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Characterizing Uncertainty for Regional Mitigation and Adaptation Decisions

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Uncertainty in Climate Change Research: An Integrated Approach
NCAR Workshop, August 13, 2012

Uncertainty Characterization

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Uncertainty Characterization

Quantitative and Non-Quantitative Methods

- Qualitative methods include scenario/case analysis, bounding methodologies

Uncertainty Quantification

- Bayesian probabilistic characterization
- Dempster-Shafer characterization
- Possibilistic methods
- Robust Bayes methods
- Other nonprobabilistic methods

- Monte Carlo analysis
  - Random sampling
  - Importance sampling
  - Latin Hypercube
  - Markov Chain Monte Carlo
- Surrogate models
- Nonprobabilistic measure propagation
- Propagation of moments
- Adjoint methods

Uncertainty Propagation

- Bound propagation
- Qualitative/semi-quantitative data fusion
- Qualitative measure propagation

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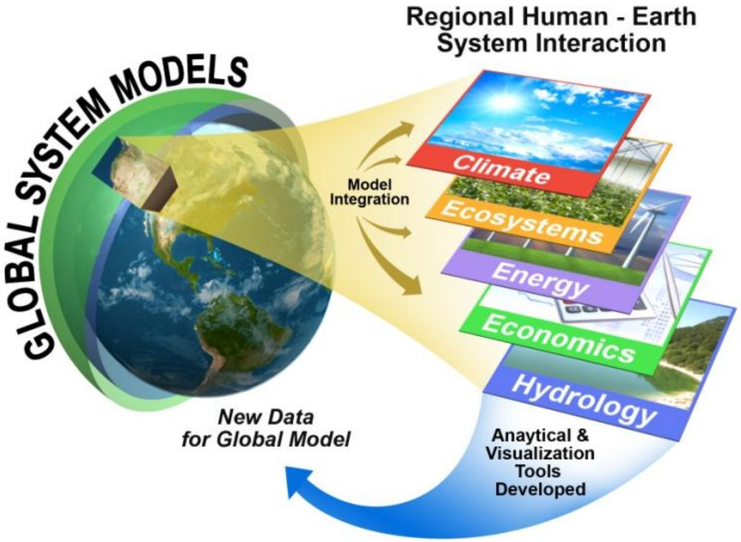
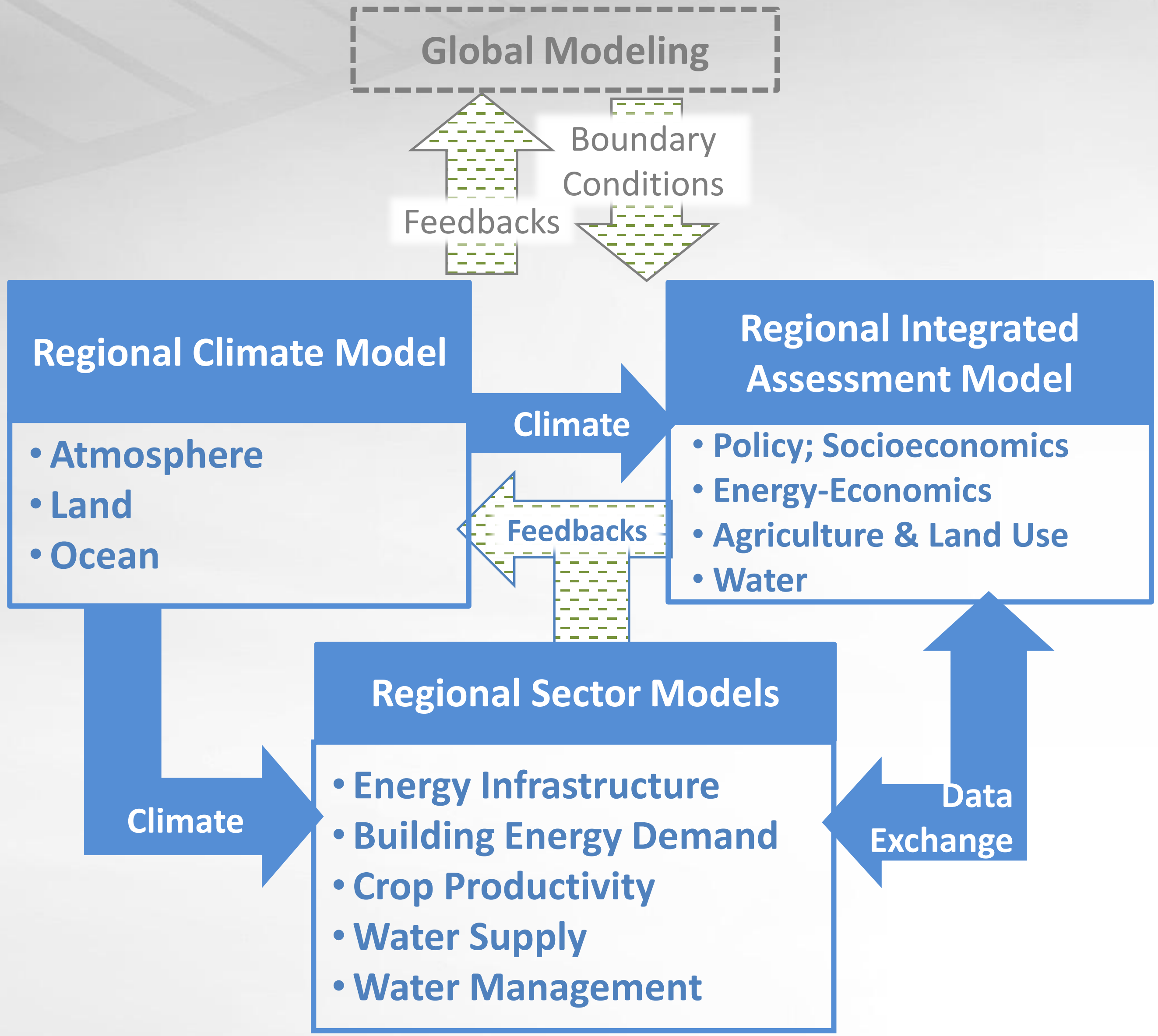
Characterizing Uncertainty for Regional Mitigation and Adaptation Decisions

