Renewable & Appropriate Energy Laboratory

RAEL

The Science and Policy of Carbon Free Energy

Daniel Kammen

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University of California, Berkeley

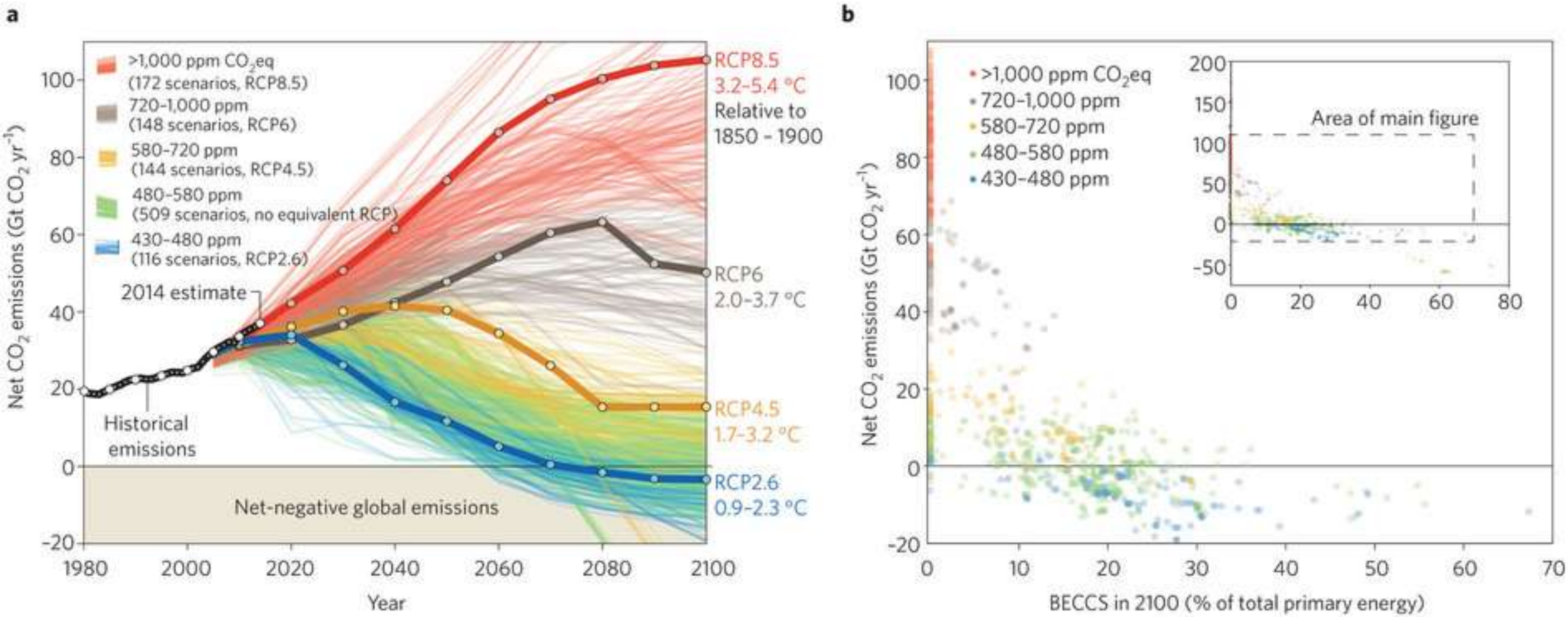
Science Envoy for the U. S. State Department

"Innovation in Energy and Measures against Climate Change"
Cannon Institute for Global Studies – November 30, 2016

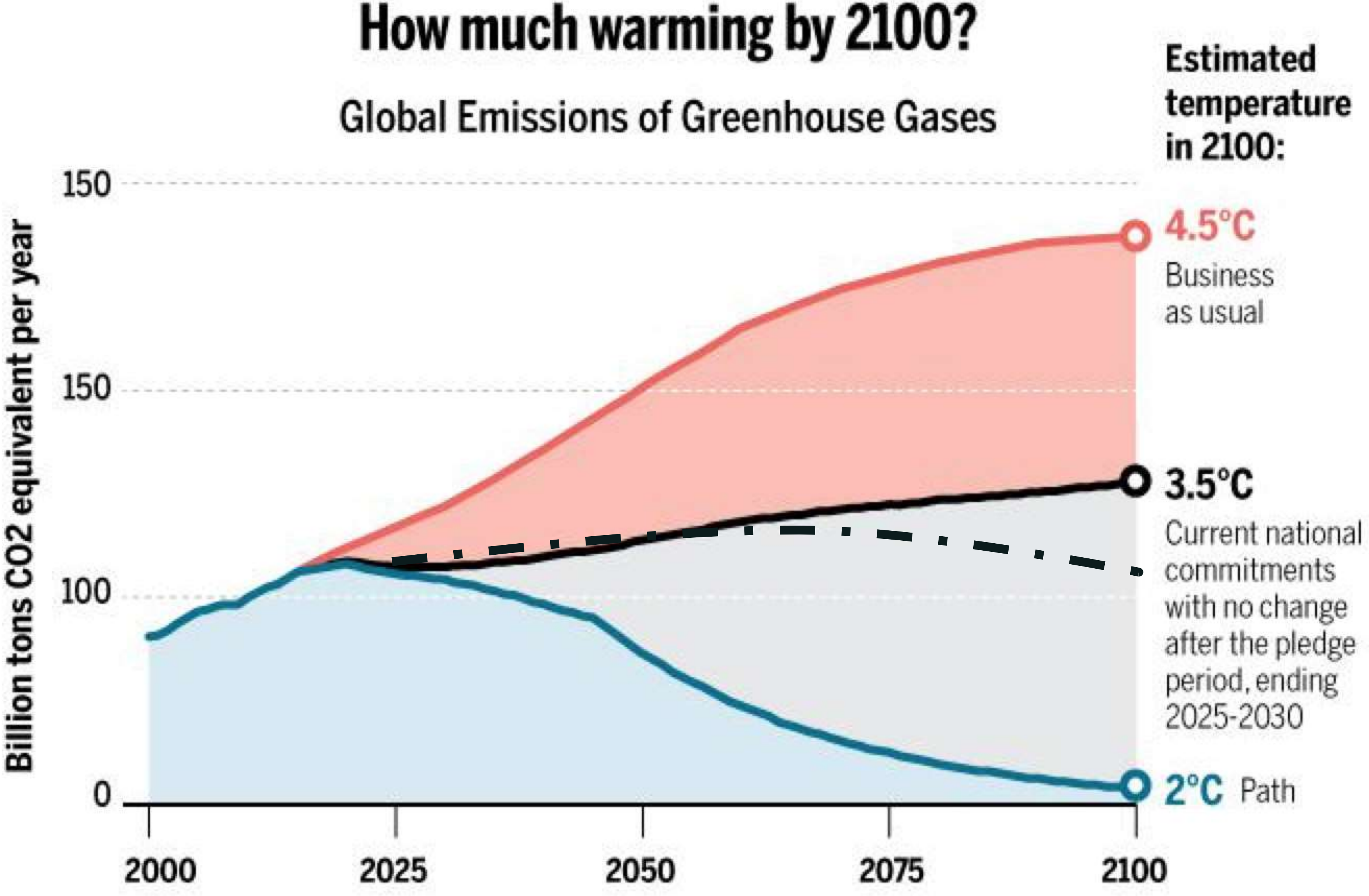
Overview:

- Two slides to set the stage

What we need to do:



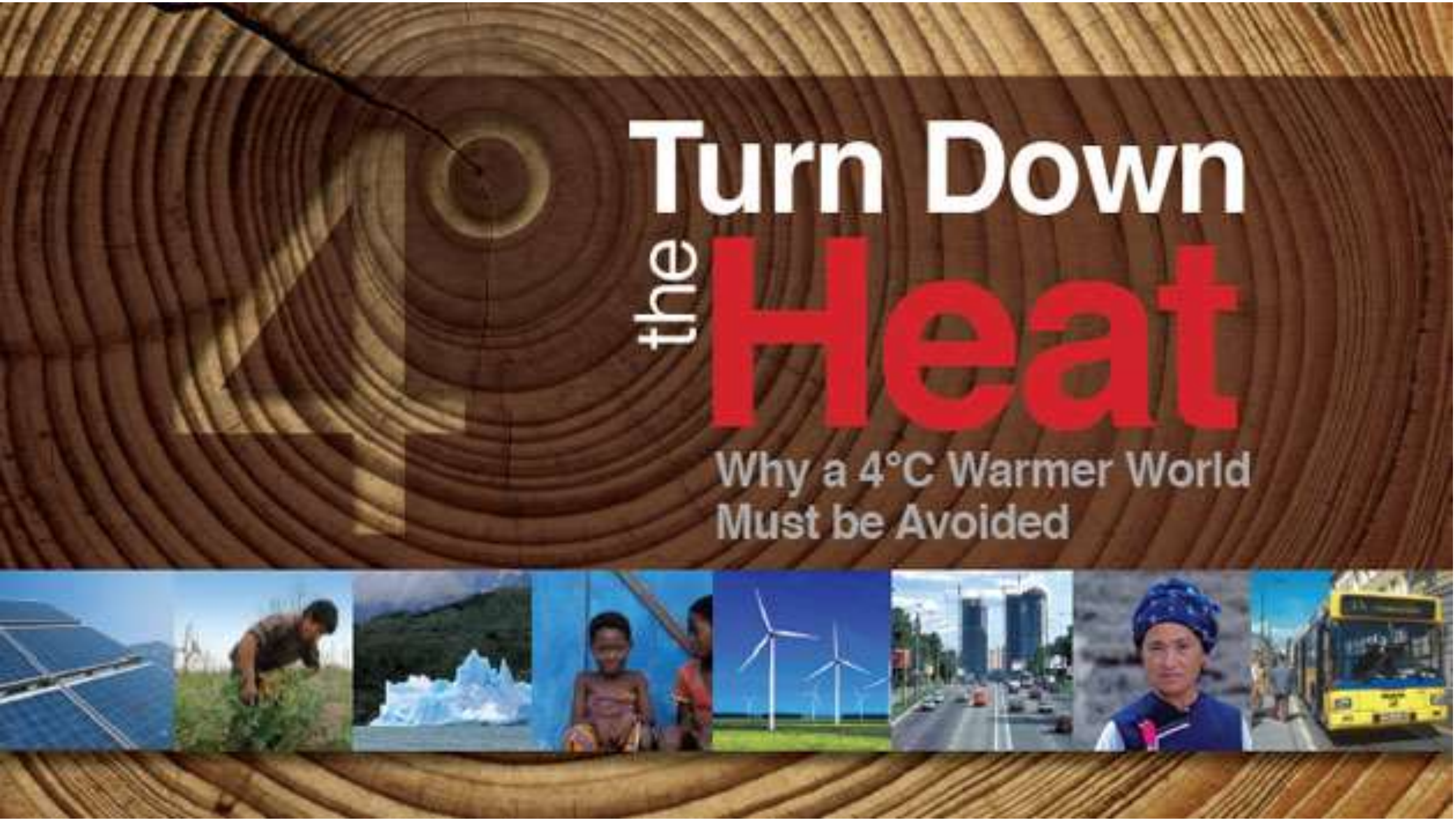
Fuss et al.
(2014)



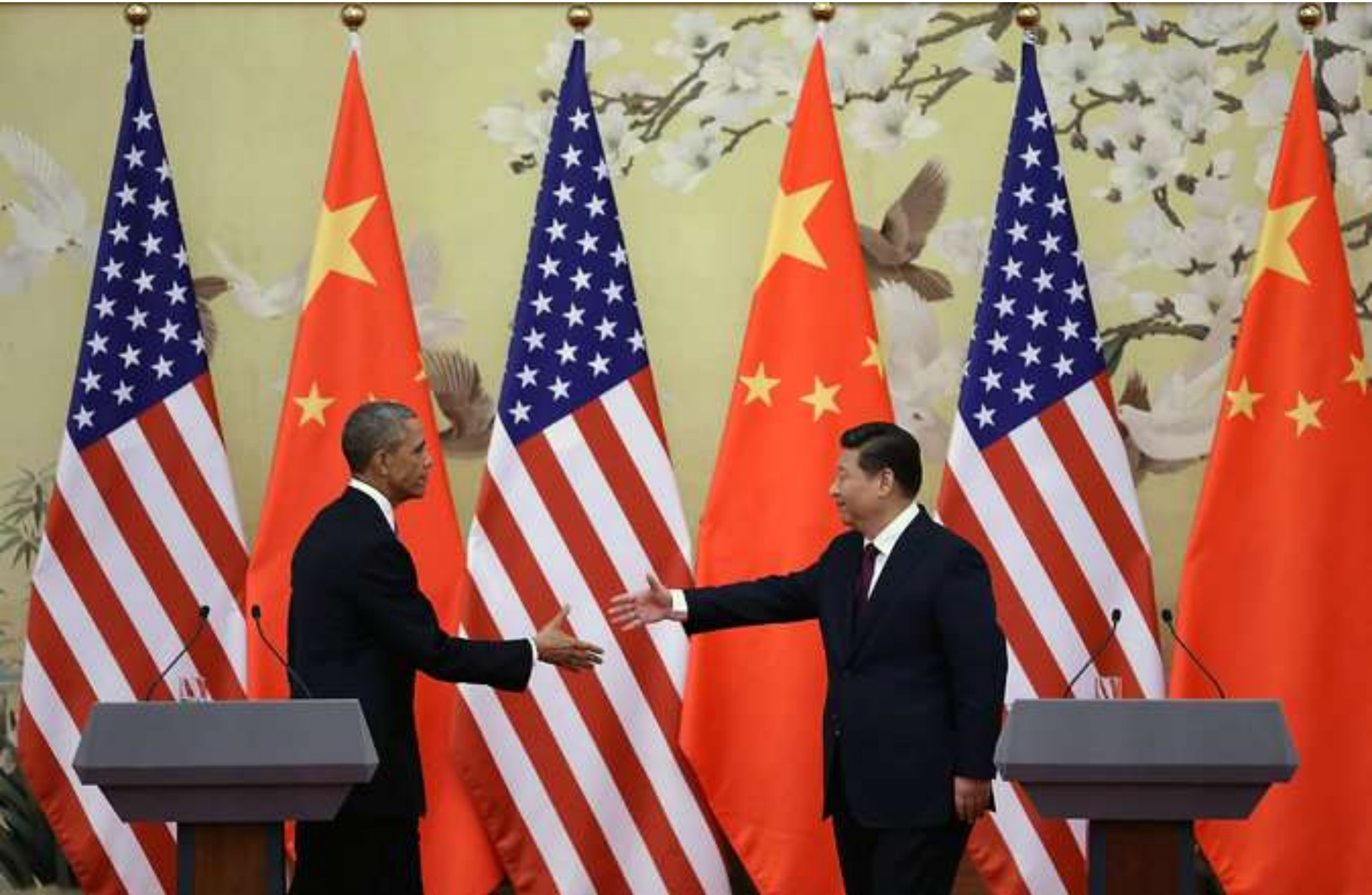
How much warming by 2100?

