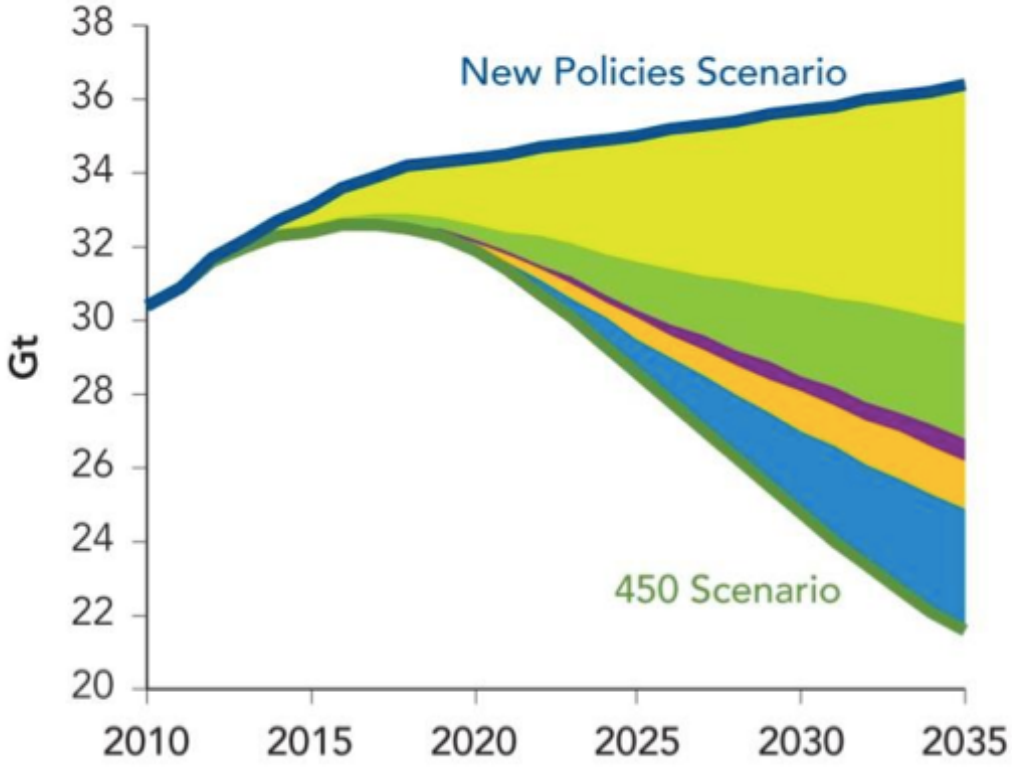
Energy Efficiency and the Rebound Effect

Inês M. L. Azevedo

Associate Professor
Engineering and Public Policy Department
Carnegie Mellon University

co-Director
Climate and Energy Decision Making (CEDM)

Energy efficiency and behavior change strategies are needed in order to reduce GHG emissions.

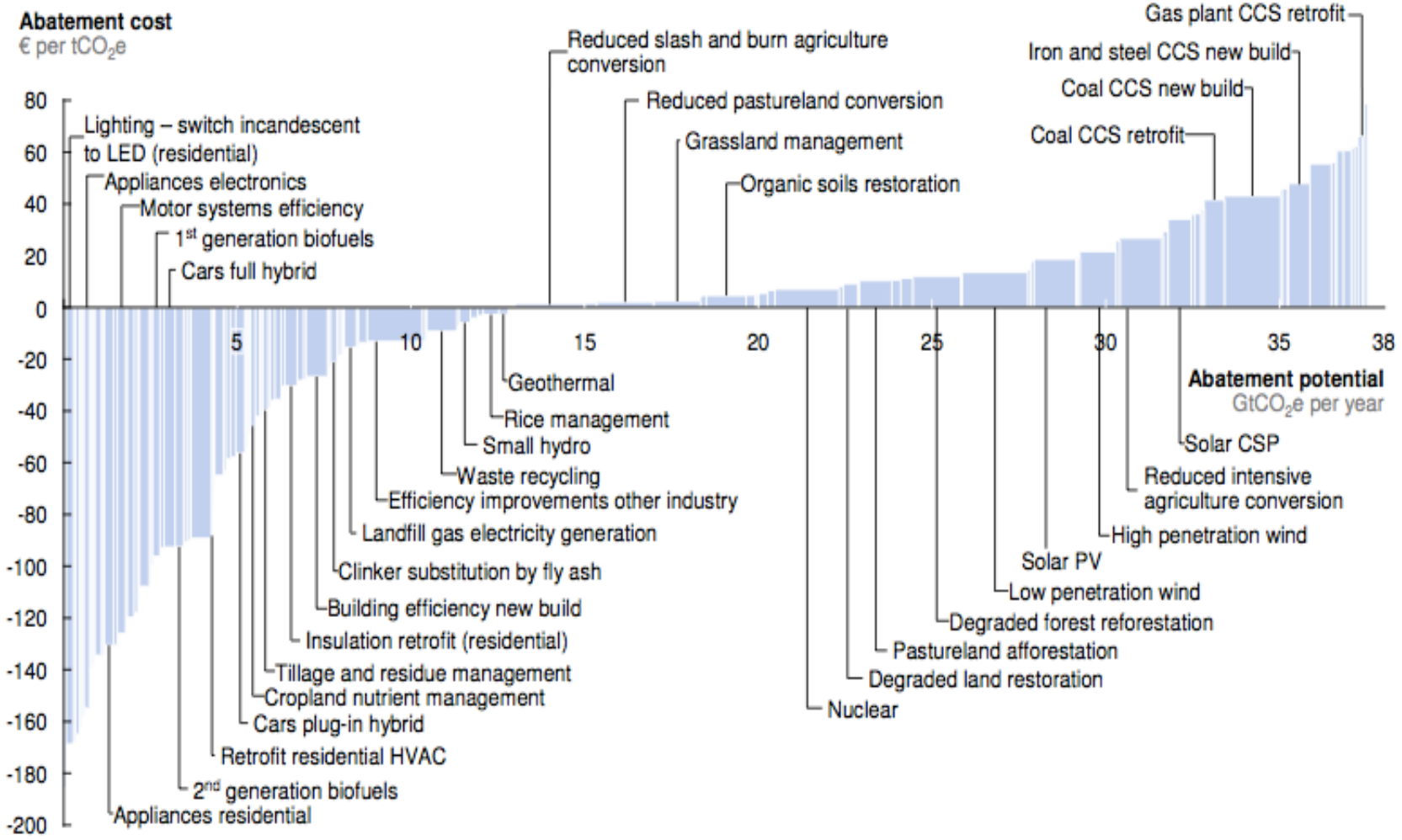


	Abatement	
	2020	2035
Efficiency	72%	44%
Renewables	17%	21%
Biofuels	2%	4%
Nuclear	5%	9%
CCS	3%	22%
Total (Gt CO_2)	2.5	14.8

Source: IEA, 2013, Energy Efficiency Market Report

© Ines Lima Azevedo

Bottom-up engineering economic studies show that there is a large potential with no net costs.

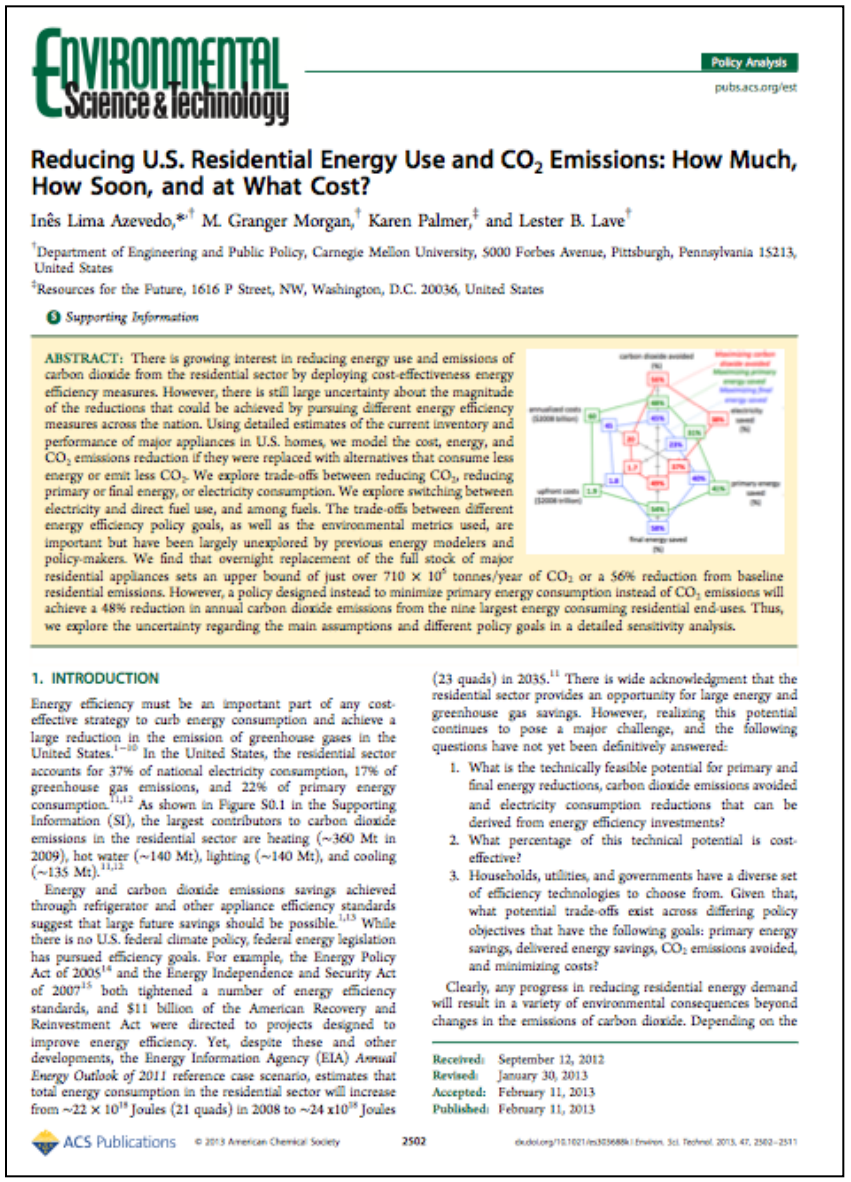


Source: McKinsey, 2010

© Ines Lima Azevedo

Potential for Energy Efficiency in the U.S. Residential Sector

- What are the economic costs and GHG savings from investing in energy efficient appliances in the U.S. residential sector?
- What are the trade-offs between different indicators (electricity, CO_2, primary energy, costs)?
- To answer these and other questions we have developed the Regional Residential Energy Efficiency Model (RREEM)



ENVIRONMENTAL Science & Technology

Policy Analysis

pubs.acs.org/est

Reducing U.S. Residential Energy Use and CO_2 Emissions: How Much, How Soon, and at What Cost?

