Energy Scenario Exploration with Modeling to Generate Alternatives (MGA)

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Talk Outline

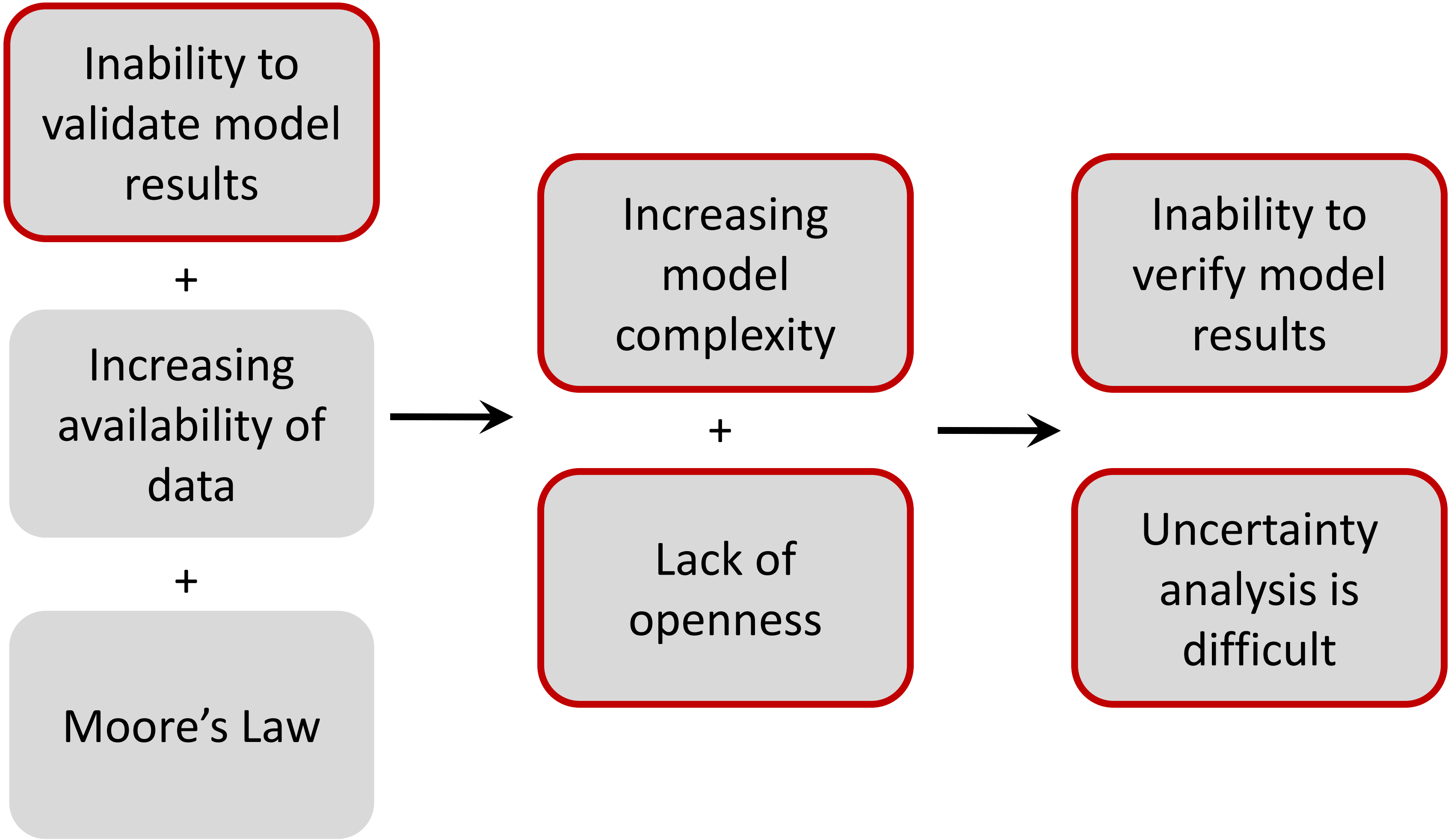
Brief motivation and introduction to the modeling framework (Temoa)

Description of Modeling to Generate Alternatives (MGA)

Application of MGA to a Temoa case study involving the U.S. electric and light duty transport system

Motivation and Introduction

Problems with the status quo



Inability to validate model results

+

Increasing availability of data

+

Moore’s Law

→

Increasing model complexity

+

Lack of openness

→

Inability to verify model results

Uncertainty analysis is difficult

Tools for Energy Model Optimization and Analysis (Temoa)

Temoa is a **bottom up, technology explicit model with perfect foresight**, similar to the TIMES model generator.

Goals

1. Repeatable analysis

- Data and code stored in a public web repository (github)
- Open source software stack

2. Rigorous treatment of uncertainty

- Designed to utilize high performance computing resources
- Stochastic optimization; modeling-to-generate alternatives

Temoa Capability

Current

- Visualization of energy system map
- Input/output data stored in a relational database
- Optional Excel output produced from database
- Configuration file used to specify model options

Project website: http://www.temoaproject.org
Source code: https://github.com/TemoaProject/temoa

Uncertainty Analysis with MGA

Types of Uncertainty

There are many ways to categorize uncertainty.

A key distinction:

- **Parametric**: uncertainty regarding the assumed value of model inputs.
- **Structural**: imperfect and incomplete nature of the equations describing the system

Modeling to Generate Alternatives (MGA)

MGA changes the structure of the model to find alternative solutions

MGA explores an optimization model's near optimal, feasible region [†]

MGA generates alternative solutions that are **maximally different in decision space** but perform well with respect to modeled objectives

The resultant MGA solutions provide modelers and decision-makers with a set of alternatives for further evaluation

[†] Brill (1979), Brill et al. (1982), Brill et al. (1990)

Hop-Skip-Jump (HSJ) MGA

Brill et al. (1982)

Steps:

1. Obtain an initial optimal solution by any method
2. **Add a user-specified amount of slack to the optimal objective function value**
3. Encode the adjusted objection function value as an additional upper bound constraint
4. **Formulate a new objective function that minimizes the decision variables that appeared in the previous solutions**
5. Iterate the re-formulated optimization
6. Terminate the MGA procedure when no significant changes to decision variables are observed in the solutions

Case Study

Motivation

U.S. electric and light duty transportation systems account for approximately 60% of national CO_2 emissions

Following the OPEC oil embargo, the electric and transportation sectors have evolved independently: petroleum is 0.7% of U.S. electricity fuel supply and 91% of light duty transportation

Plug-in vehicles rapidly deployed over the last 5 years and may lead to a significant future coupling of the electric and transport sectors