Global Emissions of Greenhouse Gases

Source: 27-Sep-2015 Climate Scoreboard ©Climate Interactive www.ClimateScoreboard.org


Turn Down
the Heat
Why a 4°C Warmer World
Must be Avoided

A revolution on climate politics
U.S.-China Joint Announcement on Climate Change




Paris, Franc
PRESIDENT
SECRET
ETAIRE EXECUTIVE CCNUCC
evian

Overview:

- Introduction to the Renewable and Appropriate Energy Laboratory (RAEL)

- Systems science across scales

- Toward a new industrial policy in the age of *inequality*

Renewable and Appropriate Energy Laboratory

Renewable & Appropriate Energy Laboratory
RAEL

Berkeley
UNIVERSITY OF CALIFORNIA

http://rael.berkeley.edu

Resources:

Website: http://rael.berkeley.edu

Twitter: @dan_kammen

Timeline

Founded

1999

Recognized for contributions to the Nobel Peace Prize

2007

DANIEL M. KAMMEN

NOBEL PEACE PRIZE

Berkeley

BICYCLE PARKING

Honoring the Berkeley Faculty

NL

who contributed to the reports of the IPCC, which was awarded the Nobel Peace Prize in 2007 for its work on climate change, together with former US Vice-President Al Gore

Parking not reserved for IPCC contributors

All cyclists are welcome

Over 50 PhDs

10 companies

LargestEnergy class at UCB

2010

Partners with Natel Energy, Grid Alternatives and U. Tokyo

2016

GRID ALTERNATIVES

NATEL ENERGY

東京大学
THE UNIVERSITY OF TOKYO

National and International Roles

THE WHITE HOUSE

Summit on Climate Change & the Road through Paris

Business & Science Coming Together

Monday, October 19, 2015
Eisenhower Executive Office Building – South Court Auditorium
12:30 PM – 4:00 PM

Welcome & Opening Remarks

Brian Deese, Senior Advisor & Assistant to the President for Climate, Conservation & Energy

Remarks: Science, Technology, and the Road Through Paris

Dr. John Holdren, Assistant to the President for Science & Technology & Director, Office of Science & Technology Policy

Negotiations State-of-Play in the Final Stretch to Paris

Tom Reynolds, Strategic Communications Advisor, White House Communications
Todd Stern, Special Envoy for Climate Change, State Department

Panel Discussion: Reducing Carbon Pollution

Dan Utech, Deputy Assistant to the President for Energy & Climate Change
Deborah Gordon, Director, Energy & Climate Program, Carnegie Endowment for Intl. Peace
Shailesh Jejurikar, President of Fabric & Home Care, Procter & Gamble
Dan Kammen, Distinguished Professor of Energy, UC Berkeley
Kevin McKnight, Vice President, Environment, Heath & Safety, & Chief Sustainability Officier, Alcoa
Kathleen McLaughlin, Chief Sustainability Officer, Walmart

Remarks

Ernest Moniz, Secretary of Energy

Panel Discussion: Building Climate Resilience

Christy Goldfuss, Managing Director, Council on Environmental Quality
John Balbus, Senior Advisor for Public Heath, National Inst. of Enviro. Health Sciences
Chris Field, Founding Director, Carnegie Institution's Department of Global Ecology & Melvin & Joan Lane Professor for Interdisciplinary Environmental Studies, Stanford University
Barry Parkin, Chief Sustainability Officer, Mars, Incorporated
Kathrin Winkler, Chief Sustainability Officer, EMC

Closing Remarks

Vice President Joe Biden

RAEL Policy Design & Implementation

Key analysis of the California Energy Crisis

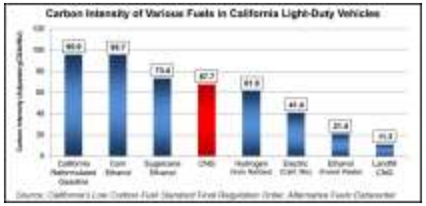
2000 - 01

Contributions to AB32, California's Global Warming Solutions Act

2006

Develops First Version of the Low-Carbon Fuel Standard, appears on '60 Minutes'

2007



Partners to develop Property Assessed Clean Energy

2009

Overview:

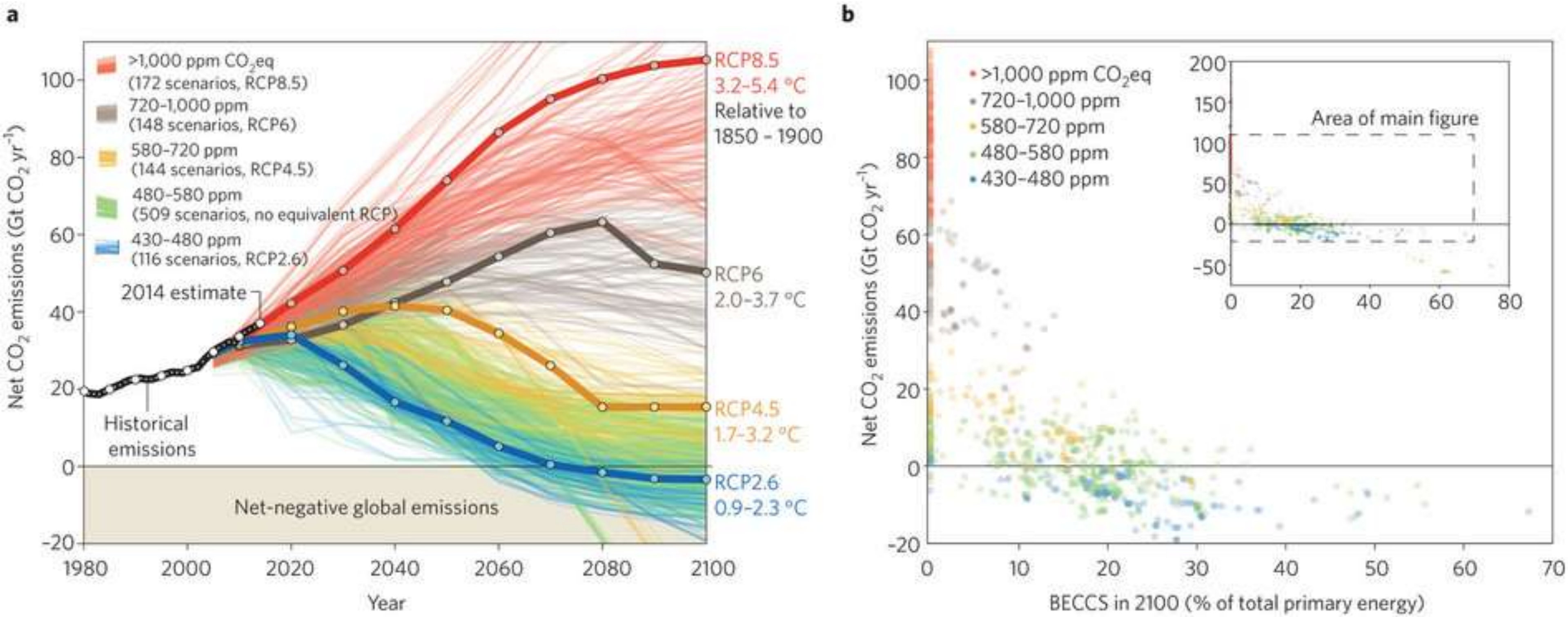
- **Introduction to the Renewable and Appropriate Energy Laboratory (RAEL)**

- **Systems science across scales**

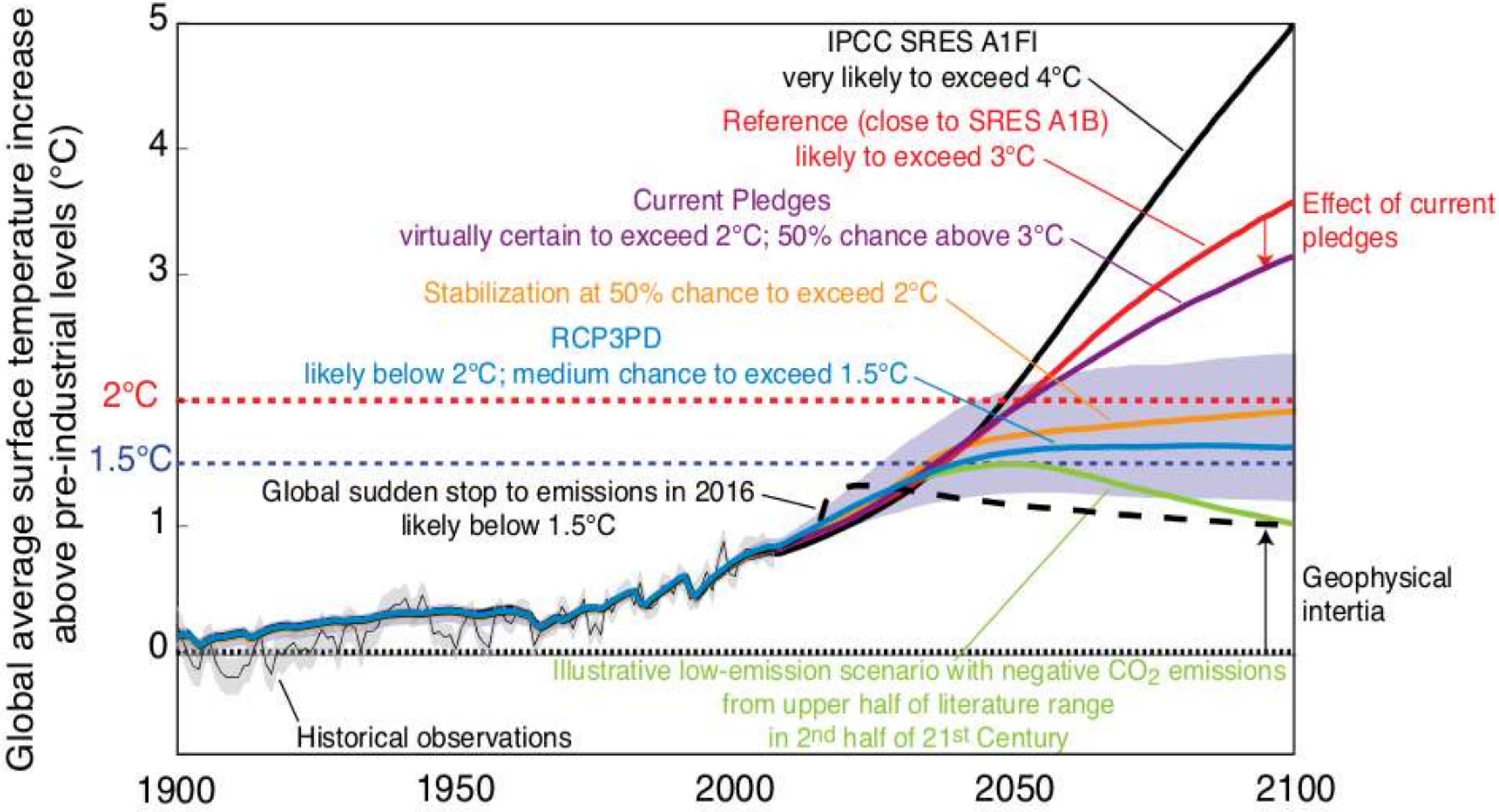
- **Toward a new industrial policy in the age of *inequality***

An 80 Percent Reduction in Greenhouse Gas Emissions

(and if we delay we must go *carbon negative*)

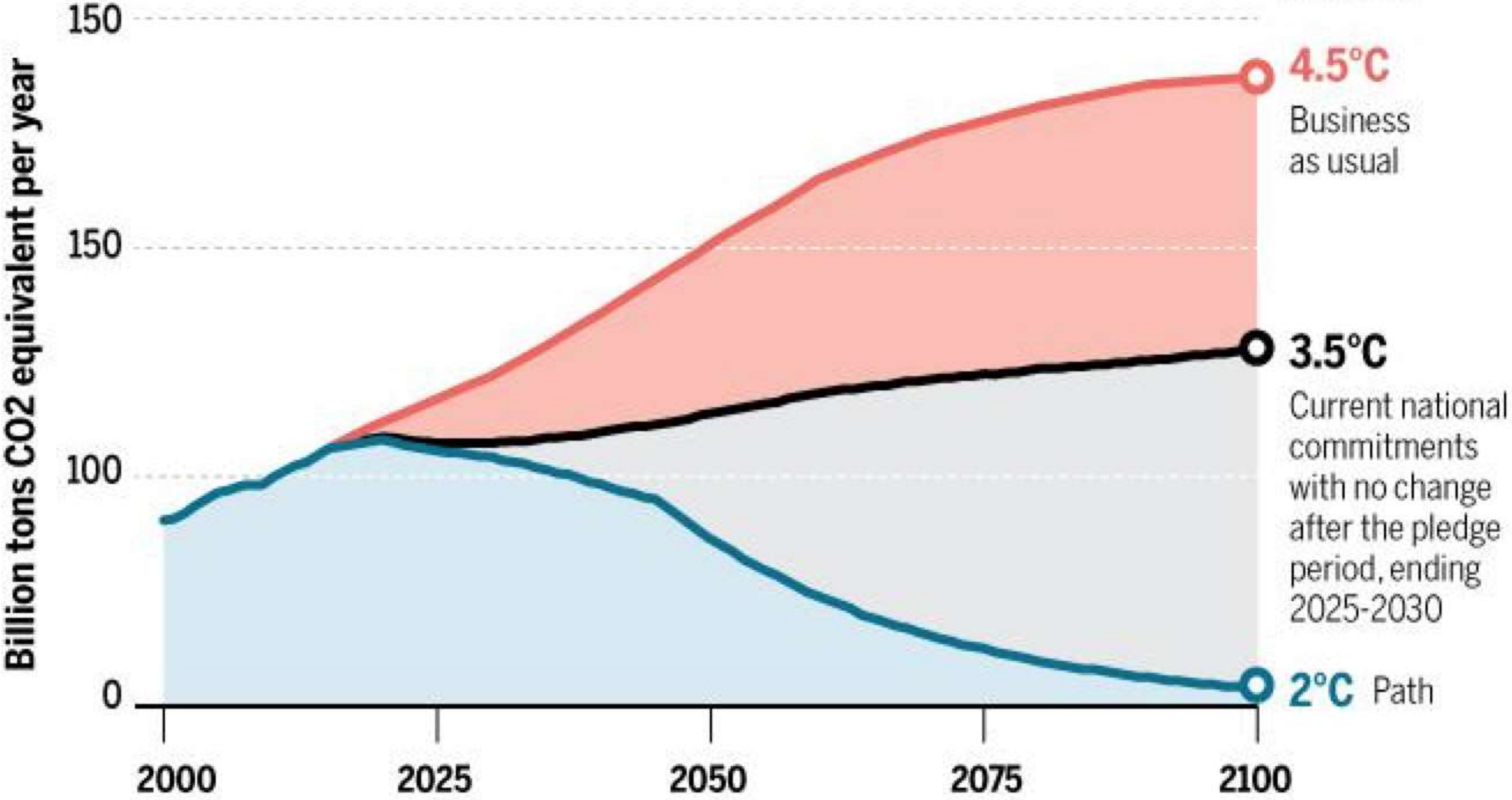


Fuss et al. (2014)


Global average surface temperature increase above pre-industrial levels (°C)
5
4
3
2°C
1.5°C
1
0
1900
1950
2000
2050
2100
IPCC SRES A1FI
very likely to exceed 4°C
Reference (close to SRES A1B)
likely to exceed 3°C
Effect of current pledges
Current Pledges
virtually certain to exceed 2°C; 50% chance above 3°C
Stabilization at 50% chance to exceed 2°C
RCP3PD
likely below 2°C; medium chance to exceed 1.5°C
Global sudden stop to emissions in 2016
likely below 1.5°C
Geophysical intertia
Illustrative low-emission scenario with negative CO₂ emissions
from upper half of literature range
in 2nd half of 21st Century
Historical observations

How much warming by 2100?

