Research on Tap: Sustainable Energy Research

Questrom School of Business
Energy Transitions in the United States, 1780-2010

Cutler Cleveland

Professor, Department of Earth & Environment
College of Arts & Sciences
Energy Transitions in the United States, 1780-2010


Boston University Office of the Vice President and Associate Provost for Research
Global Energy Demand in a Warming Climate

Ian Sue Wing
Associate Professor, Department of Earth & Environment
College of Arts & Sciences

Enrica De Cian
Senior Researcher
Fondazione Eni Enrico Mattei – FEEM
Global Energy Demand in a Warming Climate

We econometrically model the long-run temperature sensitivity of demand for 3 fuels in 5 sectors, and couple the resulting estimates with earth system model simulations of climate circa 2050.

**Model**

\[ \Delta q_{i,t} = \log \text{per capita fuel} \times \text{sector energy consumption} \]

\[ \varepsilon_{T,i,t}, \varepsilon_{H,i,t} = \text{days exposed to population-weighted temperature bins, population-weighted humidity bins} \]

\[ \mathbf{X} = \text{vector of controls} \]

\[ \Delta q_{i,t} = \alpha_i + \left[ \sum_j \beta_j \Delta \varepsilon_{T,i,t} + \sum_k \gamma_k \Delta \varepsilon_{H,i,t} + \Delta \mathbf{X}_t \eta \right] + \theta \left[ q_{i,t-1} - \sum_j \gamma_j \varepsilon_{T,i,t-1} - \sum_k \gamma_k \varepsilon_{H,i,t-1} + \mathbf{X}_{t-1} \lambda \right] + u_{i,t} \]

**Data**

Balanced panel of 29-48 countries (depending on fuel-sector combination), 1978-2010, stratified into tropical/temperate by Koeppen-Geiger classification

\( q \): final energy (International Energy Agency World Energy Balances)

\( \varepsilon_T, \varepsilon_H \): derived from gridded 3-hourly historical temperature and humidity fields from the Global Land Data Assimilation System

**Research on Tap:** BU Research on a Sustainable Energy Future
Greening the Bi-Polarization of Global Economic Governance

Kevin Gallagher

Professor of Global Development
Policy/Research Director, Center for Finance, Law & Policy,
Frederick S. Pardee School of Global Studies
College of Arts & Sciences
Greening the Bi-Polarization of Global Economic Governance

- New trade and investment treaties covering 80 percent of world GDP
- Trans-Atlantic Trade and Investment Partnership (TTIP)
- Trans-Pacific Partnership (TPP)
- US-China and US-India BITs
- GEGI Sustainable Energy Agenda
- Reduce fossil fuel subsidies
- Policy space for sustainable energy policy

CHINA: Abandoning World Bank
- New development banks that dwarf lending of World Bank and MDBs
- CDB-CHEXIM
- AIIB and NDB
- $100 billion regional funds
- GEGI Sustainability Energy Agenda
- Database on China energy lending
- Task Force on Development Banks and Sustainable Development

UNITED STATES: Abandoning WTO

Research on Tap: BU Research on a Sustainable Energy Future
Why the Paris Accord May Be Worse Than Nothing

Laurence Kotlikoff

William Fairfield Warren Distinguished Professor/Professor,
Department of Economics
College of Arts & Sciences
When Should I Pump?

Why the Paris Accord May Be Worse Than Nothing
Governing the Environmental Impacts of Energy

Henrik Selin

Associate Professor, Frederick S. Pardee School of Global Studies
College of Arts & Sciences
Governing the Environmental Impacts of Energy

Research on Tap: BU Research on a Sustainable Energy Future
Climate Change and Contingent Adaptation: Lessons from South Asian Mega Cities

Madhu Dutta-Koehler

Associate Professor of the Practice/Program Coordinator, Department of City Planning & Urban Affairs
Metropolitan College
adaptation v. development

acute risks

environmental v. economic

severe resource constraints

climate risk management

2 billion+ urban dwellers

28 megacities

3 primary challenges

CONTINGENT ADAPTATION

kolkata & dhaka

water scarcity

climatic impacts

climate filters

100,000,000,000
Where Does the CO$_2$ in Cities Come From?

