Strategic Insight about Demand Reduction in Emission Scenarios

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Decomposition of mitigation sources from the IGSM model for a Reference (dynamics as usual) future with the global concentration of CO2 constrained to 450ppm (Climate Change Science Program, 2007)
Scenarios of many types powerfully shape perceptions about the future that frame near term decisions.

“2 billion people will still be without electricity…”

“We need to double the nuclear power capacity…”

“We need technologies that don’t exist yet…”

“Stabilizing climate change requires…”
Strategic Insights from Scenario Analysis

U.S. Climate Change Science Program Scenarios

Interpreting Policy Implications

Decomposing Key Drivers

Six Types of Demand Reduction

Sensitivity of Results to Demand Reduction

Direct Equivalent Method
Climate Change Science Program Scenarios

5 Scenarios

3 Models

2 Years
Energy Technology Portfolios for Stabilization

IGSM

MERGE

MiniCAM

Reference Scenarios

2000 2100

U.S. Climate Change Science Program (SAP 2.1, 2007)

Legend:
- Non-Biomass Renewables
- Nuclear
- Commercial Biomass
- Coal: w/ CCS
- Coal: w/o CCS
- Natural Gas: w/ CCS
- Natural Gas: w/o CCS
- Oil: w/ CCS
- Oil: w/o CCS
- Energy Reduction

Reference
Energy Technology Portfolios for Stabilization

Reference Scenarios

Level 4 Scenarios

750 ppm CO₂ only
Energy Technology Portfolios for Stabilization

IGSM

MERGE

MiniCAM

Reference Scenarios

Level 3 Scenarios

650 ppm CO₂ only
Energy Technology Portfolios for Stabilization

**IGSM**

**MERGE**

**MiniCAM**

**Level 2 Scenarios**

550 ppm CO\textsubscript{2} only
Energy Technology Portfolios for Stabilization

Reference Scenarios

Level I Scenarios

450 ppm CO₂ only

Legend:
- Non-Biomass Renewables
- Nuclear
- Commercial Biomass
- Coal: w/ CCS
- Coal: w/o CCS
- Natural Gas: w/ CCS
- Natural Gas: w/o CCS
- Oil: w/ CCS
- Oil: w/o CCS
- Energy Reduction
Strategic Insights from Scenario Analysis

- U.S. Climate Change Science Program Scenarios
- Interpreting Policy Implications
- Decomposing Key Drivers
- Six Types of Demand Reduction
- Sensitivity of Results to Demand Reduction
- Direct Equivalent Method
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

- Reference: REF
- Intervention: 450ppm CO2 only
- Model: IGSM

Possible Future
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

- Reference: REF
- Intervention: 450ppm CO2 only
- Model: IGSM

Annual CO₂ Emissions (GtC)

Stabilization
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

Reference: REF
Intervention: 450ppm CO2 only
Model: IGSM

Carbon Sequestration
What does it mean? Decomposing Mitigation Sources

Sources of Emissions Reductions

Annual CO₂ Emissions (GtC)

Reference: REF
Intervention: 450ppm CO₂ only
Model: IGSM

Biomass
Carbon Sequestration
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

Annual CO₂ Emissions (GtC)

Reference: REF
Intervention: 450ppm CO₂ only
Model: IGSM

Supply-Side
Biomass
Carbon
Sequestration
What does it mean? Decomposing Mitigation Sources

Sources of Emissions Reductions

- Carbon Sequestration
- Biomass
- End-Use Efficiency & Structural Change
- Supply-Side

Reference: REF
Intervention: 450ppm CO2 only
Model: IGSM
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

- Less Economic Activity
- End-Use Efficiency & Structural Change
- Supply-Side Biomass
- Carbon Sequestration

What caused these changes?
What intervention “policy” is most frequently applied in scenario analysis?

A benevolent omniscient dictator institutes a worldwide cap-and-trade program in which everyone plays, no players are obligated to mitigate more than others, and everyone can mitigate anywhere at anytime with low transaction costs.

As a result, everyone faces the same global carbon price, equal to the marginal cost of abatement.

Though this policy is not feasible to implement, it is used as a proxy:

“A global uniform carbon price has been applied as a proxy of pressure on the system to induce a variety of mitigation measures.”