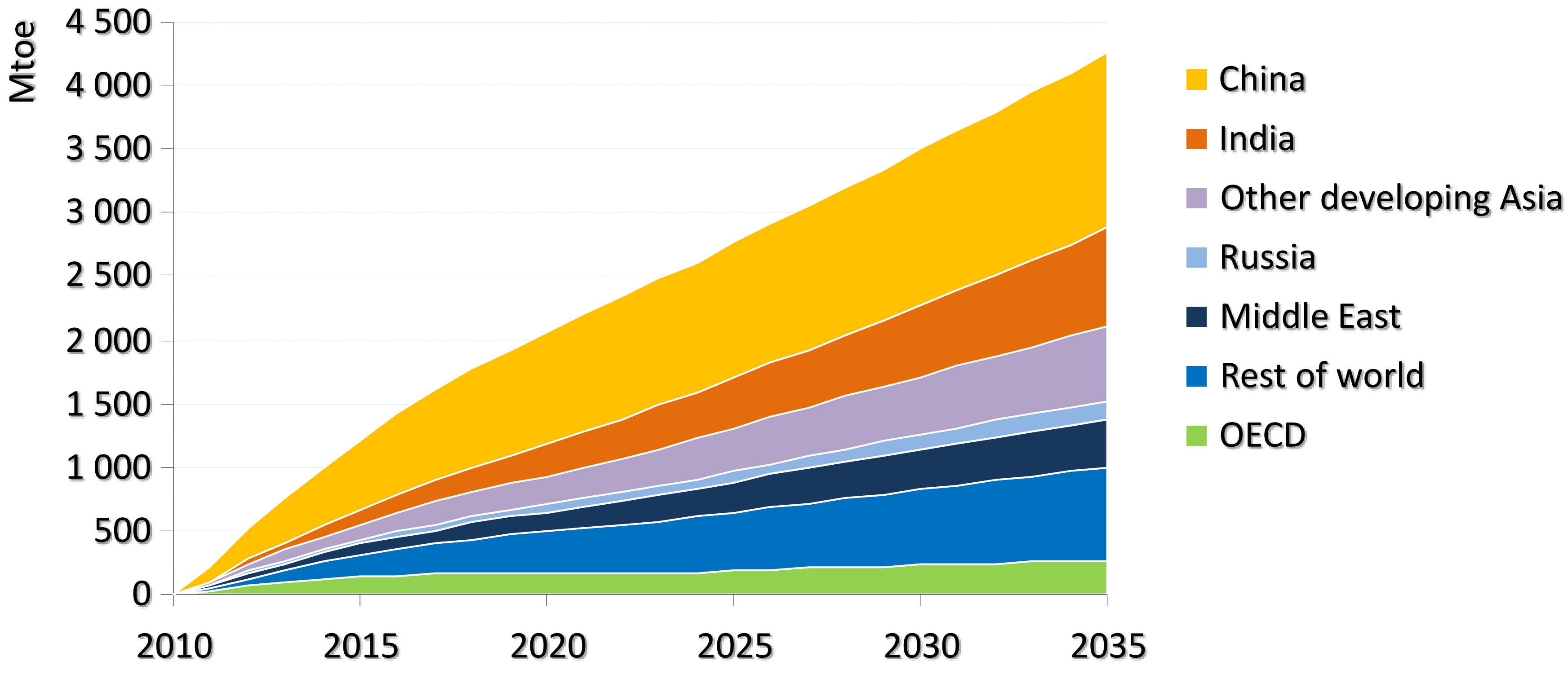
Global Emissions of Greenhouse Gases



Source: 27-Sep-2015 Climate Scoreboard ©Climate Interactive www.ClimateScoreboard.org

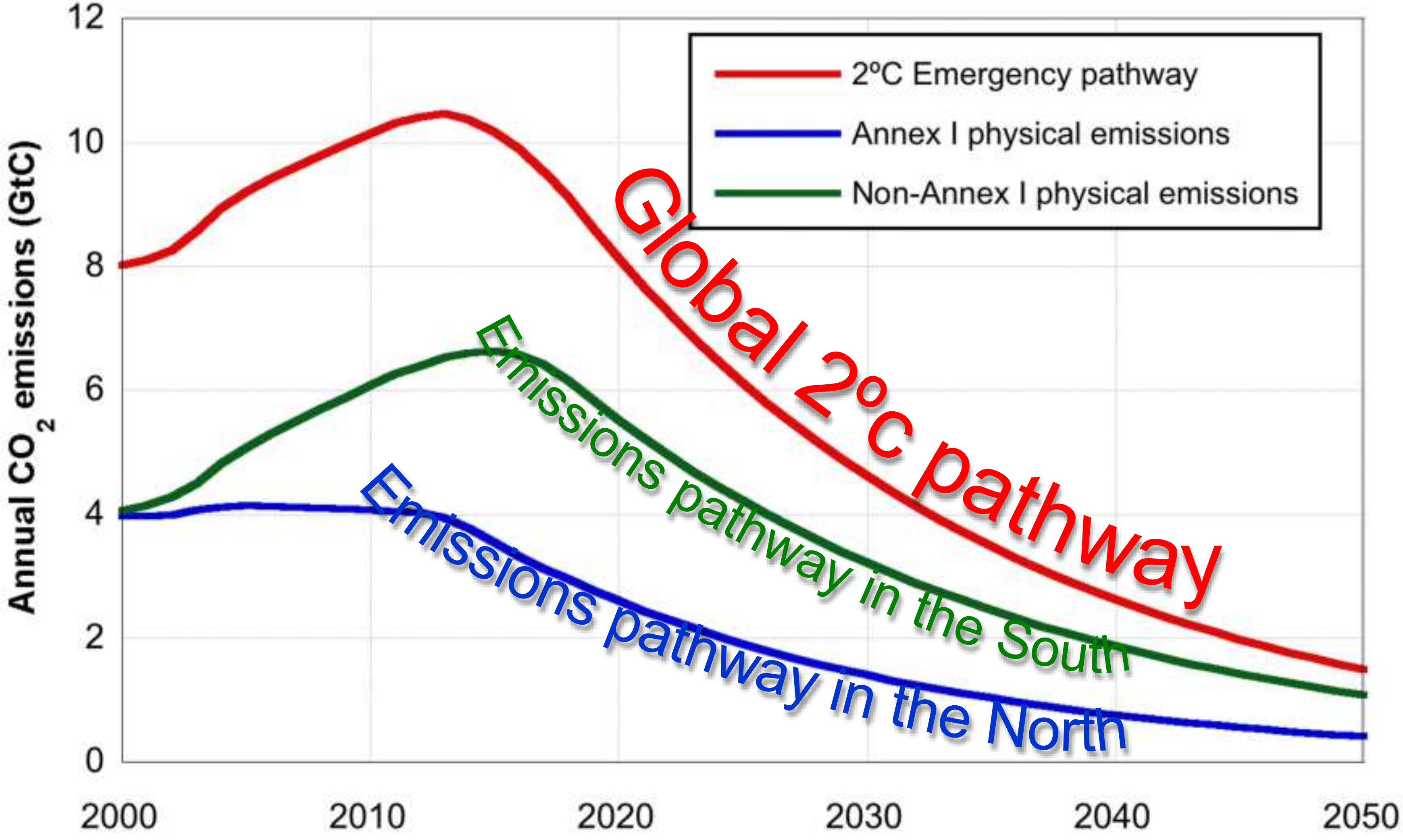
Emerging economies continue to drive global energy demand

Growth in primary energy demand



Global energy demand increases by one-third from 2010 to 2035, with China & India accounting for 50% of the growth

The climate challenge



What kind of climate regime can enable this to happen…?

Bears bringing their best

UC Berkeley in recent rankings

	Best Public College (U.S. News and World Report, 2017)	Academic Ranking of World Universities (Shanghai Jiao Tong University, China)	The World Reputation Rankings (Times Higher Education, U.K.)	Best College (Money Magazine)	College Guide Rankings (Washington Monthly)
U.S. (Public)	1	1	1	2	3
U.S. (All)				5	7
Worldwide		3	13		

RAEL Generates Science Based Business, Spinoffs & Partners

RENEWABLE FUNDING

2009 #1 'world changing idea', *Scientific American*

NATEL ENERGY

1 GW micro-hydro contract, Bhutan

[e] enphase ENERGY

Worlds largest microinverter company

EES Ventures

GRID ALTERNATIVES

EcoEquity

Energy Biosciences Institute

$500 million grant from BP

powerhive

Largest capitalization of minigrid company

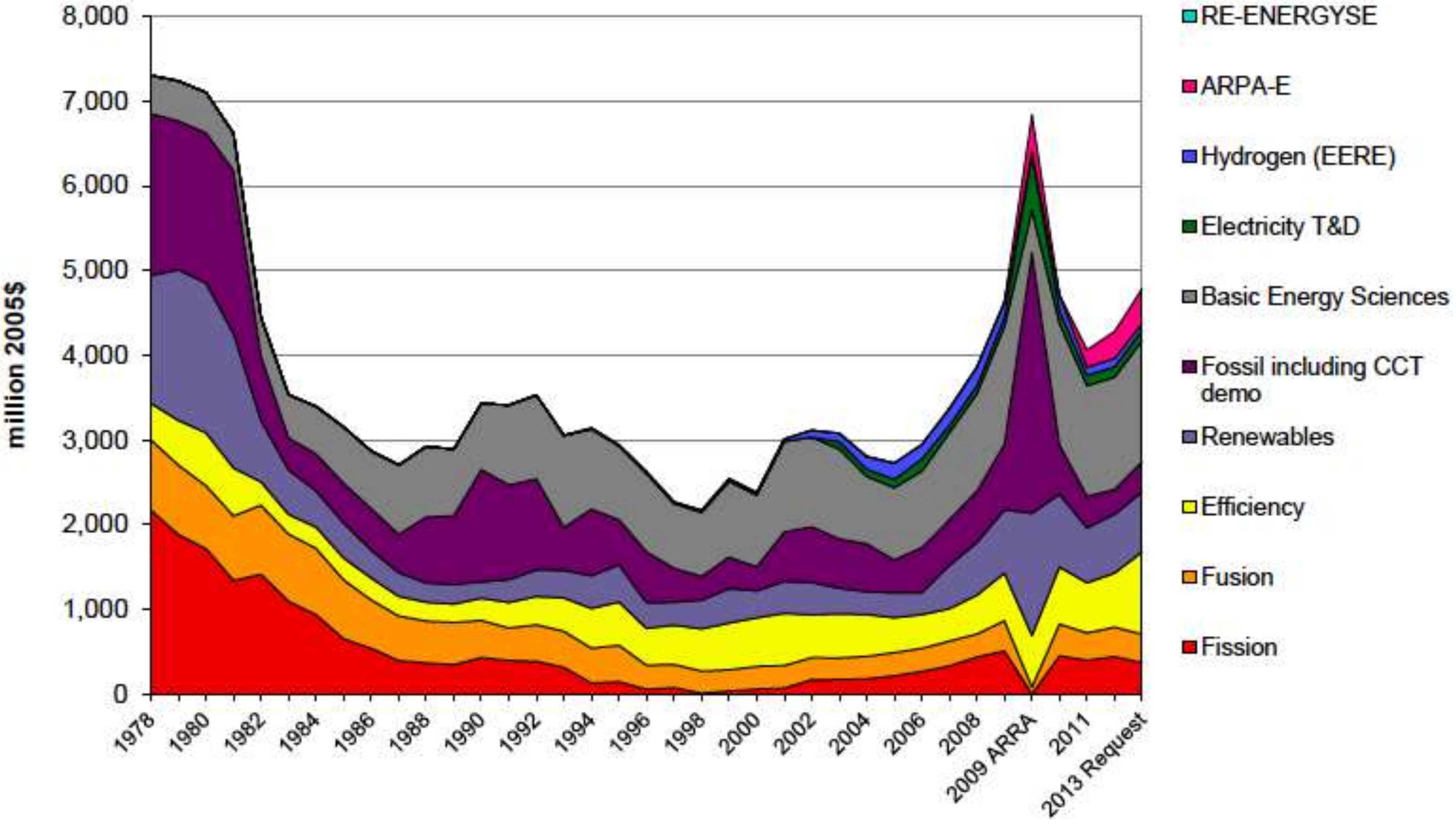
WORLD BANK GROUP
Energy & Extractives

National Geographic/Shell
Great Energy Challenge

Top 100 Worldwide Universities Granted U.S. Utility Patents in 2015

1	UNIVERSITY OF CALIFORNIA, THE REGENTS OF	489
2	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	278
3	STANFORD UNIVERSITY	205
4	UNIVERSITY OF TEXAS	191
5	TSINGHUA UNIVERSITY	184
6	CALIFORNIA INSTITUTE OF TECHNOLOGY	183
7	WISCONSIN ALUMNI RESEARCH FOUNDATION	161
8	JOHNS HOPKINS UNIVERSITY	143
9	COLUMBIA UNIVERSITY	119
10	UNIVERSITY OF MICHIGAN	117
11	HARVARD COLLEGE, PRESIDENT AND FELLOWS	106
26	NATIONAL TAIWAN UNIVERSITY	71
27	RUTGERS UNIVERSITY	65
27	UNIVERSITY OF MARYLAND	65
29	NATIONAL CHENG KUNG UNIVERSITY	64
30	RESEARCH FOUNDATION OF STATE UNIVERSITY OF NEW YORK	62
30	UNIVERSITY OF UTAH RESEARCH FOUNDATION	62
30	UNIVERSITY OF MASSACHUSETTS	62
33	INSTITUTE OF MICROELECTRONICS, CHINESE ACADEMY OF SCIENCES	60
34	KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY	59
35	UNIVERSITY OF NORTH CAROLINA	58
35	UNIVERSITY OF PITTSBURGH	58

