# Integrated Assessment Modeling of Energy Consumption Behavior and Carbon Emissions

Thomas Sanquist, Bin Shui and **Heather Orr**



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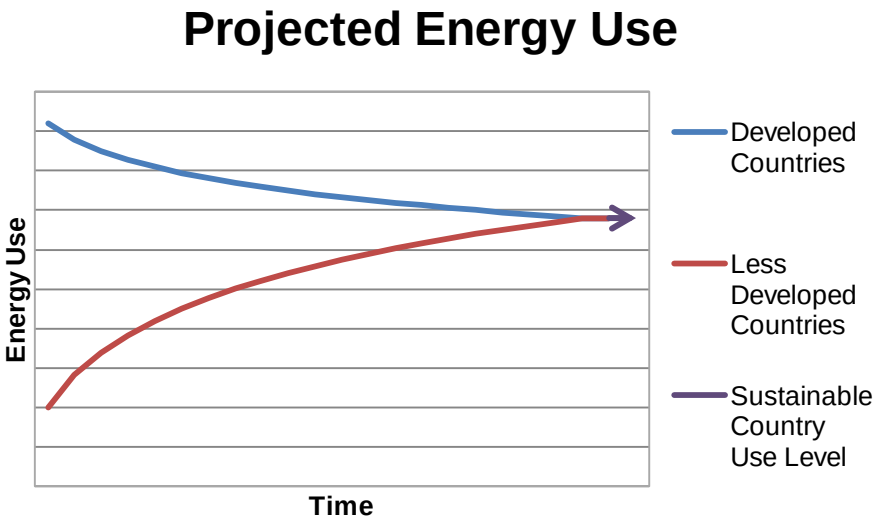
# Mission & Vision

- International stability depends on understanding policy-behavior-energy use dynamics, agreeing on change targets and successfully implementing
- Develop behavioral-energy use prediction model to help understand how carbon caps will be achieved internationally
  - OECD nations will need to reduce
  - Less Developed Countries need to aim for sustainable development
- IPCC concludes it is necessary to "mainstream" mitigation and adaptation
- Stabilization will directly affect many aspects of everyday life – understanding behavioral impacts and influences is essential

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# National Security Implications

- Threats to national security may now arise less from the relationship of nation to nation and more from the relationship of man to nature….dwindling reserves threaten the security of nations everywhere (Brown, Worldwatch Institute, 1977).
- "Each of us can help end America's addiction to oil. Using less fuel in our cars and trucks reduces overall demand….and reduces carbon emissions…we can support electric personal transport, with liquid fuels used primarily for aircraft and the military…..these steps may seem small….collectively they can make us more secure" (CNA Military Advisory Board, 2009).



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# National Security Implications, continued

- National security challenges (Climatic Cataclysm: The foreign policy and national security implications of climate change. Brookings Institute, 2008).
  - Expected climate change – 2.3$^{o}$F by 2040
    - US as first responder
    - Immigration pressure
    - Loss of basing capability
  - Severe Climate Change – 4.7$^{o}$F by 2040
    - Regional nuclear war potential
    - Border issues
  - Catastrophic Climate Change – 10.8$^{o}$F by 2040
    - Struggle for survival

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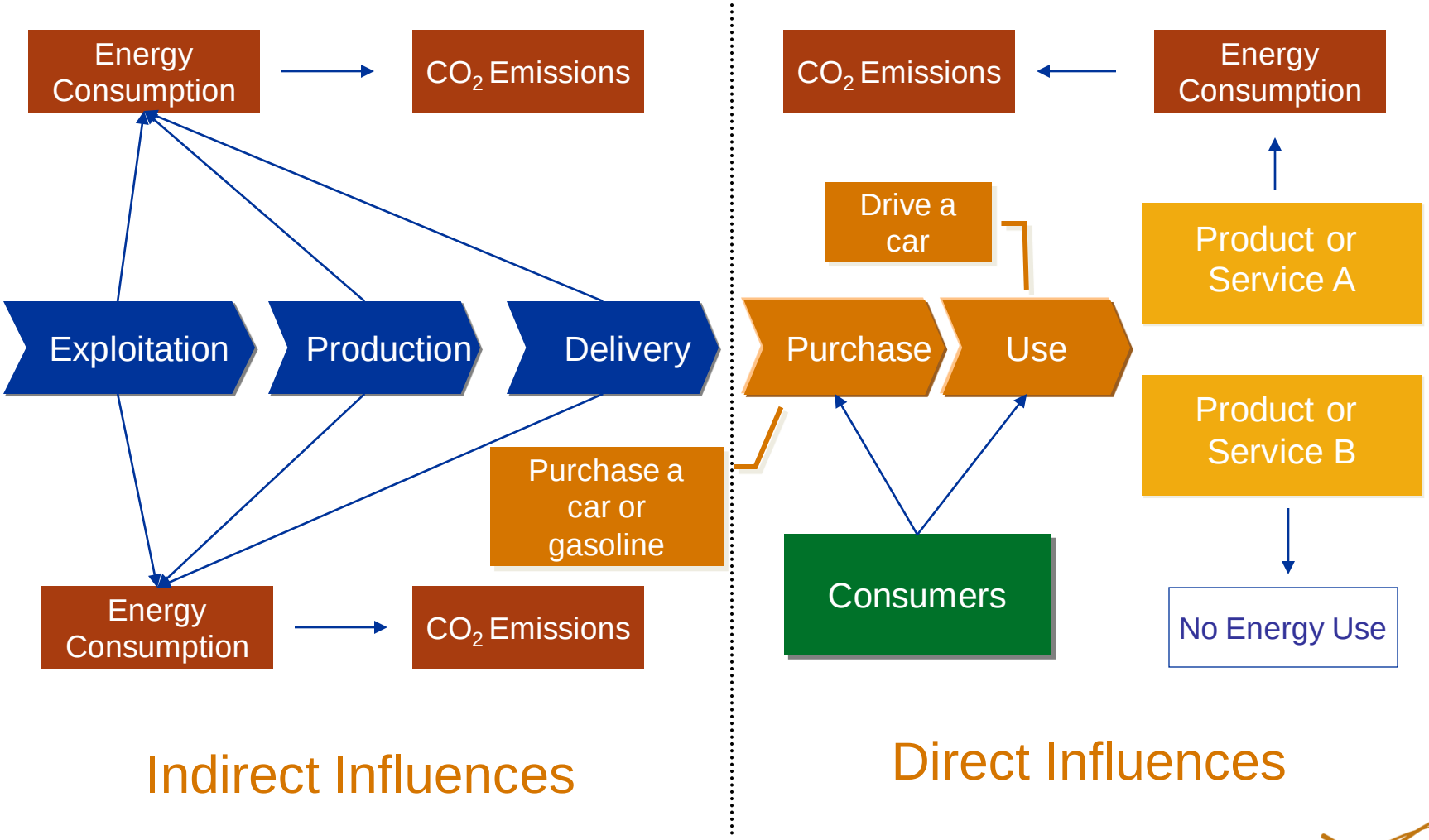
# Research Questions (among others...)

