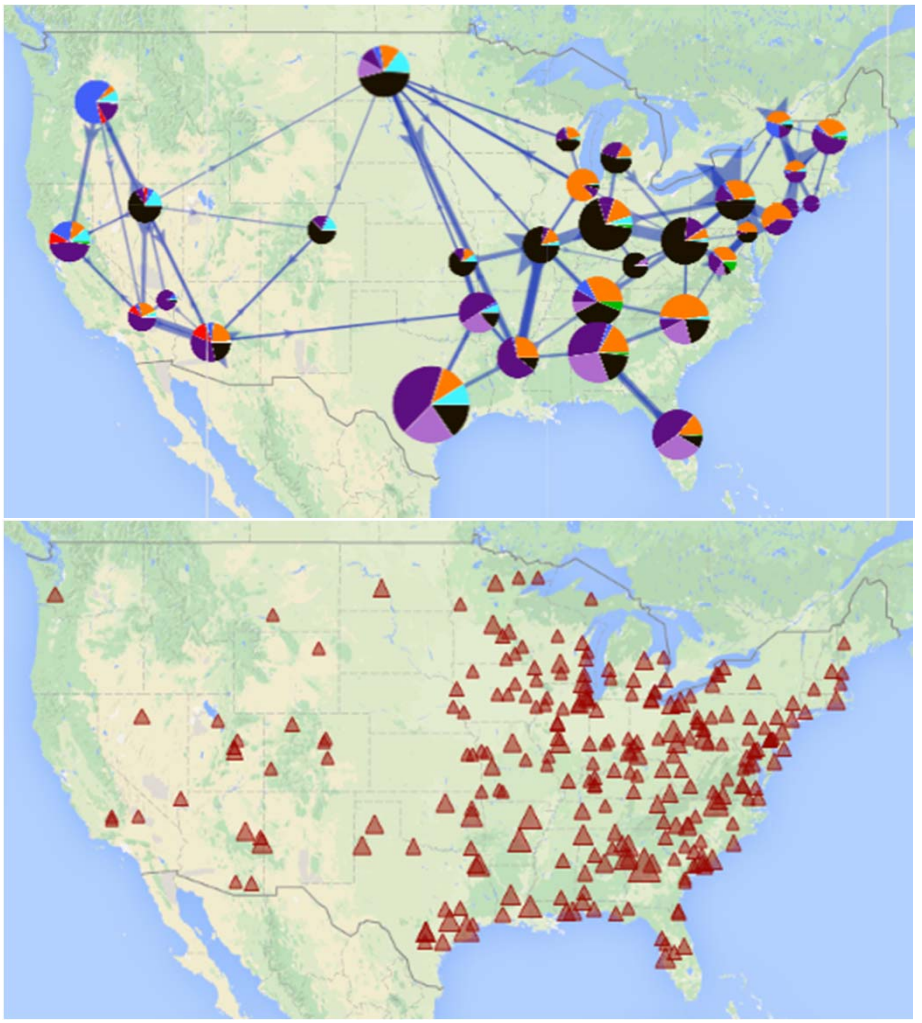
Framework for Analysis of Climate-Energy-Technology Systems

- TIMES bottom-up LP
- Multi-region in each sector
- Detailed power sector
  - 32 regions and 11,000 units
- Gas supply curves based on AEO elasticities
- Can be run with power sector only or with full end use modeling



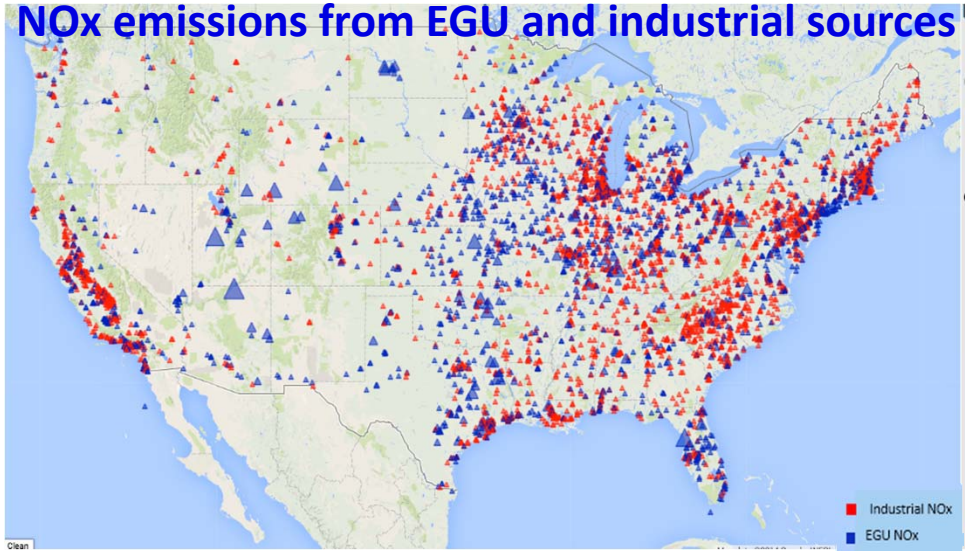
FACETS contains a highly detailed power sector