U.S. DOE Energy RD&D
FY1978-FY2013 Request



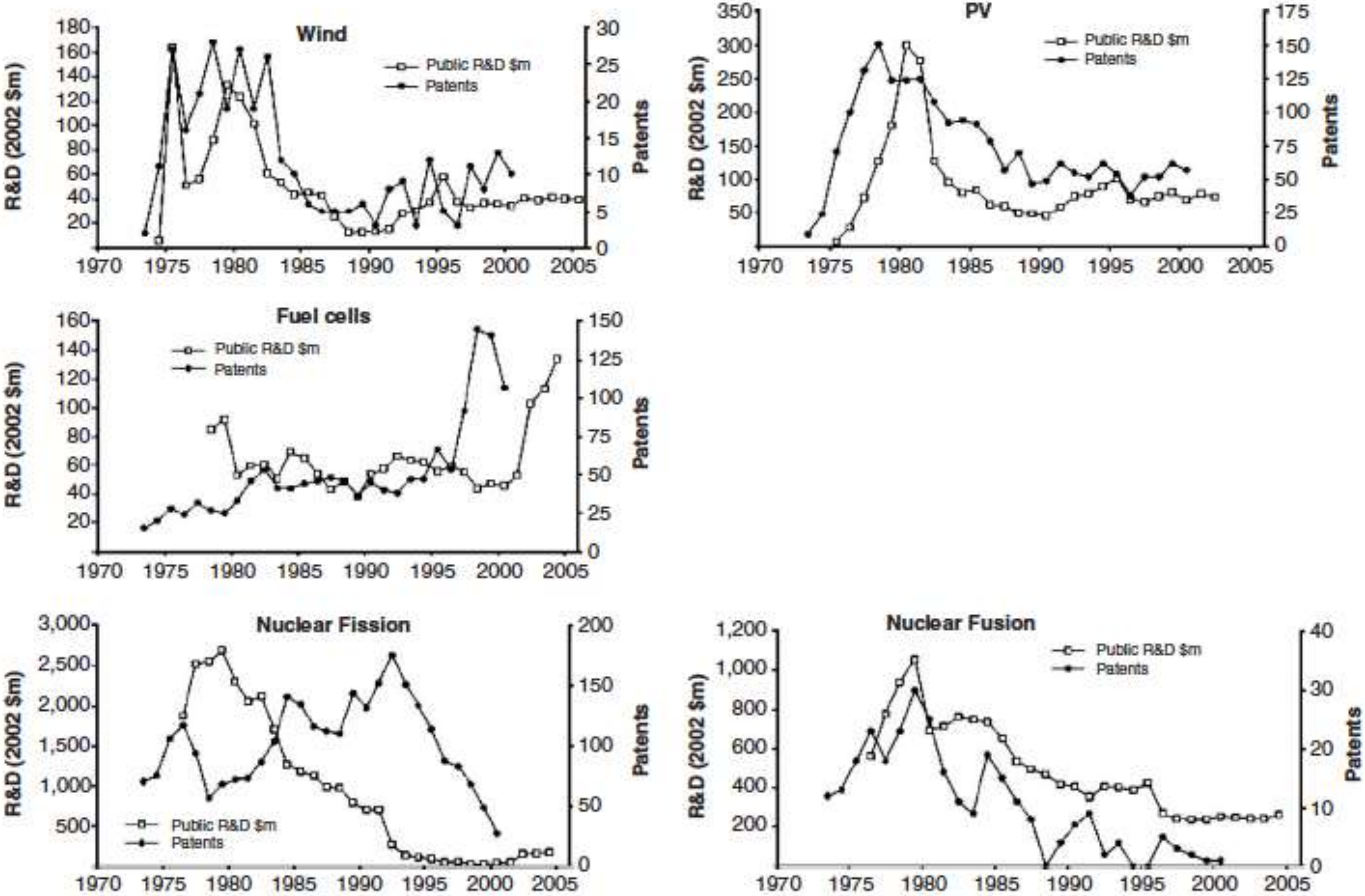
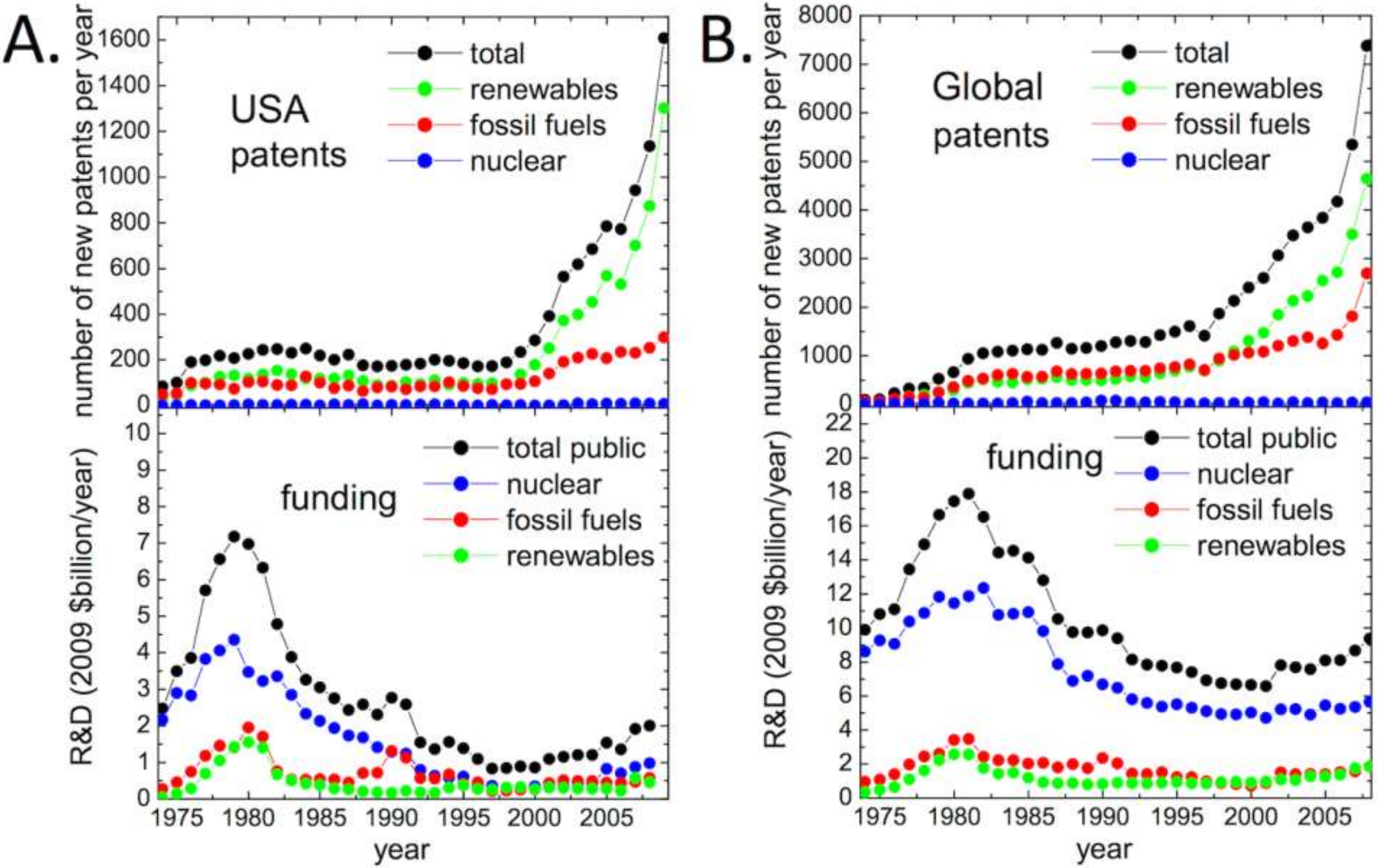
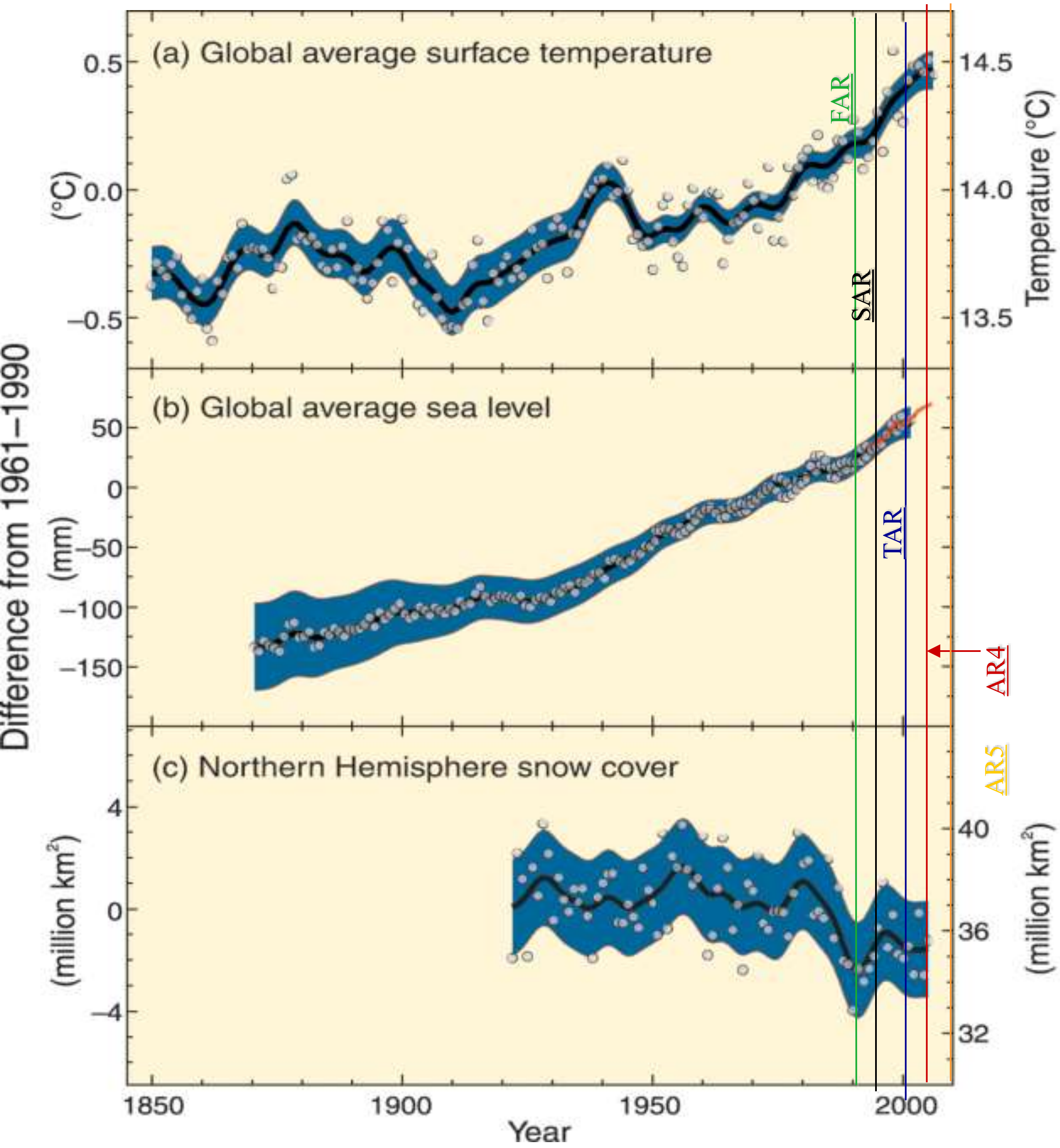


Fig. 7. Patenting and federal R&D. Patenting is strongly correlated with federal R&D. To provide comparisons with U.S. R&D funding, foreign patents are excluded. The data include granted patents in the U.S. patent system filed by U.S. inventors only. Patents are dated by their year of application to remove the effects of the lag between application and approval. This lag averages 2 years.