- How can human behavior change reduce energy use and Greenhouse Gas (GHG) emissions?
- What data are available to address these questions?
- How has energy consumption changed over time and how is this reflected in specific lifestyle elements?
- What are the means for altering behavior and how much effect can we expect?
- How do predicted behavior changes relate to available and anticipated energy supply, GHG reduction targets and various measures of well-being?
- How well can we predict at state, nation, global level?

# Direct & Indirect Energy Consumption

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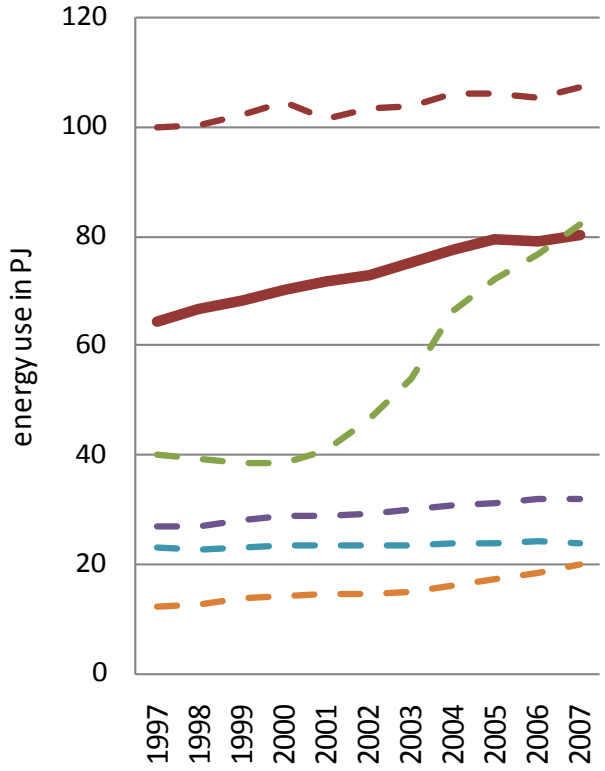
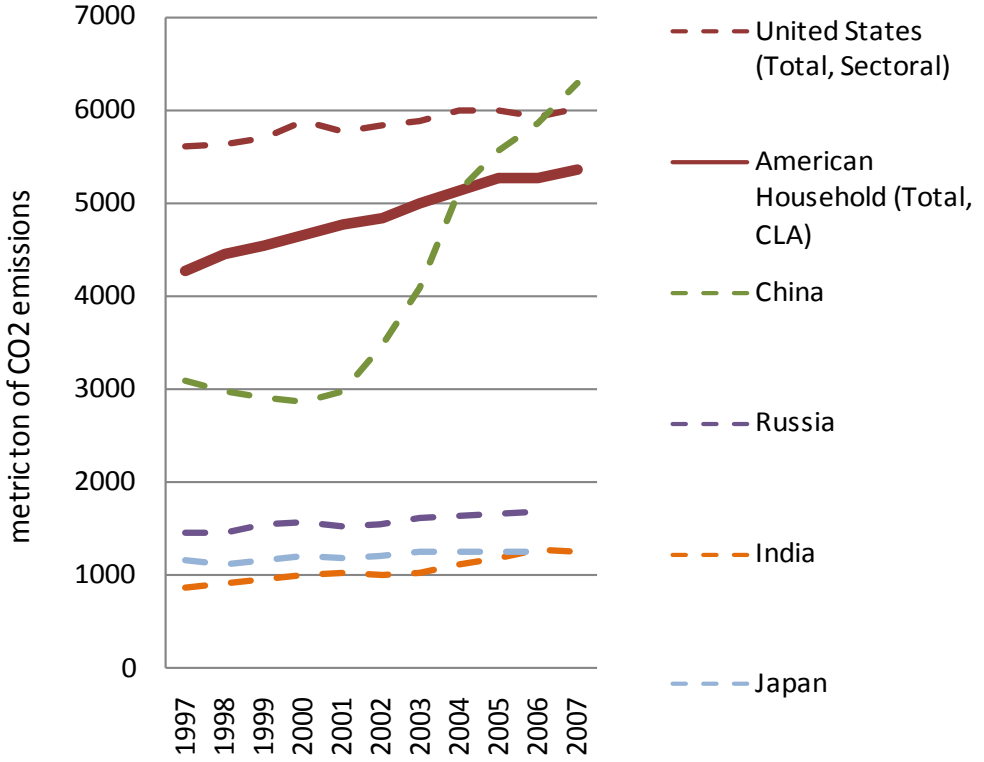
# Total Energy and CO2 Emissions of US Household Consumption