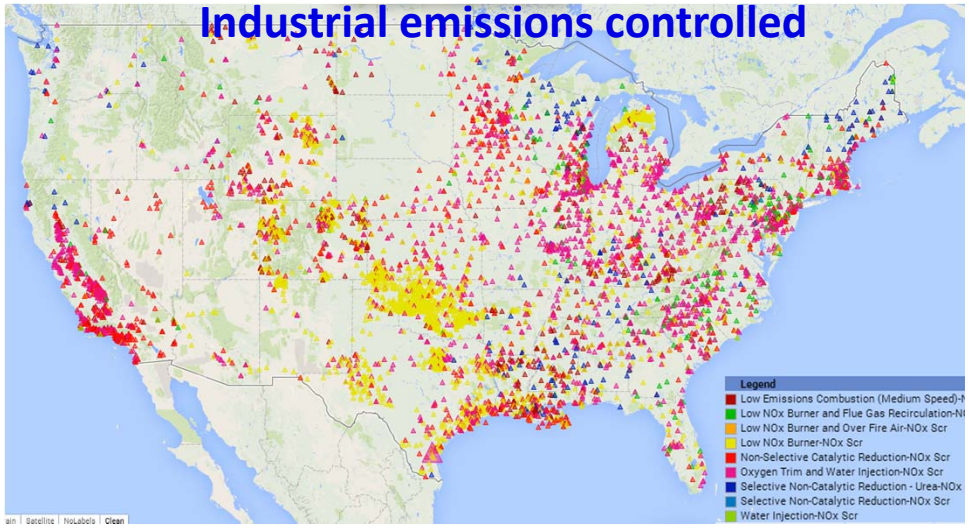
- Unit level modeling within regions that represent key transmission constraints
- Units characterized by capacity, efficiency, availability, costs, fuel choices, and online year
- Each unit is tagged by state, county, and geo-coordinates
- New units can have build rate limits/costs and lead times
- Transmission infrastructure limits and expansion options are explicit



Modular system allows level of detail to be analysis-driven

- For EPA's Clean Air Markets Division, industrial boilers and their emissions are represented at the unit level
- Each source may be controlled using detailed EPA mitigation cost data
- This sectoral detail is easily turned off for other analyses





Mercury and Air Toxics and Clean Energy Standard Analysis:

What are the costs of having to make MATS compliance decisions before future carbon policies are known?

Modeling MATS compliance is complex

- Mercury and acid gas emissions depend on coal type and quality, boiler type, and emissions control equipment
- Emissions constraints are imposed at the unit level
- Many compliance routes may be available to each unit

Emissions control retrofit options in FACETS

Equipment	Capital Cost (2004$/KW)	Addition to Fixed O&M ($/KW-yr)	Addition to Variable O&M (mills/kwh)	Removes	Removal Rate
FGD	378-662	5.9-18.0	1.9	SO2	95%
				HCl	99%
				Hg	depends on configuration
DSI alone	30-110	0.4-2.0	5.9	SO2	70%
				HCl	90%
DSI plus FF	154-291	0.4-2.0	5.9	SO2	70%
				HCl	90%
SCR	154-219	0.5-2.3	1.1	NOx	90%
				Hg	depends on configuration
ACI alone	5-27	0.0	2.4	Hg	90%
ACI plus FF	144-228	0.5-0.9	0.5	Hg	90%

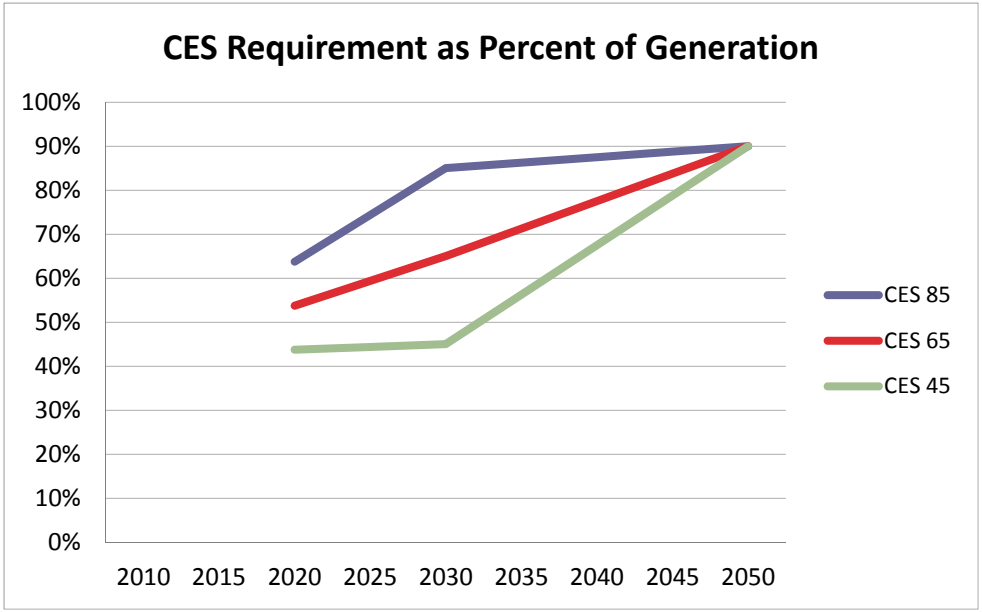
How to handle all this data?