Goal: Examine alternative technology pathways for achieving low carbon emissions

Study Design

Run three scenarios to benchmark MGA:

- Base case
- 40% cut in 2015 CO_2 emissions by 2050
- 80% cut in 2015 CO_2 emissions by 2050

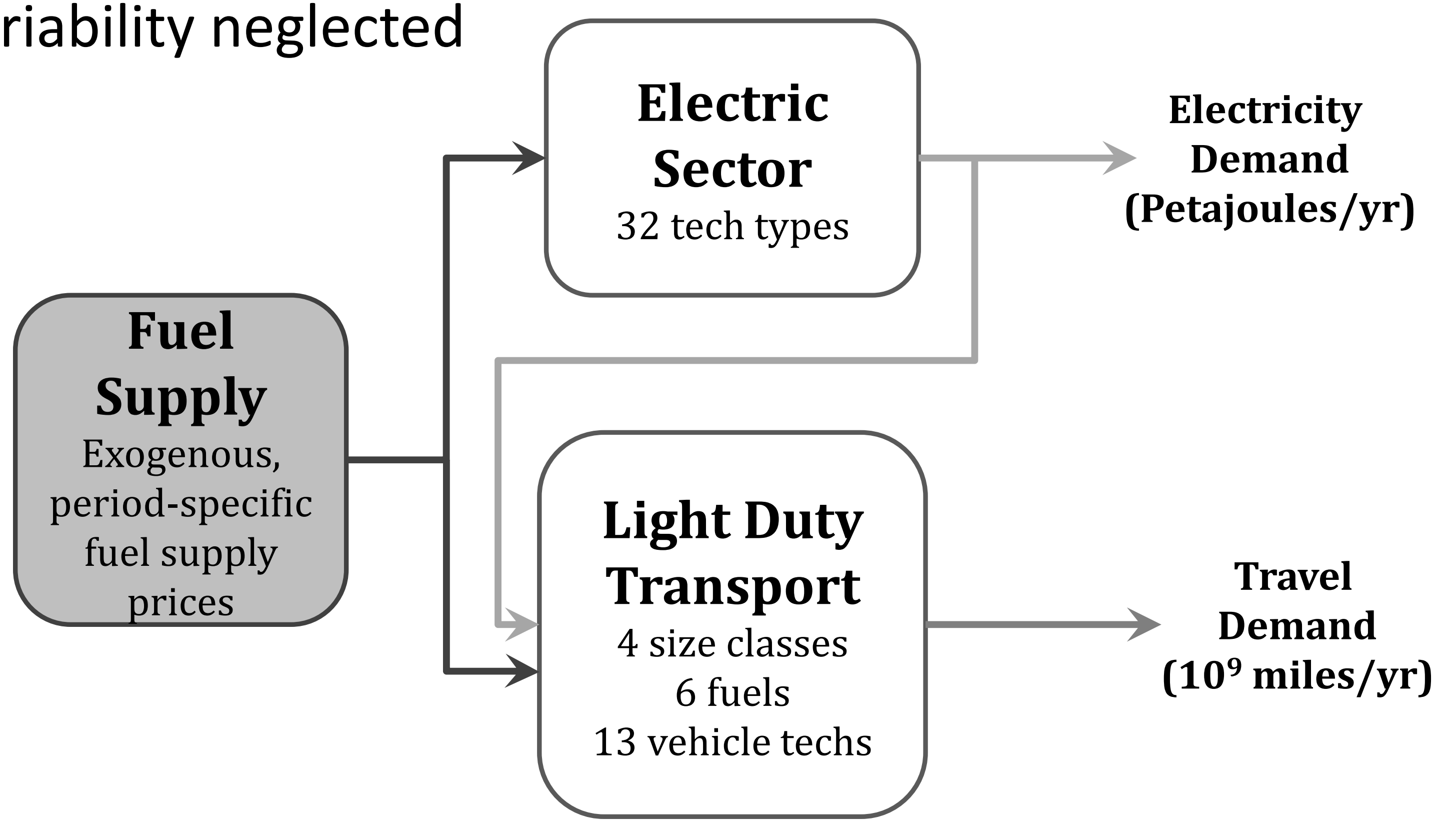
Test two different MGA weighting algorithms

Run MGA at different slack values

Examine outputs and look for insights

Input Dataset

- Approximately 110 processes spanning electric and transport sectors
- Model time horizon is 2015 to 2050; 5-year time periods
- Four diurnal time segments (i.e., morning, mid-day, evening, night)
- Seasonal variability neglected



