Energy Efficiency and Climate Data

CEDM

Estimating Responses to Prices in Residential Energy Consumption in the U.S. and in the E.U.

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Carnegie Mellon University

Center on Climate and Energy Decision Making (CEDM)

- www.cedm.epp.cmu.edu
- Started in 2010
- Distributed center, anchored at CMU
- As been prepared over the last year and is going to officially start in the next month
- $1.2 million per year for 5 years

The goal is…

- …To have an interdisciplinary collaborative group that will assist private and public organizations to make climate and energy-related decisions in ways that are:

    - scientifically informed
    - cost-effective
    - socially equitable
    - behaviorally realistic

The investigators…

…in our new Center care deeply about:

1. making serious progress in solving the climate problem
2. educating a new generation of young investigators, policy analyst and problem solvers
3. developing, demonstrating and promulgating new methods for framing and addressing climate decision problems, especially those in technology and public policy, in which uncertainty is of central importance

Making serious progress in solving the climate change problems requires:

- Decision-making on greenhouse gas mitigation strategies
- Adaptation strategies
- Dealing with unexpectedly rapid or large changes/impacts

	Decision problem & proposal section	Agent-based methods	Consumer choice & behavior	Decision & B-C analysis	Expert elicitation methods	Engineering-economic analysis	Group decision tools	Health &/or environmental effects	Legal & regulatory analysis	Life-cycle assessment	Mental models	Optimization	Real options	Risk perception & comm.	Robust decision methods	Simulation modeling	Statistics & econometrics	Lead investigators
GHG EMISSION ABATEMENT	2.1 Integration of variable power sources	○		●		●	●			●		●	●		●	●	●	CMU: Apt, (Lave), Morgan Duke: Patiño; George Mason: Axtell
	2.2 Adoption and integ. of plug hybrids	○	●	●	○	●			○	●		●	○	○		●		CMU: Apt, Michalek; RAND Pgh: Samaras
	2.3 Public choice of elec. gen. mix		●			●	●				●			●				CMU: Bruine de Bruin, Fischhoff UBC: McDaniels
	2.4 Promoting energy efficieny		●	●	○	●	○			○	○	●				●	●	CMU: Azevedo, Davidson, Fischhoff, (Lave) UBC: Dowlatabadi
	2.5 Assessment of carbon footprints		●	●		●			●	●			○	●	○	○		CMU: Griffin, Hendrickson, (Lave), Matthews, Weber; UBC: Dowlatabadi
	2.6 Adaptive manage-ment in CCS regulation			●				●	●					○		●		CMU: Morgan, (McCoy), Rubin; UCalg: Keith UBC: McDaniels; VT Law: Dworkin
ADAPTATION TO CLIMATE CHANGE IMPACTS	2.7 Water and low carbon energy production		●			●		○	●	●		○		●	●	●	●	CMU: Matthews, Morgan, (McCoy), Rubin RAND Santa Monica: Lempert
	2.8 Hurricane impacts & flooding			●		●			●					●	●	○	●	CMU: Grossmann; Wharton: Kunreuther, Michel-Kerjan; VT Law: Dworkin
	2.9 D-A assessment of hurricane modification			●	○				●					●		●		CMU: Grossmann, Morgan; UCalg: Keith UBC: McDaniels; Penn State: Keller
	2.10 Thermal and acidification impacts on ocean biota			●	●		○	●	●					●	●	●		CMU: Azevedo, Morgan, Small Woods Hole: Doney; UBC: McDaniels
ABATEMENT/ ADAPTATION INTERACTION	2.11 Externalities of variable power sources	○		●		●	●			●		●	●			●	●	CMU: Apt, (Lave), Morgan, Rubin, Matthews Duke: Patiño; UCalg: Keith
	2.12 Energy impacts of water desalinizaton			●		●									○	●		CMU: Apt, Morgan, Matthews RAND Santa Monico: Lempert
	2.13 CC and air quality interaction					●	●	●				○		●		●		CMU: Adams, (Donahue), (Pandis), (Robinson) UBC: Dowlatabadi, McDaniels
	2.14 AC in public space for health in heat waves			●		●		●						○				CMU: Casman; UBC: Dowlatabadi
DEALING WITH UNEXPECTEDLY RAPID OR LARGE CHANGE OR IMPACTS	2.15 Direct air scrubbing & sequestration			●	○	●	○	●					●	●		●		CMU: (Lowry), Rubin; UCalg: Keith
	2.16 Assessment and governance of albedo modification			●	○	●	○	●					●	●		●		CMU: Morgan; UCalg: Keith; Penn.St: Keller Oxford: (Allen)

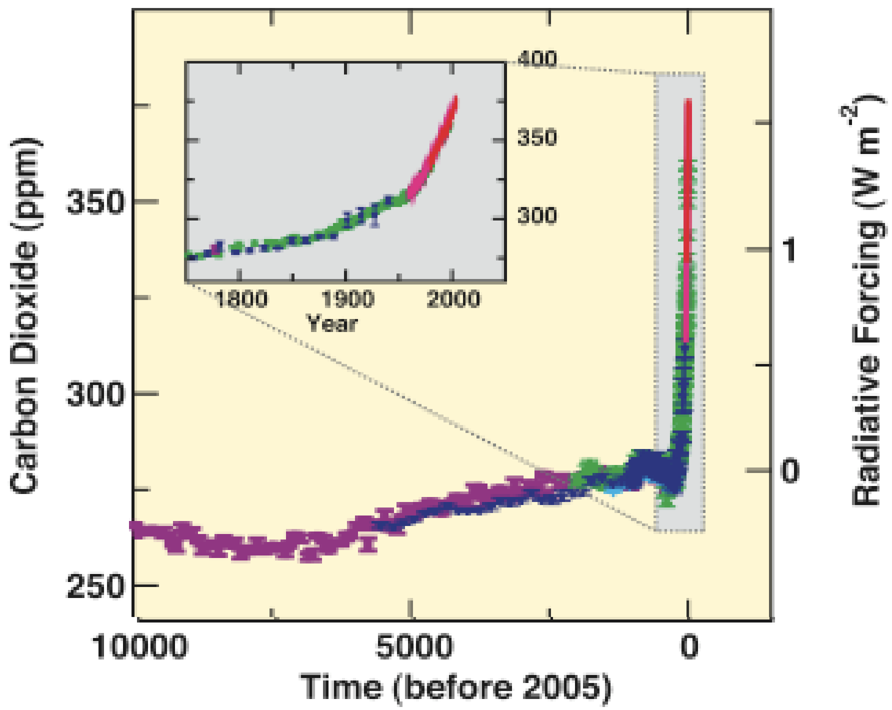
Fig 1: Summary of research planned in the proposed Center. Solid dots indicate areas in which applications are definitely planned. Gray dots indicate areas in which we hope to develop applications. Investigators who will participate but are not supported in this proposal's budget are shown in brackets.

- Some early progress..