Nemet and Kammen, 2007



Trancik, et al, PLoS, 2014



FAR - 1st IPCC Assessment (1990): unequivocal detection of human impact not likely for a decade

SAR - 2nd (1995): balance of evidence suggests discernible human influence

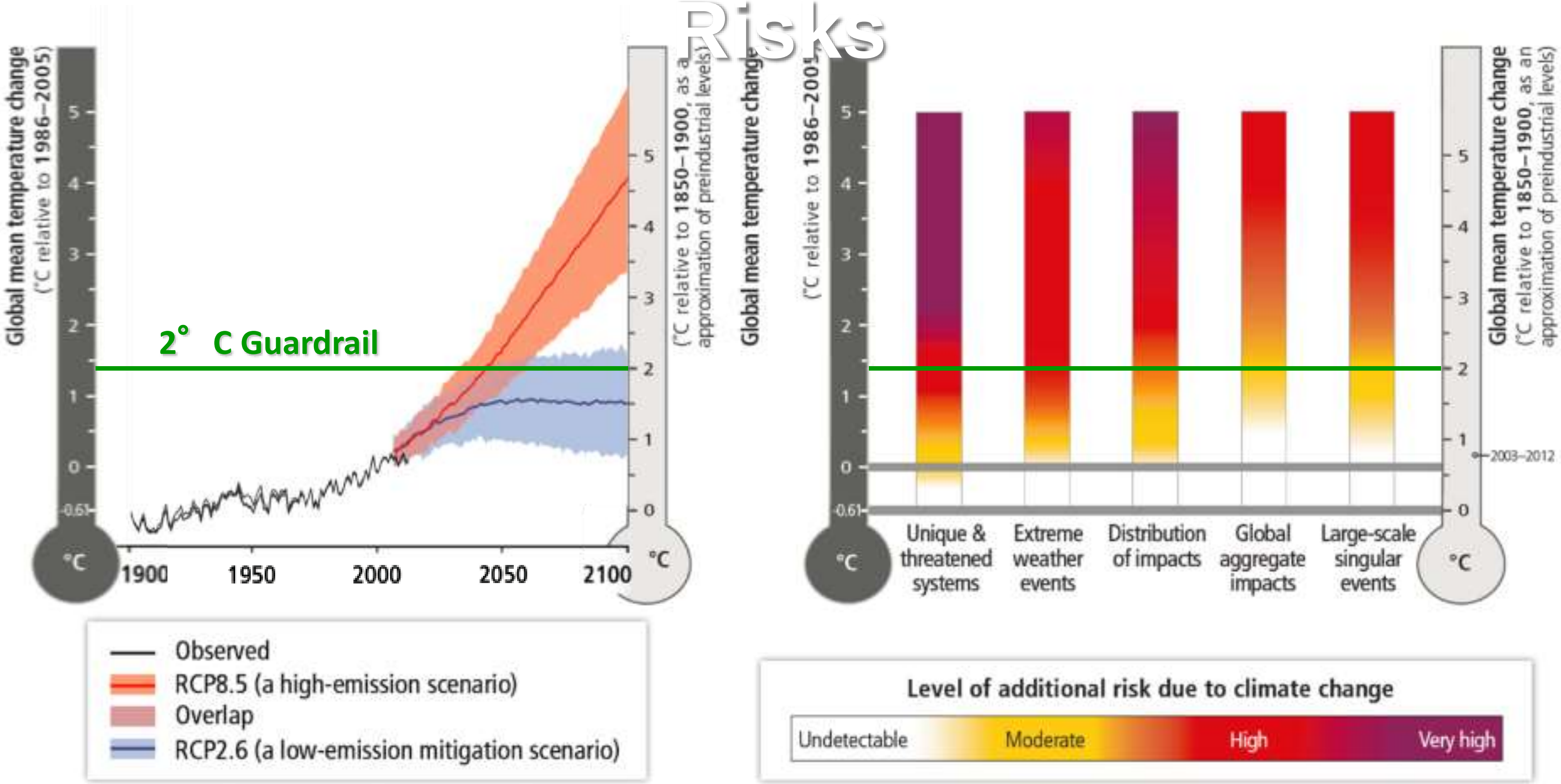
TAR - 3rd (2001): most of the warming in the last 50 years is likely (>66%) due to human activities

AR4 - 4th (2007): most of the warming very likely (> 90%) due human activity; *warming will most strongly and quickly impact the global poor*

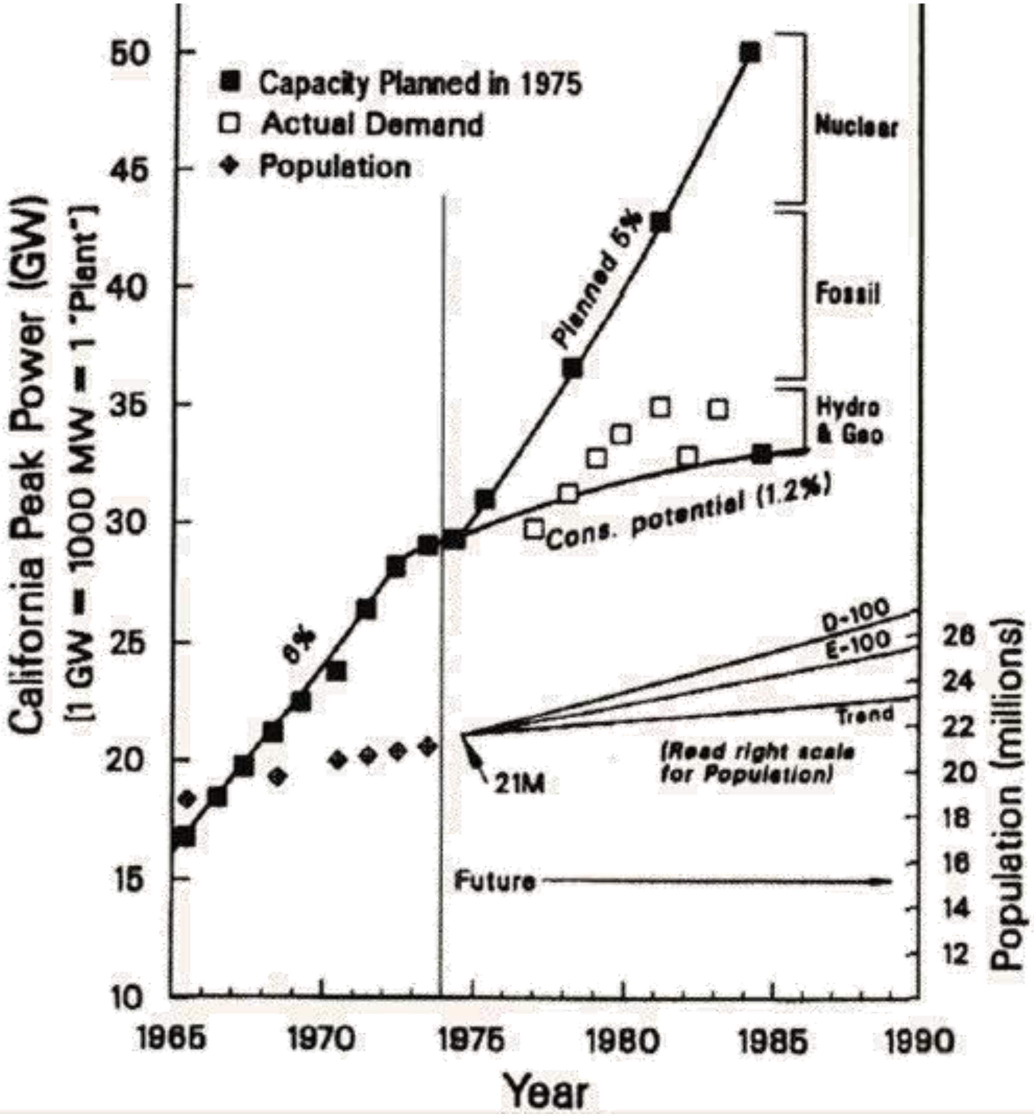
SRREN (2011): 80% clean by 2050 *possible, if …*

AR5: 95% confidence warming is human caused and … *to be continued*

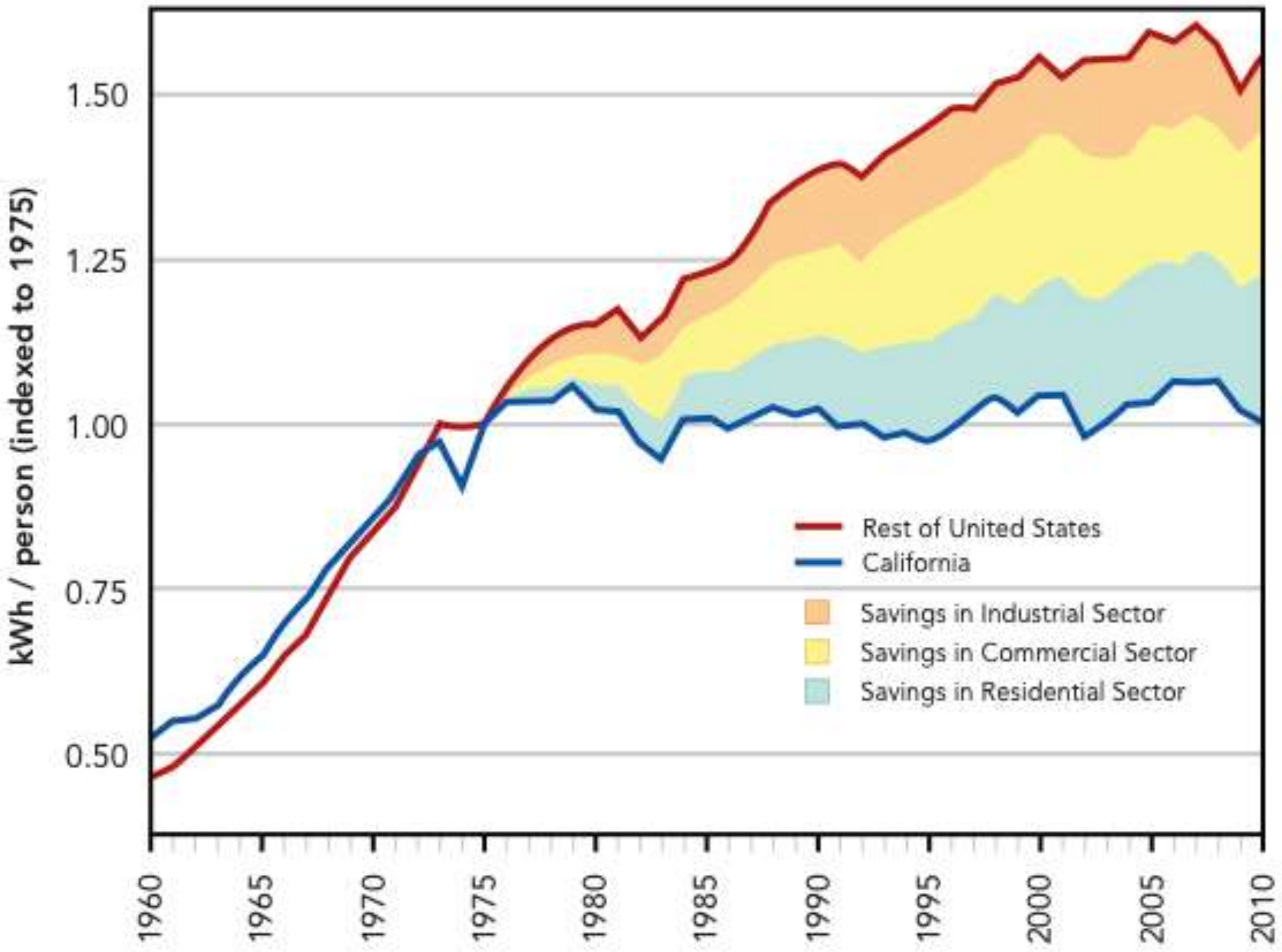
IPCC AR5 (2014): Climate Projections and Associated Risks



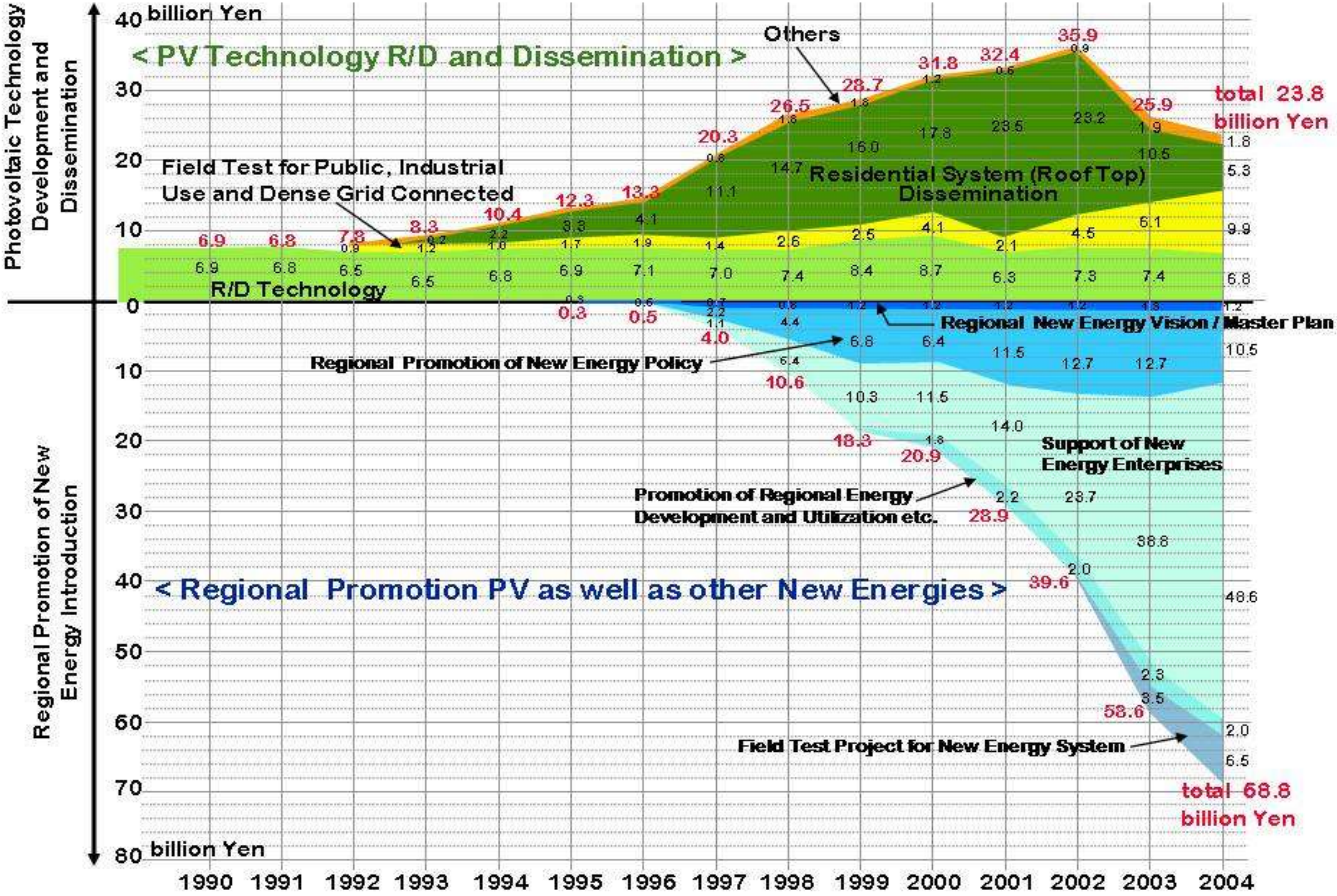
CA Peak Power: Testimony by Goldstein and Rosenfeld (Dec. 1974)