Inês Lima Azevedo,*† M. Granger Morgan,† Karen Palmer,‡ and Lester B. Lave†

†Department of Engineering and Public Policy, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, United States

‡Resources for the Future, 1616 P Street, NW, Washington, D.C. 20036, United States

Supporting Information

ABSTRACT: There is growing interest in reducing energy use and emissions of carbon dioxide from the residential sector by deploying cost-effectiveness energy efficiency measures. However, there is still large uncertainty about the magnitude of the reductions that could be achieved by pursuing different energy efficiency measures across the nation. Using detailed estimates of the current inventory and performance of major appliances in U.S. homes, we model the cost, energy, and CO_2 emissions reduction if they were replaced with alternatives that consume less energy or emit less CO_2. We explore trade-offs between reducing CO_2, reducing primary or final energy, or electricity consumption. We explore switching between electricity and direct fuel use, and among fuels. The trade-offs between different energy efficiency policy goals, as well as the environmental metrics used, are important but have been largely unexplored by previous energy modelers and policy-makers. We find that overnight replacement of the full stock of major residential appliances sets an upper bound of just over 710×10^6 tonnes/year of CO_2 or a 56% reduction from baseline residential emissions. However, a policy designed instead to minimize primary energy consumption instead of CO_2 emissions will achieve a 48% reduction in annual carbon dioxide emissions from the nine largest energy consuming residential end-uses. Thus, we explore the uncertainty regarding the main assumptions and different policy goals in a detailed sensitivity analysis.

1. INTRODUCTION

Energy efficiency must be an important part of any cost-effective strategy to curb energy consumption and achieve a large reduction in the emission of greenhouse gases in the United States.[1−10] In the United States, the residential sector accounts for 37% of national electricity consumption, 17% of greenhouse gas emissions, and 22% of primary energy consumption.[11,12] As shown in Figure S0.1 in the Supporting Information (SI), the largest contributors to carbon dioxide emissions in the residential sector are heating (~360 Mt in 2009), hot water (~140 Mt), lighting (~140 Mt), and cooling (~135 Mt).[11,12]

Energy and carbon dioxide emissions savings achieved through refrigerator and other appliance efficiency standards suggest that large future savings should be possible.[1,13] While there is no U.S. federal climate policy, federal energy legislation has pursued efficiency goals. For example, the Energy Policy Act of 2005[14] and the Energy Independence and Security Act of 2007[15] both tightened a number of energy efficiency standards, and $11 billion of the American Recovery and Reinvestment Act were directed to projects designed to improve energy efficiency. Yet, despite these and other developments, the Energy Information Agency (EIA) *Annual Energy Outlook of 2011* reference case scenario, estimates that total energy consumption in the residential sector will increase from ~22 × 10^{18} Joules (21 quads) in 2008 to ~24 x10^{18} Joules (23 quads) in 2035.[11] There is wide acknowledgment that the residential sector provides an opportunity for large energy and greenhouse gas savings. However, realizing this potential continues to pose a major challenge, and the following questions have not yet been definitively answered:

1. What is the technically feasible potential for primary and final energy reductions, carbon dioxide emissions avoided and electricity consumption reductions that can be derived from energy efficiency investments?
2. What percentage of this technical potential is cost-effective?
3. Households, utilities, and governments have a diverse set of efficiency technologies to choose from. Given that, what potential trade-offs exist across differing policy objectives that have the following goals: primary energy savings, delivered energy savings, CO_2 emissions avoided, and minimizing costs?

Clearly, any progress in reducing residential energy demand will result in a variety of environmental consequences beyond changes in the emissions of carbon dioxide. Depending on the

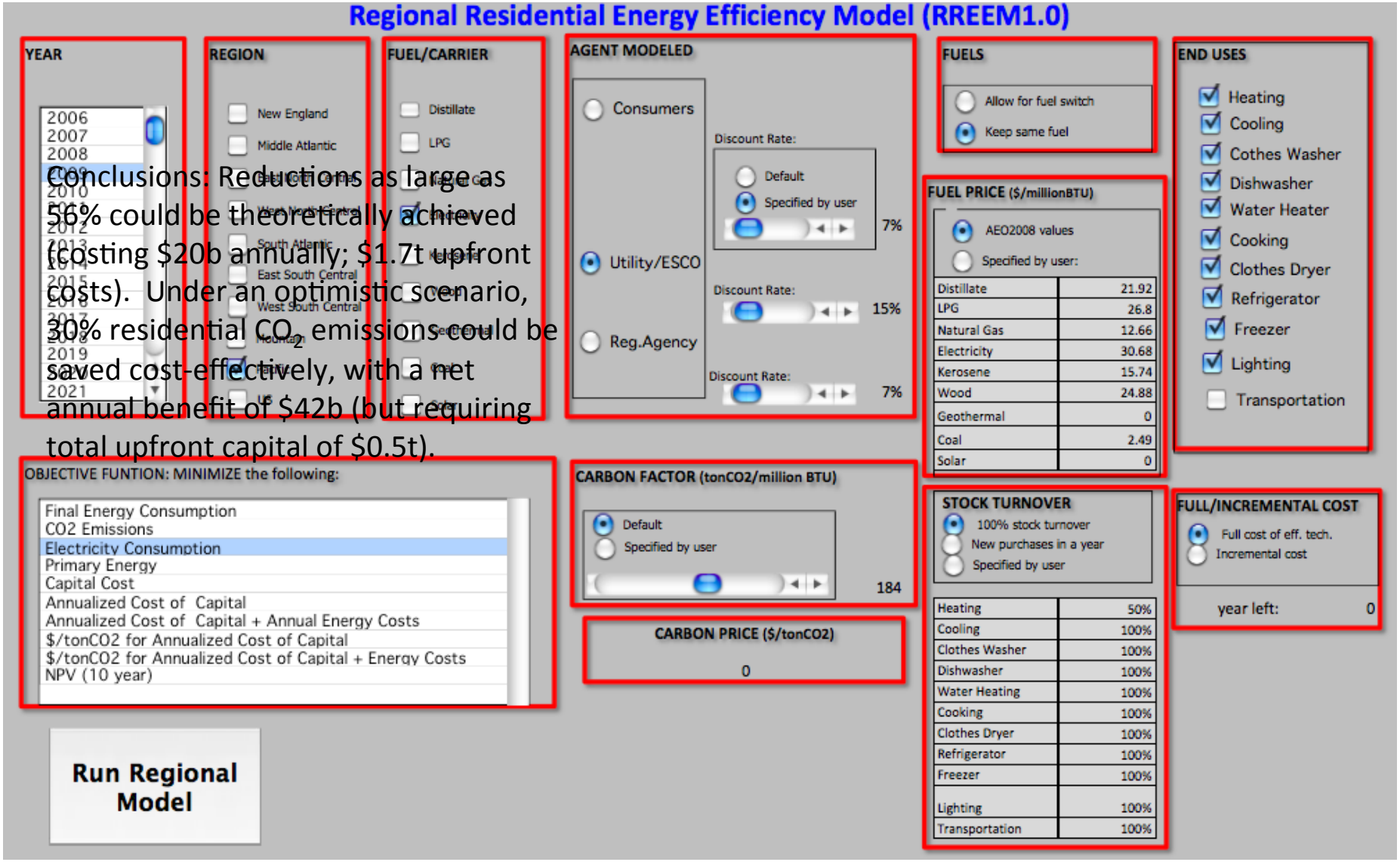
Received: September 12, 2012
Revised: January 30, 2013
Accepted: February 11, 2013
Published: February 11, 2013

 © 2013 American Chemical Society dx.doi.org/10.1021/es3036888 | Environ. Sci. Technol. 2013, 47, 2502−2511

Source: Azevedo et al.:"Energy Efficiency in the U.S. Residential Sector", **ES&T, 2013**.

© Ines Lima Azevedo

RREEM: Residental Regional Energy Efficiency Model



Conclusions: Reductions as large as 56% could be theoretically achieved (costing $20b annually; $1.7t upfront costs). Under an optimistic scenario, 30% residential CO_2 emissions could be saved cost-effectively, with a net annual benefit of $42b (but requiring total upfront capital of $0.5t).

© Ines Lima Azevedo

Utility funded EE and DSM programs has been increasing.

Table 2. 2010 Expenditures for Utility Customer-Funded Energy Efficiency (EE) Programs

Rank	Combined Electric & Gas EE Spending ($M)		Electric EE Spending ($M)		Gas EE Spending ($M)	
1	CA	$1,139	CA	$938	CA	$201
2	NY	$521	NY	$482	NJ	$126
3	NJ	$317	MA	$245	MA	$72
4	MA	$317	WA	$218	MI	$41
5	WA	$247	NJ	$191	IA	$40
6	FL	$176	FL	$165	NY	$39
7	OR	$158	OR	$135	MN	$36
8	MN	$144	TX	$114	UT	$36
9	CT	$119	CT	$108	OH	$32
10	MI	$116	MN	$107	WA	$29
Top 10 States	*$M*	$3,255		$2,702		$653
	% of U.S.	68%		68%		78%
Remainder of U.S.	*$M*	$1,531		$1,246		$185
	% of U.S.	32%		32%		22%
Total U.S.	*$M*	$4,786		$3,948		$838

Source: CEE (2012), with several modifications

Source: LBNL, 2013. http://emp.lbl.gov/sites/all/files/lbnl-5803e.pdf

© Ines Lima Azevedo

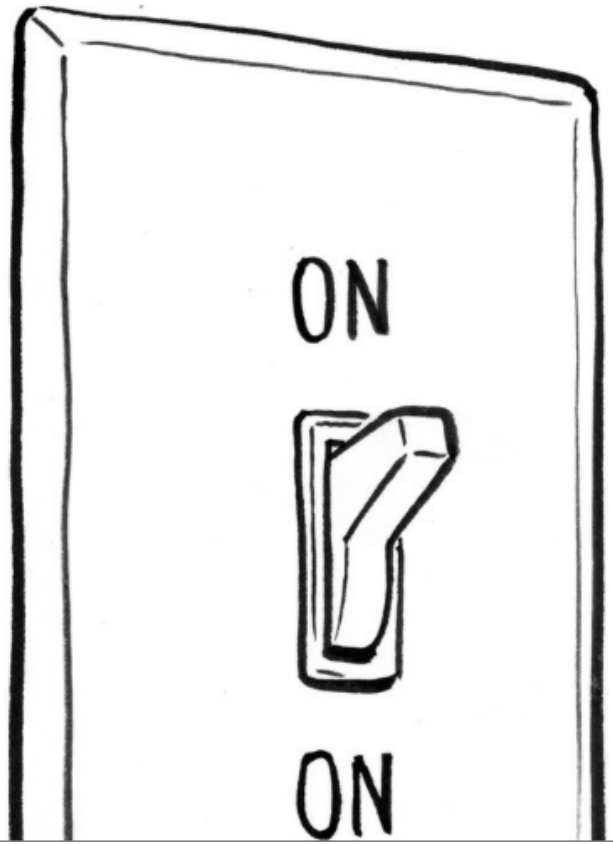
Will these energy saving be achieved?

- Every so often the debate on “rebound effects” re-emerges…

The Opinion Pages | OP-ED CONTRIBUTORS

The Problem With Energy Efficiency

By MICHAEL SHELLENBERGER and TED NORDHAUS OCT. 8, 2014



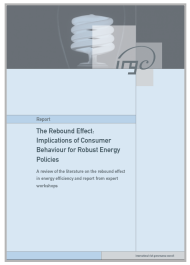
OAKLAND, Calif. — ON Tuesday, the Royal Swedish Academy of Sciences awarded the 2014 Nobel Prize in Physics to three researchers whose work contributed to the development of a radically more efficient form of lighting known as light-emitting diodes, or LEDs.

In announcing the award, the academy said, “Replacing light bulbs and fluorescent tubes with LEDs will lead to a drastic reduction of electricity requirements for lighting.” The president of the Institute of Physics noted: “With 20 percent of the world’s electricity used for lighting, it’s been calculated that optimal use of LED lighting could reduce this to 4 percent.”