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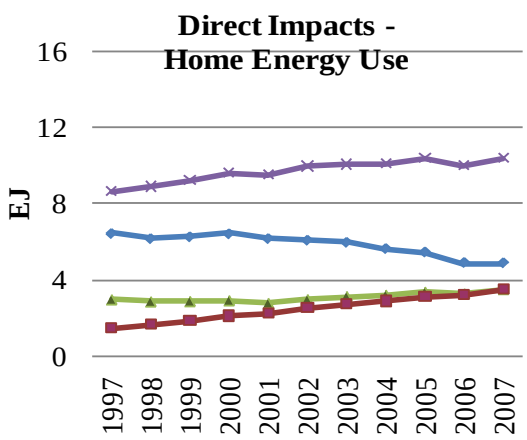
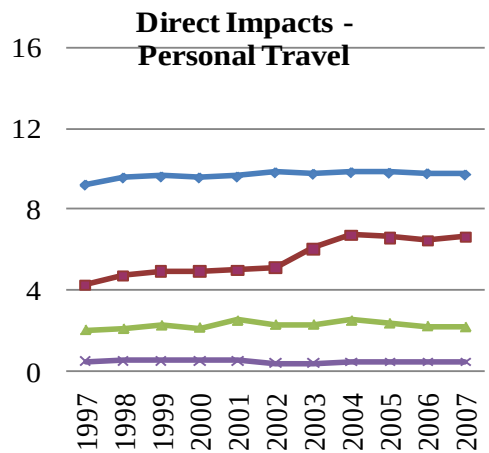
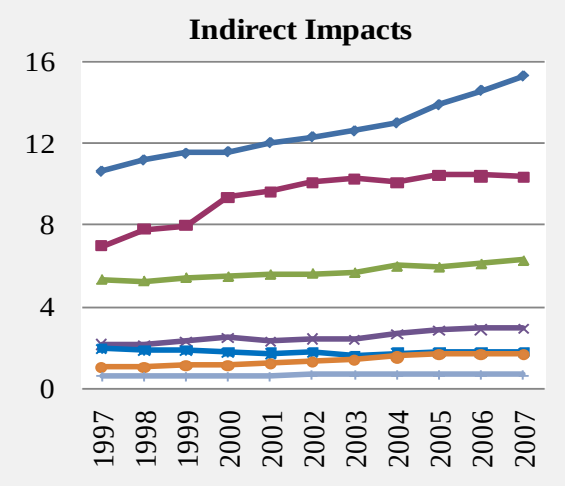
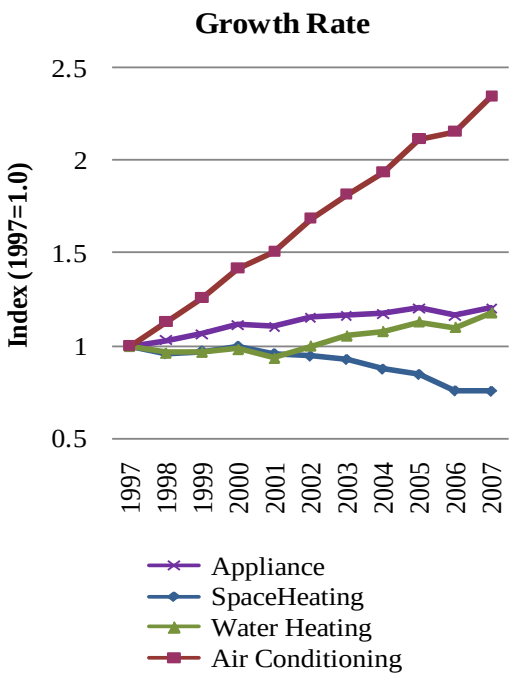
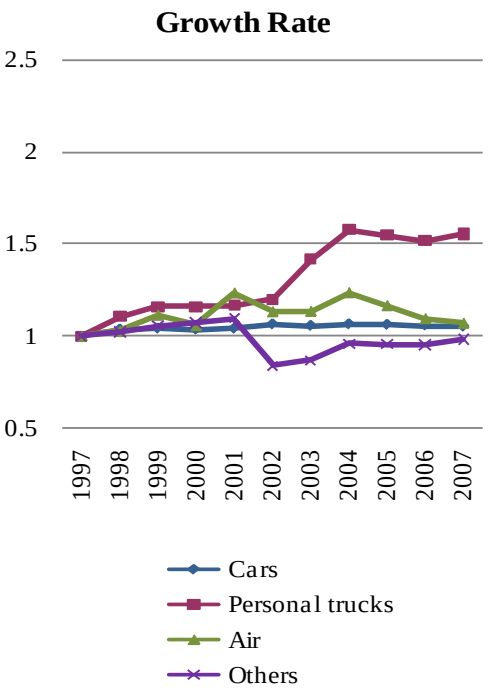
# Growth Rates of Household Consumption