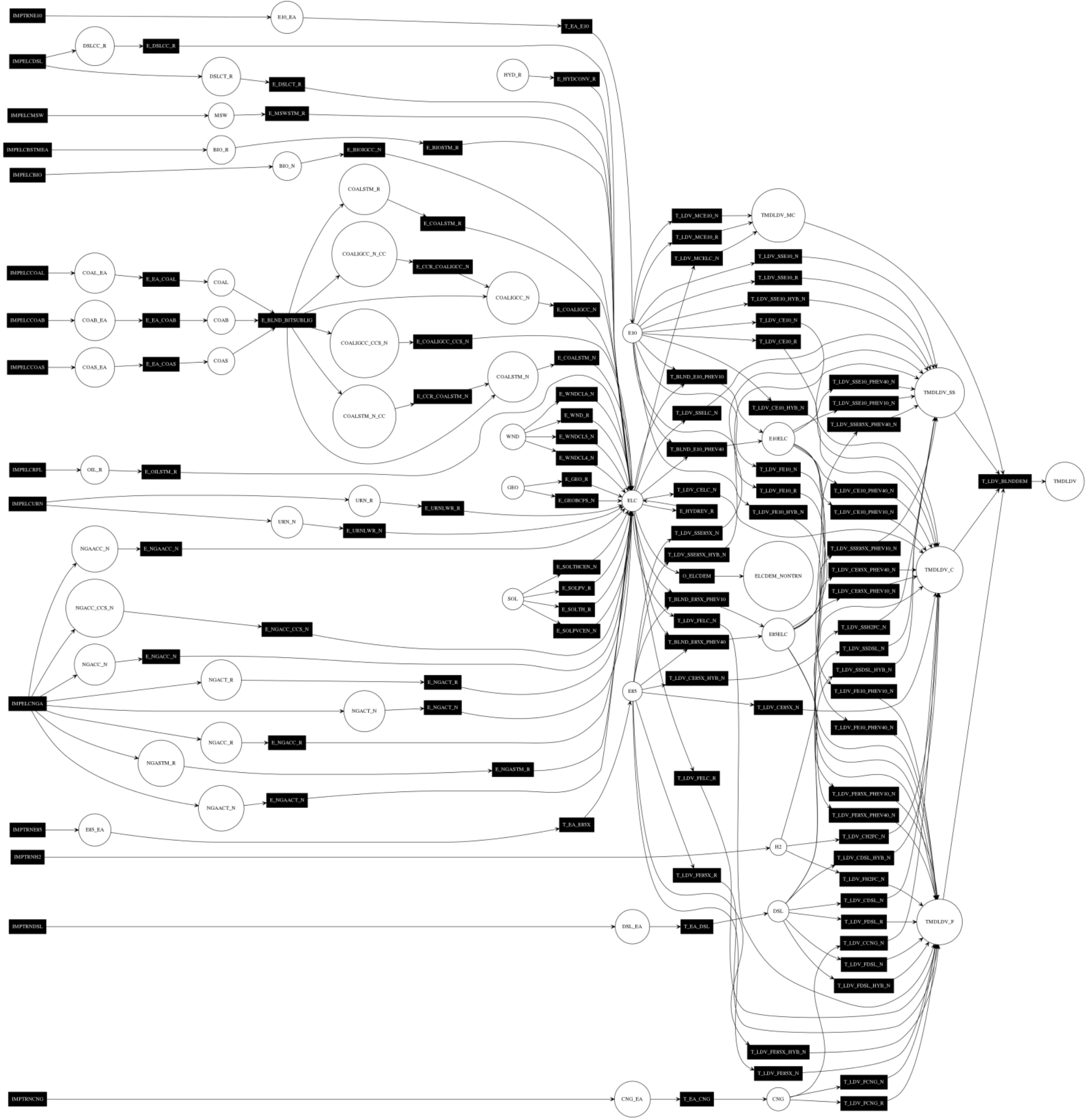
Electric Sector
32 tech types

Electricity Demand (Petajoules/yr)

Fuel Supply
Exogenous, period-specific fuel supply prices

Light Duty Transport
4 size classes
6 fuels
13 vehicle techs

Travel Demand (10^9 miles/yr)