- Specifying unit level fuel choices, emissions, and control options explicitly would be effort-prohibitive and error prone
- Veda-TIMES shell develops model data based on rules
- Many rules are based on codes in unit names and descriptions

  EPLT -< Plant name >.<Fuels>.<Coal transport cost category>.<County>-<State>.<Plant type>.<Plant size category>.<Retrofit equipment>
- These enable modeling new policies/issues by simply writing new rules

MATS – Clean Energy Standard Analysis

- MATS compliance 2017
- CES begins in 2023
- Three trajectories tested
- *Foresight* scenarios "see" the CES while making MATS retrofit-or-retire decisions
- *Myopic* scenarios don't

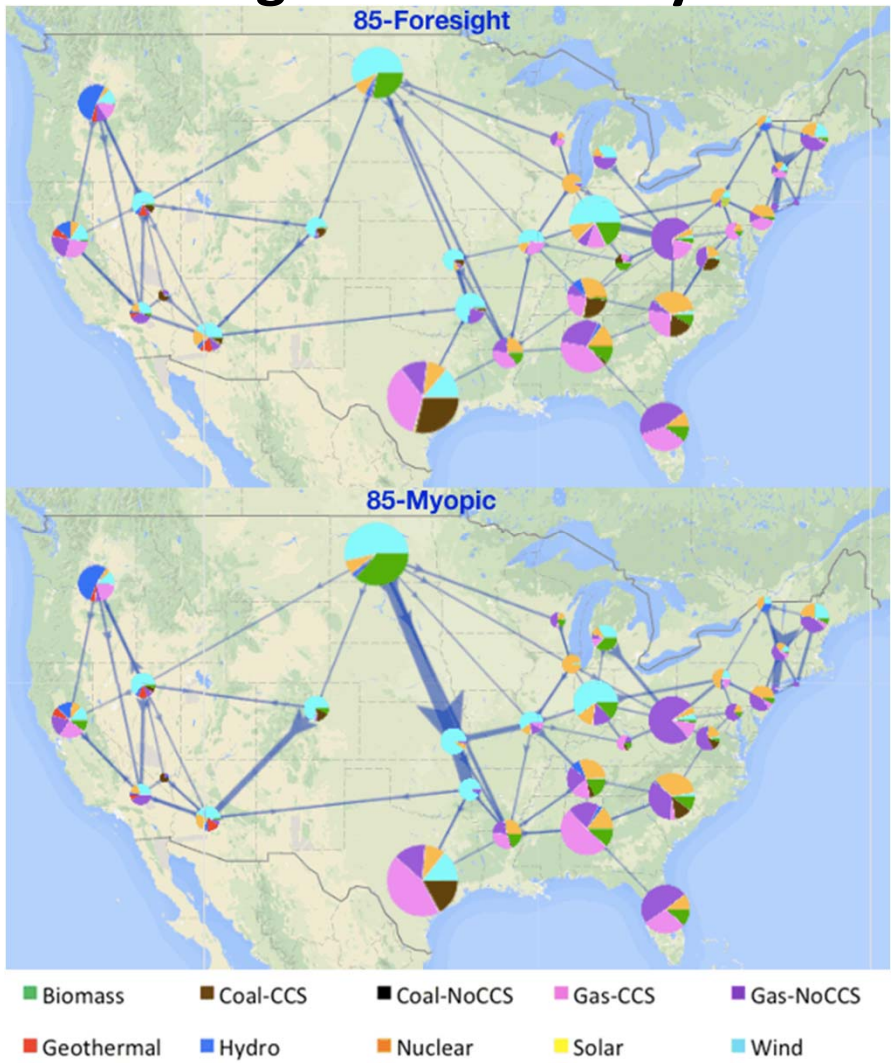


Generation Type	CES Credit per MWh
Biomass, Geothermal, Hydro, Nuclear, Solar, Wind	1
Gas Combined Cycle	0.5
Coal or Gas with CCS	0.9

System cost impacts depend on CES stringency

Scenario	Increase over Reference	Increase from Myopia
85-MY	35.6%	23%
65-MY	16.5%	9%
45-MY	8.1%	1%
85-FS	28.9%	
65-FS	15.1%	
45-FS	8.0%	