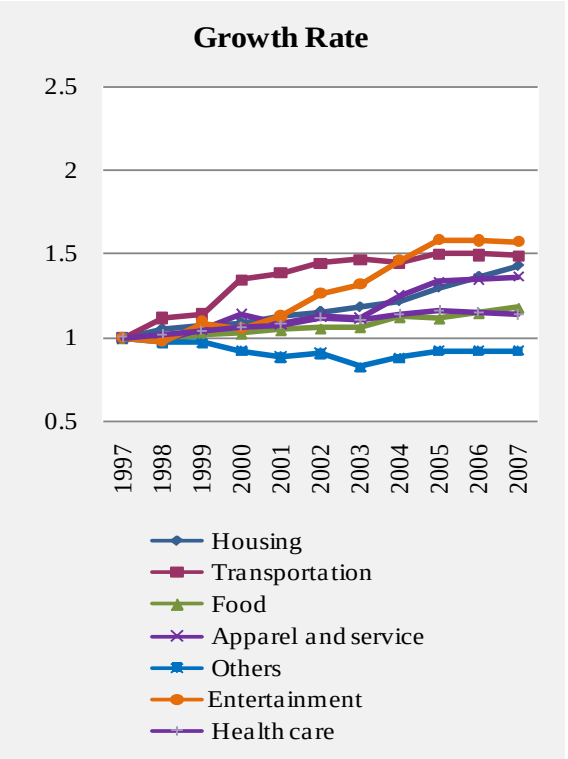


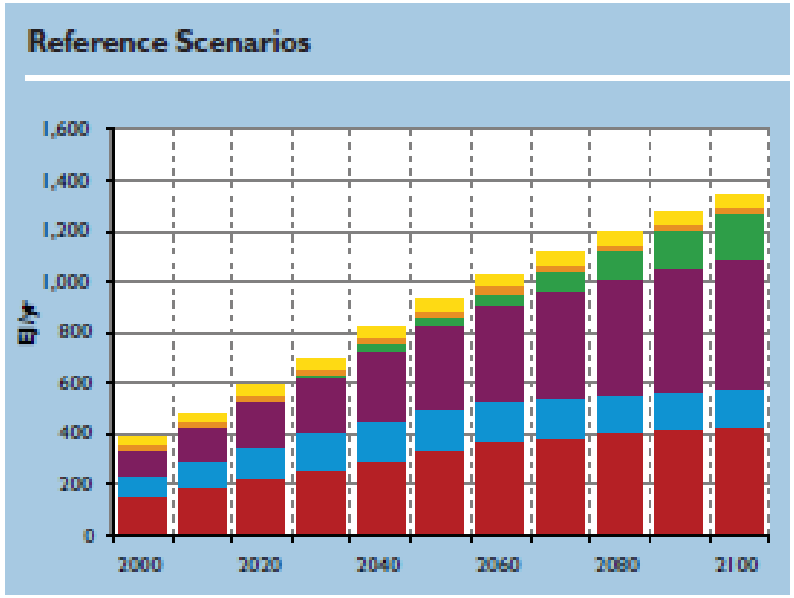



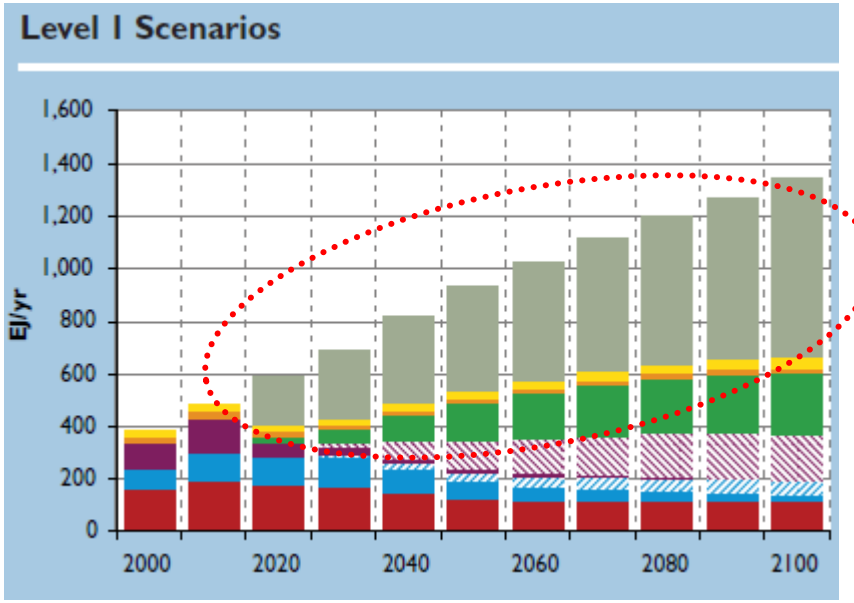



# Modeling Goal: Behavior Change Prediction in Relation to Climate Change Stabilization



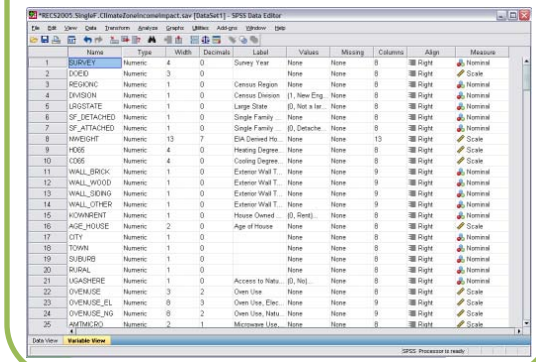

- Non-Biomass Renewables
- Nuclear
- Commercial Biomass
- Coal: w/ CCS
- Coal: w/o CCS
- Natural Gas: w/ CCS
- Natural Gas: w/o CCS
- Oil: w/ CCS
- Oil: w/o CCS
- Energy Reduction

The grey area:
The role of behavior

# Procedure

RECS data from EIA
600 Variables

Choose ~200 Behavioral and Structural Variables



Include variables not in PCA (e.g. structural)

## PCA Analysis

**Rotated Component Matrix**[a]

| | Component 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Heating Degree Days | -.053 | -.058 | -.842 | -.003 | .176 | .006 | .014 | .091 | -.014 |
| Cooling Degree Days | -.045 | .002 | .888 | -.065 | -.062 | .008 | .053 | .053 | .012 |
| Age of House | -.159 | -.141 | -.140 | -.111 | .150 | -.004 | -.732 | -.065 | .022 |
| Oven Use, Electric | .072 | .045 | -.077 | -.037 | .060 | .078 | .133 | .630 | .030 |
| Dish Washer Use | .181 | .298 | -.068 | .178 | .367 | .022 | .318 | .182 | .086 |
| Clothes Washer Use | -.063 | .593 | -.023 | .344 | .134 | .060 | -.107 | .393 | .090 |
| Clothes Dryer Use, Electric | -.060 | .396 | .053 | .337 | .107 | -.002 | -.006 | .640 | .055 |
| Number Ceiling Fans | .015 | -.064 | .498 | .130 | .339 | .190 | .160 | .131 | .035 |
| Number TVs | .150 | .287 | .103 | .153 | .255 | .506 | .085 | -.005 | .042 |
| VCR | .052 | -.005 | -.013 | .144 | .040 | .819 | .049 | .019 | .082 |
| DVD | .152 | .100 | .020 | .154 | -.017 | .776 | .025 | .008 | .024 |