IMPTRNE10
E10_EA
T_EA_E10
IMPELCDSL
DSLCC_R
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E_HYDCONV_R
IMPELCMSW
MSW
E_MSWSTM_R
IMPELCBSTMEA
BIO_R
E_BIOSTM_R
IMPELCBIO
BIO_N
E_BIOIGCC_N
COALSTM_R
E_COALSTM_R
COALIGCC_N_CC
E_CCR_COALIGCC_N
COALIGCC_N
E_COALIGCC_N
IMPELCCOAL
COAL_EA
E_EA_COAL
COAL
IMPELCCOAB
COAB_EA
E_EA_COAB
COAB
E_BLND_BITSUBLIG
COALIGCC_CCS_N
E_COALIGCC_CCS_N
IMPELCCOAS
COAS_EA
E_EA_COAS
COAS
COALSTM_N
E_COALSTM_N
COALSTM_N_CC
E_CCR_COALSTM_N
WND
E_WNDCL6_N
E_WND_R
E_WNDCL5_N
E_WNDCL4_N
IMPELCRFL
OIL_R
E_OILSTM_R
GEO
E_GEO_R
E_GEOBCFS_N
IMPELCURN
URN_R
E_URNLWR_R
URN_N
E_URNLWR_N
NGAACC_N
E_NGAACC_N
SOL
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E_SOLPV_R
E_SOLTH_R
E_SOLPVCEN_N
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NGAACT_N
E_NGAACT_N
IMPTRNE85
E85_EA
T_EA_E85X
IMPTRNH2
IMPTRNDSL
DSL_EA
T_EA_DSL
IMPTRNCNG
CNG_EA
T_EA_CNG
E10
ELC
E85
H2
DSL
CNG
T_LDV_MCE10_N
T_LDV_MCE10_R
T_LDV_MCELC_N
TMDLDV_MC
T_LDV_SSE10_N
T_LDV_SSE10_R
T_LDV_SSE10_HYB_N
T_LDV_CE10_N
T_LDV_CE10_R
T_BLND_E10_PHEV10
T_LDV_SSELC_N
T_LDV_CE10_HYB_N
E10ELC
T_BLND_E10_PHEV40
T_LDV_SSE10_PHEV40_N
T_LDV_SSE10_PHEV10_N
T_LDV_SSE85X_PHEV40_N
TMDLDV_SS
T_LDV_FE10_N
T_LDV_FE10_R
T_LDV_FE10_HYB_N
T_LDV_CELC_N
E_HYDREV_R
T_LDV_CE10_PHEV40_N
T_LDV_CE10_PHEV10_N
T_LDV_BLNDDEM
TMDLDV
T_LDV_SSE85X_N
T_LDV_SSE85X_HYB_N
O_ELCDEM
ELCDEM_NONTRN
T_LDV_SSE85X_PHEV10_N
T_LDV_CE85X_PHEV40_N
T_LDV_CE85X_PHEV10_N
TMDLDV_C
T_BLND_E85X_PHEV10
T_LDV_FELC_N
T_BLND_E85X_PHEV40
E85ELC
T_LDV_SSH2FC_N
T_LDV_SSDSL_N
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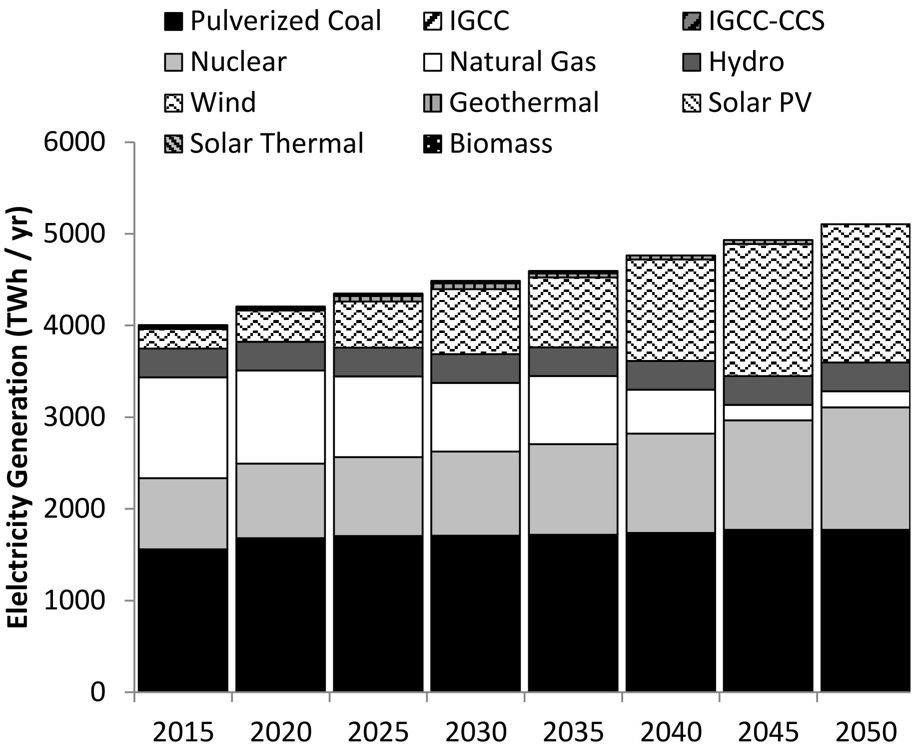
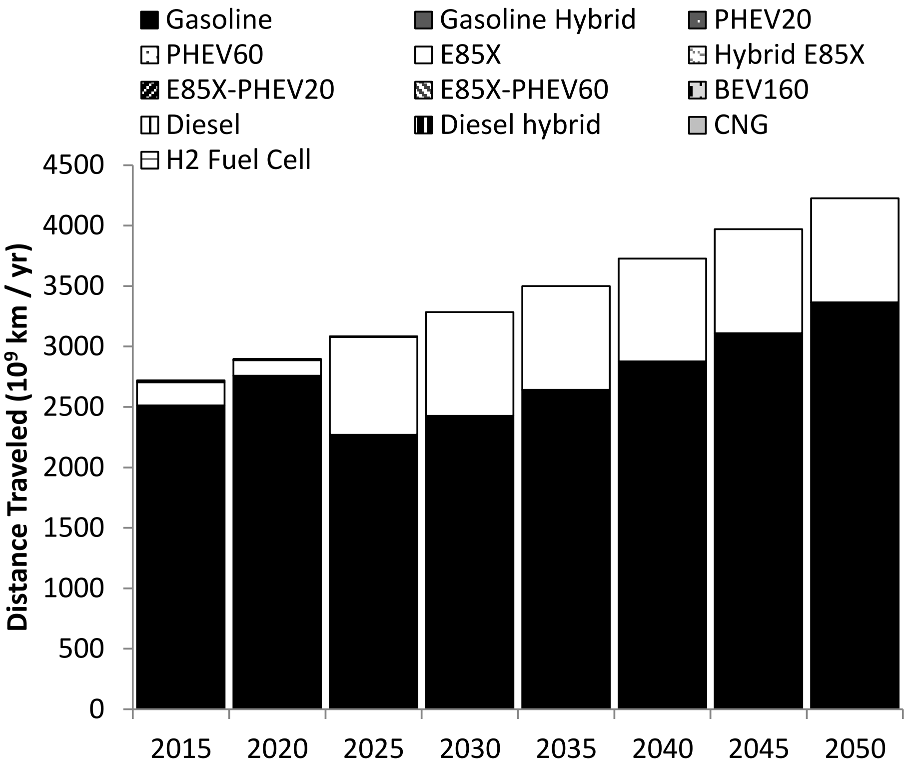
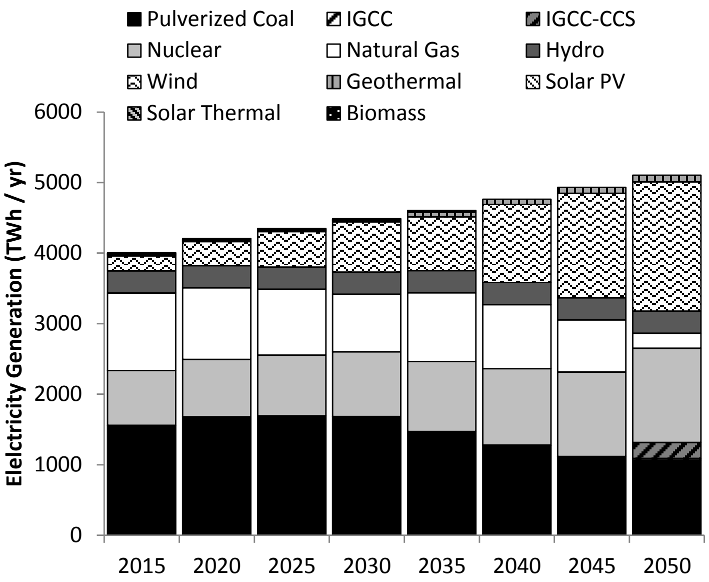
T_LDV_FE85X_PHEV40_N
T_LDV_CH2FC_N
T_LDV_CDSL_HYB_N
T_LDV_FE85X_R
T_LDV_FH2FC_N
T_LDV_CDSL_N
T_LDV_FDSL_R
TMDLDV_F
T_LDV_CCNG_N
T_LDV_FDSL_N
T_LDV_FDSL_HYB_N
T_LDV_FE85X_HYB_N
T_LDV_FE85X_N
T_LDV_FCNG_N
T_LDV_FCNG_R