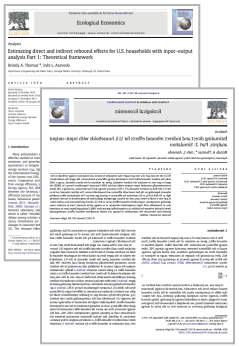
The winners, Shuji Nakamura, an American, and Isamu Akasaki and Hiroshi Amano, both from Japan, justly

© Ines Lima Azevedo

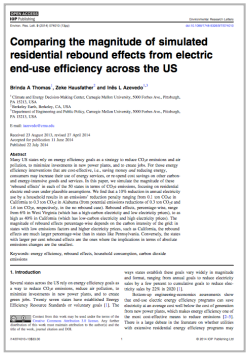
We have been working on several aspects of this "rebound effects" problem over the course of the last couple of years, and setting up a coherent research agenda:



IRGC, 2013. We have produced a report for the International Risk Council, widely briefed to policy makers, on the misunderstandings and confusion on what are rebound effects. *(with Brinda Thomas, Ortwin Renn, Marco Sonnberger, Granger Morgan)*



Ecological Economics, 2013. We have produced two papers developing and applying a framework that combines a behavior consumer model with life-cycle assessment to estimate the magnitude of rebound effects from different types of efficiency interventions. Finding: Rebound effects are generally small and there is no evidence of backfire. *(with Brinda Thomas)*



Environmental Research Letters, 2014. We have estimated the differences in rebound effects for electricity efficiency measures for each U.S. state. Rebound effects, percentage-wise, range from 6% in West Virginia (which has a high-carbon electricity and low electricity prices), to as high as 40% in California (which has low-carbon electricity and high electricity prices). *(with Brinda Thomas and Zecke Hausfather)*

© Ines Lima Azevedo

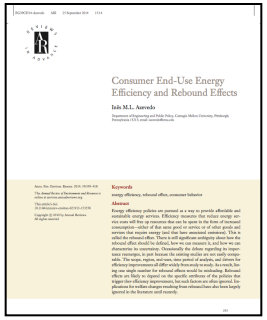
We have been working on several aspects of this "rebound effects" problem over the course of the last couple of years, and setting up a coherent research agenda:

Energy Policy

Should policy-makers allocate funding to vehicle electrification or end-use energy efficiency as a strategy for climate change mitigation and energy reductions? Rethinking electric utilities efficiency programs

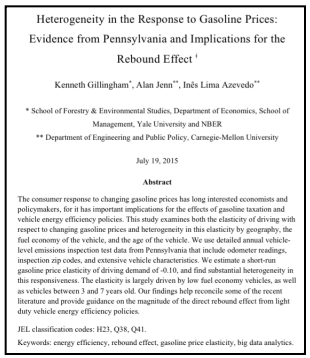
Brinda A. Thomas, Inês L. Azevedo *

Energy Policy 2014. We developed a decision space for utilies to either incentivize end-use energy efficiency or electric vehicles, and how the decision space would be affected by rebound effects in electricity and transporation. *(with Brinda Thomas)*


Consumer End-Use Energy Efficiency and Rebound Effects

Inês M.L. Azevedo

Annual Reviews of the Environment and Resouces. A review of the literature on rebound effects from different fields and a map of research needs.


Heterogeneity in the Response to Gasoline Prices: Evidence from Pennsylvania and Implications for the Rebound Effect †

Kenneth Gillingham*, Alan Jenn**, Inês Lima Azevedo**

* School of Forestry & Environmental Studies, Department of Economics, School of Management, Yale University and NBER

** Department of Engineering and Public Policy, Carnegie-Mellon University

July 19, 2015

Abstract

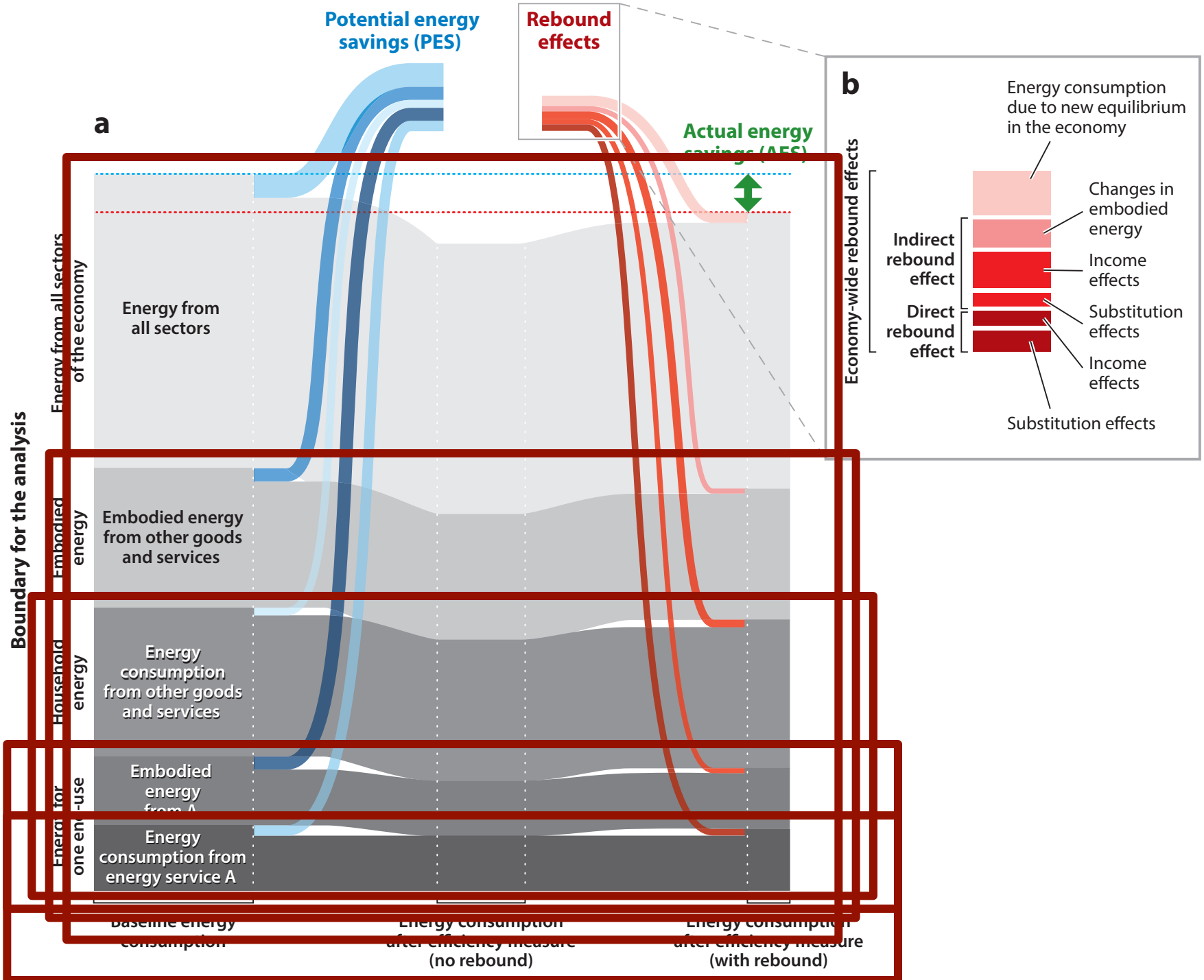
The consumer response to changing gasoline prices has long interested economists and policymakers, for it has important implications for the effects of gasoline taxation and vehicle energy efficiency policies. This study examines both the elasticity of driving with respect to changing gasoline prices and heterogeneity in this elasticity by geography, the fuel economy of the vehicle, and the age of the vehicle. We use detailed annual vehicle-level emissions inspection test data from Pennsylvania that include odometer readings, inspection zip codes, and extensive vehicle characteristics. We estimate a short-run gasoline price elasticity of driving demand of -0.10, and find substantial heterogeneity in this responsiveness. The elasticity is largely driven by low fuel economy vehicles, as well as vehicles between 3 and 7 years old. Our findings help reconcile some of the recent literature and provide guidance on the magnitude of the direct rebound effect from light duty vehicle energy efficiency policies.

JEL classification codes: H23, Q38, Q41.

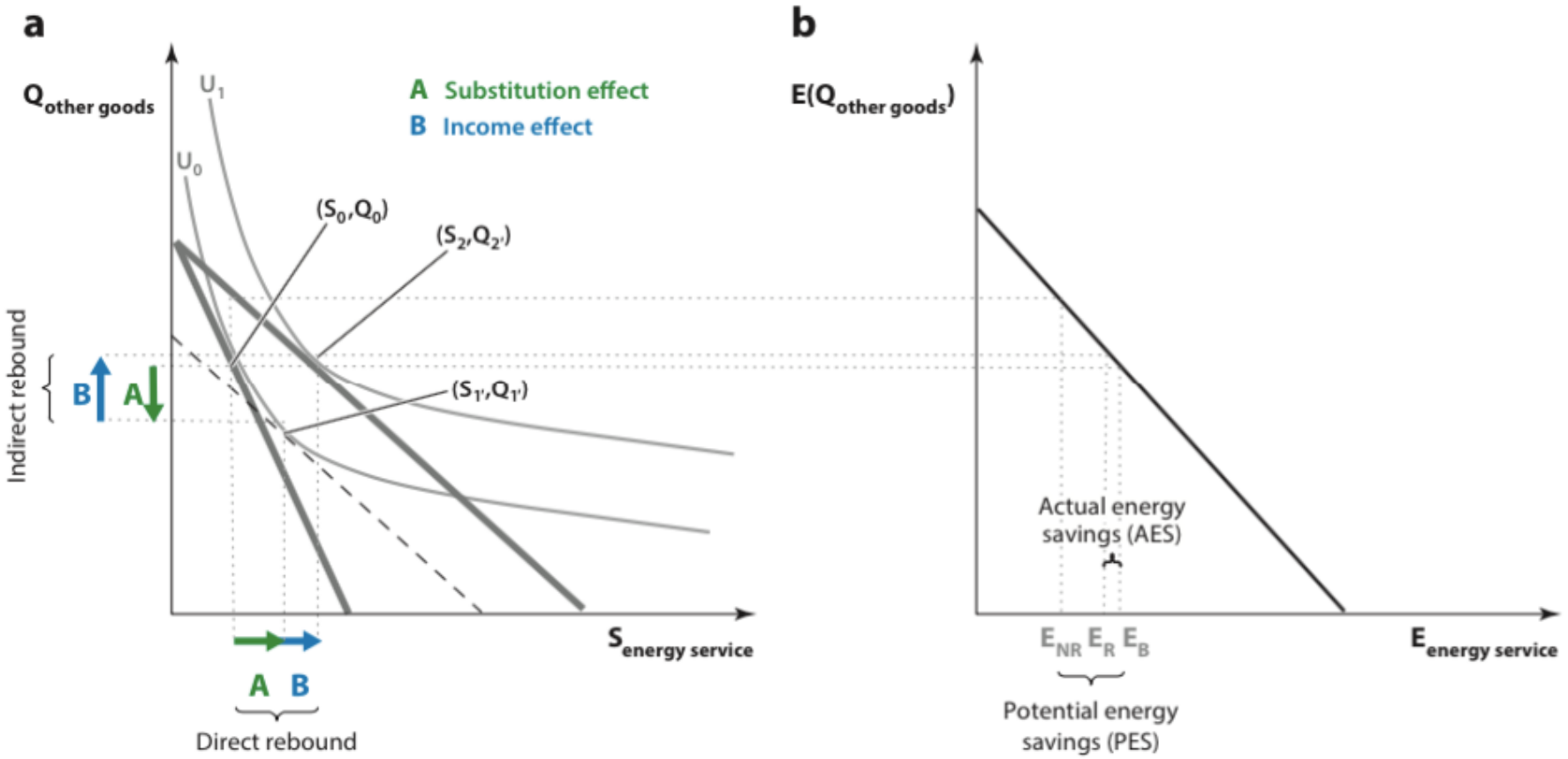
Keywords: energy efficiency, rebound effect, gasoline price elasticity, big data analytics.