- van Vuuren, RIVM 2001
What does it mean?
Decomposing Mitigation Sources

Sources of Emissions Reductions

Carbon Shadow Price

US$2000/MtC

$0

$2,000

$4,000

$6,000

2000

2050

2100

Annual CO2 Emissions (GtC)

Reference: REF
Intervention: 450ppm CO2 only
Model: IGSM

Less Economic Activity
End-Use Efficiency & Structural Change
Supply-Side Biomass Carbon Sequestration
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Direct Equivalent Method
Carbon Intensity of Energy

Energy Intensity of Economy

Average Income

People

Carbon Emissions

\[
\frac{P}{\text{GDP}} \times \frac{E}{\text{GDP}} \times \frac{C}{E} = C
\]

“Kaya Identity” (Kaya, 1991)
\[ \text{Energy Intensity of Economy} = \frac{E}{GDP} \]

\[ \text{Carbon Intensity of Energy} = \frac{C}{E} \]

\[ \text{Carbon Emissions} = C \]
Energy Intensity of Economy

Average Income

End Use

Energy Service

GDP

Energy Service

Carbon Intensity of Energy

Carbon Emissions

People

Final Energy

Primary Energy

Meter

End Use

Energy Service

Coal

Power Station and Grid

Electricity

Radian Energy

Illumination

Primary Energy

Energy Intensity of Economy

Carbon Intensity of Energy

Carbon Emissions

\[
\frac{P}{\text{GDP}} \times \frac{E}{\text{GDP}} = C
\]
Primary Energy

Final Energy

End Use

Energy Service

People

Average Income

Energy Intensity of Economy

GDP

PE

Carbon Intensity of Energy

Carbon Emissions

\[ \frac{C}{PE} = C \]
Carbon Intensity of Energy = Carbon Emissions / Energy Intensity of Economy

Primary Energy

Final Energy

End Use

Energy Service

People

Average Income

Energy Intensity of Economy

Energy Supply Loss Factor

Carbon Intensity of Energy

Carbon Emissions

P

GDP

FE

PE

C

= C
Carbon Intensity of Energy

Energy Supply Loss Factor

End Use Energy Service

Fraction Disposed to Atmosphere

Carbon Emissions

\[
C = \frac{C}{TC} + \frac{PE}{PE} - \frac{FE}{FE} + \frac{GDP}{GDP} - \frac{P}{P}
\]
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Direct Equivalent Method
Decomposing Key Drivers

- **Carbon per unit of energy (2000=1)**
  - 2000: 0.0%
  - 2050: 0.5%
  - 2100: 1.0%

- **Fraction Not Sequestered (2000=1)**
  - 2000: 0.0
  - 2050: 0.5
  - 2100: 1.0

- **Energy use / productivity (2000=1)**
  - 2000: -1.4%
  - 2050: -1%
  - 2100: 0.0%

- **PE/FE (2000=1)**
  - 2000: 0.3%
  - 2050: 0.0%
  - 2100: 0.0%

- **GDP / capita (2000=1)**
  - 2000: 1971-1980 = -1%
  - 2050: 1980-2000 = -1.4%
  - 2100: 1995-2000 = -2%
  - 2050: 1920-2000 = -0.4%

**Carbon Shadow Price**

- US$2000/MtC
  - 2000: $0
  - 2050: $2,000
  - 2100: $4,000
  - 2050: $6,000
Decomposing Key Drivers

- **GDP / P**
- **FE / GDP**
- **PE / FE**
- **TC / PE**
- **C / TC**

**Carbon Shadow Price**

- GDP / capita (2000=1)
- Energy use / productivity (2000=1)
- PE / FE (2000=1)
- Carbon per unit of energy (2000=1)
- Fraction Not Sequestered (2000=1)

- 1971-1980 = -1%
- 1980-2000 = -1.4%
- 1995-2000 = -2%
- 1971-2000 = 0.3%
- 1920-2000 = -0.4%

- 2000 2050 2100
- 0 0.5 1.0 1.5 2.0
- 0.0 0.5 1.0 1.5 2.0
- 0.0 0.5 1.0 1.5 2.0
- 0 0.5 1.0 1.5 2.0

- Reference
- Intervention
Decomposing Key Drivers

- **GDP/P**
- **FE/GDP**
- **PE/FE**
- **TC/PE**
- **C/TC**

**Carbon Shadow Price**

- $0$ to $6,000$ (US$2000/MtC)