- How can we manage the complexity and dimensionality of uncertainty characterization (UC) in regional scale modeling?

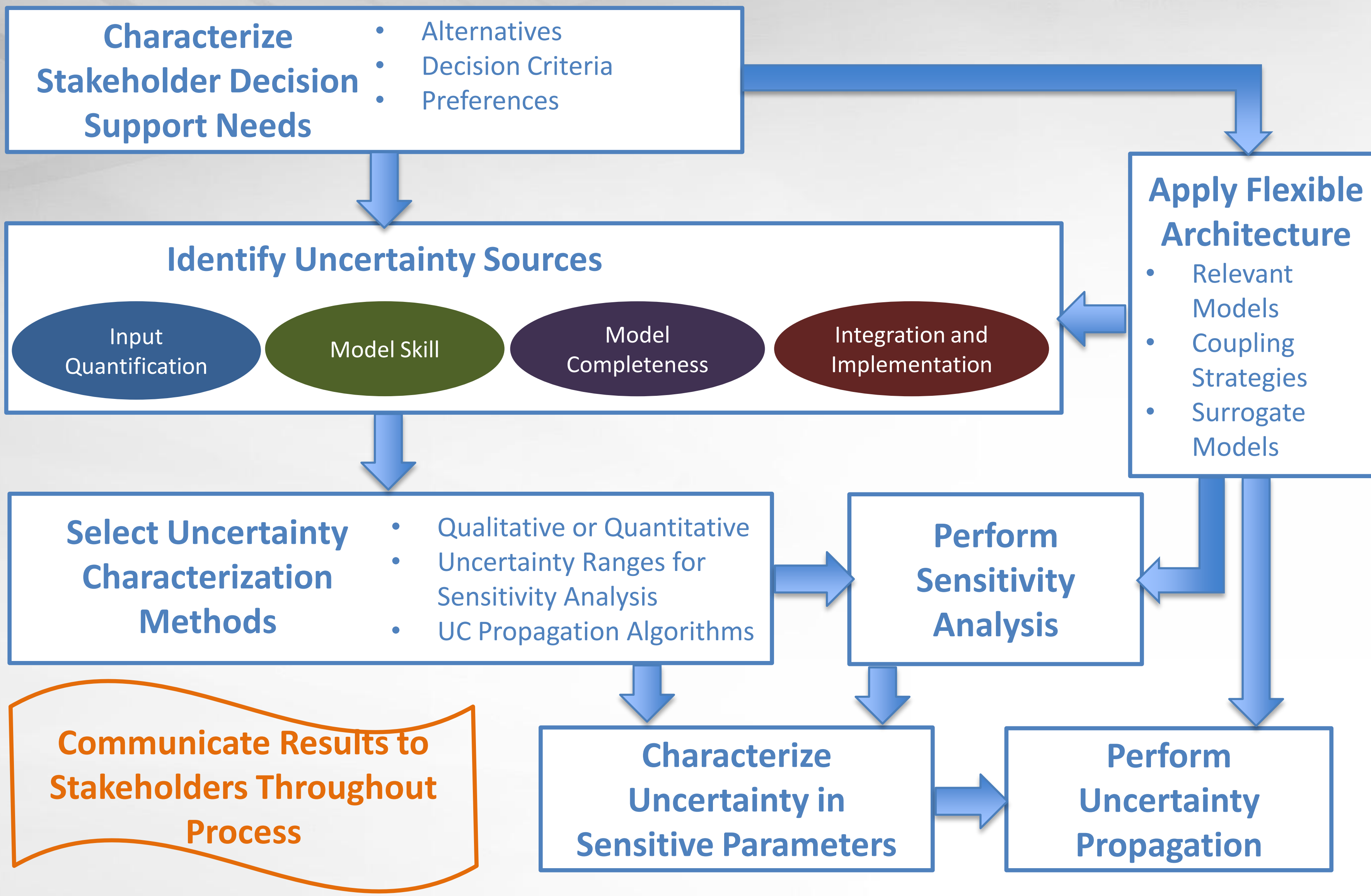


- A focus on stakeholder decision support needs ensures that:
  - Stakeholders and modelers work on what matters
  - UC becomes tractable.

The integrated Regional Earth System Modeling (iRESM) Framework



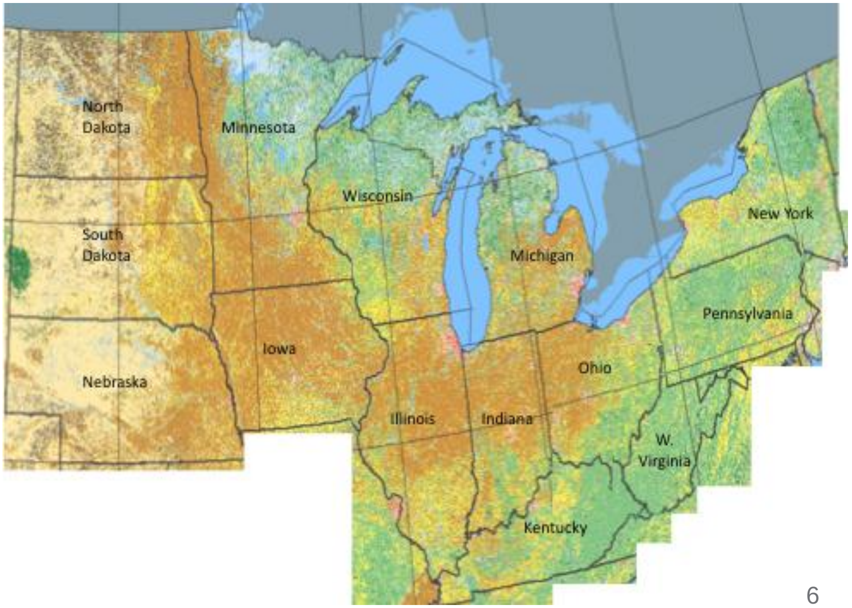
iRESM Decision-Relevant Uncertainty Characterization



iRESM Pilot Study Region

Stakeholder organizations met with to date:

- Wisconsin Bioenergy Initiative
- Wisconsin Climate Change Initiative (represents a wide range of stakeholders)
- Nelson Institute for Environmental Studies, University of Wisconsin
- Center for Sustainability and the Global Environment, University of Wisconsin
- Center for Science, Technology and Public Policy, Humphrey School of Public Affairs, University of Minnesota
- Minnesota Forest Resources Council
- Minnesota Pollution Control Agency
- Iowa State University, Climate Science Program, Agricultural Meteorology
- University of Iowa, Center for Global and Regional Environmental Research
- Great Lakes Commission
- Midwest Independent System Operators (MISO)
- International Plant Nutrition Institute
- U.S. Department of Agriculture, ARS
- Illinois Department of Agriculture
- Chesapeake Energy
- Illinois Energy Office, Illinois Department of Commerce & Economic Opportunity
- Illinois EPA
- City of Chicago Department of Environment
- Great Lakes and St. Lawrence Cities Initiative
- Metropolitan Water Reclamation District of Greater Chicago
- Pennsylvania State University, several departments



Developing the Decision Typology: Energy-Related Decisions

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Code	Mitigation Types	Code	Adaptation Types	Code	Approach	Code	Decision Criteria	Code	Decision Process
M1	Carbon tax	A1	Improve building codes; retrofit existing HVAC	D1	Regional policy mandate	C1	Economic benefits	P1	State-level task force or committee
M2	Renewable Portfolio Standard (RPS)	A2	Reduce thermoelectric operations	D1.1	Regional incentives	C2	Energy independence	P2	Legislation
M3	Cap and trade	A3	Increase urban tree cover; green roofs	D2	Meeting RPS requirements	C3	Peak demand	P3	Scientific advisory group
M4	Improve building codes; Retrofit existing HVAC	A4	Increase generation in urban areas	D3	In-state sourcing	C4	Emissions	P4	Governor's executive order
M5	etc.	A5	etc.	D4	etc.	C5	etc.	P5	etc.

Applying the Typology: An Example

- Decision maker: Midwest Governors Association
- Decision: Improved regional building standards—at what level?
- Decision criteria: economics, emissions, peak demand (reduce demand during heat waves)
- Decision process: multi-state policy decision

Code	Mitigation Decision Types	Code	Adaptation Decision Types	Code	Type of Decision	Code	Decision Criteria	Code	Decision Process
M1	Carbon tax	**A1**	**Improve building codes; retrofit existing HVAC**	**D1**	**Regional policy mandate**	**C1**	**Net benefits**	**P1**	**State-level task force or committee**
M2	Renewable Portfolio Standard (RPS)	A2	Reduce thermoelectric operations	D1.1	Regional incentives	**C2**	**Economic benefits**	**P2**	**Legislation**
M3	Cap and trade	A3	Invest in dry cooling; cooling towers	D2	Meeting RPS requirements	**C3**	**Peak demand**	**P3**	**Scientific advisory group**
M4	**Improve building codes; retrofit existing HVAC**	A4	Increase generation in urban areas	D2.1	In-state sourcing	**C4**	**Reduced emissions**	**P4**	**Governor's executive order**