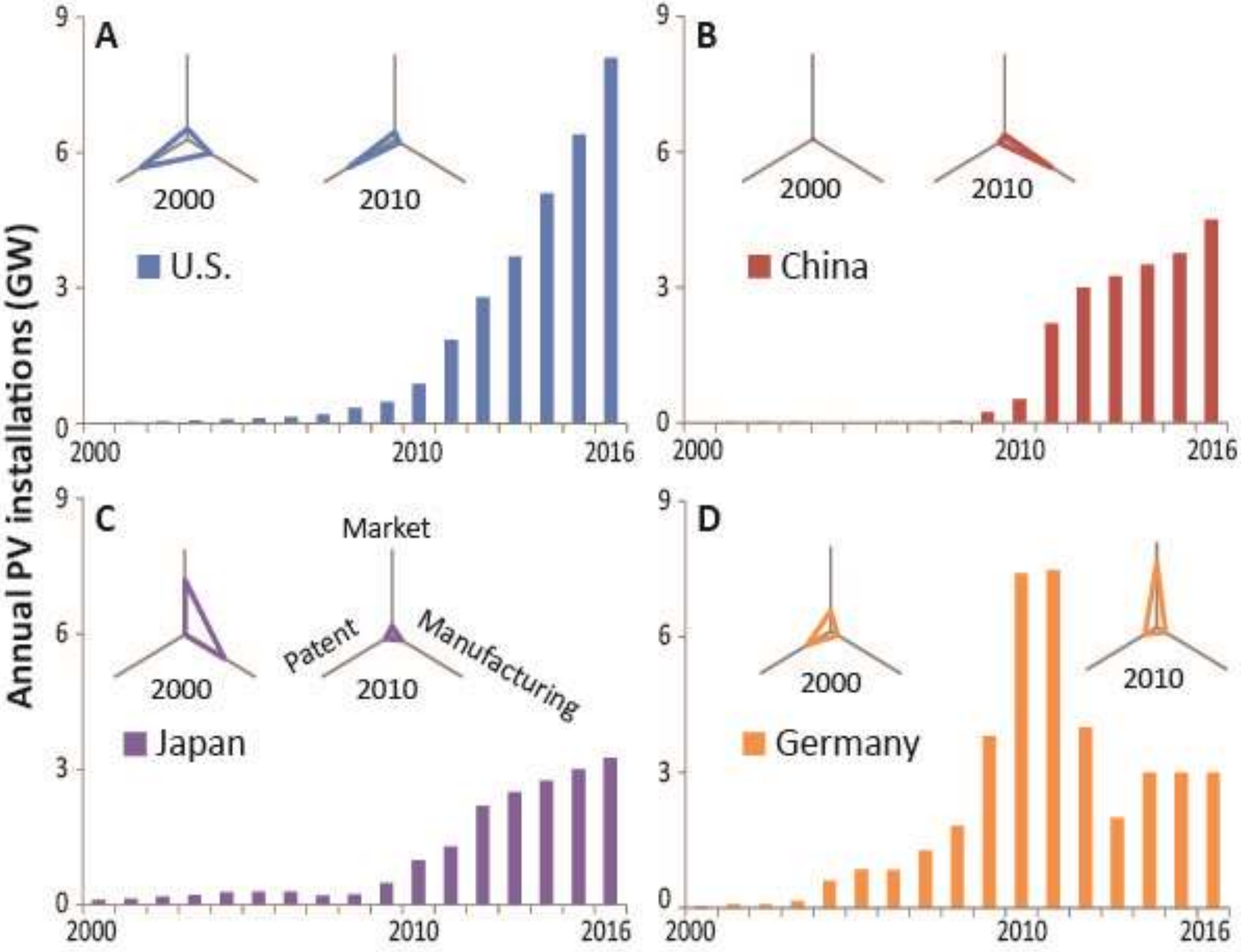
California Advancing Energy Efficiency



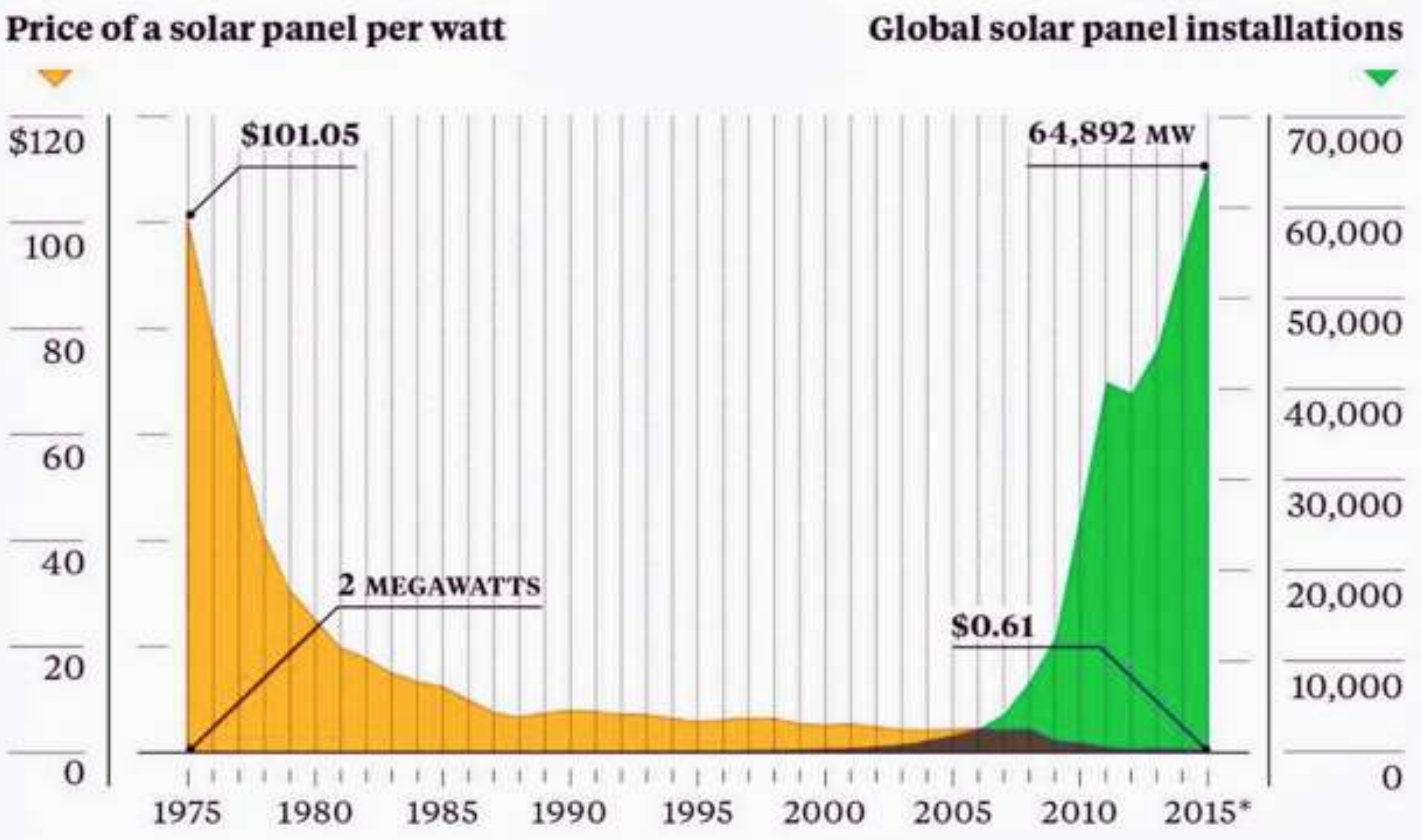
Japanese “Sunshine” Program
way too much detail, but technology push/demand pull is clear



The Evolving Solar Energy Economy



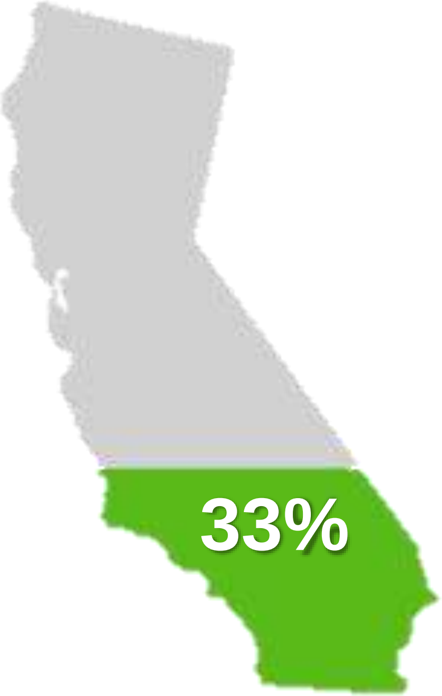
Falling Solar Prices Lead to Rapid Growth



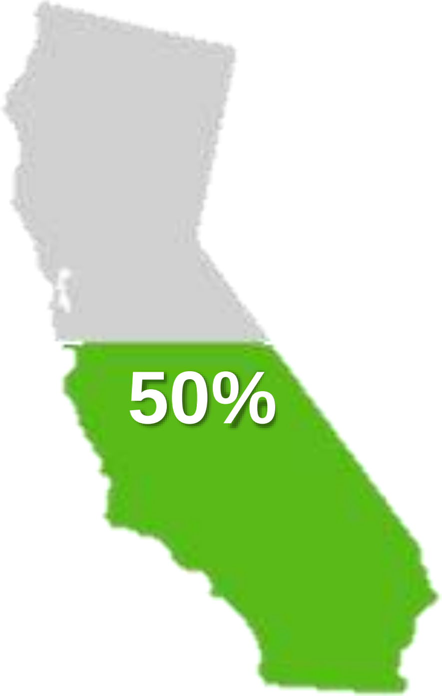
*Estimate. Sources: Bloomberg, Earth Policy Institute, www.earth-policy.org

The Challenge is Big...

2013

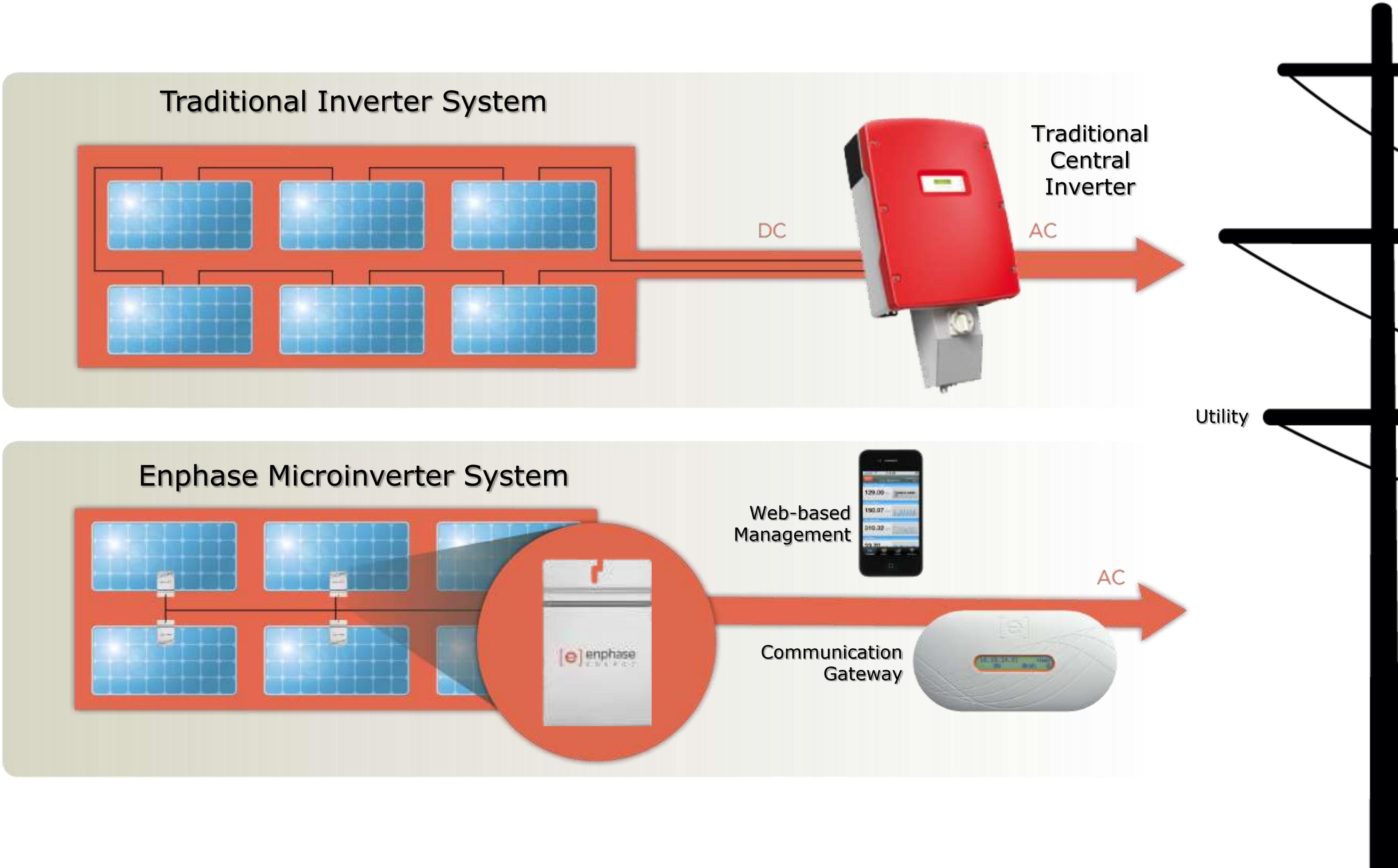


2020



2030

Microinverters: A device-level subtle revolution



Traditional Inverter System

DC

Traditional Central Inverter

AC

Utility

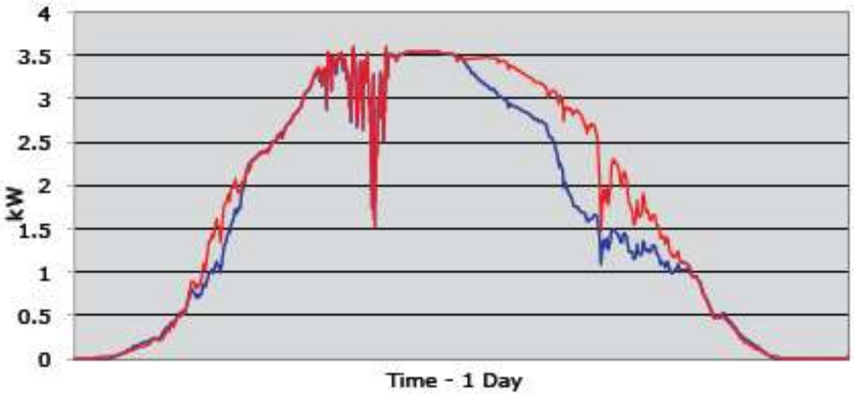
Enphase Microinverter System

Web-based Management

AC

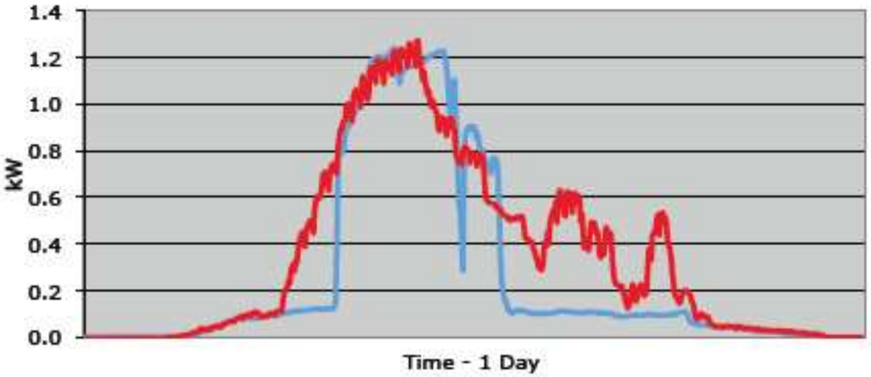
Communication Gateway

Micro-inverters versus traditional designs



Energy Advantage: 10.24%

- ⇨ SMA SB6000US (95.5%) - Blue
- ⇨ Enphase – Red
- ⇨ Location: Petaluma, CA
- ⇨ Date: November 2007