Lucy Hutyra

Associate Professor, Department of Earth & Environment
College of Arts & Sciences
WHERE DOES THE CO$_2$ IN CITIES COME FROM?

- 70% of CO$_2$ emissions are attributable to urban areas
- New technologies to measure CO$_2$, but how do we attribute the sources?
- Does biology in cities contribute significantly?

**Research on Tap: BU Research on a Sustainable Energy Future**
Demand Projection for Natural Gas in Boston

Nathan Phillips

Professor, Department of Earth & Environment
College of Arts & Sciences
Improving Performance & Sustainability of Commercial Buildings

Michael Gevelber

Associate Professor,
Department of
Mechanical Engineering
College of Engineering
Improving Performance & Sustainability of Commercial Buildings

**Commercial Buildings:** 12% of US energy use, but 37% electricity, & 18% US carbon.  **Waste:** > 53%!

**Focus:** HVAC → 40-60% energy use
- What drives HVAC energy use?
- New HVAC control architecture
- What drives EE decisions & action?

**University as a Laboratory:**
~12 million sq ft. Projects in large buildings with advanced HVAC controls as well as brownstones

**Public Housing (Madison Park):** are operations efficient, where invest? Role of tenants, opportunities for behavior modification?

**Extension to Cities:** how identify meaningful opportunities for greater EE across the city? What does BERDO data tell us & how use?

**MPDC Apartment Electricity Use**

- **Ruggles Shawmut**
- **Haynes**

<table>
<thead>
<tr>
<th>Apartment Size (sq ft)</th>
<th>Electricity Use (kBTU/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>444 sq ft</td>
<td>5,000</td>
</tr>
<tr>
<td>592 sq ft</td>
<td>15,000</td>
</tr>
<tr>
<td>650 sq ft</td>
<td>20,000</td>
</tr>
<tr>
<td>775 sq ft</td>
<td>25,000</td>
</tr>
<tr>
<td>850 sq ft</td>
<td>30,000</td>
</tr>
<tr>
<td>910 sq ft</td>
<td>35,000</td>
</tr>
<tr>
<td>1374 sq ft</td>
<td>50,000</td>
</tr>
</tbody>
</table>

Haynes tenants pay electric bills, while RS do not! 5x variation in use
Devices and Processes for Energy and Environmental Sustainability

Uday Pal

Professor, Department of Materials Science & Engineering
College of Engineering
Devices and Processes for Energy and Environmental Sustainability

Green Production of Energy Intensive Metals
(Pal, Basu, Gopalan)

Waste to Energy Conversion
(Pal, Goldfarb, Gopalan)

Energy Conversion and Storage
(Gopalan, Pal, Basu, Ryan, Ludwig, Smith)

Fuel Processing and CO₂ Sequestration
(Gopalan, Pal)

Solid Oxide Membrane-Based Technologies

- One unit operation
- Less energy intensive
- Less capital intensive
- Zero direct carbon emission
- Oxygen byproduct
- Non consumable molten salt

Our Proposal: Tungsten/Tungsten Oxide Grid-Scale Energy Storage

Value proposition
- Novel utility scale rapid response energy storage and conversion system

Fuel Cell and Electrolyzer
Approach: Water splitting combined with reformation of hydrocarbons in two physically separated chambers

• Demonstrated fast heat-up (~15 min) and extreme thermal gradients (~200°C)
• Successful demonstration of H₂ generation at 25W (0.2 l/min) output
• Results repeated after a thermal cycle

Membrane Reactor

- Syn-gas or CO₂
- Pure H₂
- Fuel
- Steam

Syn-Gas Out
Solid Oxide Membrane (TSR)
Solid Oxide Membrane Reactor

Fuel Cell

Approach:

Fuel Cell and Electrolyzer

Annual Energy value
40 billion gallons of gasoline

250 million tons MSW generated in 2012
54% Land-filled and 12% incinerated

Other carbon-hydrocarbon waste
(4 lb/person-day)

2012 Land-filled and incinerated waste: 250 million tons

- Li, Mg, Ca, Ti, Ta, Al, Si, Dy, Nd, Yb

Pure H₂

- Water splitting
- Membrane Reactor

Approach:

- US Generation Capacity (1,100 GW)
- Existing Storage Capacity (22 GW) - Mostly Pumped Hydro

Research on Tap: BU Research on a Sustainable Energy Future

Boston University Office of the Vice President and Associate Provost for Research
Lighting Is a Platform for Sensing and Control

Thomas Little

Professor & Associate Dean of Educational Initiatives,
Department of Electrical & Computer Engineering
College of Engineering
Lighting Is a Platform for Sensing and Control

Center for Lighting Enabled Systems and Applications (LESA)

Real-Time Data Collection & Analysis

Position & Occupancy Information

Personalized Microclimate Optimization

Light Rendering

Air Delivery

Building Management System Integration

Dashboard
Sustainable Large-scale Solar Energy Conversion by Water-free Cleaning of Solar Panels and Mirrors by Electrodynamic Screens

Malay Mazumder  
Research Professor, Department of Electrical & Computer Engineering  
College of Engineering

Mark Horenstein  
Professor, Department of Electrical Computer Engineering  
College of Engineering

Nitin Joglekar  
Associate Professor/Dean’s Research Fellow, Department of Operations & Technology Management  
Questrom School of Business

Boston University Office of the Vice President and Associate Provost for Research
Sustainable Large-scale Solar energy Conversion by Water-free Cleaning of Solar Panels and Mirrors by Electrodynamic Screens

**Problem:** Dust causes major energy-yield loss and degrades the optical performance of solar panels and mirrors.

For a 0.3 GW solar plant in Southwest US, more than a million gallons of deionized water is needed per year and cleaning costs $>1M/yr.

To reach 200 GW (20% of the US power consumption), the deluge water cleaning will require an unsustainable level of water consumption.

**Solution:** BU, in collaboration with industrial partners and Sandia National Lab, developed a transparent electrodynamic screen (EDS) as a water-free cleaning method, for removing dust, as frequently as needed, from solar collectors.

**Research Activities:** Established feasibility of the EDS film method for solar fields during 2013-2015; supported by DOE, MassCEC and Industrial Partners.


The projects supported graduating 2 PhDs, 6 MS/MEng, 8 BS in ECE, ME, & MSE and 1 Post Doc. Funding from DOE, MassCEC, and Industrial Partners.

**Results**
The Transition to Platforms in Energy is Inevitable

Marshall Van Allstyne

Professor/Chair of IS
Department/Dean’s Research Fellow, Department of Information Systems
Questrom School of Business
The Transition to Platforms in Energy is Inevitable

<table>
<thead>
<tr>
<th>FIRM</th>
<th>MARKET CAP</th>
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<tbody>
<tr>
<td>Apple</td>
<td>532</td>
</tr>
<tr>
<td>Google</td>
<td>488</td>
</tr>
<tr>
<td>Microsoft</td>
<td>402</td>
</tr>
<tr>
<td>Berkshire Hathaway</td>
<td>310</td>
</tr>
<tr>
<td>Exxon Mobile</td>
<td>308</td>
</tr>
</tbody>
</table>

- Firm: Apple, Google, Microsoft, Berkshire Hathaway, Exxon Mobile
- Market CAP: 532, 488, 402, 310, 308

- The transition to platforms in energy is inevitable.
- Top 3 of 5 are platforms.
- An open architecture + a governance model.
- Spare capacity & information.