| TV Use | -.033 | .273 | .088 | -.266 | -.156 | .415 | -.089 | .169 | .108 |
| Tools With Rechargeable Batteries | .220 | -.097 | -.054 | .501 | .101 | .109 | .115 | .141 | .076 |
| Cell Phone | .238 | .112 | .160 | .619 | .058 | .065 | .061 | -.055 | .055 |
| STEREO | .110 | .100 | -.053 | .607 | .000 | .137 | -.007 | -.058 | .013 |
| Number PCs | .789 | .129 | -.004 | .211 | .153 | .143 | .059 | -.007 | .130 |
| PC Time On Total, Weekly | .711 | .121 | .030 | -.100 | .102 | .065 | -.016 | .096 | .105 |
| Printer | .712 | -.015 | .005 | .408 | .119 | .059 | .105 | .022 | .012 |
| Internet | .743 | -.012 | .007 | .370 | .131 | .080 | .088 | .011 | -.012 |
| Hot water heater, electric | .043 | -.188 | .131 | -.144 | -.166 | -.020 | .020 | .676 | -.046 |
| Have a thermostat for main AC | .076 | .011 | .402 | .073 | .146 | .015 | .600 | .093 | .070 |
| Hours per day light bulbs are on | .102 | .083 | .047 | .085 | .122 | .079 | .014 | .062 | .838 |
| Hours per day energy efficient light bulbs are on | .093 | .046 | .007 | .033 | .004 | .078 | .046 | -.028 | .870 |
| Number of windows in house | .147 | -.001 | -.028 | .048 | .793 | .004 | -.145 | -.076 | .021 |
| House is adequately insulated | -.028 | -.173 | -.130 | -.011 | .138 | .065 | .675 | .024 | .026 |
| Number household members | .138 | .811 | -.006 | .101 | .038 | .182 | .010 | .007 | .032 |
| Number people age 13-19 | .090 | .750 | .029 | -.087 | -.056 | .076 | .009 | -.091 | .046 |
| HHINCOME | .420 | .122 | .006 | .344 | .398 | .025 | .240 | -.104 | .069 |
| SQRT_TOTSQFT | .218 | -.006 | -.074 | .036 | .718 | .039 | .195 | .045 | .083 |