Required iRESM Model Couplings

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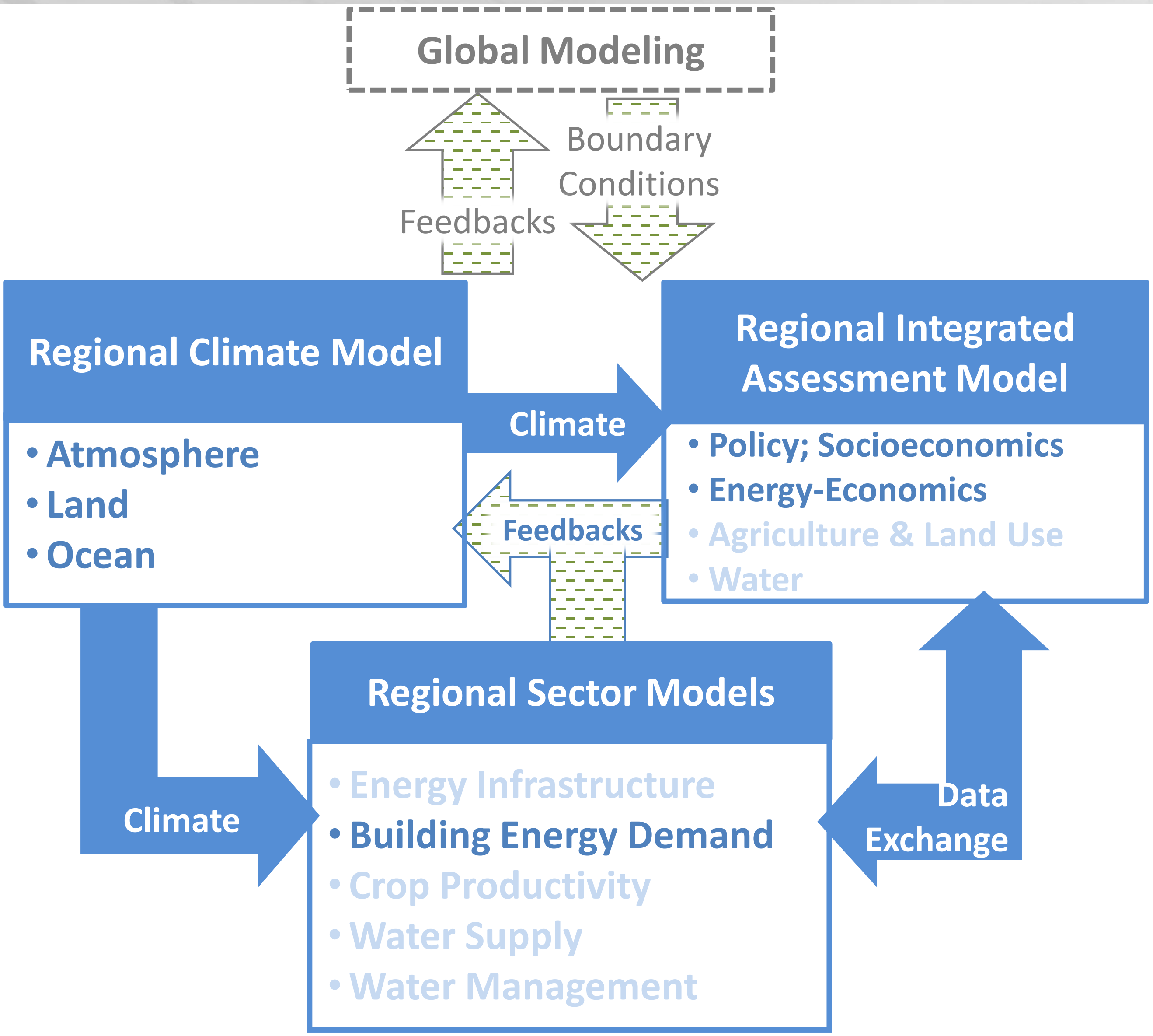

Example: Characterize Stakeholder Needs

- Building Standards Decision:
  - No Change to Standards: Regional energy codes and standards frozen at today's (2005) levels.
  - Moderate Standards: Increase stringency of regional energy codes and equipment standards to obtain 50% reduction in energy use by 2050.
  - Aggressive Standards: Increase stringency of regional energy codes and standards to obtain 80% reduction in energy use by 2050.
- Decision Criterion:
  - Building service costs per square meter of floor space.