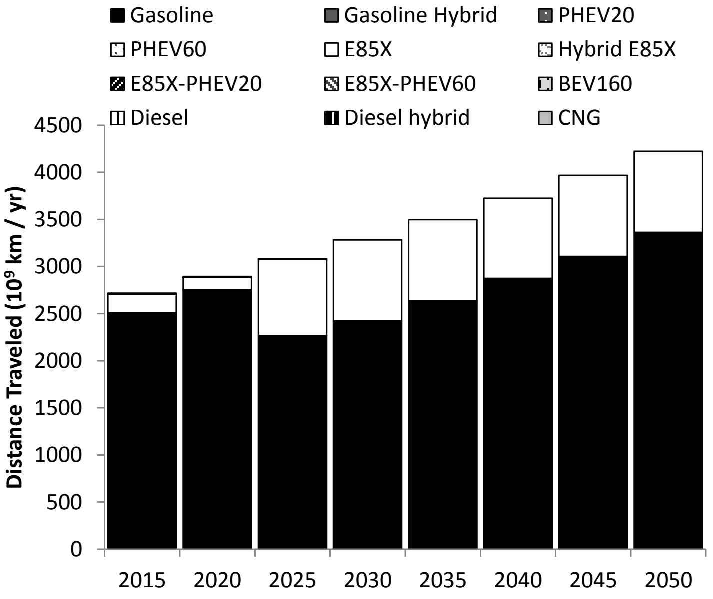
Base Case Results





40% CO$_2$ Reduction Scenario

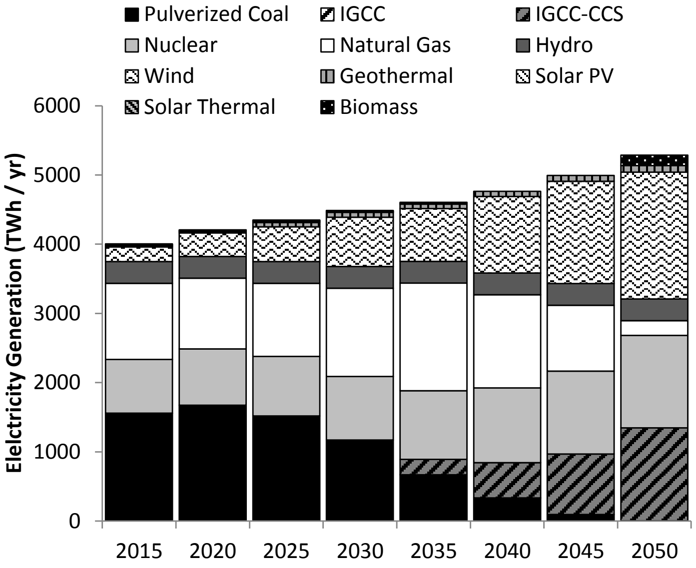


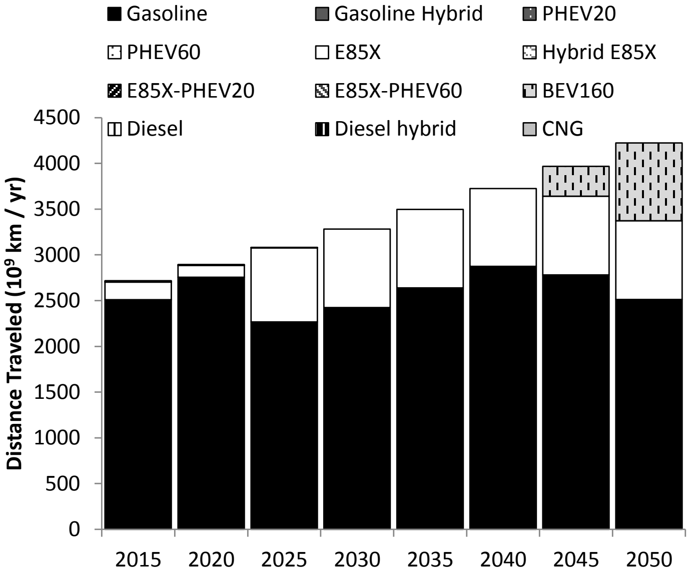


Increased cost over base:

0.5%

80% CO$_2$ Reduction Scenario





Increased cost over base:

2%

Tuning the MGA Algorithm

MGA should be tested and customized to better suit the specific modeling context.

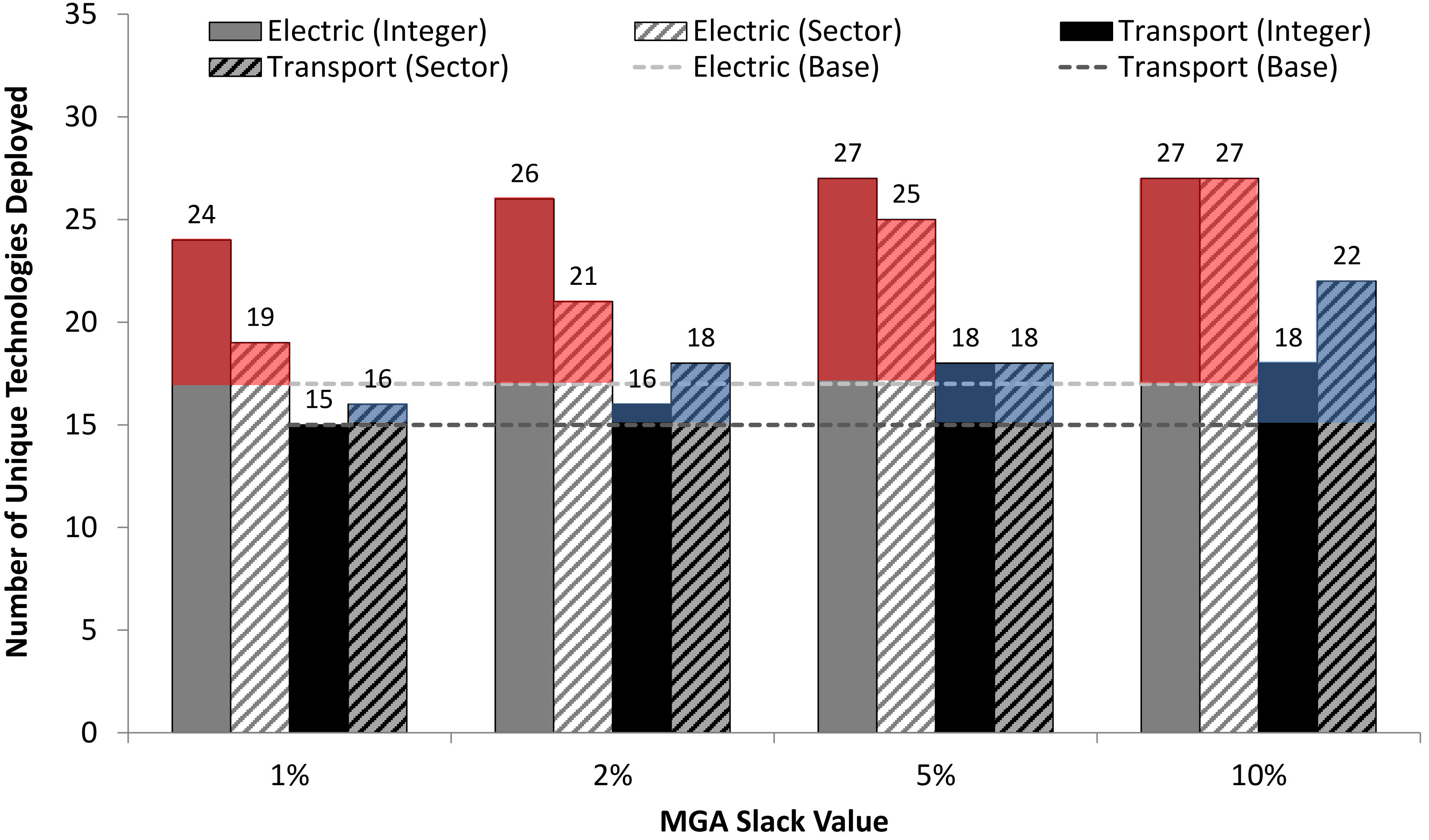
Target decision variable: total technology activity over the model time horizon

Tested two ways to assign objective function weights:

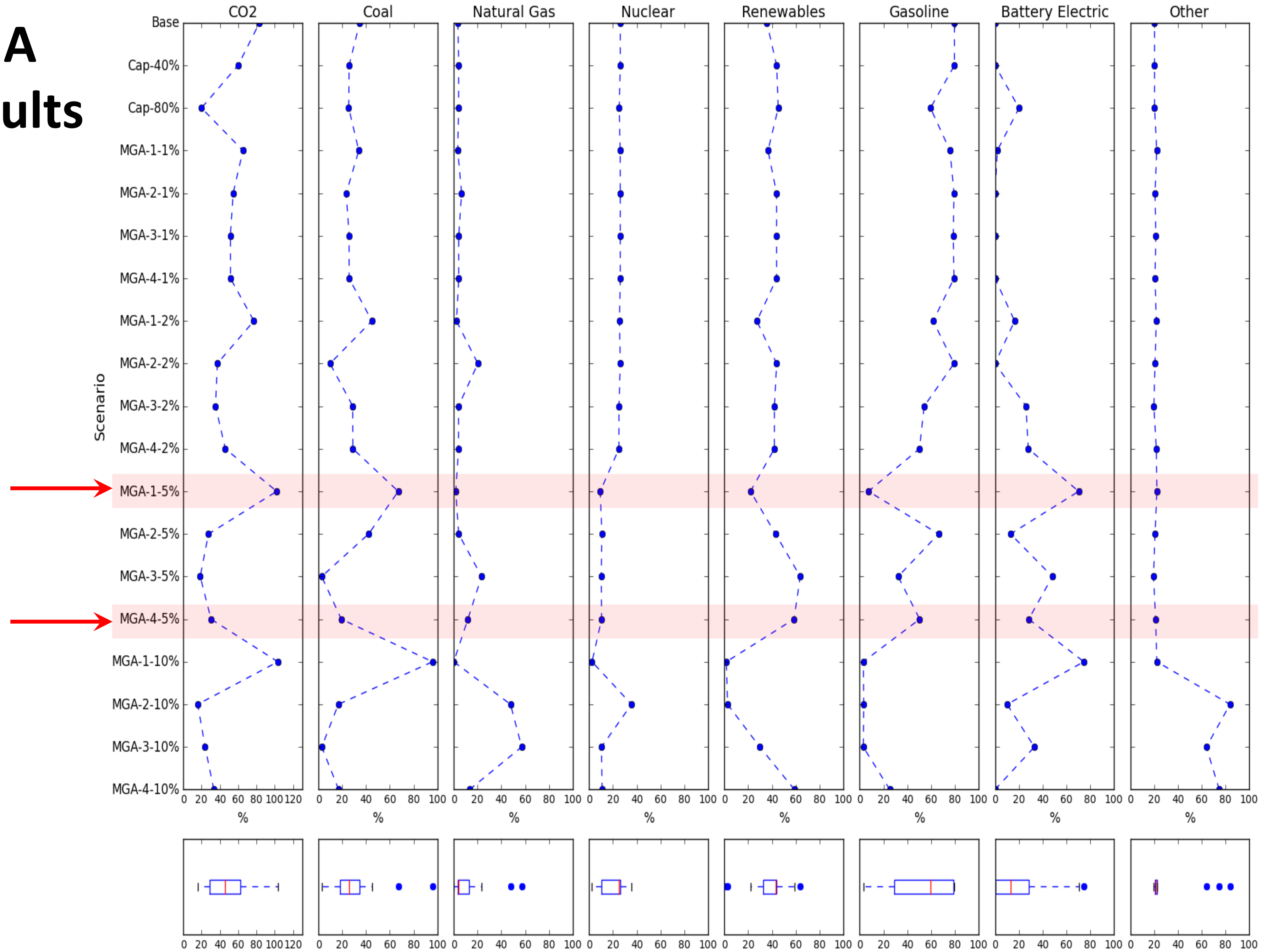
- **Integer Weighting:** Increment technology-specific MGA objective function weight by +1 after each model iteration with positive activity
- **Normalized Sector Weighting**: Increment technology-specific MGA objective function weight by normalized technology activity by sector

Goal: Deploy the maximum number of technologies to characterize flexibility in system design

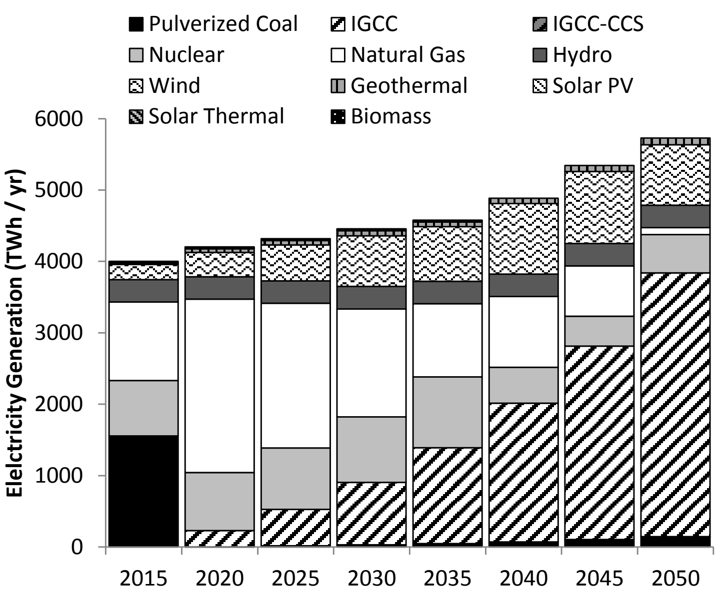
Total Technology Deployment by MGA Method