1. Developing Mitigation Strategies

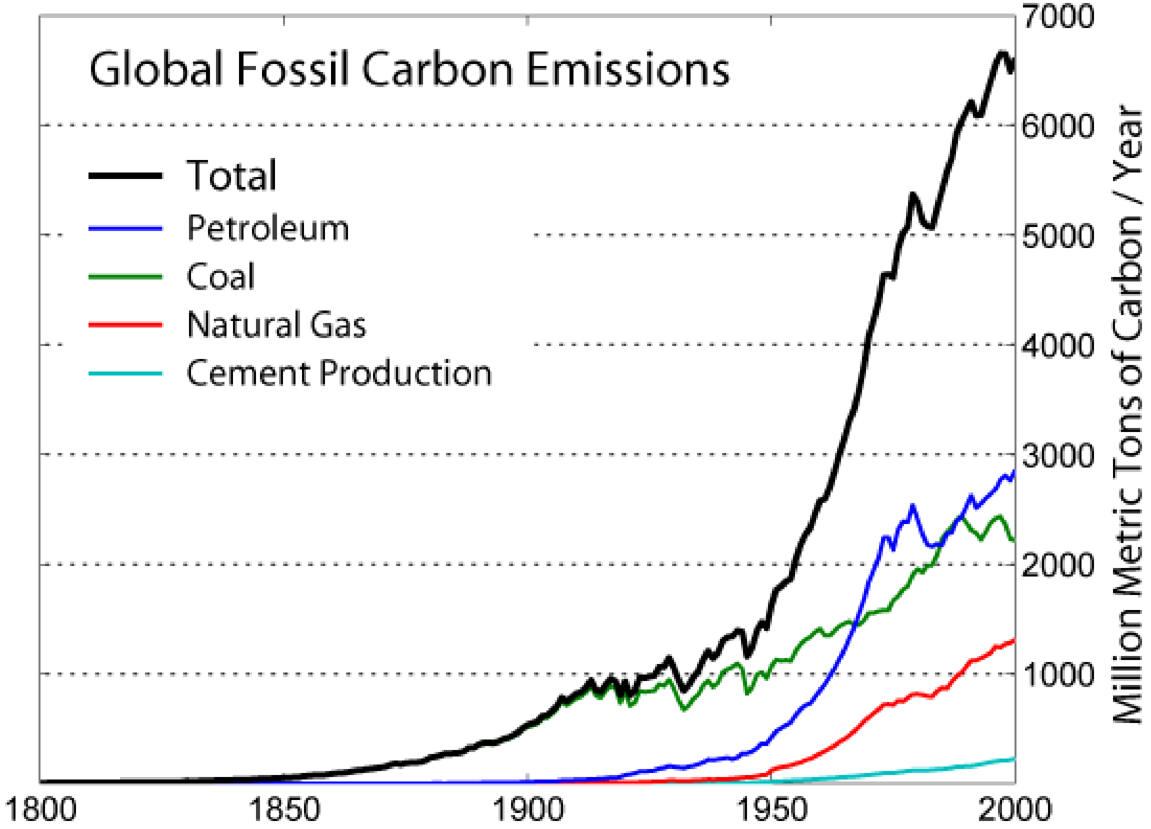
While uncertainties remain about the science of climate change, and its impacts, there is no uncertainty about one thing:

We need to reduce emissions of GHG by roughly an order of magnitude



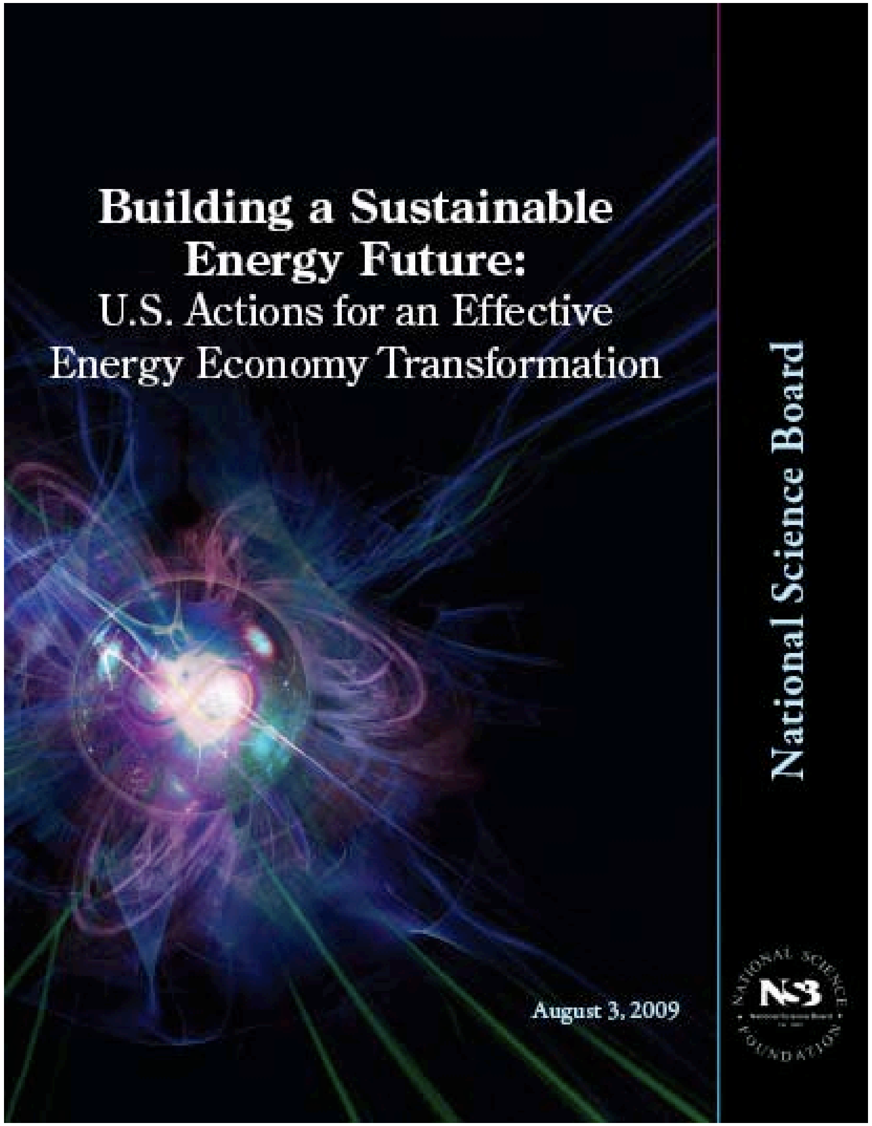
1. Developing Mitigation Strategies

That means there will have to be a massive transformation in the way we use and produce energy.



A recent NSB report calls for:

- Substantial and continuous investment in **sustainable energy R&D**
- Energy policies that facilitate the development and deployment of sustainable energy technologies established and evaluated through the use of **social and behavioral research**.
- National public awareness of sustainable energy solution regarding **energy consumption and energy efficiency**

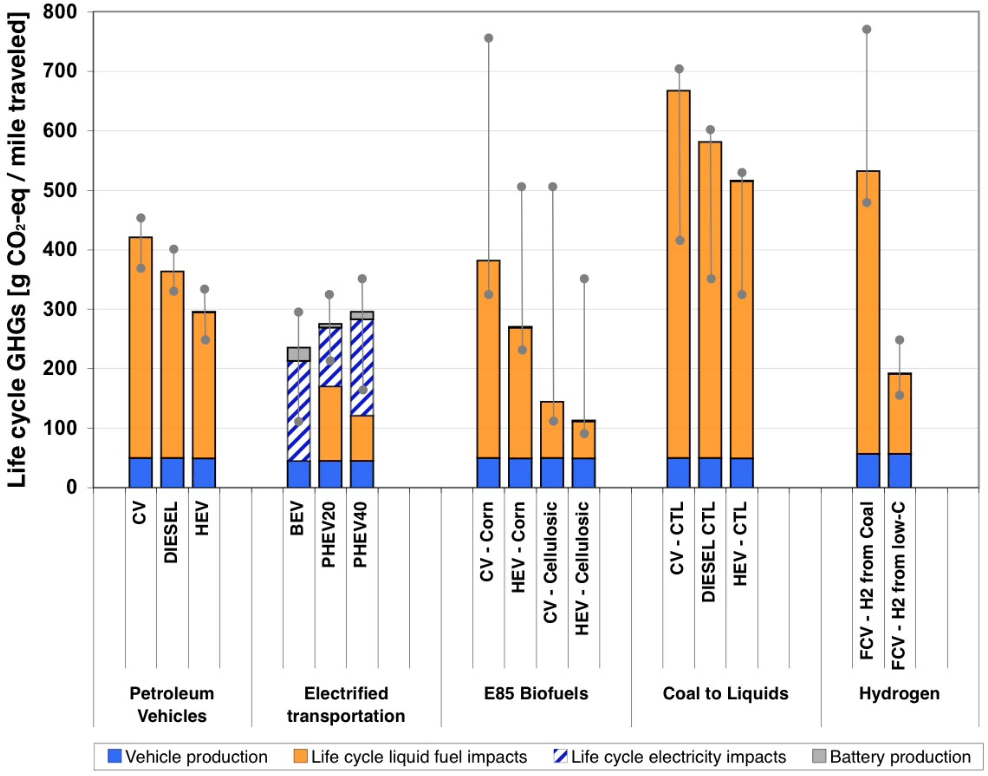


1. Developing Mitigation Strategies

Example 1: PHEV

Because the generation of electricity is at present such a large source of CO_2 emissions, we have spent quite a lot of time thinking about **what future developments might lead to *increased* demand**.