Just resubmitted: How large are rebound effects in personal transportation? A case study for Pennsylvannia. *(with Ken Gillingham and Alan Jenn)*

© Ines Lima Azevedo

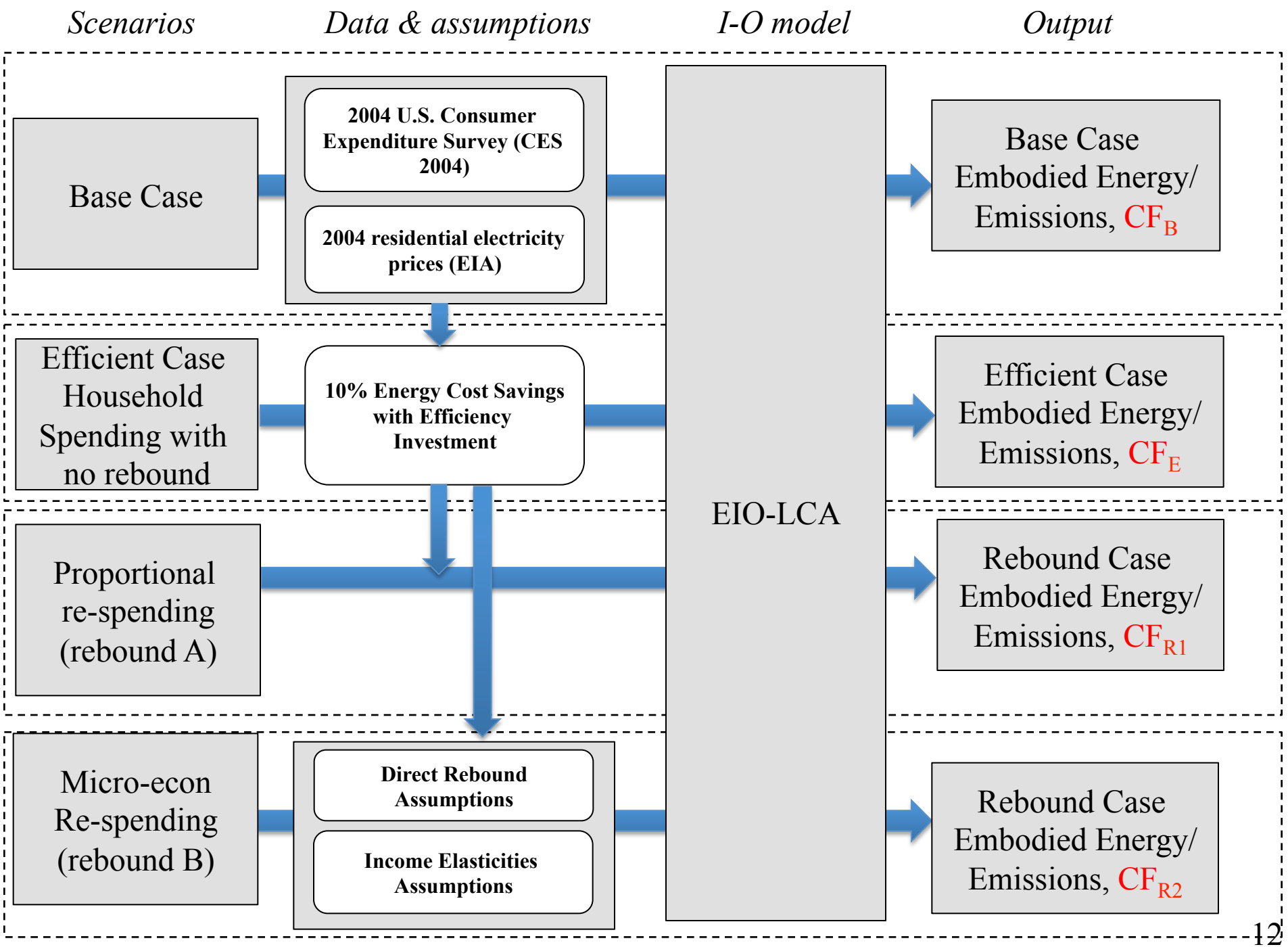

Potential energy savings (PES)
Rebound effects
Actual energy savings (AES)
a
b
Boundary for the analysis
Energy from all sectors of the economy
Energy from all sectors
Embodied energy
Embodied energy from other goods and services
Household energy
Energy consumption from other goods and services
Energy for one end-use
Embodied energy from A
Energy consumption from energy service A
Baseline energy consumption
Energy consumption after efficiency measure (no rebound)
Energy consumption after efficiency measure (with rebound)
Economy-wide rebound effects
Energy consumption due to new equilibrium in the economy
Changes in embodied energy
Indirect rebound effect
Income effects
Direct rebound effect
Substitution effects
Income effects
Substitution effects