Note: this decision and the decision criterion are intended as illustrative-only of a policy question for the Midwest Governors Association

Identify and Characterize Uncertainty Sources

- Population growth:
  - Reference growth: middle Census Bureau forecast
  - High and low growth: scaled from high and low Census Bureau forecasts at state level
- Economic growth:
  - Reference growth: GDP/worker (increase approx. 1.5% per year)
  - High and low growth: reference ± 1% per year
- Carbon policy (and climate):
  - Reference growth: A2 concentration—CO_2 concentration reaches 850 ppm by 2100.
  - Low growth: B1 550 ppm pathway—similar concentration path to RCP4.5 (550 ppm CO_2 by 2100, 650 ppm CO_2e)
- Climate models: CCSM, HadCM3, GISS

Sensitivity Analysis Results

2095	Sum Sq	Sobel Score (%)
Standards	76.346	33.761
ConcPathway	72.522	32.07
ClimateModel	0.000	0
GDP	74.149	32.79
Population	0.062	0.027
Standards:ConcPathway	1.025	0.453
Standards:ClimateModel	0	0
Standards:GDP	1.926	0.852
Standards:Population	0.003	0.001
ConcPathway:ClimateModel	0	0
ConcPathway:GDP	0.091	0.04
ConcPathway:Population	0.011	0.005
ClimateModel:GDP	0	0
ClimateModel:Population	0	0
GDP:Population	0.001	0
ROM Lack of Fit	0.008	NA
All Variables	226.144	99.999
Highlighted Variables	223.017	98.621

- Using 15 factors, we can explain 99.999 percent of the variability of building service costs present in the full factorial (162 RGCAM runs).
- Three factors explain 98.621 of the variability.
  - One of these is the decision variable (the standards policy question).
  - The other two, concentration pathway and GDP, would be selected as sensitive variables for uncertainty propagation.

What have we learned?

- A decision- or problem-focused modeling approach makes it possible to provide robust insights for decision-making on adaptation and mitigation at regional scales
- Decision focus, approaches to reduce model runtime, a flexible software environment, and a directed approach to uncertainty characterization are key
- Driving model development with a focus on specific science/decision problems is challenging
- Developing a compendium of "decision situations" coupled to model workflows, UC approaches, and engagement strategies is an important and feasible long-term objective for such modeling systems

Backup Slides

Taxonomy of Uncertainty Sources

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Such as:
- Future global emissions?
- Climate policies?
- Energy technology costs?

Such as:
- Ensembles needed to capture inter-annual variability?
- Alternative physics representations?

Such as:
- Additional phenomena?
- Competing models?
- Unknown unknowns?

Such as:
- Alternative couplings?
- Resolving scale differences?
- Harmonization?