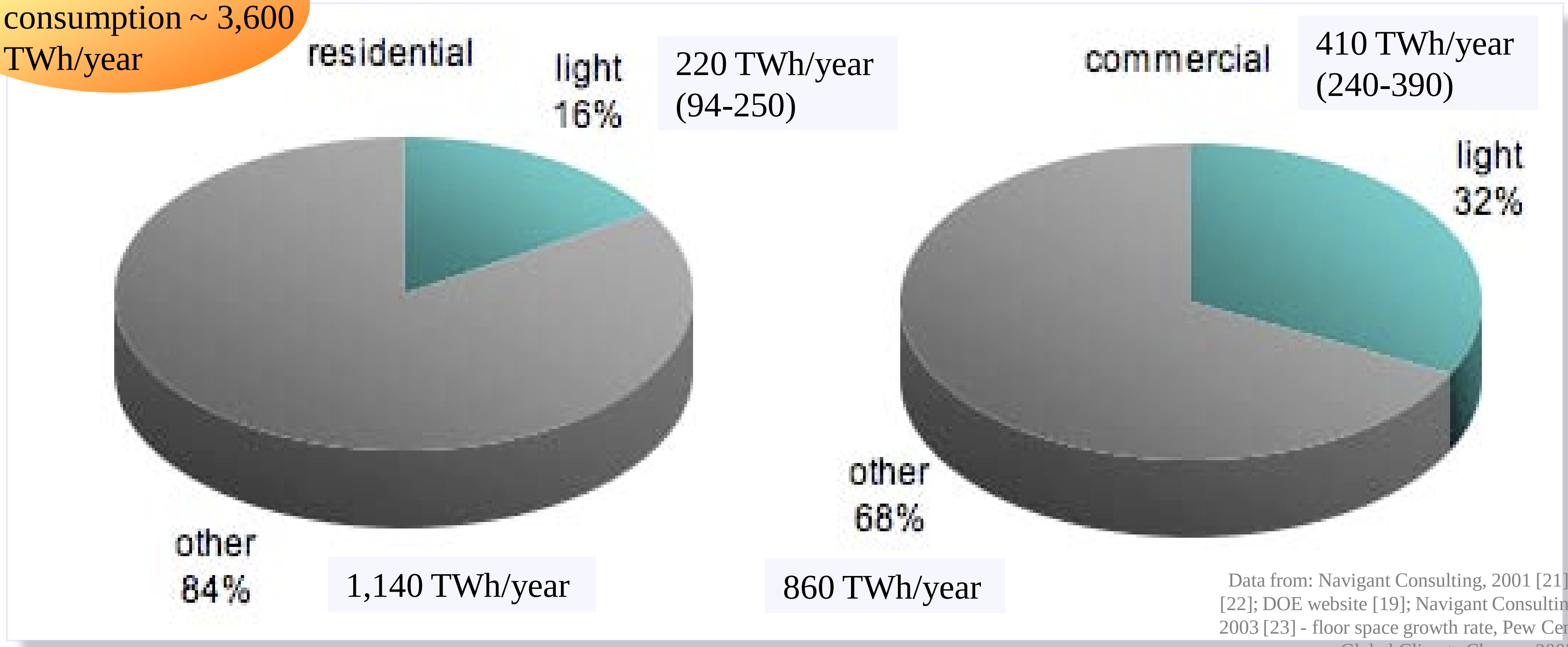
Clearly, PHEVs and EVs, while they will reduce emissions from the transportation sector, will add to the electricity sector. To date our work suggests that even here in W. PA, where much of our electricity comes from coal, the switch to short range PHEVs will result in a small decrease in CO_2 given the present generation mix.



1. Developing Mitigation Strategies

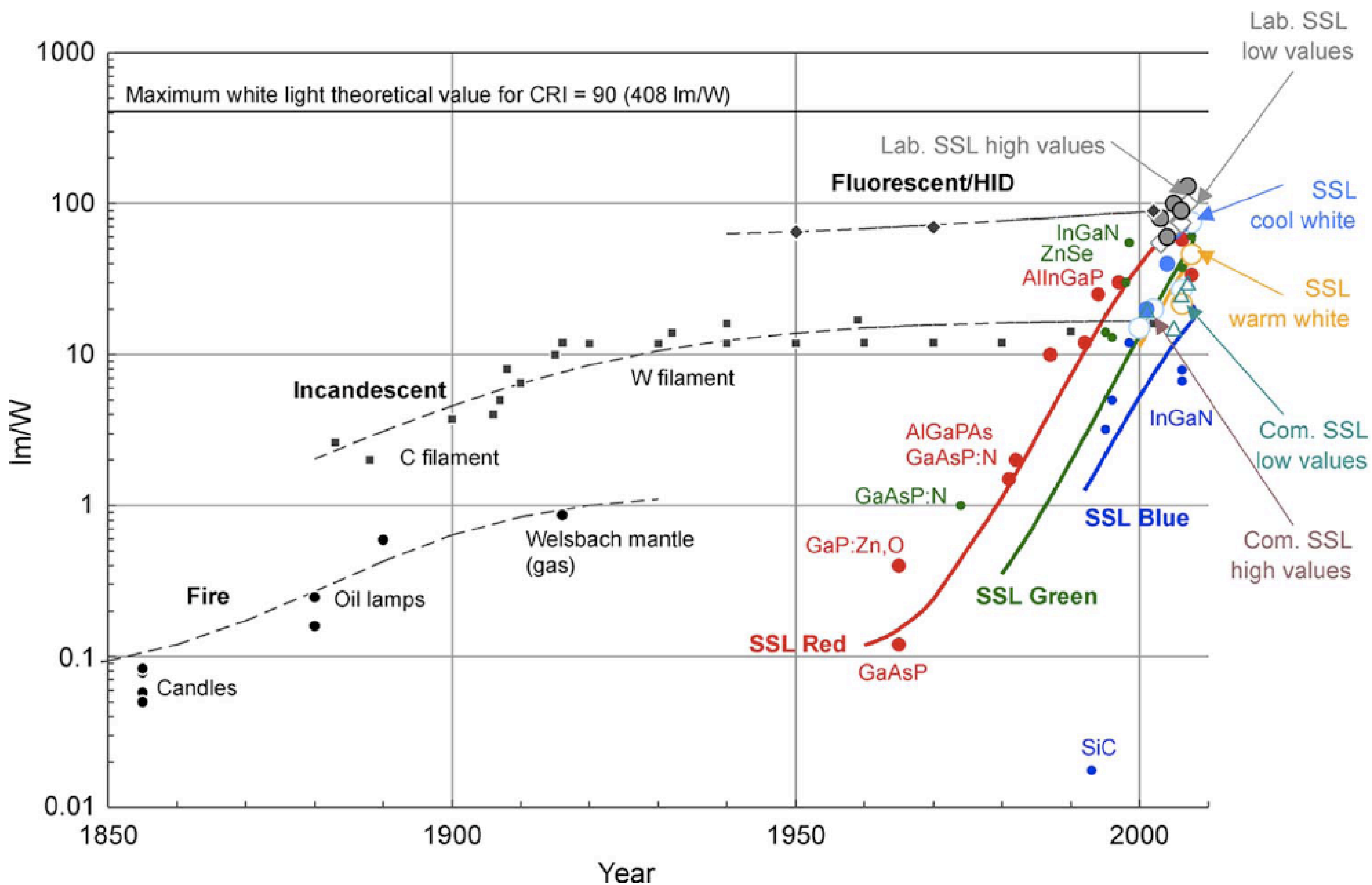
Example 2: Efficient Lighting

Total US electricity consumption ~ 3,600 TWh/year



Data from: Navigant Consulting, 2001 [21], 2005 [22]; DOE website [19]; Navigant Consulting, Inc, 2003 [23] - floor space growth rate, Pew Center on Global Climate Change, 2005 [20].