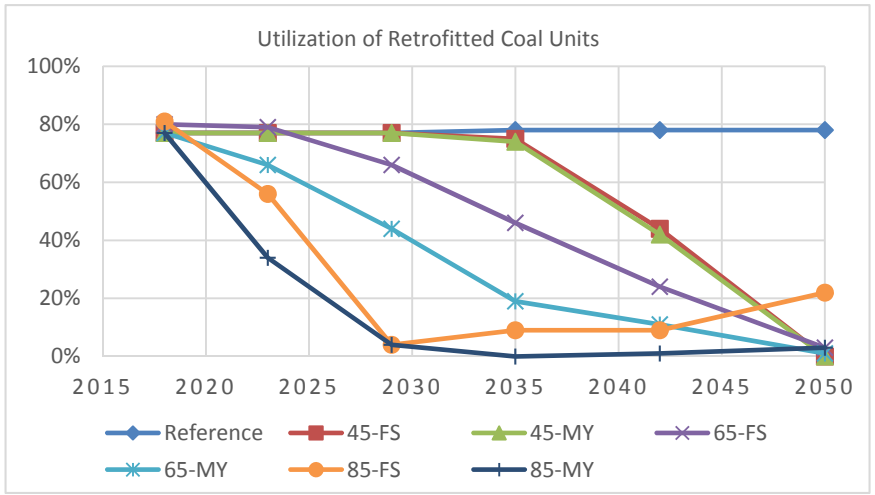
Regional generation mix and inter-regional electricity trade

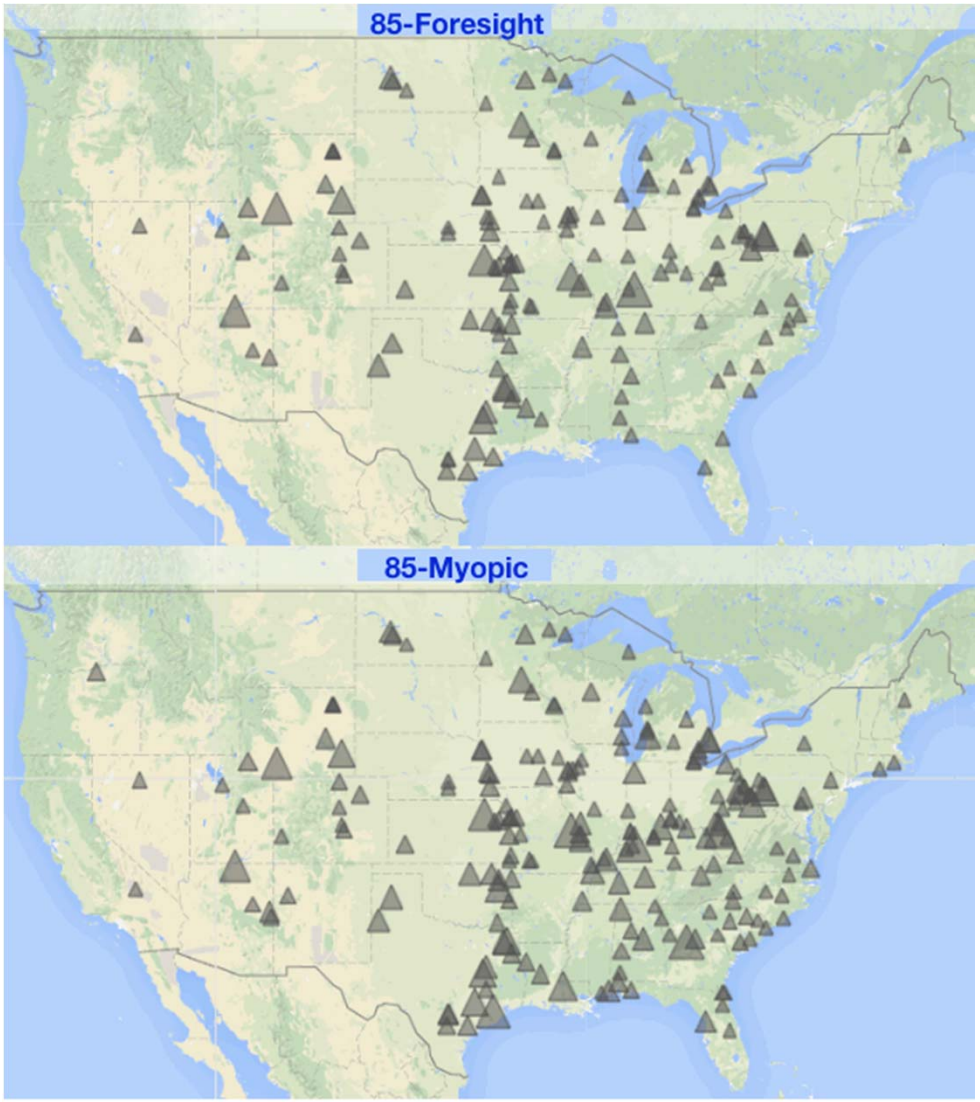


Most regions suffer a cost from myopia, but some benefit from exporting more valuable CES credits

Coal unit retrofits

- Retrofitted coal units are eventually de-utilized under the CES
- Under myopia, stranded asset costs are increased by $2-6 billion across CES stringencies
- Foresight saves up to 100% of stranded asset costs in some regions





Clean Power Plan Analysis:

What are the implications of the many uncertainties around implementation, technology costs, and fuel costs?