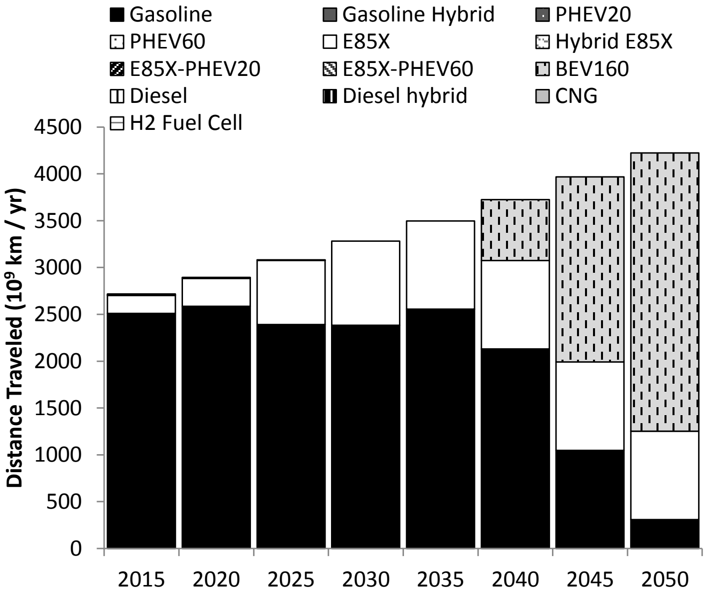


MGA Results

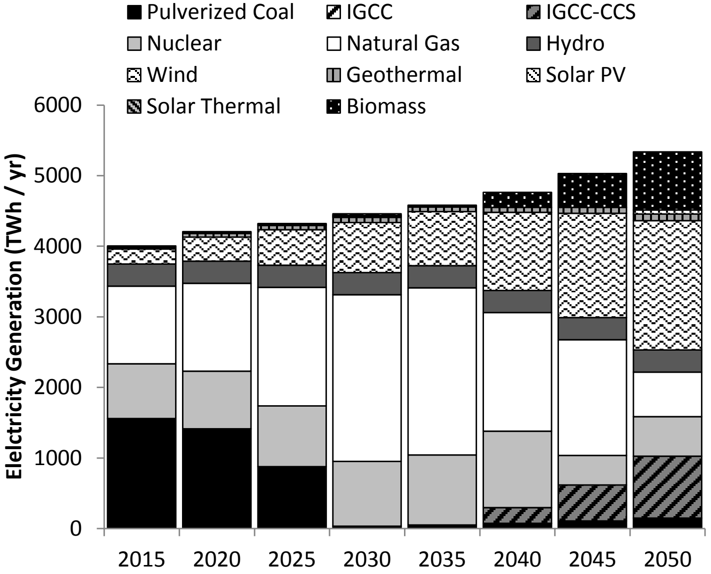

CO2
Coal
Natural Gas
Nuclear
Renewables
Gasoline
Battery Electric
Other
Scenario
Base
Cap-40%
Cap-80%
MGA-1-1%
MGA-2-1%
MGA-3-1%
MGA-4-1%
MGA-1-2%
MGA-2-2%
MGA-3-2%
MGA-4-2%
MGA-1-5%
MGA-2-5%
MGA-3-5%
MGA-4-5%
MGA-1-10%
MGA-2-10%
MGA-3-10%
MGA-4-10%
0 20 40 60 80 100 120
0 20 40 60 80 100
%

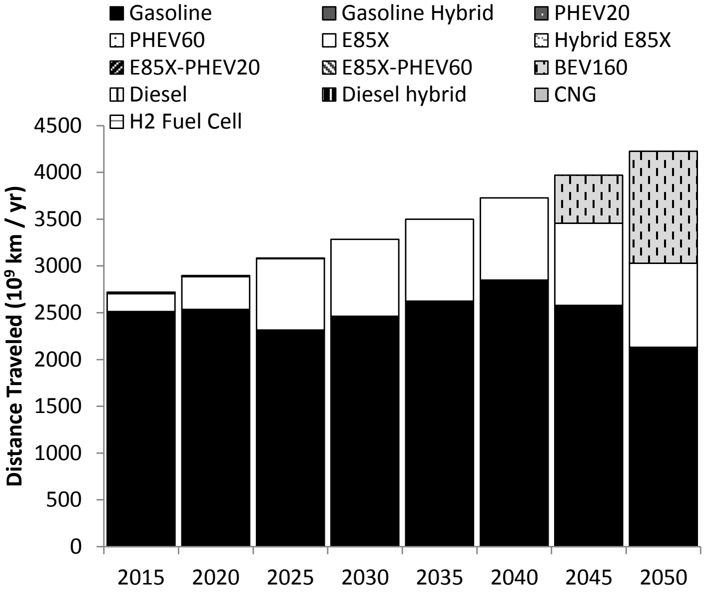
MGA Iteration 1 with 5% Slack (MGA-1-5%)





MGA Iteration 4 with 5% Slack (MGA-4-5%)