- ~20% of total electricity consumption in the US



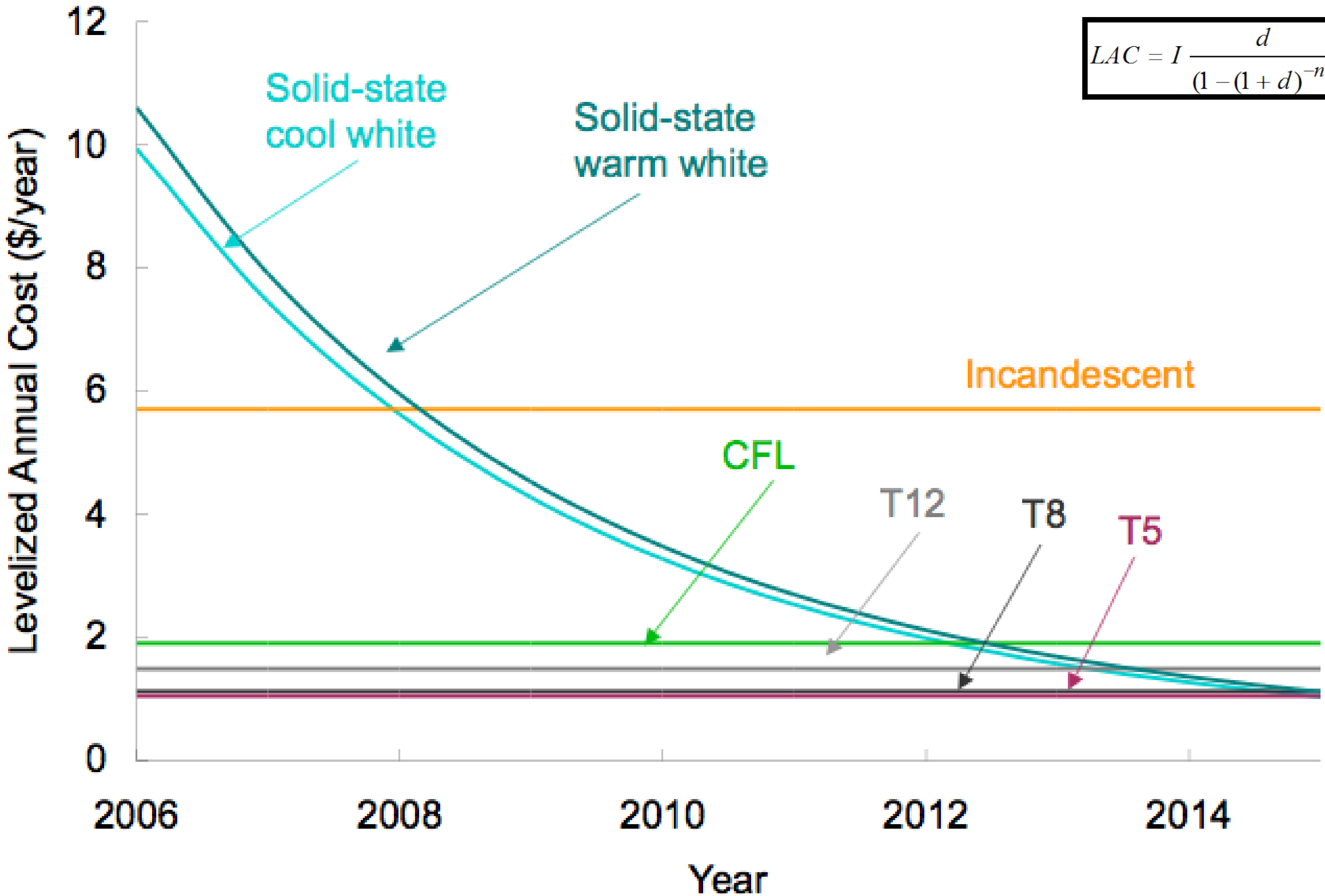
Lab. SSL low values
Lab. SSL high values
Maximum white light theoretical value for CRI = 90 (408 lm/W)
Fluorescent/HID
SSL cool white
InGaN
ZnSe
AlInGaP
SSL warm white
Incandescent
W filament
C filament
Com. SSL low values
InGaN
AlGaPAs
GaAsP:N
GaAsP:N
SSL Blue
Com. SSL high values
Welsbach mantle (gas)
GaP:Zn,O
SSL Green
Fire
Oil lamps
SSL Red
GaAsP
Candles
SiC
lm/W
Year
1000
100
10
1
0.1
0.01
1850
1900
1950
2000

P = 0.10$/kWh

Hours = 2h/day

D = 20%

$$LAC = I \frac{d}{(1-(1+d)^{-n})} + O\&M$$



2. Adaptation

…Because of the inertia in the climate system:

The world is already committed to major climate change and impacts by later this century.

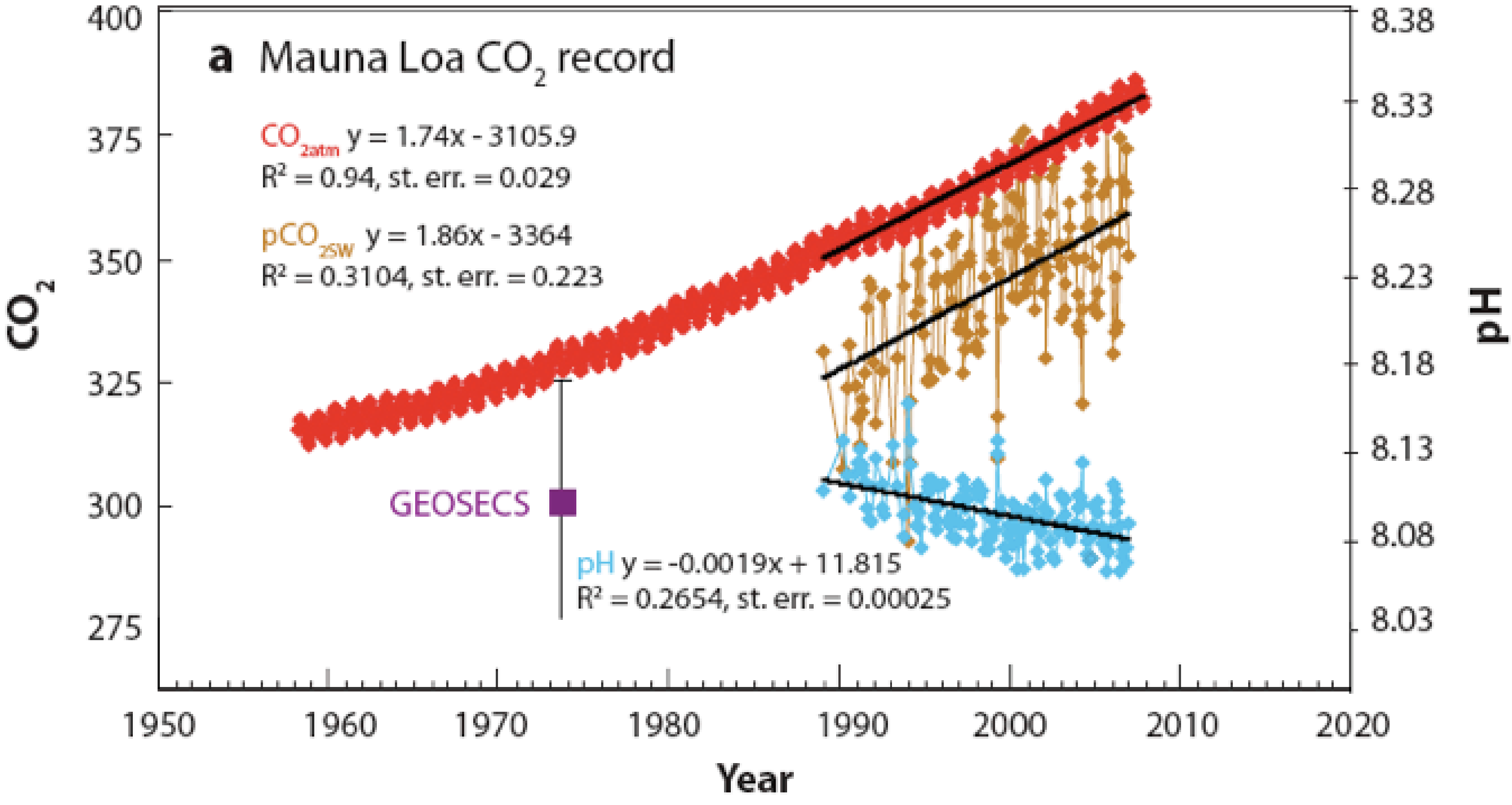
That means many people and organizations will face the need to adapt to these changes, many of which will remain highly uncertain.

Some of these adaptations will likely have impacts on energy use, thus affecting GHG emissions.