- Research on Tap: BU Research on a Sustainable Energy Future

- Platform Revolution: How networked markets are transforming the economy and how to make them work for you
  - Geoffrey Parker, Marshall W. Van Alstyne, and Sangeet Paul Choudary
T&D Nodal Location Marginal Cost Discovery for Efficient Demand-Side Provisioning of Reserves and Massive Renewable Generation Integration: A Distributed Computing and Communication Architecture

Michael Caramanis

Professor, Department of Mechanical Engineering
College of Engineering

Boston University Office of the Vice President and Associate Provost for Research
Research on Tap: BU Research on a Sustainable Energy Future

T&D Nodal Location Marginal Cost Discovery for Efficient Demand-Side Provisioning of Reserves and Massive Renewable Generation Integration: A Distributed Computing and Communication Architecture

**Research Summary**

- Synergy of Volatile Renewable Generation with Flexible Distributed Loads and DERs. Distributed MC based Prices can Commodify Demand Response
- Hundreds of thousands of Transmission and Distribution nodes where DERs are connected modeled in Market Layer where Prices are Cleared for Energy (real and reactive) and Reserves. Declaration Layer handles actual provision of reserves.
- Distributed yet Collaborative architecture based on Proximal Message Passing Algorithms allows detailed DER Preference and Capability modeling. => Customer acceptance enabled!

**Research Impact**

- Transformation of Power markets
- DERs to acquire higher value/valuation and revenues
- Significant decline in T&D Utility costs
- T&D networks resilient to growth. Required Investments Delayed
- Production of DERs -- including those not yet in the market -- will boom
- High Renewable Generation integration will become Sustainable.

**Key Research Features/Objectives**

<table>
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<tr>
<th>Features</th>
<th>Description</th>
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<tbody>
<tr>
<td>Synthetic Reserves and Ancillary Services</td>
<td>Non Rotating Assets Can provide Reserves and Reactive Power Compensation to Great Cost Advantage</td>
</tr>
<tr>
<td>Managed DERs</td>
<td>EV Battery Charging, HVAC and Heat Pumps with Variable Speed Drives, Data Centers, Smart PV Inverters/Converters for Volt/Var control</td>
</tr>
<tr>
<td>Achievable Targets/Benefits</td>
<td>- Provision of Regulating Reserve exceeding 5% of System Load. - Provision of Faster Reserves with Response time &lt; 1 sec, +/- 5% tolerance. - Reliability of Load side Reserve provision &gt; 95% exceeding conventional generation reliability of 90-93%. - Storage-like behavior with Duration 10 min to 1 hour from Duty Cycle appliances, Pre heating/pre cooling in HVAC systems</td>
</tr>
</tbody>
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**Test Plan**

- Realistic data on 500,000 node T&D network with several thousand Transmission nodes and several hundred feeder networks.
- Marginal Cost based prices will be simulated on T&D Market clearing distributed architecture.
- Real-time load flow impact of DER on distribution lines.
- Extensive Validation plan with hardware in the loop (100+ PV with smart inverters, Non Intrusive WattsWorth consumption monitors, CHP, DGs.)
MassCEC’s Resources for Universities

Kavita Ravi

*Director of Strategic Analysis, Massachusetts Clean Energy Center*
MassCEC’s Resources for Universities

Programs supporting research, commercialization and workforce development:

<table>
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<tr>
<td>Academic Collaboration</td>
<td>Supports research and other clean energy/water efforts in Massachusetts with matching funding, letters of support, conference sponsorship, clean energy adoption and industry connections.</td>
</tr>
<tr>
<td>Catalyst</td>
<td>Early-stage grants for proof-of-concepts</td>
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<tr>
<td>AmplifyMass</td>
<td>Cost-share for Massachusetts ARPA-E awardees</td>
</tr>
<tr>
<td>Offshore Wind Research and Development</td>
<td>Supports offshore wind related research</td>
</tr>
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Other programs support early stage clean energy companies.

Contact: Kavita Ravi, Kravi@masscec.com

MassCEC is a publicly-funded agency dedicated to accelerating the success of clean energy technologies in Massachusetts.