Veda rules enable modeling this very complex policy, in all its variants

State names in plant descriptions allow state-level constraints

					~UC_T: UC_RHST~2030			
UC_N	PSET_PD	Attrib_Cond	Val_Cond	PSET_CI	CSET_CN	UC_FLO	UC_ACT	2030
UC_EPA111d-Ann_Alabama	*-Alabama.*	PASTI	>.025	ELCNGA,ELCDST	ELCCO2N	1	-141.1	5347.06
UC_EPA111d-Ann_Arizona	*-Arizona.*	PASTI	>.025	ELCNGA,ELCDST	ELCCO2N	1	-93.5	3881.17
UC_EPA111d-Ann_Arkansas	*-Arkansas.*	PASTI	>.025	ELCNGA,ELCDST	ELCCO2N	1	-121.2	2522.23
UC_EPA111d-Ann_California	*-California.*	PASTI	>.025	ELCNGA,ELCDST	ELCCO2N	1	-71.5	7329.53

The past investment criterion allows plants > 25 MW to be picked out

PASTI also allows new and existing nuclear to be credited differently

			~UC_T: 2030	
UC_N	PSET_PD	Attrib_Cond	PSET_CI	UC_ACT
UC_EPA111d-Ann_Alabama	*-Alabama.*	PASTI	ELCNUC	-8.5
UC_EPA111d-Ann_Arizona	*-Arizona.*	PASTI	ELCNUC	-5.6
UC_EPA111d-Ann_Arkansas	*-Arkansas.*	PASTI	ELCNUC	-7.3
UC_EPA111d-Ann_California	*-California.*	PASTI	ELCNUC	-4.3

			~UC_T: 2030	
UC_N	PSET_PD	Attrib_Cond	PSET_CI	UC_ACT
UC_EPA111d-Ann_Alabama	*-Alabama.*	-PASTI	ELCNUC	-141.1
UC_EPA111d-Ann_Arizona	*-Arizona.*	-PASTI	ELCNUC	-93.5
UC_EPA111d-Ann_Arkansas	*-Arkansas.*	-PASTI	ELCNUC	-121.2
UC_EPA111d-Ann_California	*-California.*	-PASTI	ELCNUC	-71.5

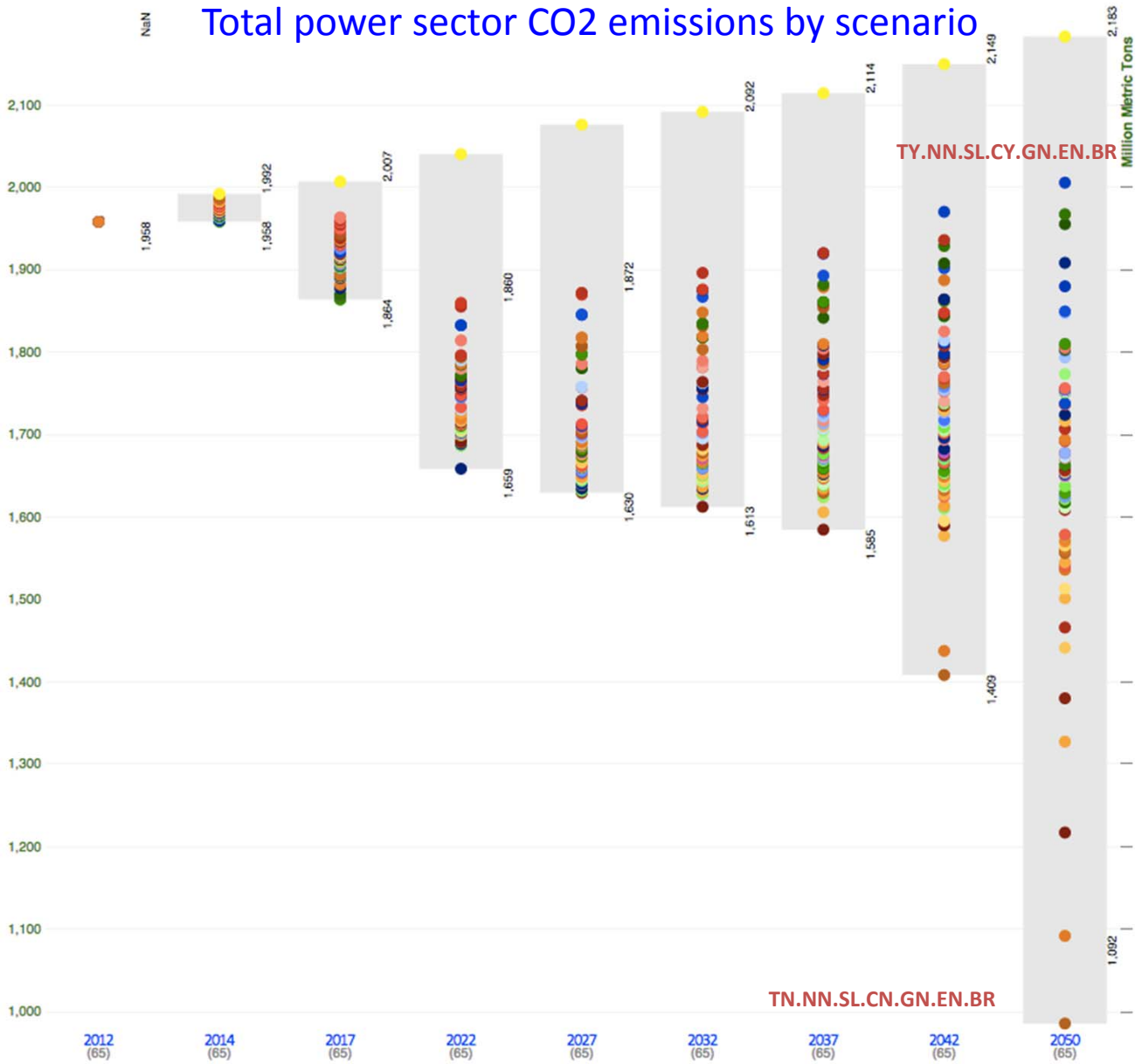
And a scenario generation workbook allows parametric combination of scenario dimensions, including different versions of the 111d constraint