This is why our goal to focus on problems of adaptation as well

2. Adaptation

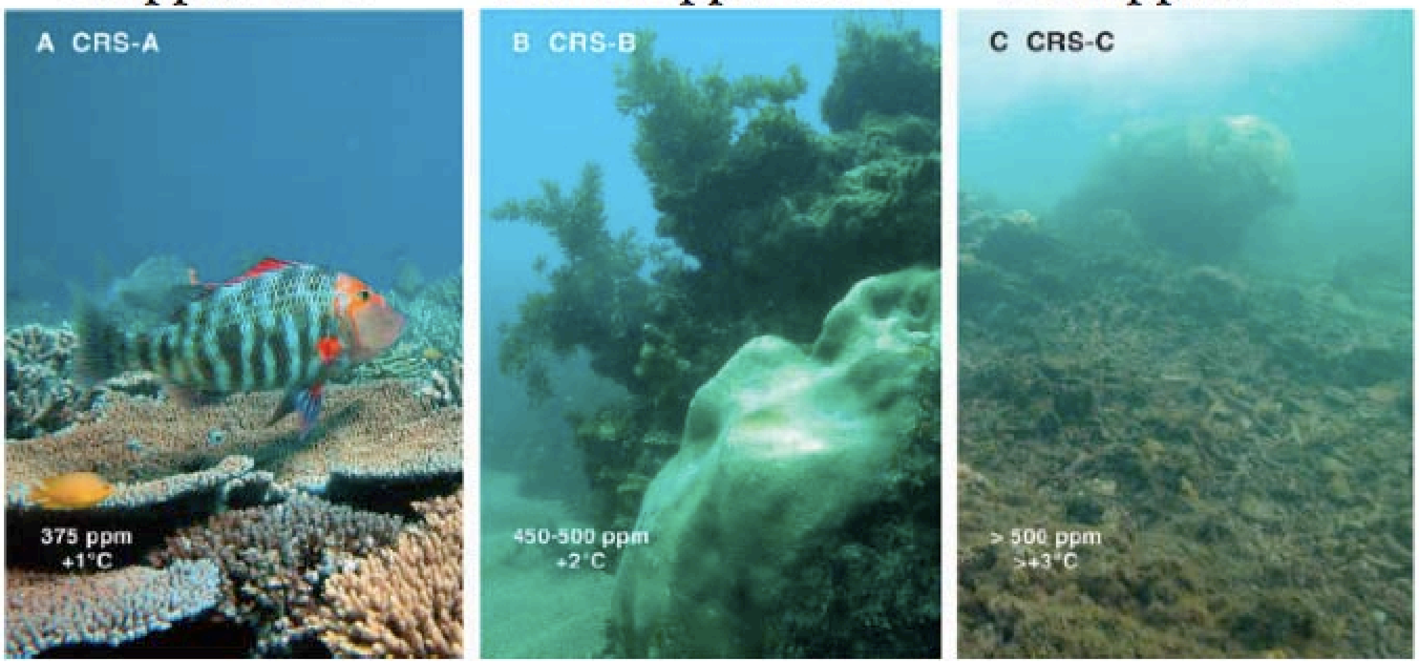
Example 2: Impacts of Ocean Acidification



2. Adaptation

…likely means the demise of coral reefs *and all the ecosystems they support*.

375ppm +1°C 450-500ppm +2°C >500ppm >3°C

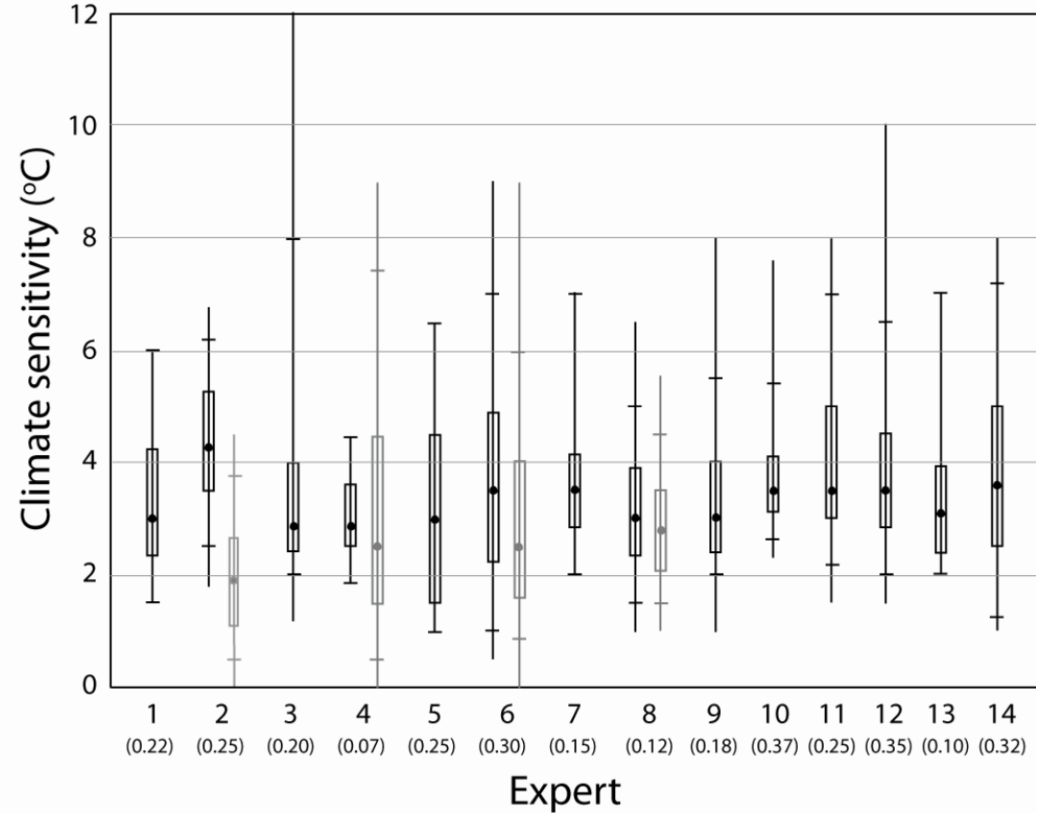


rce: O. Hoegh-Guldberg et al., "Coral
s under rapid climate change and ocean
ification," *Science*, 318, pp. 1737-1742,
ember 14, 2007.

- We will explore strategies to assess economic and non-economic impacts of ongoing ocean acidification.
- Starting point will be work already completed on assessing the economic impacts of acidification on U.S. commercial fisheries and global impacts on ecosystem services

3. Rapid/Unexpected Changes

There are still high tails on the CDFs of climate sensitivity, aerosol effects, etc. There is also significant possibility that the climate system could undergo a sudden "state change."



We have included projects that explore some of the issues that would be raised by unexpected rapid or large changes or impacts.

Figures from Morgan, Adams and Keith, 2006, Zickfeld, Morgan, Keith and Frame, in review.

Educational and other outreach

We have:

- Built on a range of the materials the Center will develop to create a set of materials and a program to support high school teachers to develop units related to climate, energy and DMUU.
- Work with the Koshland Museum of Science to provide content for the new set of interactive decision exhibits and supporting class-room materials they plan.
- Continue the many external advisory activities and participation by all our investigators in many national and international committees, conferences, etc.

Sources: Pittsburgh Pub. School and Koshland Science Museum

- I will now describe a case study in detail where climate data are relevant for energy/climate policies and decision making…

Estimating Responses to Prices in Residential Energy Consumption in the U.S. and in the E.U.

Azevedo, I. L., Morgan, M. G., Lave, L. "Residential and regional electricity consumption in the US and EU: How much will higher prices reduce CO_2 emissions?". *The Electricity Journal* Jan./Feb. 2011, Vol. 24, Issue 1 1040-6190

Introduction

- Fossil fuels burned in the production of electricity for residential, commercial and industrial sectors are large contributors to GHG emissions from the United States (US) and the European Union (EU).

- An effective climate policy will need to attain large reductions of emissions from electricity and in each of these sectors.

Introduction

- In the US, the residential sector accounts for 37% of national electricity consumption,17% of GHG emissions, and 22% of primary energy consumption.

- While it is widely acknowledged that the residential sector holds the potential for large energy and GHG, the design of effective policies to realize that potential is challenging.