Extraction Method: Principal Component Analysis. | Rotation Method: Va

a. Rotation converged in 8 iterations.

| pc use | laundry | climate | affluence | size house | tv use | newer hou | large applia | light use |
|---|---|---|---|---|---|---|---|---|

## Regression

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics: R Square Change | F Change | df1 | df2 |
|---|---|---|---|---|---|---|---|---|
| 1 | .405[a] | .164 | .163 | .56790 | .164 | 423.458 | 1 | 2163 |
| 2 | .498[b] | .248 | .247 | .53876 | .084 | 241.250 | 1 | 2162 |
| 3 | .563[c] | .316 | .316 | .51366 | .069 | 217.442 | 1 | 2161 |
| 4 | .617[d] | .380 | .379 | .48919 | .064 | 222.614 | 1 | 2160 |
| 5 | .653[e] | .426 | .425 | .47078 | .046 | 173.230 | 1 | 2159 |
| 6 | .680[f] | .462 | .460 | .45611 | .035 | 142.141 | 1 | 2158 |
| 7 | .702[g] | .492 | .491 | .44308 | .031 | 129.780 | 1 | 2157 |
| 8 | .717[h] | .514 | .513 | .43345 | .022 | 97.919 | 1 | 2156 |
| 9 | .729[i] | .532 | .530 | .42562 | .018 | 81.034 | 1 | 2155 |
| 10 | .740[j] | .547 | .545 | .41872 | .015 | 72.605 | 1 | 2154 |
| 11 | .746[k] | .557 | .555 | .41427 | .010 | 47.598 | 1 | 2153 |
| 12 | .751[l] | .564 | .562 | .41109 | .007 | 34.406 | 1 | 2152 |
| 13 | .755[m] | .570 | .567 | .40837 | .006 | 29.772 | 1 | 2151 |
| 14 | .756[n] | .572 | .569 | .40772 | .002 | 7.842 | 1 | 2150 |
| 15 | .757[o] | .573 | .570 | .40723 | .001 | 6.158 | 1 | 2149 |
| 16 | .758[p] | .574 | .571 | .40677 | .001 | 5.881 | 1 | 2148 |

a. Predictors: (Constant), large appliance use factor
b. Predictors: (Constant), large appliance use factor, climate factor
c. Predictors: (Constant), large appliance use factor, climate factor, Price per kWH
d. Predictors: (Constant), large appliance use factor, climate factor, Price per kWH, pc use factor
e. Predictors: (Constant), large appliance use factor, climate factor, Price per kWH, pc use factor, size house factor

Examine excluded variables, factors not easily defined

# Principal Component Analysis

| | Component | | | | | |
|---|---|---|---|---|---|---|
| | IT Lifestyle | Large New House | Number People | Climate | TV/Light Use | Large Appliances |
| Heating Degree Days | -.035 | -.062 | -.010 | -.901 | .025 | .046 |
| Cooling Degree Days | -.096 | .266 | -.027 | .855 | .055 | .072 |
| Age of House | -.162 | -.484 | -.154 | -.128 | .150 | -.091 |
| Oven Use, Electric | .052 | .138 | .181 | -.149 | .120 | .635 |
| Dish Washer Use | .305 | .355 | .433 | -.189 | -.001 | -.008 |
| Clothes Washer Use | .086 | .066 | .857 | -.014 | .103 | .064 |
| Clothes Dryer Use, Electric | .006 | .127 | .753 | .012 | .039 | .341 |
| Number Ceiling Fans | .121 | .411 | .058 | .324 | .182 | .028 |
| Number TVs | .274 | .197 | .282 | .023 | .514 | -.174 |
| TV Use | -.178 | -.106 | .132 | .112 | .750 | .063 |
| Number PCs | .853 | .087 | .117 | .002 | .111 | -.017 |
| PC Time On Total, Weekly | .701 | -.008 | -.023 | .042 | .230 | .135 |
| Internet | .765 | .132 | .108 | -.001 | -.034 | -.017 |
| Hot water heater, electric | -.057 | -.007 | -.034 | .162 | -.078 | .816 |
| Have a thermostat for main AC | .051 | .863 | -.005 | .146 | .058 | .039 |
| Hours per day light bulbs are on | .240 | .153 | .047 | -.060 | .502 | .063 |
| Number household members | .178 | -.071 | .665 | .075 | .241 | -.151 |
| HHINCOME | .634 | .282 | .215 | -.068 | -.110 | -.169 |
| SQRT_TOTCSQFT | .102 | .838 | .018 | .035 | .152 | .028 |