UNCERTA Y SOURCE IDENTIFICATION

Input Quantification

Uncertainty in model input parameter values

Model Skill

Uncertainty in the model's predictive abilities

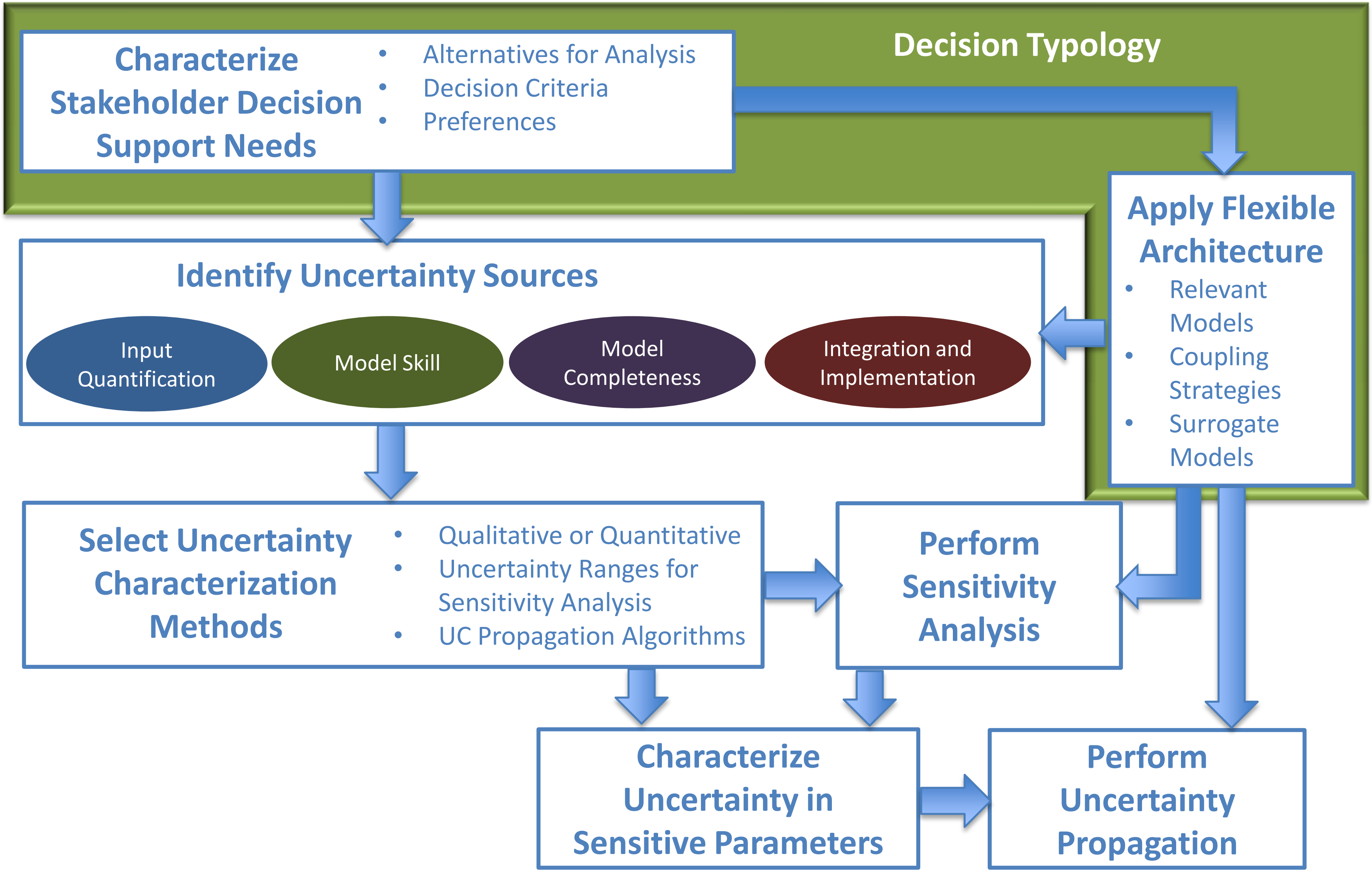
Model Completeness

Uncertainty due to model's inability to capture all phenomena

Integration and Implementation

Uncertainty due to software and hardware challenges of a model suite

Uncertainty Characterization Process



iRESM Decision-Relevant Uncertainty Characterization

1. Stakeholder Engagement

- Select pilot region
- Perform literature review
- Identify and meet with stakeholder organizations