111d Scenario Dimensions: TX NX SX CX GN EX BX

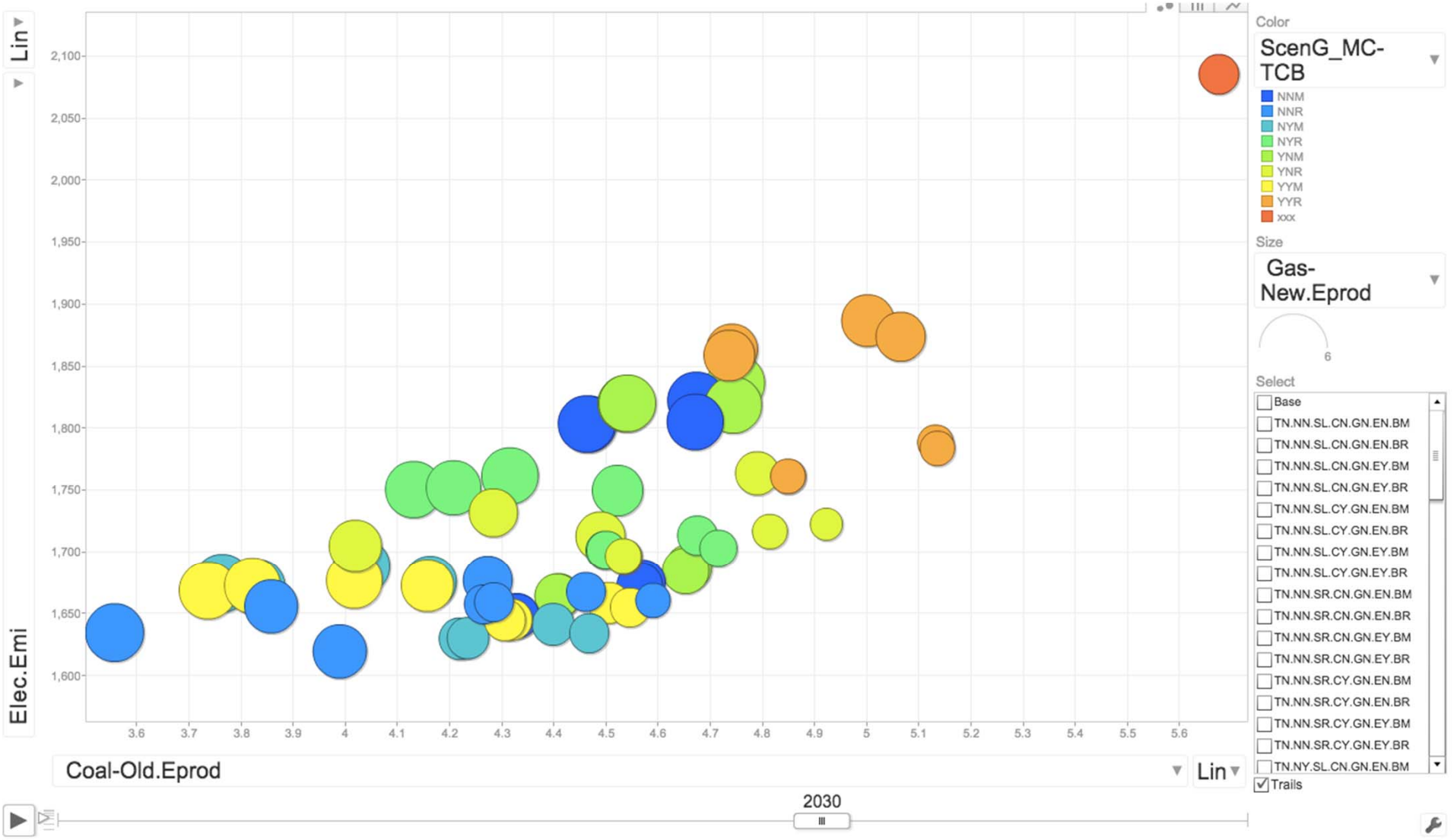
- **T**rade in interstate 111d "credits":
  - **N**o: all states individually comply
  - **Y**es: full national trading
- New **N**uclear builds:
  - **N**o: none allowed beyond currently under construction
  - **Y**es: new builds allowed
- **S**hale gas supplies:
  - **R**eference: AEO 2014 Reference
  - **L**ow: AEO 2014 Low resources
- Include new gas **C**ombined cycle in constraint:
  - **N**o: 111d as currently proposed
  - **Y**es: Include new combined cycle and high-utilization turbine units in the rate calculation
- **G**rid expansion:
  - **N**o: interregional transmission capacity remains fixed at current levels
- **E**nergy efficiency:
  - **Y**es: EPA's state estimates are exogenously imposed as load reductions.
  - **N**o: EE load reductions are not made available. States comply with their budgets without EE
- **B**asis:
  - **R**ate: June 2014 proposed state rate budgets
  - **M**ass: November 2014 illustrative state mass budgets