# Regression – Predicting KWH Use

Model Summary

| Model | Adjusted R Square | Std. Error of the Estimate | R Square Change | Significance (p value) |
|---|---|---|---|---|
| Large New House Factor | .153 | .57141 | .153 | .000 |
| Large Appliance Factor | .263 | .53298 | .110 | .000 |
| Age youngest household member | .353 | .49940 | .090 | .000 |
| Price per KWH | .402 | .48031 | .049 | .000 |
| IT Lifestyle Factor | .451 | .46016 | .049 | .000 |
| Number People, laundry, dishwasher Factor | .485 | .44553 | .035 | .000 |
| Climate Factor | .517 | .43163 | .032 | .000 |
| TV/Light Use Factor | .548 | .41745 | .031 | .000 |
| Number Separate Freezers | .562 | .41095 | .014 | .000 |
| Access to Natural Gas | .573 | .40572 | .011 | .000 |
| Number of windows in house | .582 | .40135 | .009 | .000 |
| Hot Tub, Electric | .589 | .39785 | .007 | .000 |
| Number of Heating Thermostats | .595 | .39500 | .006 | .000 |
| Cell Phone | .597 | .39415 | .002 | .001 |
| Person at home all day | .599 | .39332 | .002 | .002 |
| Fax Machine | .600 | .39284 | .001 | .012 |
| Cordless Phone | .601 | .39240 | .001 | .016 |
| House in the City | .601 | .39205 | .001 | .028 |
| House is shaded by trees | .602 | .39173 | .001 | .034 |
| Microwave Use, Weekly | .603 | .39143 | .001 | .039 |

# Next step: Dynamic Regression Model

RECS 1997 $y_0 = b_0 + a_{01}x_1 + a_{02}x_2 + \ldots\ldots + a_{0i}x_i + e_0$

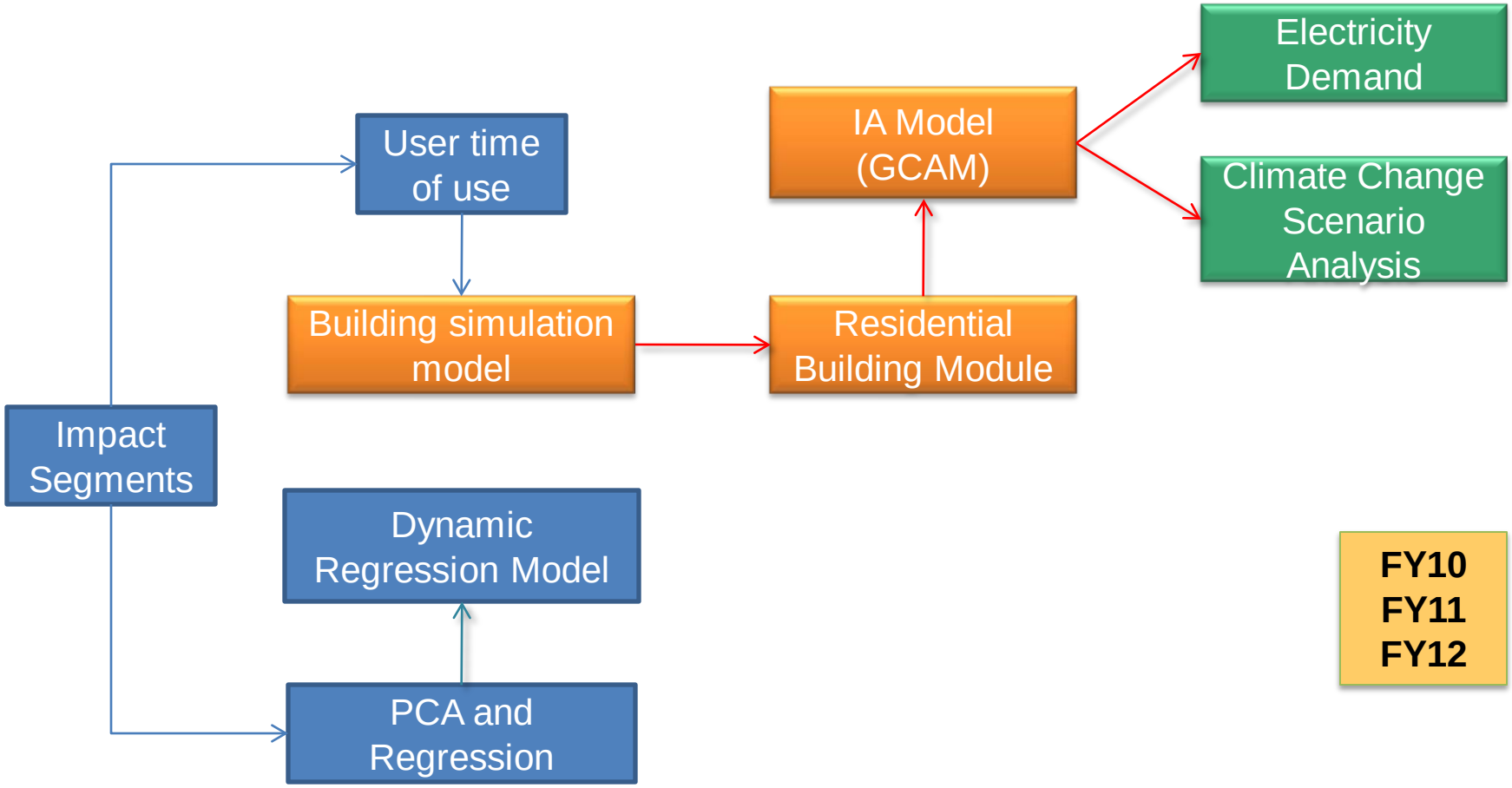
RECS 2001 $y_4 = b_4 + a_{41}x_1 + a_{42}x_2 + \ldots\ldots + a_{4i}x_i + e_4$