**GDP / capita (2000=1)**
- Reference: 2.0
- Intervention: 2.5

**Energy use / productivity (2000=1)**
- Reference: 1.0
- Intervention: 0.5

**PE/FE (2000=1)**
- Reference: 1.0
- Intervention: 0.7

**Carbon per unit of energy (2000=1)**
- Reference: 2.0
- Intervention: 1.5

**Fraction Not Sequestered (2000=1)**
- Reference: 0.0
- Intervention: 0.5

- **1971-1980 = -1%**
- **1980-2000 = -1.4%**
- **1995-2000 = -2%**

- **1971-2000 = 0.3%**
- **1920-2000 = -0.4%**
### Primary Energy

- **CRUDE OIL**
- **OIL REFINERY AND DISTRIBUTION SYSTEM**

### Final Energy

- **MOTOR GASOLINE**
- **AUTOMOBILE**
- **MOTIVE POWER**
- **DISTANCE TRAVELED**

### Productive Use

- **POWER STATION AND GRID**
- **ELECTRICITY**
- **LAMP**
- **RADIANT ENERGY**
- **ILLUMINATION**

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- **Efficiency**: More energy delivered per energy input
- **Fuel Switching**: Moving from coal to natural gas
- **Electrification**: Changing the share of electricity in FE
### Primary Energy vs. Final Energy vs. Productive Use

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<th>Primary Energy</th>
<th>Final Energy</th>
<th>Productive Use</th>
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<td>Primary Energy</td>
<td>Delivered Energy</td>
<td>End-Use Technology</td>
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</tbody>
</table>

#### Energy Conversion Examples:
- **Crude Oil** → Oil Refinery and Distribution System → Motor Gasoline → Automobile → Motive Power → Distance Traveled
- **Coal** → Power Station and Grid → Electricity → Lamp → Radiant Energy → Illumination

#### Key Concepts:
- **Conservation**: Less non-productive energy use
- **Energy Intensity**: More productivity per energy input
- **Structural Change**: Same productivity, less energy use (Shift toward service economy)
California vs. USA: Efficiency in Electric Power Sector

Per Capita Electricity Sales (not including self-generation) (kWh/person) (2005 to 2008 are forecast data)

Slide from Art Rosenfeld, California Energy Commission
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- Sensitivity of Results to Demand Reduction
- Direct Equivalent Method
Examining the Role of Efficiency

- Less Economic Activity
- End-Use Efficiency & Structural Change
- Energy Supply Losses
- Solar
- Wind
- Hydropower
- Biomass
- Nuclear
- Fossil Fuel Switching
- C. Seq. w/ Biomass
- C. Seq. w/ Fossil
- Land-Use
- Non-CO2 gases

High growth reference case (A2) limited to 670ppm CO2-eq (MSG-MACRO, IIASA GGI, 2006)
## Examining the Role of Efficiency

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- **Carbon Intensity of Energy Supply**
- Examining the Role of Efficiency
Examining the Role of Efficiency

Indexed to 1990=1

High growth reference case (A2) limited to 670ppm CO2-eq (MSG-MACRO, IIASA GGI, 2006)
Examining the Role of Efficiency

Economic Welfare (GDP per Capita)

Energy Intensity of Economic Activity

Energy Supply Loss Factor

Carbon Intensity of Energy Supply

Fraction Disposed to Atmosphere

Indexed to 1990 = 1

High growth reference case (A2) limited to 670ppm CO2-eq (MSG-MACRO, IIASA GGI, 2006)
Examining the Role of Efficiency

Economic Welfare (GDP per Capita)

Energy Intensity of Economic Activity

Energy Supply Loss Factor

Carbon Intensity of Energy Supply

Fraction Disposed to Atmosphere

What if...?

Carbon Shadow Price

Indexed to 1990=1
What difference does 0.5% make?

What if the energy intensity improvement in this scenario was on par with the prevailing trend of the last 20 years?
Summary of Findings

- When sufficient data is disclosed, **two decomposition techniques** can explore scenario results from any model for any future – fast.

- Analyzing sources and key drivers of mitigation is **necessary** to interpret **policy-relevant implications** of scenarios generated with (infeasible) **proxy policy interventions**.

- This analysis is **model agnostic**. It does **not** investigate the origins of demand reduction from each model (e.g. AEEI function or a marginal cost curve for demand reduction.) Data for either are hard to gather.

- Regardless of method, energy scenarios for climate stabilization do not:
  - discern between conservation (behavior) and end-use efficiency (technology)
  - characterize policies focused on non-price barriers to end-user behavioral change
Summary of Findings

- Application of these decomposition techniques indicate that the contribution of energy efficiency is often understated...

- Which strains energy supply options causing scenarios to deploy high-risk technologies on a large scale.

- Environmental and social impacts of most large-scale supply-side mitigation have not been well investigated.
  - “We tend to like best the things about which we know the least.”

- Even when efficiency is taken into account, the level of effort implied by stabilization scenarios is staggering.

- This justifies even more attention on behavioral change as a ready source of mitigation that is poorly characterized in stabilization scenarios.
Thank you

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