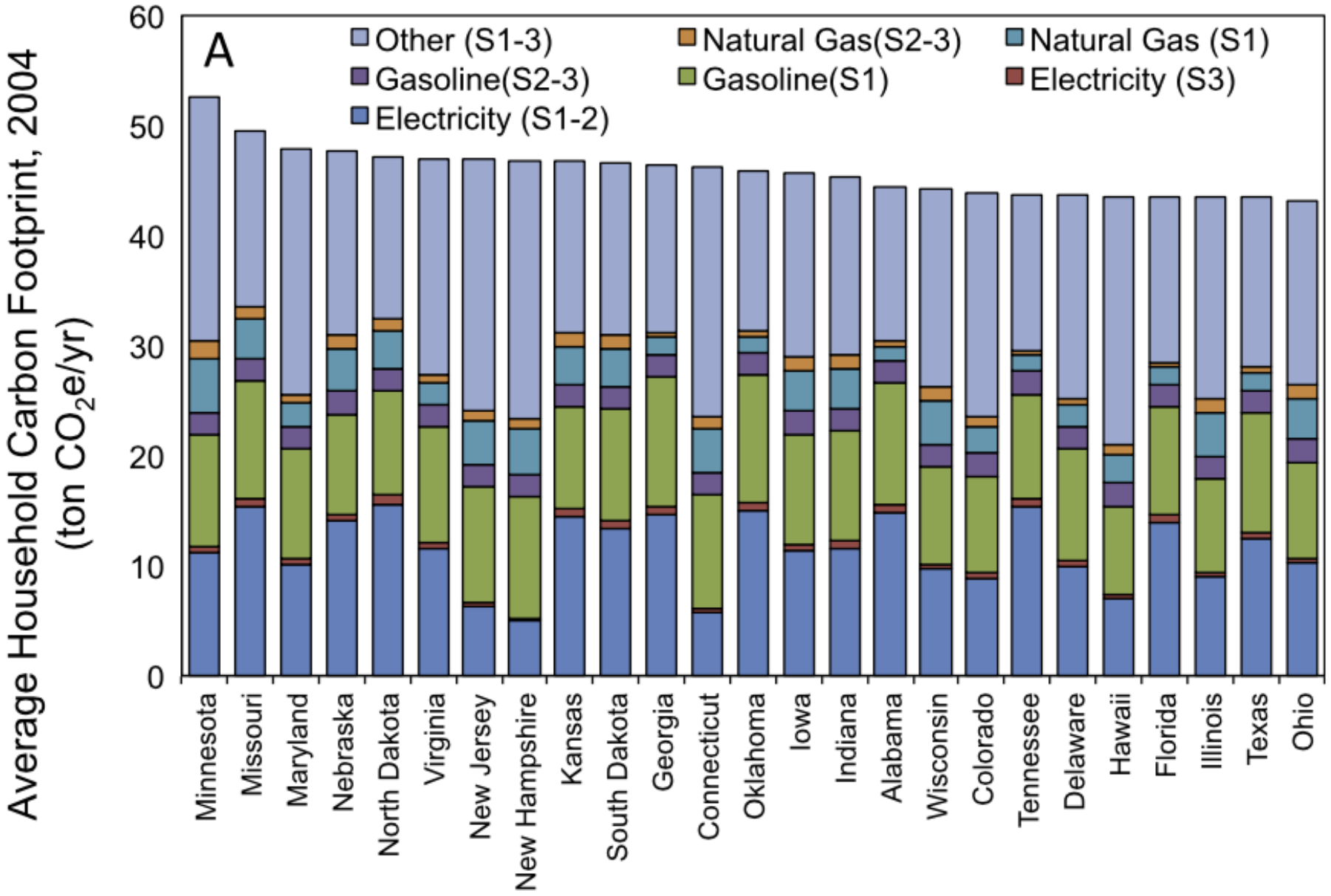
Theorerical framework

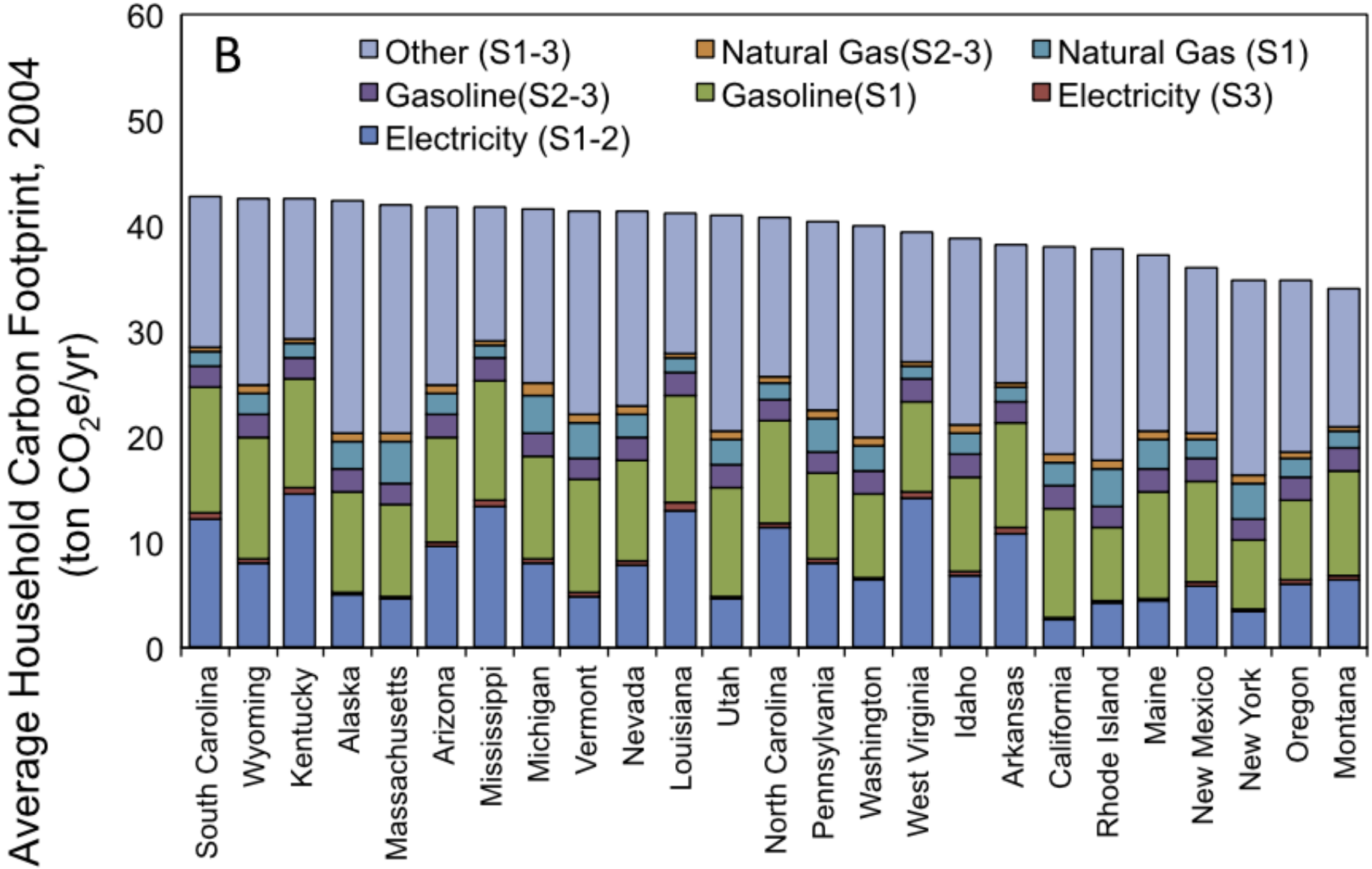


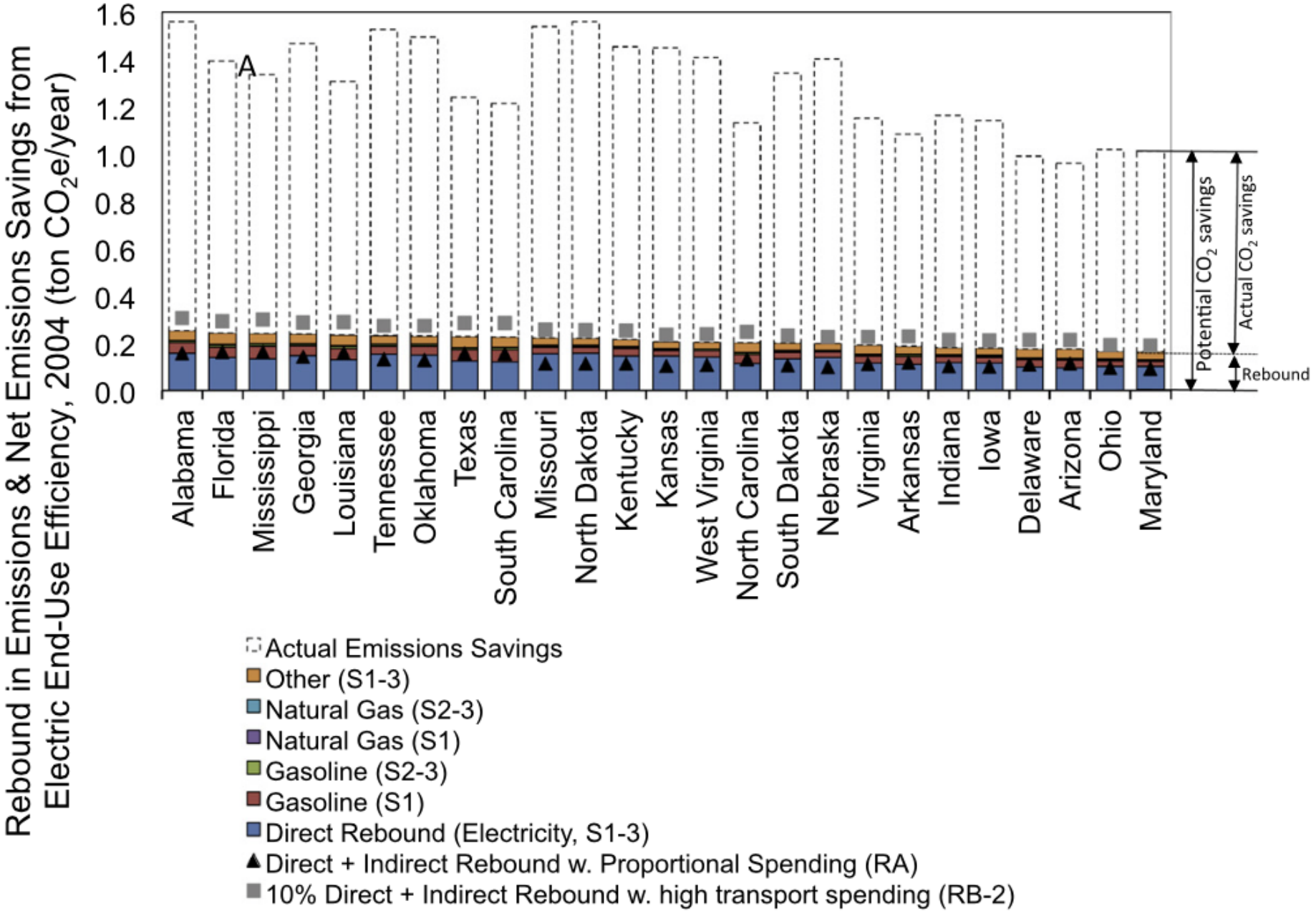
Source: Azevedo, ARER, 2015

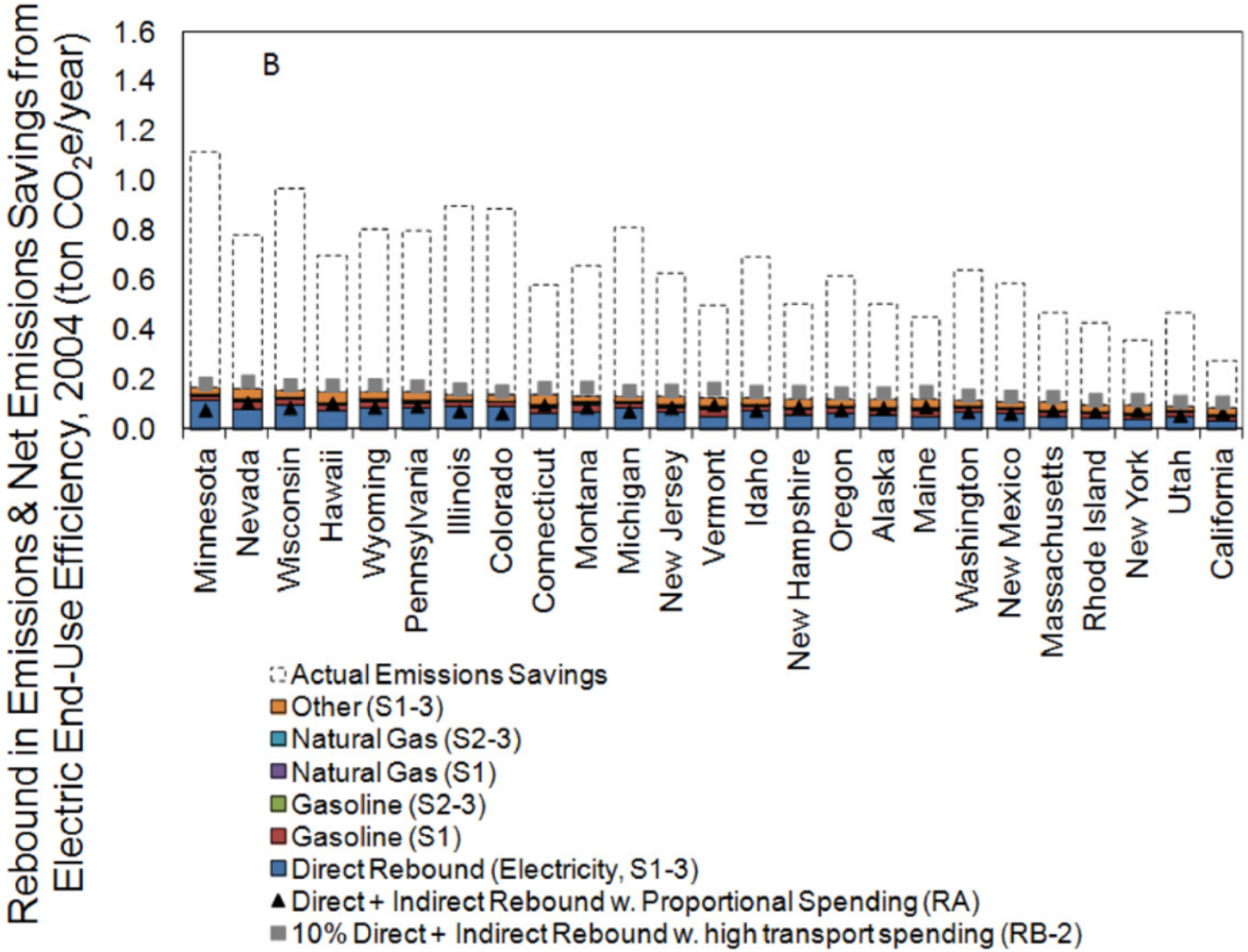
© Ines Lima Azevedo


Scenarios
Data & assumptions
I-O model
Output
Base Case
2004 U.S. Consumer Expenditure Survey (CES 2004)
2004 residential electricity prices (EIA)
Base Case Embodied Energy/ Emissions, CF_B
Efficient Case Household Spending with no rebound
10% Energy Cost Savings with Efficiency Investment
Efficient Case Embodied Energy/ Emissions, CF_E
EIO-LCA
Proportional re-spending (rebound A)
Rebound Case Embodied Energy/ Emissions, CF_R1
Micro-econ Re-spending (rebound B)
Direct Rebound Assumptions
Income Elasticities Assumptions
Rebound Case Embodied Energy/ Emissions, CF_R2


A
Other (S1-3)
Natural Gas(S2-3)
Natural Gas (S1)
Gasoline(S2-3)
Gasoline(S1)
Electricity (S3)
Electricity (S1-2)
Average Household Carbon Footprint, 2004
(ton CO_2e/yr)
0
10
20
30
40
50
60
Minnesota
Missouri
Maryland
Nebraska
North Dakota
Virginia
New Jersey
New Hampshire
Kansas
South Dakota
Georgia
Connecticut
Oklahoma
Iowa
Indiana
Alabama
Wisconsin
Colorado
Tennessee
Delaware
Hawaii
Florida
Illinois
Texas
Ohio


B
Other (S1-3)
Natural Gas(S2-3)
Natural Gas (S1)
Gasoline(S2-3)
Gasoline(S1)
Electricity (S3)
Electricity (S1-2)
Average Household Carbon Footprint, 2004
(ton CO_2e/yr)
0
10
20
30
40
50
60
South Carolina
Wyoming
Kentucky
Alaska
Massachusetts
Arizona
Mississippi
Michigan
Vermont
Nevada
Louisiana
Utah
North Carolina
Pennsylvania
Washington
West Virginia
Idaho
Arkansas
California
Rhode Island
Maine
New Mexico
New York
Oregon
Montana


Rebound in Emissions & Net Emissions Savings from Electric End-Use Efficiency, 2004 (ton CO_2e/year)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
A
Alabama
Florida
Mississippi
Georgia
Louisiana
Tennessee
Oklahoma
Texas
South Carolina
Missouri
North Dakota
Kentucky
Kansas
West Virginia
North Carolina
South Dakota
Nebraska
Virginia
Arkansas
Indiana
Iowa
Delaware
Arizona
Ohio
Maryland
Potential CO_2 savings
Actual CO_2 savings
Rebound
Actual Emissions Savings
Other (S1-3)
Natural Gas (S2-3)
Natural Gas (S1)
Gasoline (S2-3)
Gasoline (S1)
Direct Rebound (Electricity, S1-3)
Direct + Indirect Rebound w. Proportional Spending (RA)
10% Direct + Indirect Rebound w. high transport spending (RB-2)


Rebound in Emissions & Net Emissions Savings from Electric End-Use Efficiency, 2004 (ton CO_2e/year)
B
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Minnesota
Nevada
Wisconsin
Hawaii
Wyoming
Pennsylvania
Illinois
Colorado
Connecticut
Montana
Michigan
New Jersey
Vermont
Idaho
New Hampshire
Oregon
Alaska
Maine
Washington
New Mexico
Massachusetts
Rhode Island
New York
Utah
California
Actual Emissions Savings
Other (S1-3)
Natural Gas (S2-3)
Natural Gas (S1)
Gasoline (S2-3)
Gasoline (S1)
Direct Rebound (Electricity, S1-3)
Direct + Indirect Rebound w. Proportional Spending (RA)
10% Direct + Indirect Rebound w. high transport spending (RB-2)

Are the rebound effects always small?