- Moreover, there are large difference in trends across countries…

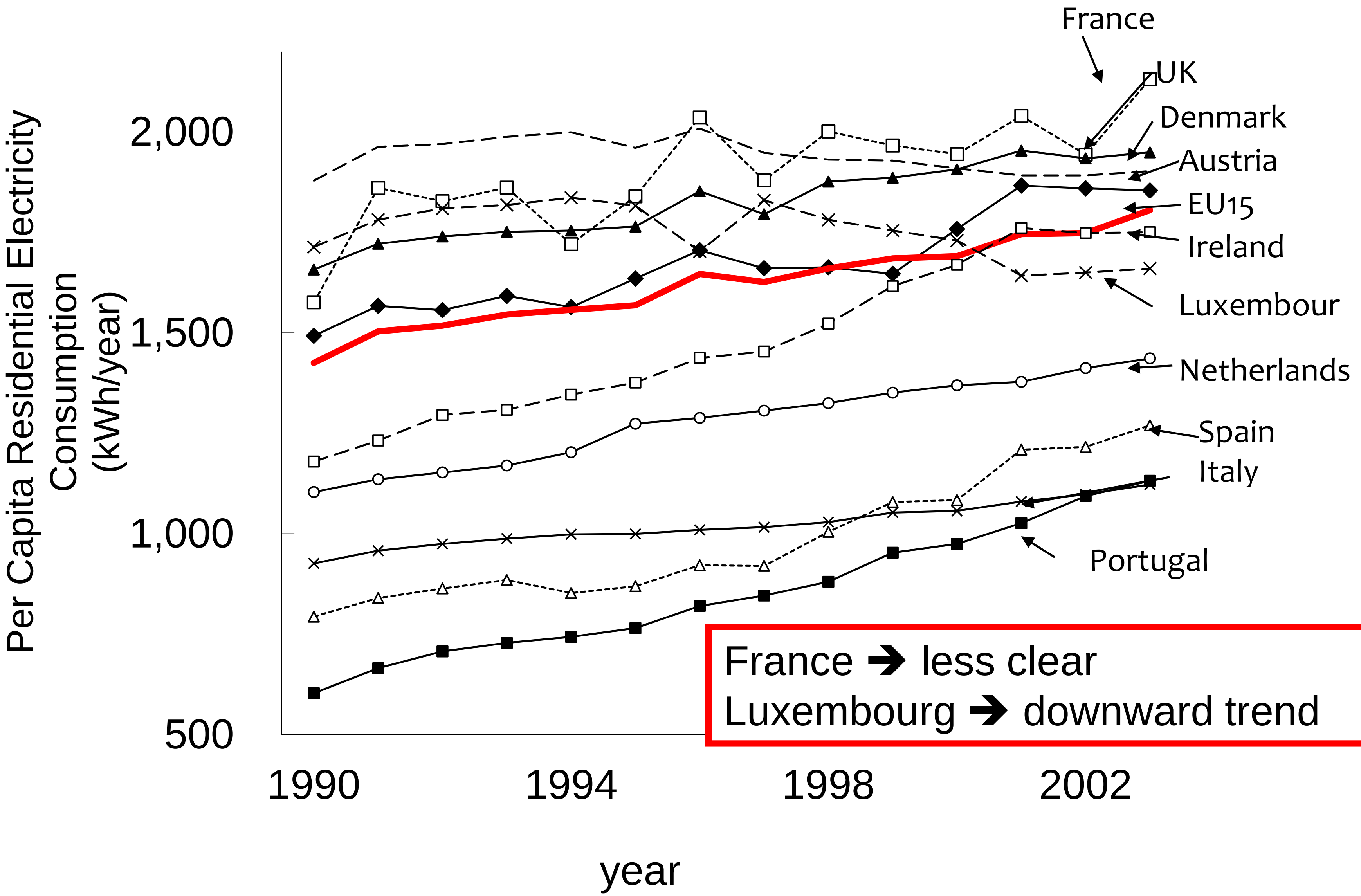
We are interested in…

- Understanding how people react to electricity price changes

- This is important for climate policy and decision making because…
  - If a carbon price/tax is in place, some of the costs might be passed on to consumers (i.e., higher electricity prices)
  - If people invest in energy efficiency devices, they might be lowering to effective price of energy services…
    - this might lead to an "energy efficiency rebound"
    - price elasticity are a good proxy for estimates of this "rebound effect"