RECS 2005 $y_8 = b_8 + a_{81}x_1 + a_{82}x_2 + \ldots\ldots + a_{8i}x_i + e_8$

$$y_t = b_t + \sum_{i=1}^{n} a_{ti}x_i + e_t$$

$$y_t = f_b(b_t) + \sum_{i=1}^{n} f_{ai}(a_{ti})x_i + f_e(e_t)$$

# Predictive Model Development

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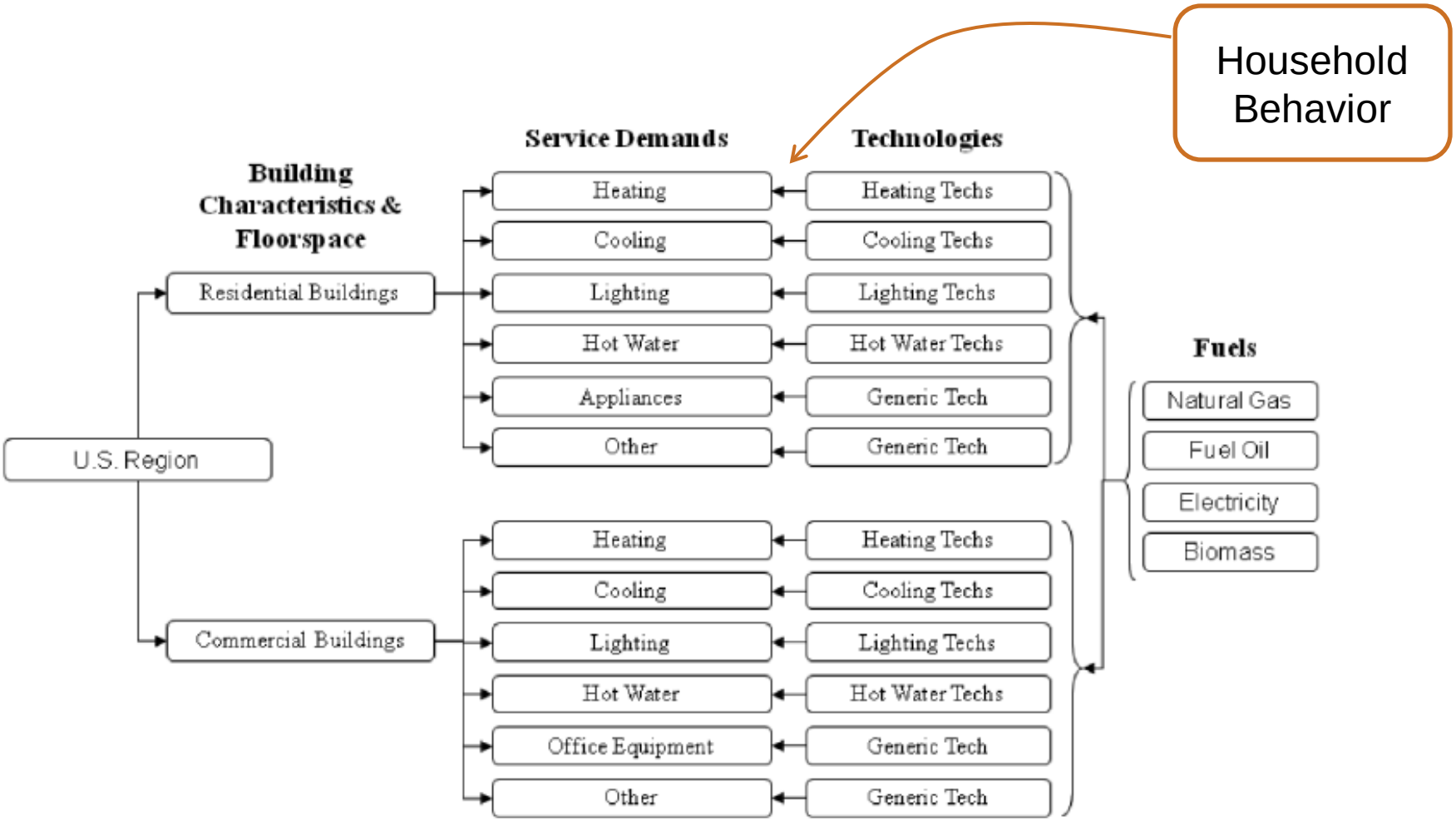
# Global Change Assessment Model approach




- Demand Function $d_{i,t} = \phi_{i,t}\ \sigma_i P_{i,t}^{-\beta_i}$

# Where to go from here

- Apply process to data from other countries for an international picture
- Run forecasts under varying climate stabilization scenarios that consider regional agreements for carbon limitations



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