- The policy design matters!

Reducing Energy Consumption with Energy Efficiency Rebate Program: Why Details Matter.

Authors: Russell M. Meyer and Inês M. L. Azevedo

Target Journal: PNAS Sustainability

Acknowledgement: Support for this work was provided by the Steinbrenner Center for Environmental Education at Carnegie Mellon University and by the Center for Climate and Energy Decision Making. Helpful discussions and comments were received from Nathaniel Horner, Alex Davis, Karen Palmer, Pedro Ferreira, Fallaw Sowell, Granger Morgan, Scott Matthews and David Dzombak.

Abstract

Do rebate programs for residential energy efficiency lead to lower electricity consumption? To move towards sustainable, low-carbon, and affordable energy systems in the U.S., energy efficiency is likely needed to play a central role. That will require robust, large-scale programs that deliver the intended savings. With the roll-out of smart meter programs, utilities and policy makers have unprecedented data to evaluate the effects associated with energy efficiency programs, and continued careful of energy efficiency and demand-side programs continues to be needed. Using an unbalanced panel of smart-meter data from a sample of approximately 30,000 households in Pacific Gas & Electric (PG&E's) service territory from 2008 to 2011, complemented with demand-side management and energy efficiency program participation, and weather information, we assessed the effect of rebates for household electrical efficiency improvements on household electricity consumption. We find that participation in the efficiency rebate program is associated with an average increase in household electricity consumption of about 7%. We suspect that the reason is largely a result of the majority of rebate program eligibility not being contingent on equipment scrappage or recycling; and thus the program is likely behaving as an equipment subsidy program leading to additional household energy services for participants rather than maintaining the same level of household energy service with higher energy efficiency. These results strongly suggest that systematic effort must be made to use randomized controlled trials where programs are pretested to examine whether households act as expected by program planners, and that continued evaluation of energy efficiency and demand-side management programs is needed.

© Ines Lima Azevedo

There is still a lack to systematic evaluation of actual energy savings associated with different programs.

- There is a large uncertainty concerning the magnitude of the effect of different programs and their persistence over time.

- Davis et al. (2013): studied the effects of a large-scale refrigerator and AC program in Mexico – they find that refrigerator replacements reduced electricity consumption by 7% and that that air conditioning replacements actually *increased* electricity consumption.

- Data from **smart-meters**, using **big-data analytics** coupled with information about the **programs** and **consumers**, and proper experimental design may help provide insights regarding the actual savings.

© Ines Lima Azevedo

We use PG&E data to assess the effect of a appliance rebate program.

From PG&E, via the Wharton Customer Analytics Initiative:

1. Smart-meter data:
~30,000 customers from 2008 to 2011 with 15-min interval readings

2. Program participation:
Household participation in programs & rebates (BPP, CARE, SmartAC, SmartRate, DirectAccess, ClimateSmart)

3. Household location defined by Census Block

We complemented that dataset with:

4. Demographic information
at the census block (2010) demographic information (median income, median home value, % renters, % poor, education)

5. Weather data
Daily temperature data from NOAA (daily high and low temperatures

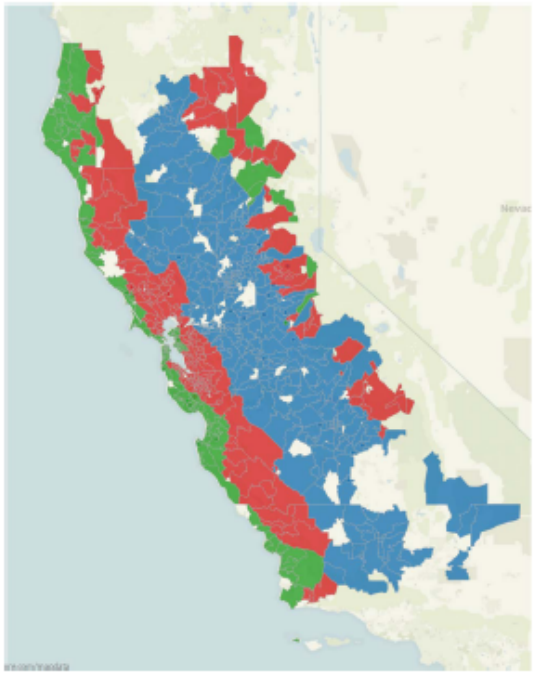
© Ines Lima Azevedo

PG&E Smart Meter Program

- PG&E began the roll out of smart meters to residential consumers in early 2008.
- Smart meters communicate 15-minute energy readings back to a base station, from which they are then relayed back to PG&E.
- There was no option to allow customers to opt-out of having a smart meter installed over the period of the data set.
- There were no dropouts in the program other than for households in which the customer moved.
- Households are identified by a service point id (for the location) and an account id (for the customer).

© Ines Lima Azevedo

Smart meter data

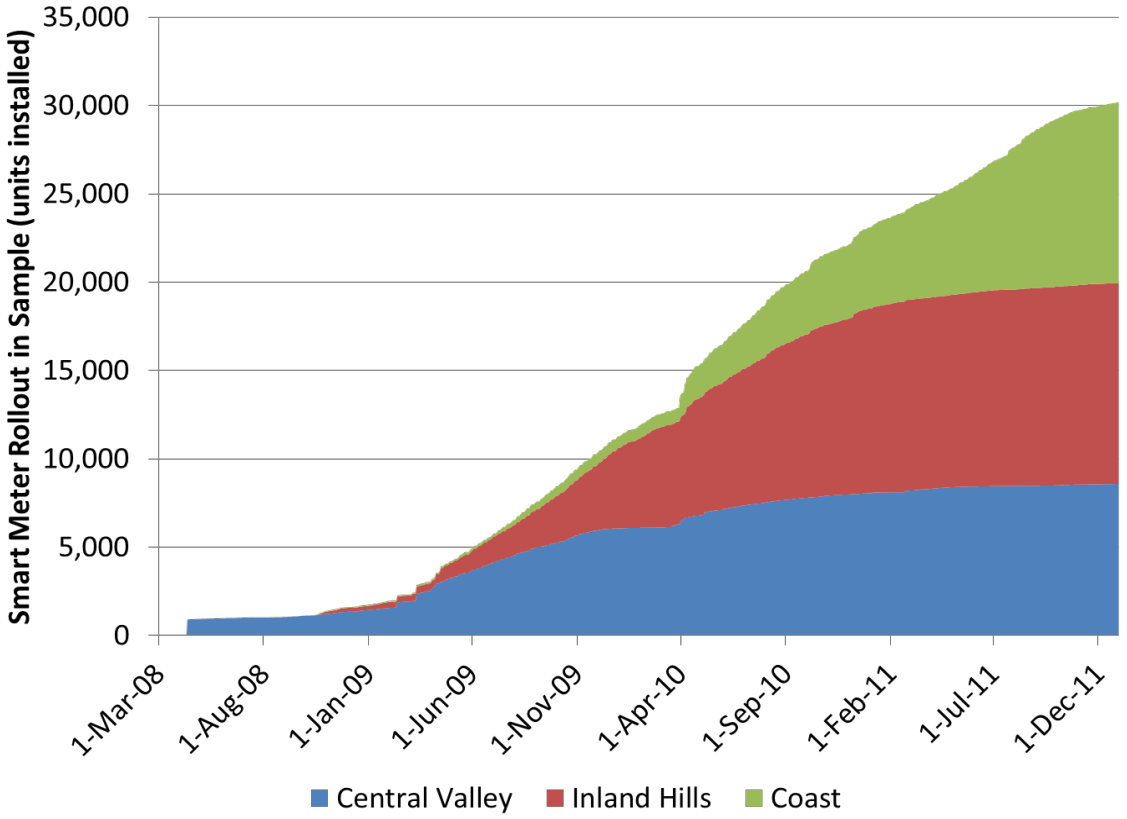


Climate Zones

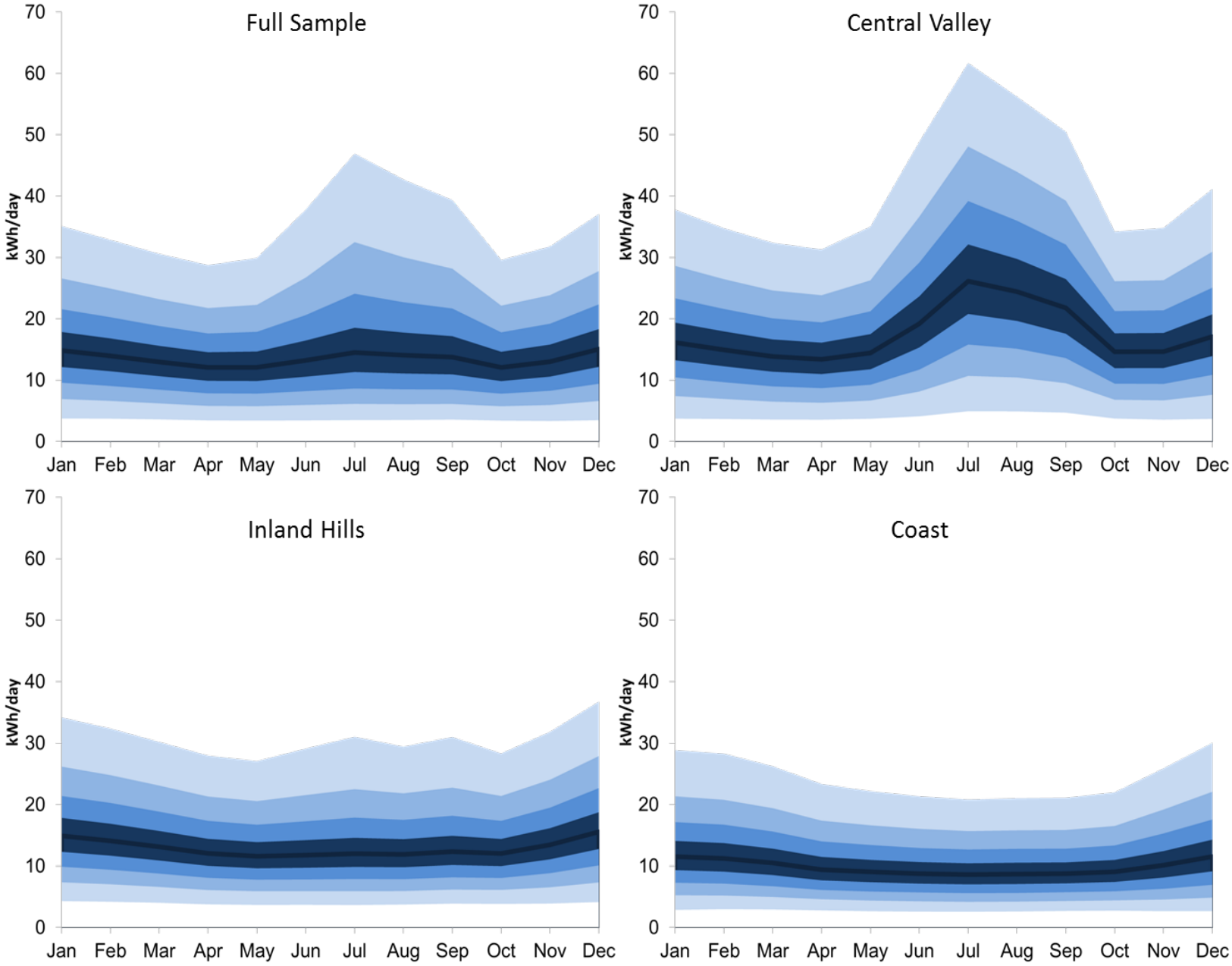
Coastal

Inland Hills

Central Valley



© Ines Lima Azevedo


Full Sample
Central Valley
Inland Hills
Coast
kWh/day
0
10
20
30
40
50
60
70
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

The rebate program

- Efficiency rebates are awarded following the purchase of qualifying equipment and application by the customer to PG&E.
- Rebate program existed before and during our entire observation period.
- PG&E makes applications available to its customers on its website as well as via a mail-in form.
- The rebates are funded via a “public goods charge”, which is included in the electric rate base by the California Public Utilities Commission.
- Households are eligible to participate in the rebate program multiple times.