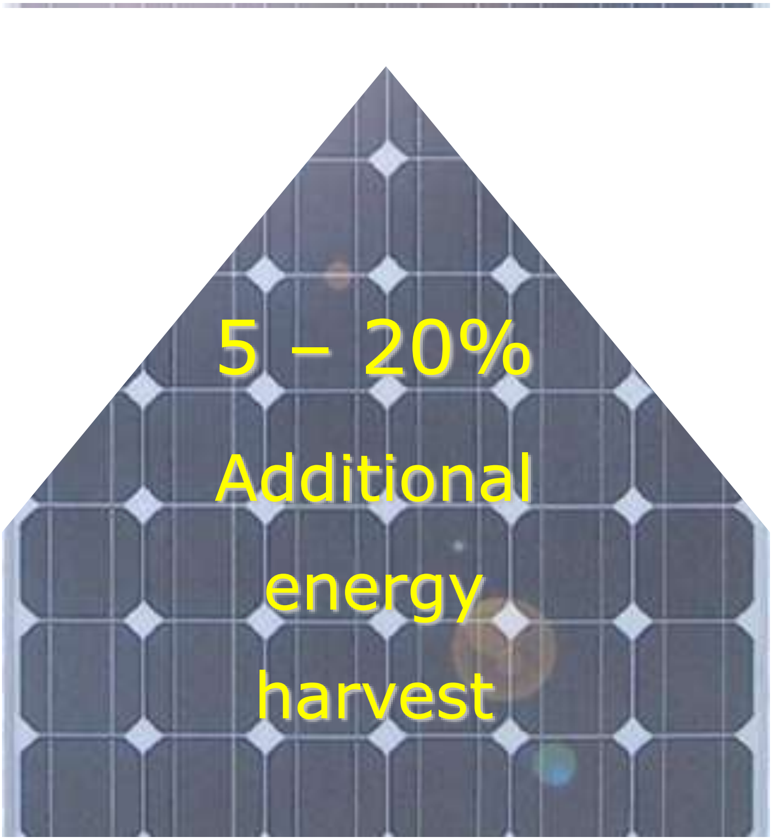


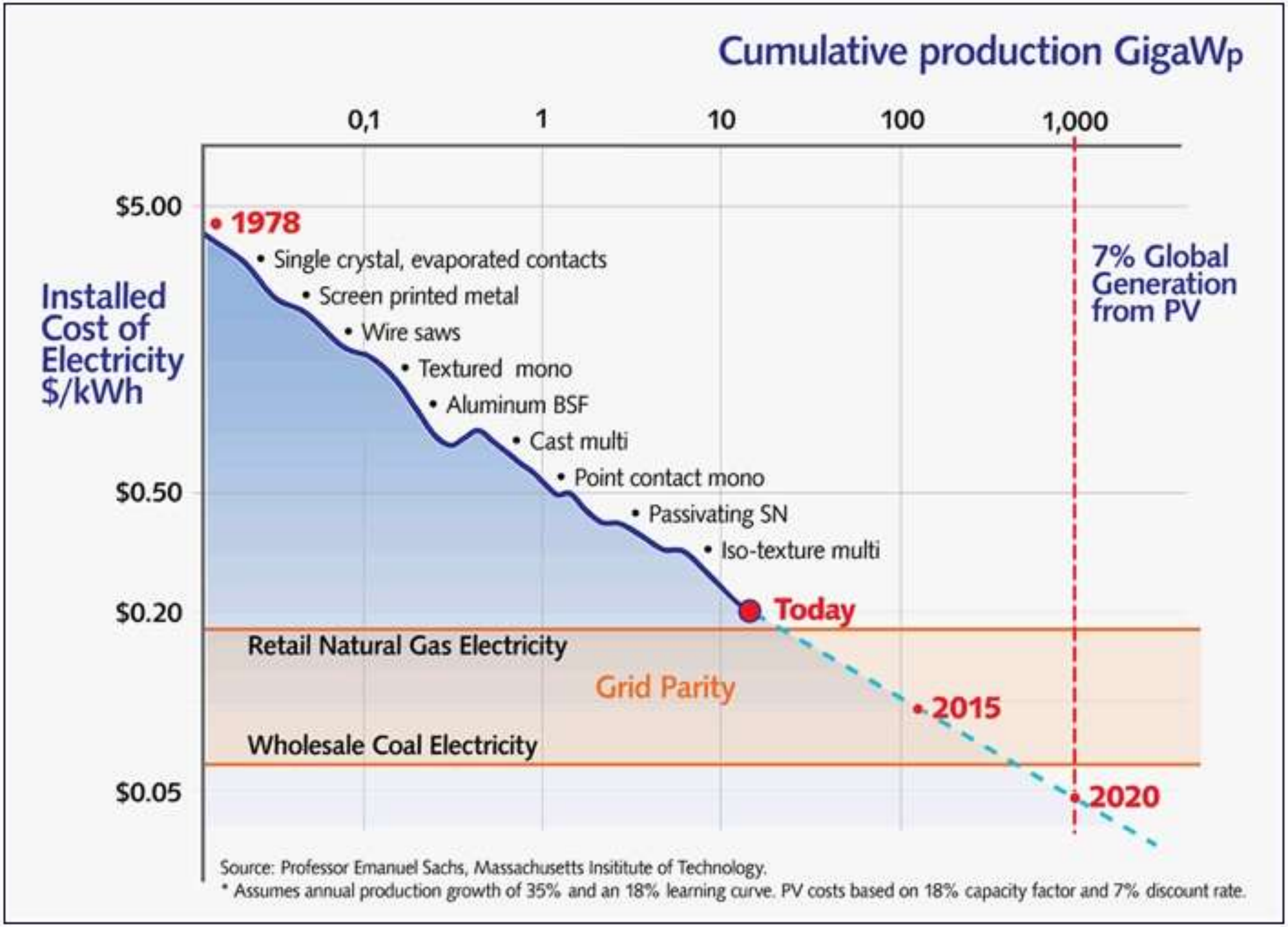
Energy Advantage: 33.63%

- ⇨ Xantrex GT3 (94.5%) - Blue
- ⇨ Enphase – Red
- ⇨ Location: Grass Valley, CA
- ⇨ Date: December 2007

Microinverter Output vs Traditional Inveters

- Per-module maximum power production impacted by
- Cost comparable to conventional inverters

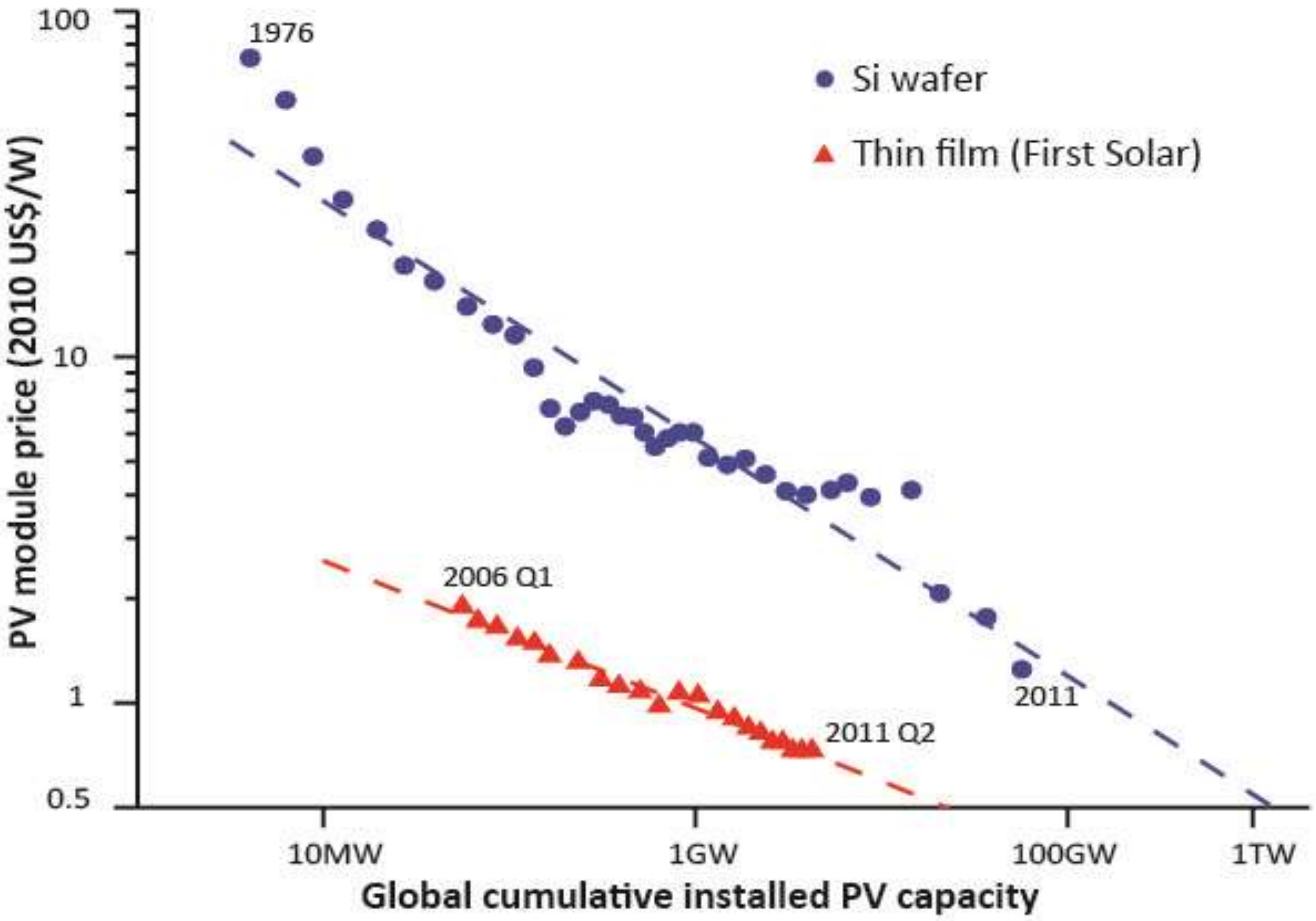




Source: Professor Emanuel Sachs, Massachusetts Insititute of Technology.

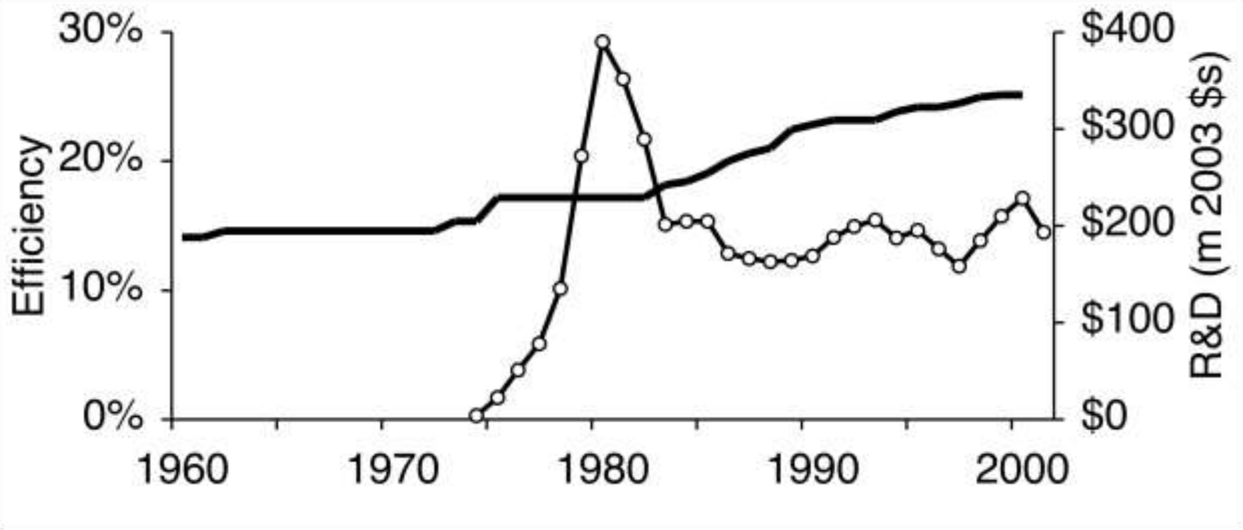
*Assumes annual production growth of 35% and an 18% learning curve. PV costs based on 18% capacity factor and 7% discount rate.