Emissions reductions vary greatly across scenarios

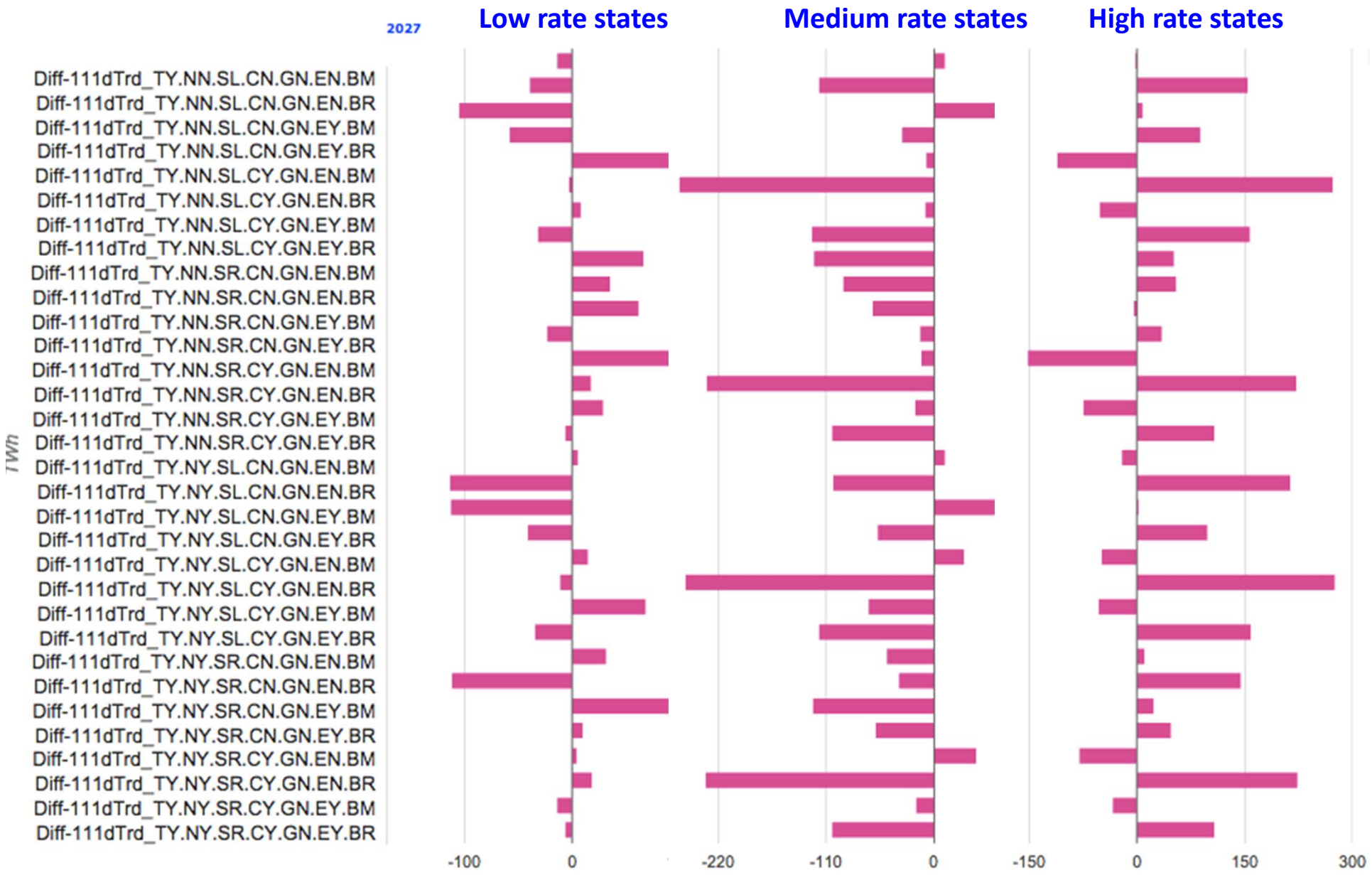
- Emissions reductions from 2012 levels:
  - 5-15% in 2022
  - 3-18% in 2032
- Some scenarios show rebound over time, while in others the cap continues to become more stringent