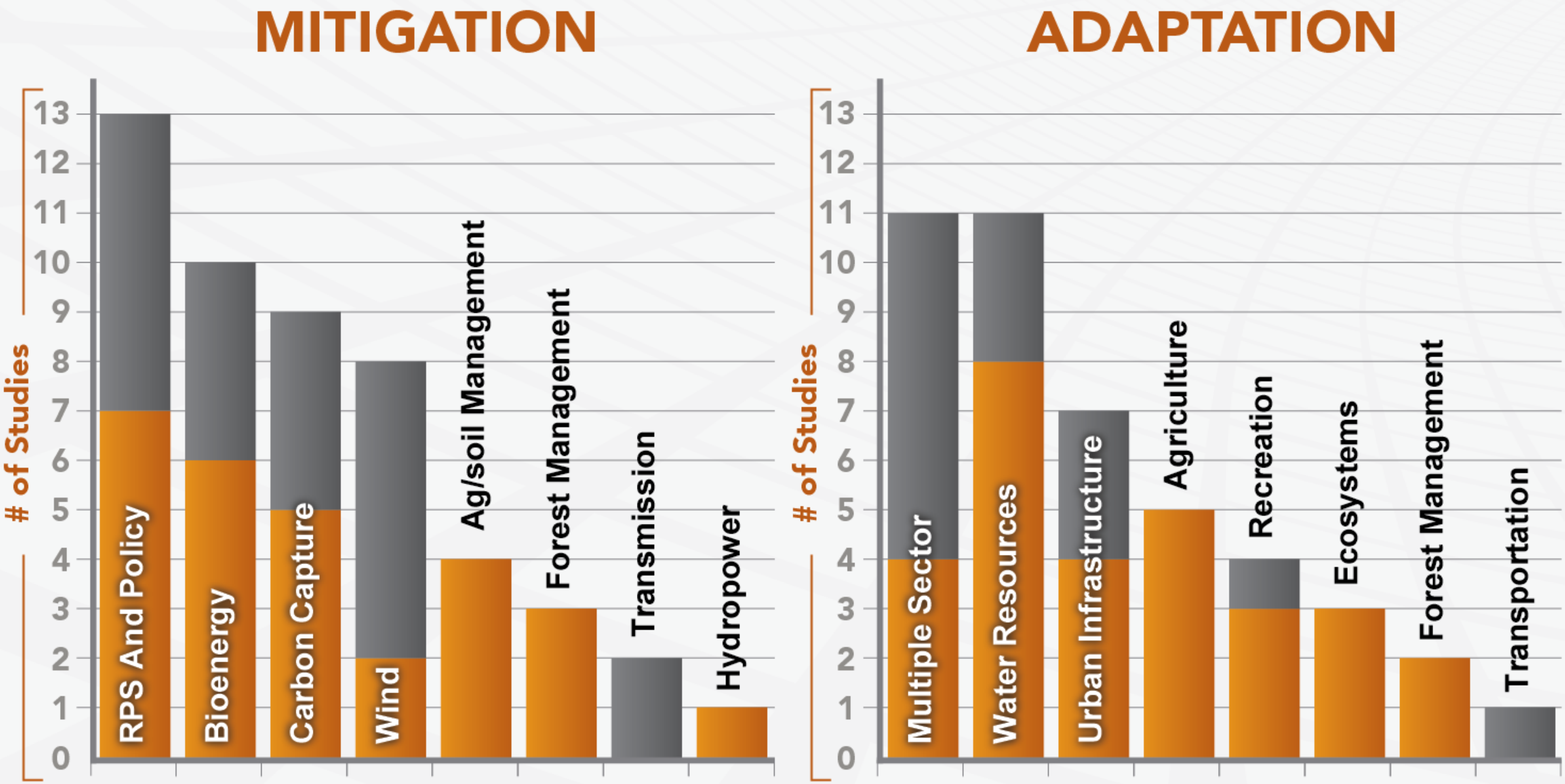
2. Decision Typology

- Mitigation and adaptation decisions for the region
- Decision criteria important for decision making
- Decision making processes
- iRESM model couplings needed for particular decisions

3. Uncertainty Characterization

- Uncertainty source identification for decision-relevant models and inputs
- Sensitivity analysis using decision criteria as the metrics
- Uncertainty propagation of sensitive parameters only

Literature Review Reveals Pilot Region Decisions Underway or in Prospect



Rice JS, RH Moss, PJ Runci, KL Anderson, and EL Malone. 2012. "Incorporating stakeholder decision support needs into an integrated regional Earth system model." *Mitigation and Adaptation Strategies for Global Change*. DOI: 10.1007/s11027-011-9345-3.

Insights: What We Have Learned

- The need for a decision- or problem-focused modeling approach:
  - Makes modeling and UC relevant and feasible
- Using data from stakeholder interviews to create a typology of decisions
  - Useful for identifying the need for standardized work flows
- Improved understanding of Midwest decision support interests
  - Clarified adaptation and mitigation options and decision situations
- The need for perseverance
  - Informing model development with a focus on decision making is challenging