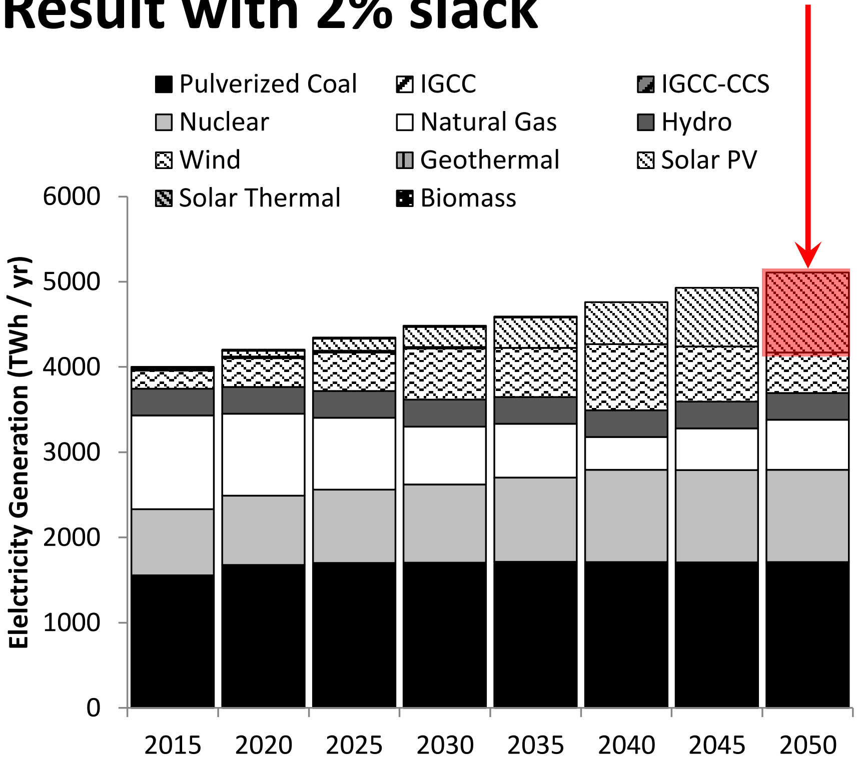




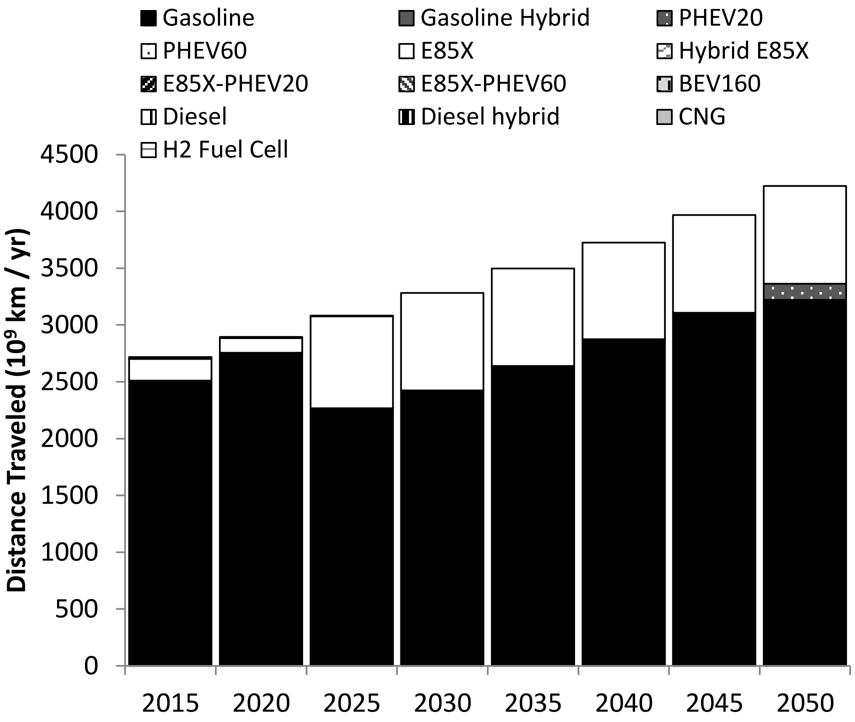
Focus on Solar PV

- Solar PV only appears at 10% slack
- Modify MGA integer method to minimize all previously deployed technologies **except** solar PV

Result with 2% slack



18% market share in 2050



Insights

Many technologies deployed in MGA runs are not present in base and CO_2 cap scenarios:

- IGCC, biomass, and solar PV in the electric sector
- PHEV20, diesel, and diesel hybrids in the transport sector

Cheap coal-fired electricity often coupled with high electric vehicle deployment in order to meet cost target

Wide variation in coal, natural gas, wind, and gasoline vehicle utilization

Variation in technology deployment increases with MGA slack value

Conclusions

MGA represents a simple method for systematically exploring the decision space of an energy system model

Results highlight the false precision underlying the often limited results produced with conventional scenario analysis

Energy system models should be used to interactively probe the decision space in a way that challenges our mental models and leads to new insight

Perhaps the most useful deliverable is not a set of projections, but a tool of exploration that allows users to interrogate the model.

Acknowledgments

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National Science Foundation
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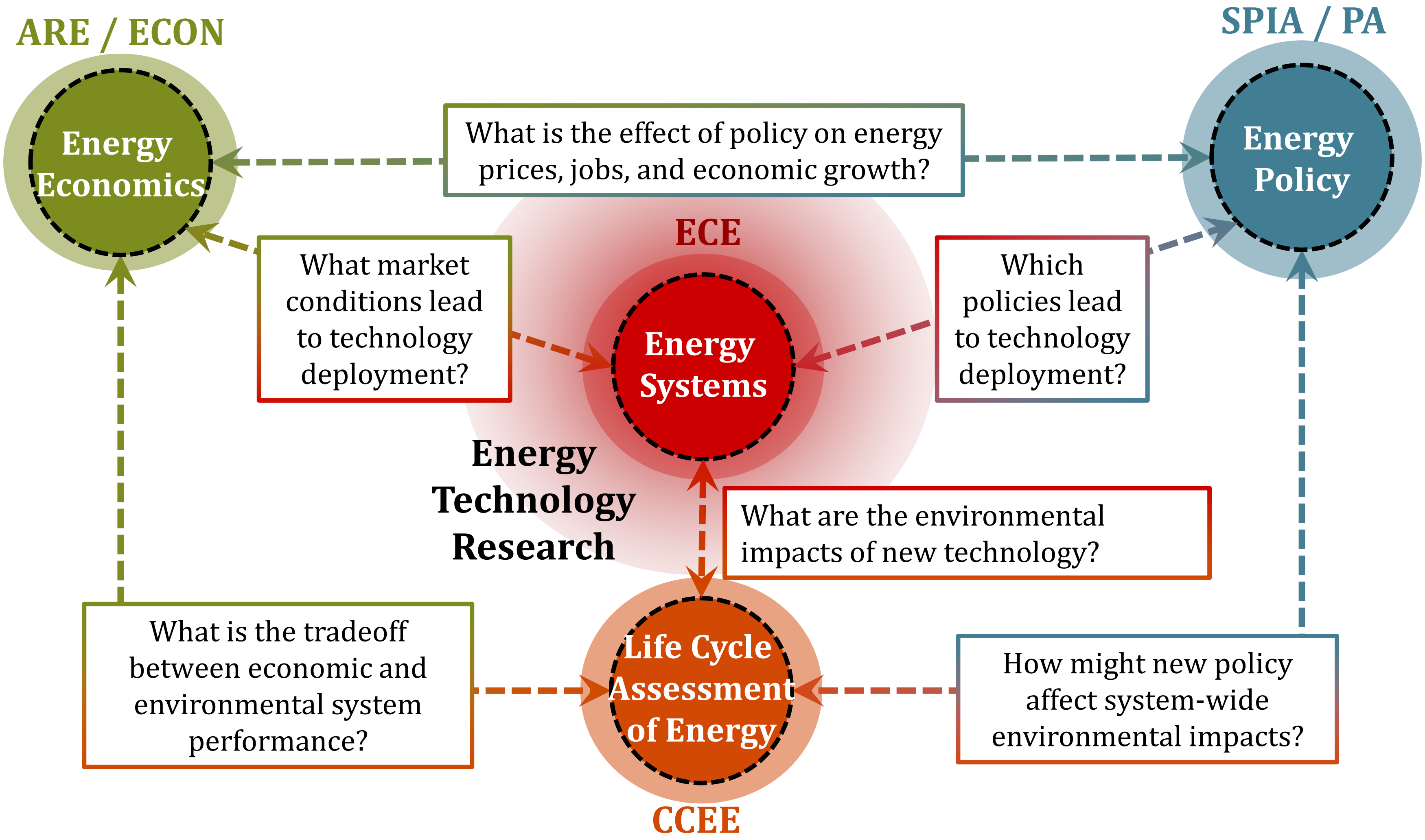
New Energy Cluster at NC State



ARE / ECON

Energy Economics

What is the effect of policy on energy prices, jobs, and economic growth?

SPIA / PA

Energy Policy

What market conditions lead to technology deployment?

ECE

Energy Systems

Which policies lead to technology deployment?

Energy Technology Research

What are the environmental impacts of new technology?

What is the tradeoff between economic and environmental system performance?

Life Cycle Assessment of Energy

How might new policy affect system-wide environmental impacts?

CCEE

Ads for all four positions will be announced this fall.