Motion charts help us understand dynamics across scenario dimensions

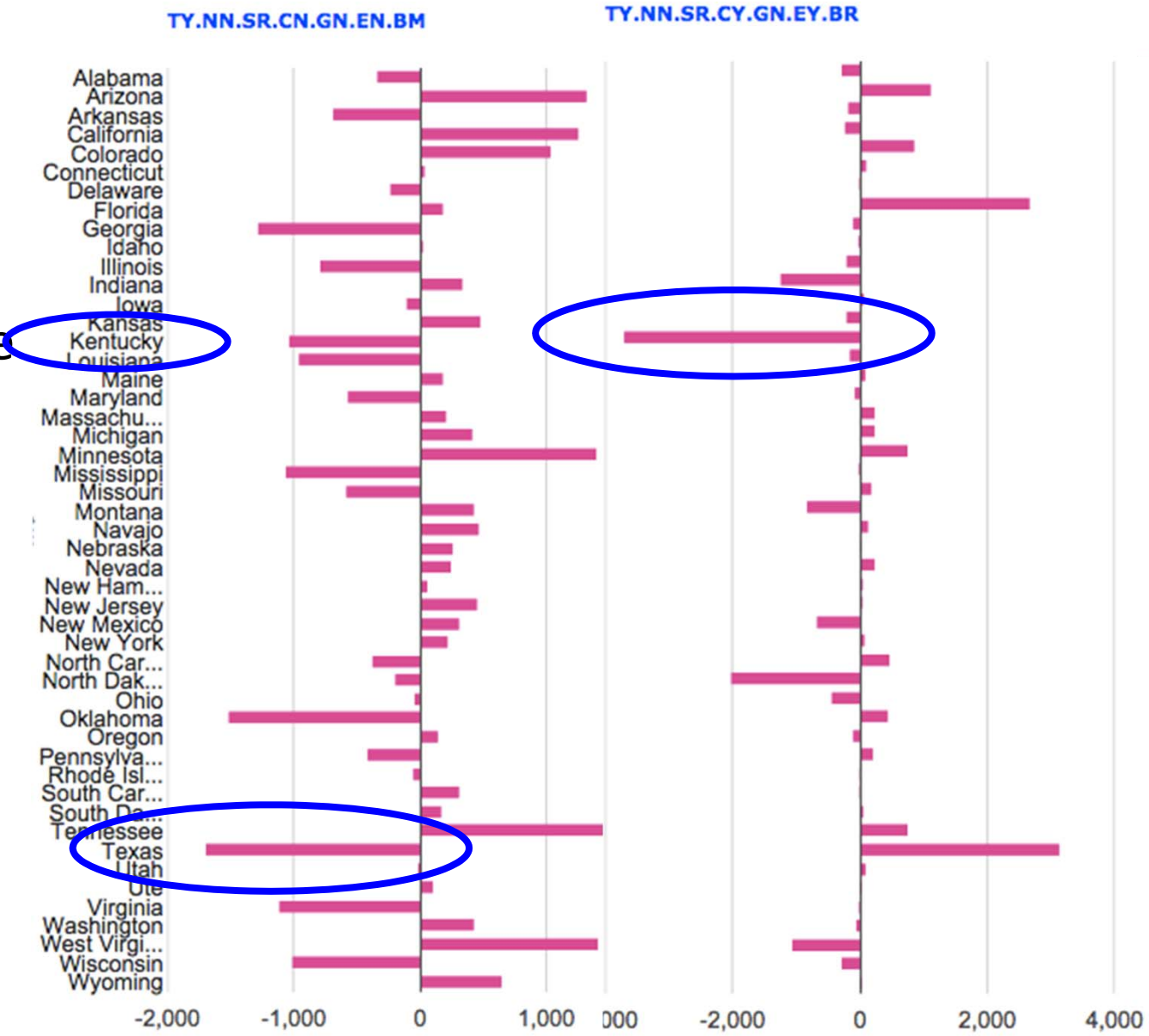


Using scenario differences, we see a shift of generation from low and medium-rate states to high rate states under rate-based trade



Credit import/export earnings are calculated in an SQL server postprocessing database

- In rate-based scenarios, exporters are high rate states that can earn the most credits for adding low rate generation
- In mass-based scenarios, exporters are those with cheaper low/zero carbon options



Implications for IEMM

- TIMES structure and Veda rules allow a very high degree of detail to be managed, with its use adjusted at runtime
- Model complex policies by adding new rules, rather than rewriting code
- Derive insights from many scenarios and communicate results visually

For more information on FACETS, see http://www.facets-model.com, or contact

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