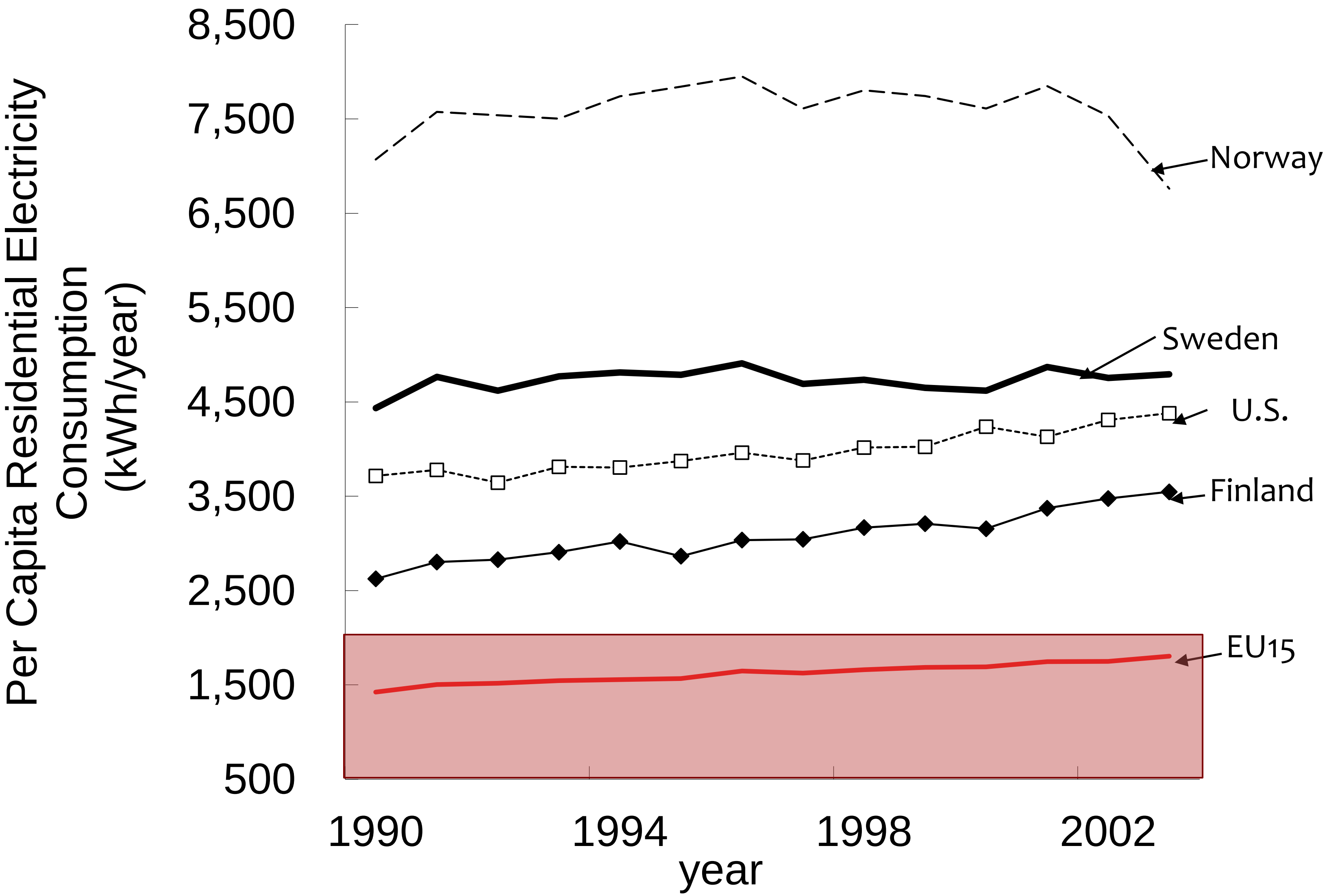
- Let's first look at some trends…

Trends in consumption 1



France ➔ less clear
Luxembourg ➔ downward trend

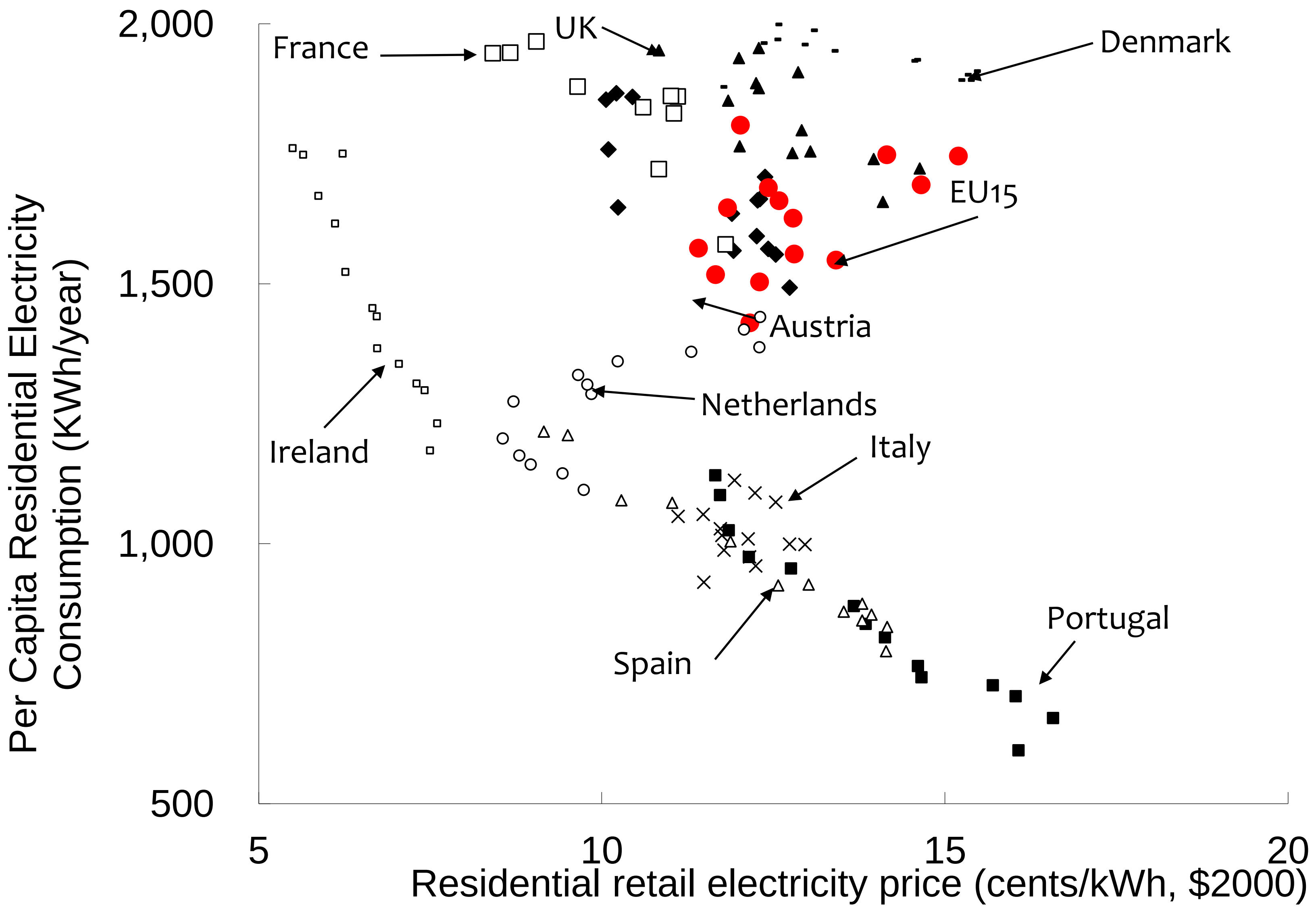
Trends in consumption 2



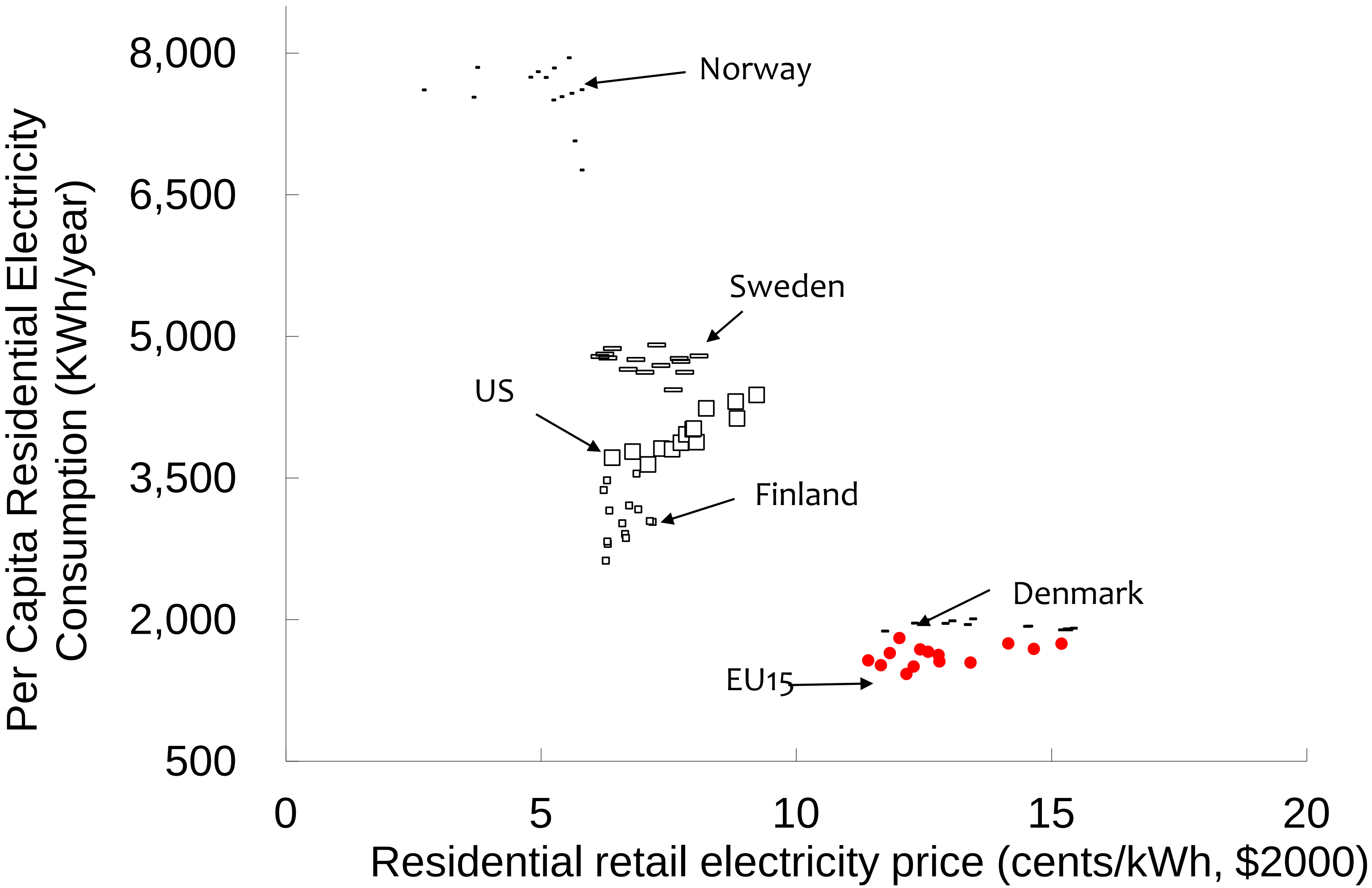
Is it fair to compare countries this way?

- … these trends over time are not really comparable if one is not controlling for differences across countries in terms of…
  - Electricity price
  - Per capita income
  - Climate differences

Consumption vs Price 1



Consumption vs Price 2



Estimating Price, Income & Weather Elasticity

- Variables such as electricity prices, personal income, or weather can be described with quantities that economists define as "own-elasticities", i.e., the ratio of the % change in electricity consumption that occurs given some % change in electricity price, income, or climate.
- There are very few international comparisons in this field…

Review of Price Elasticity Studies

Author	Region	Time Period	Price Elasticity
Houthakker, 1951 [6]	United Kingdom	1937–1938	−0.89
Fisher and Kaysen, 1962 [7]	U.S. states	1946–1957	−0.16 to −0.24
Houthakker and Taylor, 1974 [8]	U.S. states (46 states)	1960–1971	−0.13 (SR) −1.89 (LR)
Mount, Chapman and Tyrrell, 1973 [9]	U.S. states (47 states)	1947–1970	−0.14 (SR) −120 (LR)
Taylor, 1975 [10]	Review of several studies	Review of several studies	−0.90 to −0.13 (SR) −2.00 to 0 (LR)
Bohi and Zimmerman, 1984 [11]	Review of several studies	Review of several studies	−0.2 (SR) −0.7 (LR)
Maddala et al., 1997 [12]	U.S. states (49 states)	1970–1990	−0.28 to −0.06 (SR) −0.87 to 0.24 (LR)
Garcia-Cerrutti, 2000 [13]	California	1983–1997	−0.79 to 0.01
Paul, Myers and Palmer [14]	U.S. states	1990–2004	−0.15 to −0.11 (SR)
Lee and Lee [15]	25 OECD countries	1978–2004	−0.01 (LR)

Note: SR: short-run; LR: long-run.