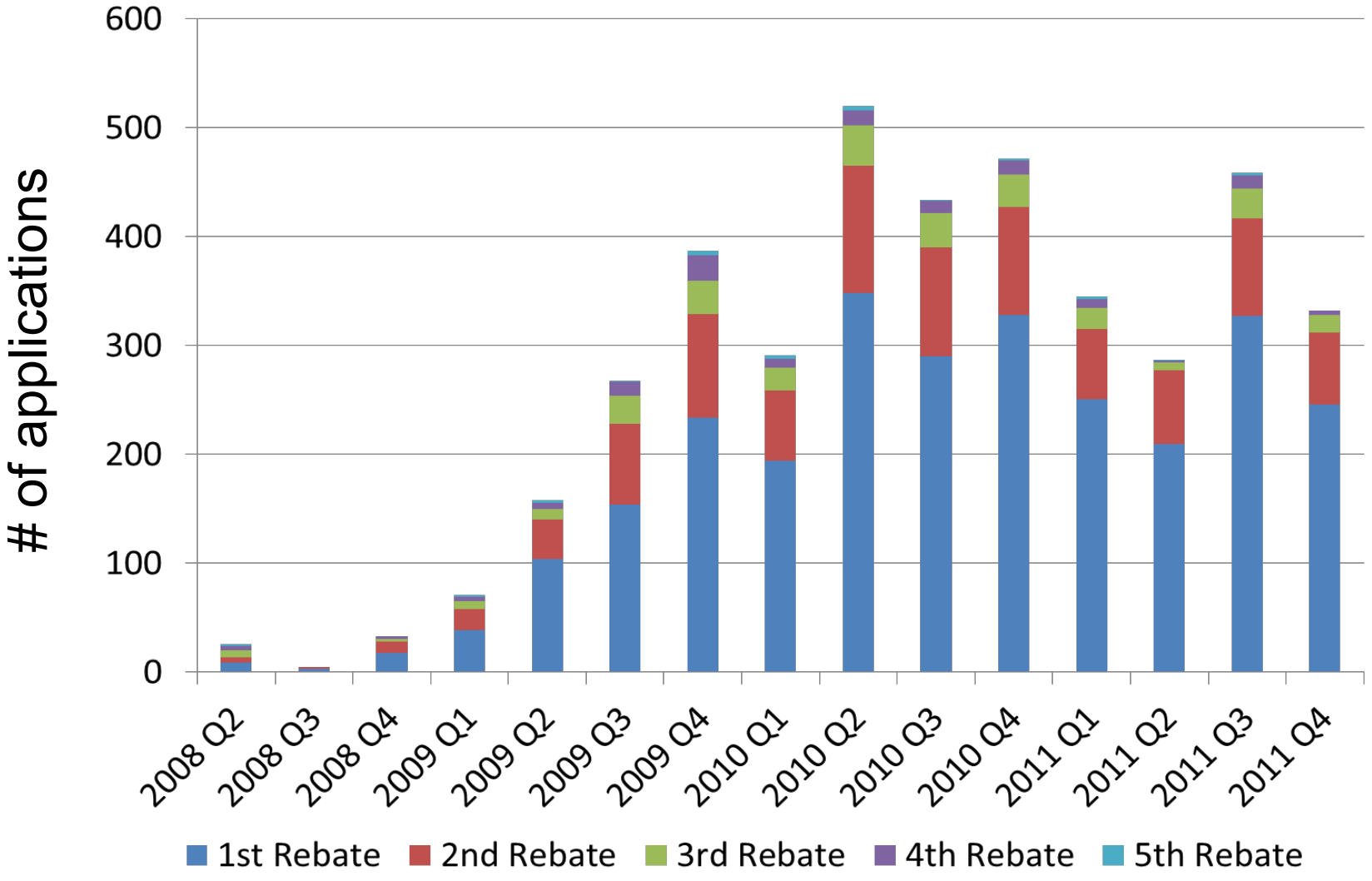
© Ines Lima Azevedo

	Rebate Code	Product	Catalog Page #	Install Date	Product Information	Quantity Installed (A)	Rebate per Unit (B)	RebateTotal (A x B)
Appliances	B34	**High Eff. Clothes Washer** CEE Tier 3, MEF ≥ 2.2, WF ≤ 4.5	1		Manufacturer _____ Model # _____	____unit(s)	$50 per unit	$
	DW03	**High Eff. Dishwasher** ≤ 324 kWh/yr., ≤ 5.8 gal/cycle	1		Manufacturer _____ Model # _____	____unit(s)	$30 per unit	$
	DW06	**Super High Eff. Dishwasher** ≤ 307 kWh/yr., ≤ 5.0 gal/cycle	1		Manufacturer _____ Model # _____	____unit(s)	$50 per unit	$
	H169	**ENERGY STAR® Room Air Conditioner**	1		Manufacturer _____ Model # _____	____unit(s)	$50 per unit	$
	H722	**Natural Gas Tank Water Heater Level 1** (EF = 0.62 to 0.64)	2		Manufacturer _____ Model # _____	____unit(s)	$30 per unit	$
	H721	**Natural Gas Tank Water Heater Level 2** (EF ≥ 0.65)	2		Manufacturer _____ Model # _____	____unit(s)	$50 per unit	$
	H154	**Electric Storage Water Heater** EF ≥ 0.93	2		Manufacturer _____ Model # _____	____unit(s)	$30 per unit	$

© Ines Lima Azevedo

Energy efficiency rebate applications over time

About **3500** households applied for at least one rebate.



© Ines Lima Azevedo

Other programs

Program	Max Part.	Description
BPP	2,407	Balanced Payment Plan: Provides a bill smoothing service, in which PG&E calculates the household's average monthly utility bill and the customer pays a flat amount for each monthly billing cycle. This value is an average annualized value
CARE	10,137	CA Alt. Rates for Energy: Provides subsidies to household's monthly energy bills based on income and occupant criteria.
Climate Smart	148	Households can voluntarily opt-in to purchasing carbon-offsets through PG&E with their monthly utility bill
Direct Access	668	Allows customers to purchase their electricity from alternative (non-PG&E) power providers, using PG&E as the distribution company (New customers have not been able to join the Direct Access program since the California energy crisis in 2001, though existing customers have been able to remain in the program)
Smart AC	1,069	Allows customers to voluntarily opt-in to a central AC curtailment program during peak-load events during the summer cooling season.
Smart Rate	154	Lower average electricity tariff (¢/kWh reduction) in exchange for accepting a higher rate (60¢/kWh) during peaking hours in some days during the summer cooling months. (these days are communicated to the consumer a day ahead via text, email, or by phone)

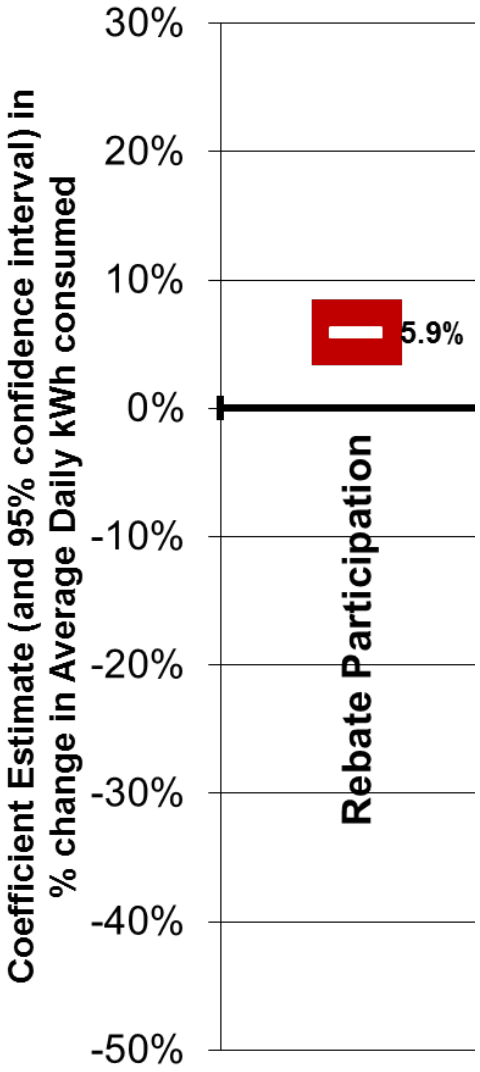
© Ines Lima Azevedo

We use a fixed effects model controlling for household specific effects:

$$\ln(kWhs_{i,t}) = \alpha + \beta_j(Temp_{i,t})_j + \gamma(RebateDummy_{i,t}) + \delta_k(TimeDummies_t)_k + \zeta(TimeTrend_t) + \varphi_q\left(Program_{i,t}\right)_q + \psi_q(RebateDummy_{i,t} * Program_{i,t})_q + \varepsilon_{i,t} \quad (1)$$

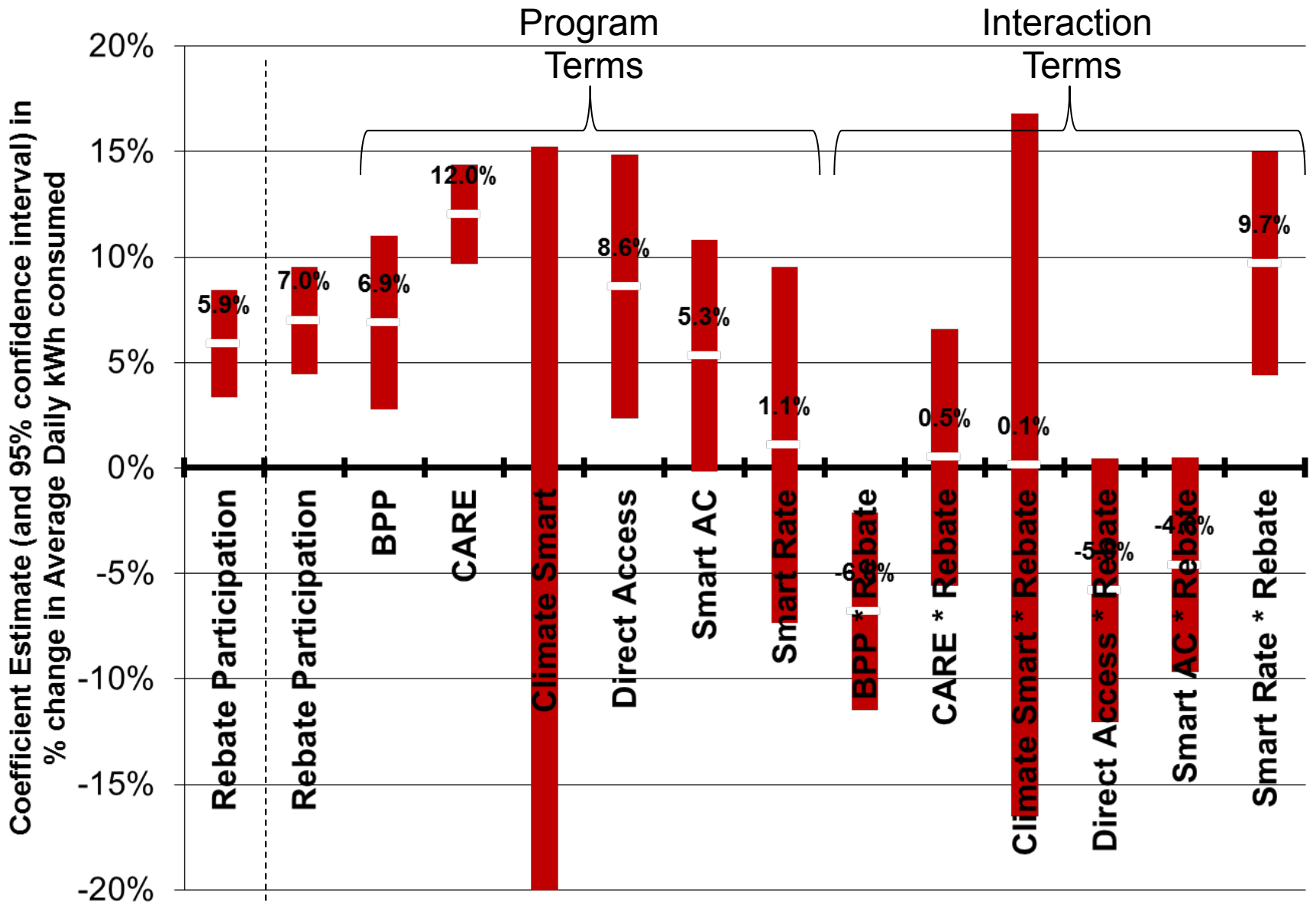
© Ines Lima Azevedo

Estimating energy consumption effects



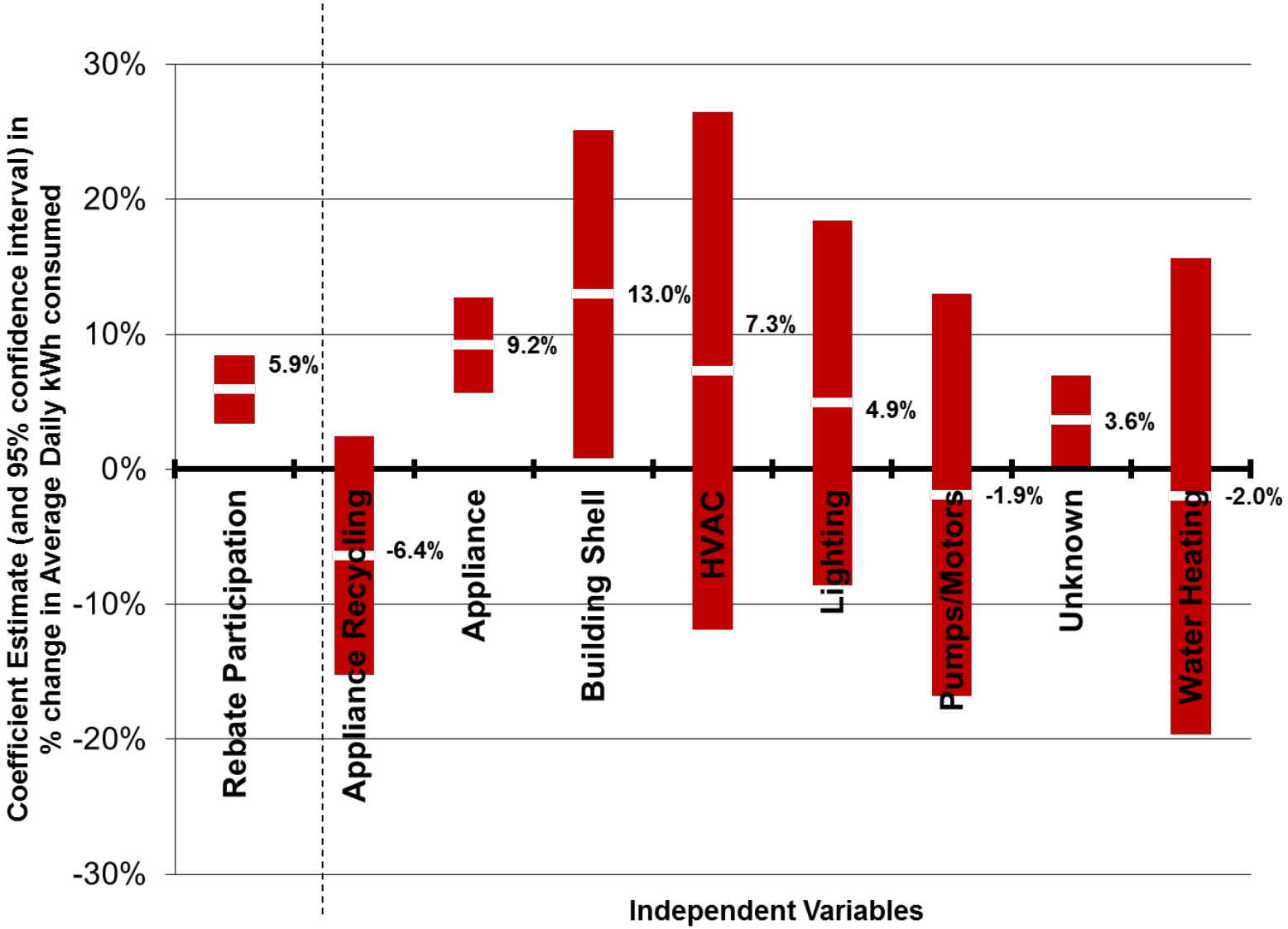
© Ines Lima Azevedo

Estimating energy consumption effects



© Ines Lima Azevedo

Estimating energy consumption effects



© Ines Lima Azevedo

Findings

- Participation in the efficiency rebate program seems to be associated with a subsequent *increase* in household electricity consumption.
  - "Appliance" rebates seem to be driving this result.
  - Because (most) rebates are not associated with mandated equipment retiring, these rebates are likely associated with the delivery of a new energy service to the household.

© Ines Lima Azevedo

Wrapping up

- Energy efficiency and behavior programs and strategies are key to achieve greenhouse gas emissions mitigation, to move towards a sustainable energy system, and are very much needed.
- However, we need to assess how different programs work, to ensure that we get needed the energy savings and GHG reductions.
- More work is needed in this space, and much of it will be enabled by the collection of data from smart meters, coupled with dig data analytics, and with proper experimental design.
  - In our work, for example, we suffer from the limitation of not having household specific demographic information.
  - Complementing big data analysis with other strategies: for example, in this case, we would like to interview PG&E costumers to understand who applied for rebates and why.

© Ines Lima Azevedo

Inês M.L. Azevedo
iazevedo@cmu.edu

This presentations & paper can be found at:

https://www.dropbox.com/sh/9skgog59wdd3m4x/AAAQzsPhamXaRmGOIOhyz7Dpa?dl=0

Acknowledgments:

the Climate and Energy Decision Making Center (CEDM); The Energy and Behavior Group at CMU; The Steinbrenner Institute for Sustainability; the Carnegie Mellon Electricity Industry Center (CEIC)

Research team for the pieces mentioned in this talk: Russell Meyer; Brinda Thomas; Alan Jenn; Zecke Hausfather; Ken Gillingham; Ortwin Renn; Granger Morgan; Marco Sonnberger.

Our papers on rebound effects:

1. Azevedo, I.L. (2014) Energy efficiency and rebound effects: a review, *Annual Reviews of Environment and Resources*, Volume 39.
2. Min, J., Azevedo, I.L., Hakkarainen, P. (2015). Net carbon emissions savings and energy reductions from lighting energy efficiency measures when accounting for changes in heating and cooling demands: a regional comparison, *Applied Energy*, Volume 141, 1, 12–18.
3. Thomas, B., Hausfather, Z., Azevedo, I.L. (2014). Comparing the magnitude of residential rebound effects from electric end-use efficiency across the US, *Environmental Research Letters*, 9 (7).
4. Thomas, B., Azevedo, I.L., (2014). Should policy-makers allocate funding to vehicle electrification or end-use energy efficiency as a strategy for climate change mitigation and energy reductions? Rethinking electric utilities efficiency programs. *Energy Policy,* 67, 28-26.
5. Azevedo, I.L., Sonnberger, M., Thomas, B., Morgan, G., Renn, O., (2013). The Rebound Effect: Implications of Consumer Behaviour for Robust Energy Policies. *International Risk Governance Council (IRGC).*
6. Thomas, B.A. Azevedo, I.L., (2013). Estimating direct and indirect rebound effects for US households with input-output analysis. Part 1: Theoretical Framework, *Ecological Economics*, 86, 199–210.
7. Thomas, B.A. Azevedo, I.L., (2013). Estimating direct and indirect rebound effects for U.S. households with input-output analysis. Part 2: Simulation. *Ecological Economics*, 86, 188–198.
8. Jenn, A., Azevedo, I.L., Gillingham, K., Heterogeneity in the Response to Gasoline Prices: Evidence from Pennsylvania and Implications for the Rebound Effect, submitted to *Energy Economics*, December 2014.
9. Meyer, R., Azevedo, I.L., Using smart-meter data to understand policy effects (*working paper*)

© Ines Lima Azevedo

08:30 – 09:15	Overview of >25 years of HDGC, CDMC and CEDM – Granger Morgan
09:15 – 10:00	Uncertainty in energy efficiency, Part 1: technologies, strategies, behavior and policy – Inês Azevedo
10:00 – 10:30	Uncertainty in energy efficiency, Part 2: technologies, strategies, behavior and policy – Alex Davis
10:45 – 11:15	Coffee break
11:15 – 11:45	Decision support for implementing the EPA Clean Power Plan Proposed Rule – Jeff Anderson
11:45 – 12:30	Marginal emissions factors, health and climate change co-benefits and trade-offs - Inês Azevedo
12:30 – 13:30	Lunch break
13:30 – 13:55	Insights from twenty years of work on expert elicitation and projections – Granger Morgan
13:55 – 14:05	Transitioning to a low carbon economy, Part 1: Insights from the RenewElec Project – Granger Morgan
14:05 – 14:30	Transitioning to a low carbon economy, Part 2: Insights from ITC and BC's Climate Policy – Hadi Dowlatabadi
14:30 – 15:10	Strategies for supporting investment decisions about large energy infrastructure in the face of regulatory and other uncertainty – Dalia Patiño
15:10 – 15:40	Coffee break
15:40 – 16:00	Reflections on Research and Governance wrt Albedo Modification – Granger Morgan
16:00 – 16:45	Insights From Our Experience in Building and Using ICAMs – Hadi Dowlatabadi
17:45 – 17:00	Muddling through on climate policy: good, but not good enough to avoid the risk of dead ends – Granger Morgan
17:00 – 17:30	Discussion and round table on what investigators in CEDM might best work on in the next several years to be most useful to the IA and energy modeling communities.

© Ines Lima Azevedo