We estimated how people react to price changes…

- In this work, we assessed the price and income elasticity for household electricity consumption in the US and in the EU.
- We focus on the response of consumers in the two regions taking their different mixes of electricity generation, rate and regulatory structures, and different overall wholesale markets as given.

Data & Method

- Annual data
- Time period of analysis: 1990 to 2004
- The impacts of weather are aggregated at country or state level (HDD and CDD)
- We use average income per capita, and therefore do not consider issues of distribution of income within each state or country

Model

- The general model tested is of the form:

$$\ln(cons_{it}) = \alpha_i + \alpha_1 \ln(price_{it}) + \alpha_2 \ln(cons\exp_{it}) + \alpha_3 \ln(hdd_{it}) + \varepsilon_{it}$$

- *i* denotes a region and *t* a year (1990 to 2003 for the EU observations and 1990 to 2004 for the US)
- *price* is the retail electricity price for the residential sector (in year 2000 $ per kWh)
- *consexp* is the per capita consumption expenditure (adjusted for PPP and in year 2000 $)
- *hdd* are the annual average heating degree day (in Celsius)
- cons is the average per capita yearly residential electricity consumption (annual kWh per capita)

Model

- Because we were specifically interested in understanding international differences, we used countries as units of observation.
- However, comparing countries with large differences in population and area would leave out aspects of scalability of energy resources and energy usage.
- Therefore, we created a second database that includes information on annual residential electricity consumption, population, heating degrees day, income, and electricity price, where unit of observations are countries for the EU and US states for the US.

Data Sources

- EU data on residential electricity consumption, heating degrees day, residential retail electricity prices and population are from ENERDATA.
- The U.S. residential electricity consumption and retail electricity price data are from EIA.
- Data on the average U.S. annual heating degree days are from NOAA.
- The data on U.S. state population and state average annual disposable income are from the U.S. Census Bureau.
- For the EU country-level observations, instead of disposable income, consumer expenditure data from the World Development Indicators of the World Bank Group are used.
- We estimate the average consumer expenditures for each U.S. state using the information on average U.S. disposable income and U.S. total consumer expenditures. U.S. disposable income and consumer expenditures are highly correlated (corr = 0.99), therefore justifying this option.

We tested 2 different models…

- In order to account for regional differences that are assumed to be time-independent over the period of analysis (e.g., fixed infrastructure and resource availability, cultural patterns and other) Model 1 uses regional-fixed effects and time-fixed effects.
- Model 2 is similar to Model 1 but instead of time-fixed effect, we explicitly include a linear time effect. Energy and climate policies in the EU and in the U.S. vary substantially.
- In order to provide models that are regionally specific while maintaining some statistical power, regional-fixed effects models were also tested for the two regions separately

Model	Equation
Model 1	$\ln(cons_{it}) = \alpha_i + \alpha_1 \ln(price_{it}) + \alpha_2 \ln(\text{cons exp}_{it}) + \alpha_3 \ln(hdd_{it}) + \alpha_4 \sum_{t=1}^{n} d_t + \varepsilon_{it}$
Model 2	$\ln(cons_{it}) = \alpha_i + \alpha_1 \ln(price_{it}) + \alpha_2 \ln(\text{cons exp}_{it}) + \alpha_3 \ln(hdd_{it}) + \alpha_4 year + \varepsilon_{it}$

Note: that d_t is a year-specific dummy variable.

Results 1

10% increase today in residential electricity price in the EU could be expected to result in a 2% percent reduction in CO_2 emissions from the residential sector.

Similarly, a 10% price increase in residential electricity price in the US could be expected to result in a 2.5% reduction in CO_2 emissions from the residential sector.

EU Country Observations; Fixed Regional Effects; Time-Trend (3)	U.S. States Observations; Fixed Regional Effects; Time-Trend (4)	EU Country Observations; Fixed Regional Effects and Fixed Temporal Effects (5)	U.S. States Observations; Fixed Regional Effects and Fixed Temporal Effects (6)
−0.205* (0.106)	−0.253*** (0.038)	−0.206* (0.113)	−0.248*** (0.040)
−0.034 (0.165)	0.076*** (0.023)	−0.208 (0.196)	0.118*** (0.036)
0.252 (0.184)	−0.019 (0.219)	0.381* (0.175)	−0.157 (0.259)
0.007 (0.005)	0.018*** (0.006)		
−8.866 (8.035)	−26.970*** (8.992)	6.000** (2.151)	9.305*** (2.639)
181	765	181	765
13	0.651	13	51
0.556	51	0.605	0.710

…e not reported but all were significant at 90 percent level.

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

What about regional variations?

- There is a lot of regional variation in carbon intensities across US states.
- Using a model with fixed regional and temporal effects, we have estimated price elasticity for each North American Electric Reliability Corporation (NERC) region
- (Running the regressions at the states level does not provide statistically significant estimates for most states).
- Using EPA’s eGRID carbon intensity electricity generation (for year 2005) at the NERC regional level, our estimates of price elasticity, and data from Energy Information Administration (EIA) on the share of residential electricity sales on total electricity sales, we have estimated the total electricity-related carbon reductions from a 10% price increase in each of these regions.

Results for NERC regions

NERC region acronym	Price Elasticity	Reductions in Residential GHG Emissions that Would Result from a 10 percent Increase in Retail Electricity prices	Share of Residential Electricity in Total Electricity Consumption in 2009	Average Carbon Intensity of CO_2 Emissions ($kgCO_2/kWh$)	Reductions in Total GHG Emissions from Electricity that Would Result from a 10 percent Increase in Retail Electricity Prices
Midwest Reliability Organization (MRO)	-0.203^{*}(0.086)	2.0%	34%	1.032	0.8%
Northeast Power Coordinating Council (NPCC)	-0.269^{**}(0.091)	2.6%	37%	0.651	1.5%
Reliability First Corporation (RFC)	-0.282^{*}(0.136)	2.8%	36%	0.885	1.3%
SERC Reliability Corporation	-0.171^{***}(0.0276)	1.7%	41%	0.856	0.9%
Western Electricity Coordination Council (WECC)					
U.S.					

Robust standard errors in par

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

For example, increasing household retail electricity prices by 10% in RFC will reduce CO_2 emissions from the residential sector by 2.8% and overall electricity emissions in the region by only 1.3%...

Conclusions & tying it back to climate data…

- Having reliable temperature (or heating and cooling degree days) for different regions (zip code, county, state, national) and at different time periods (daily, monthly, annually) is crucial this sort of econometric studies on the impa
- ct of prices changes
- Good estimates of price elasticity are important since they provide an insight on how much price mechanisms can deliver in terms of CO_2 reductions…
- They are also important to understand how much of the investments from energy efficiency will be eroded due to consumption rebound
- These price elasticity estimates should be also performed for other regions of the world so that there are realistic expectations on how much climate policies will deliver in terms of CO_2 reductions…

Acknowledgements

- Prof. Granger Morgan & Prof. Lester Lave (co-authors in **Azevedo, I. L.**, Morgan, M. G., Lave, L. “Residential and regional electricity consumption in the US and EU: How much will higher prices reduce CO_2 emissions?”. *The Electricity Journal* Jan./Feb. 2011, Vol. 24, Issue 1 1040-6190)
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- The Carnegie Electricity Industry Center at Carnegie Mellon University
- APEC

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Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
EU countries and U.S. states (Obs = 946)				
price	8.3	2.6	3	18
hdd	2,566	924	899	4,975
cons exp	19,678	4,830	4,912	33404
cons	3,800	1,505	603	7,950
EU countries (Obs = 182)				
price	10.1	3.1	3	17
hdd	2769	934	899	4975
cons exp	11,578	3002	4912	19,156
cons	2315	1825	603	7,950
U.S. states (Obs = 765)				
price	7.9	2.27	4	18
hdd	2521	917	1002	4,063
cons exp	21605	2721	16,600	33,405
cons	4153	1169	2,096	6,648