The Evolving Solar Energy Economy



Quantifying the benefits of R&D

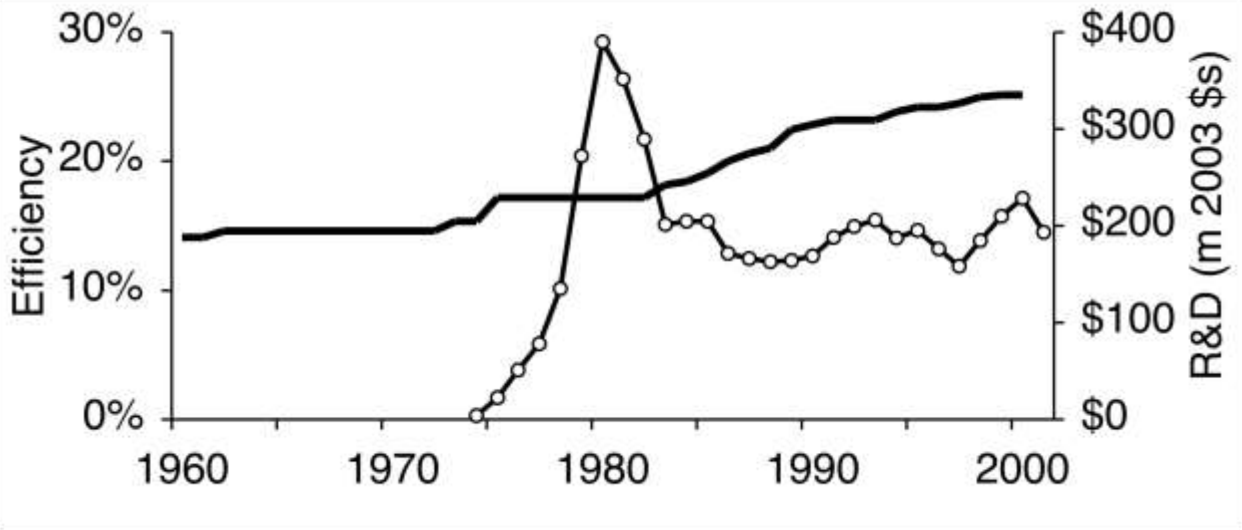
R&D Fundin



Nemet, G. F. (2006) *Energy Policy* **34(17)**: 3218 - 3232.

Quantifying the benefits of R&D

R&D Funding → Technological change →

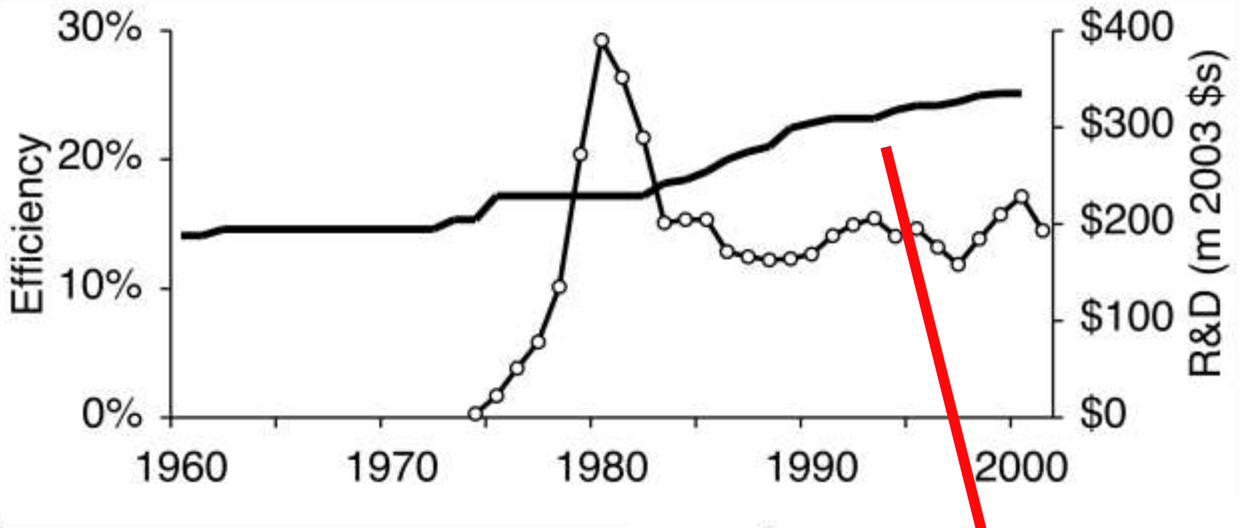


50% increase in PV efficiency occurs immediately after unprecedented >$1b global investment in PV R&D (1978-85)…

Nemet, G. F. (2006) *Energy Policy* **34(17)**: 3218 - 3232.

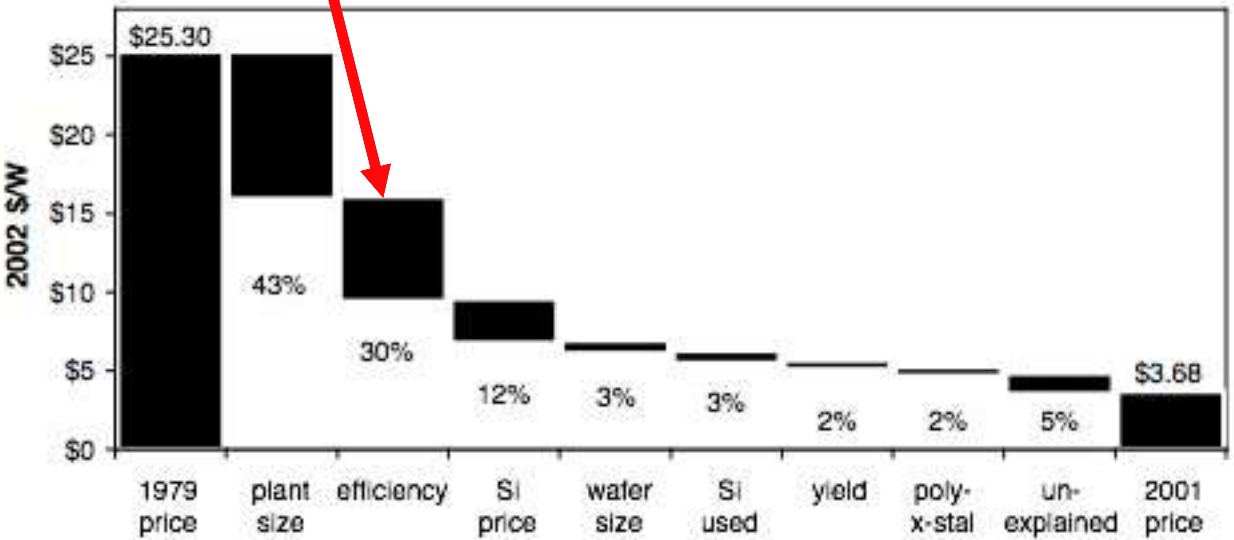
Quantifying the benefits of R&D

R&D Funding → Technological change → Cost reductions



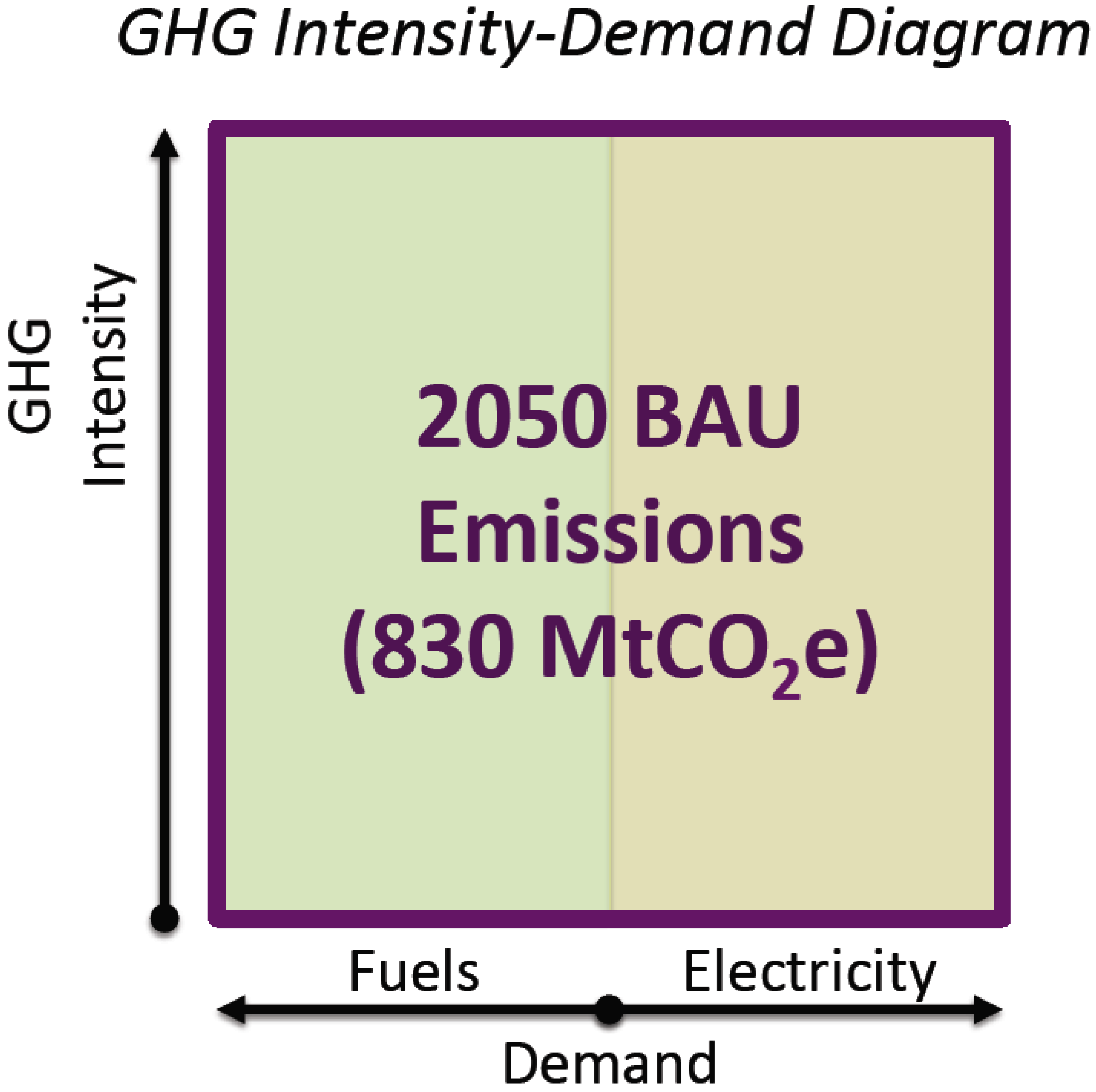
50% increase in PV efficiency occurs immediately after unprecedented >$1b global investment in PV R&D (1978-85)…

…efficiency improvements account for 30% of the cost reductions in PV over the past two decades.



Nemet, G. F. (2006) *Energy Policy* **34(17)**: 3218 - 3232.

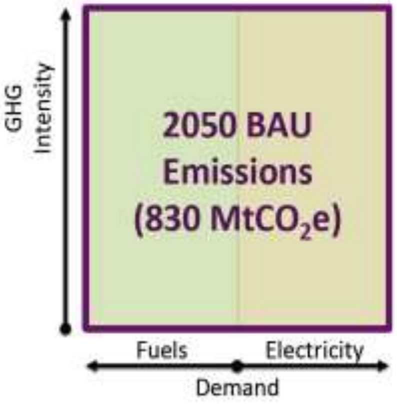
Actions to reduce emissions



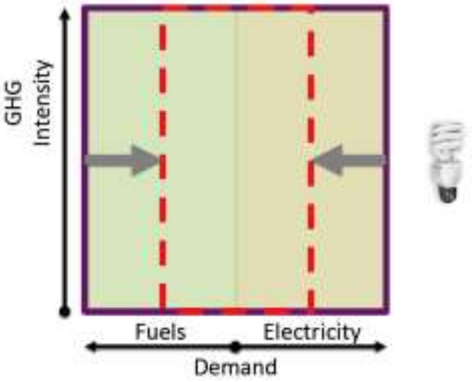
From: California's Energy Future – The View to 2050, California Council on Science and Technology, 2011

Four Actions to Reduce Emissions

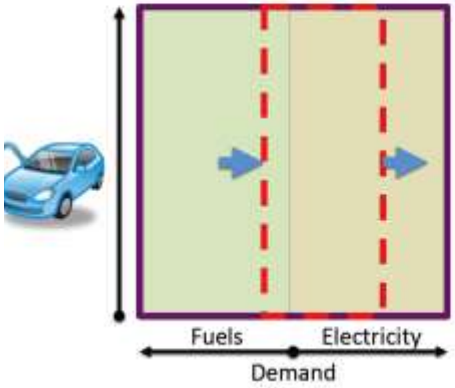
GHG Intensity-Demand Diagram



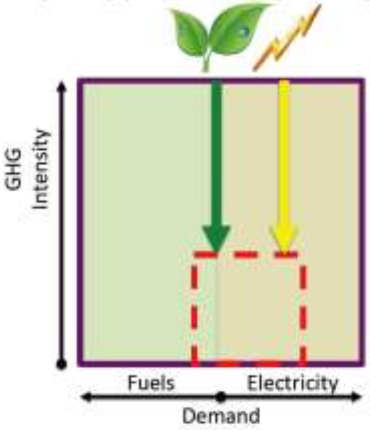
1. Efficiency



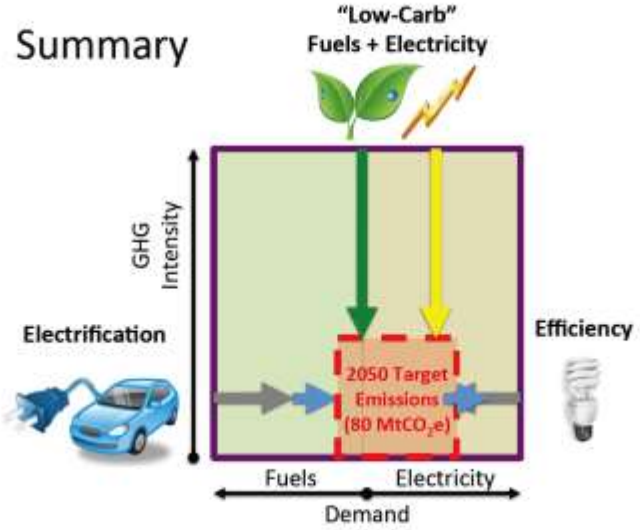
2. Electrification



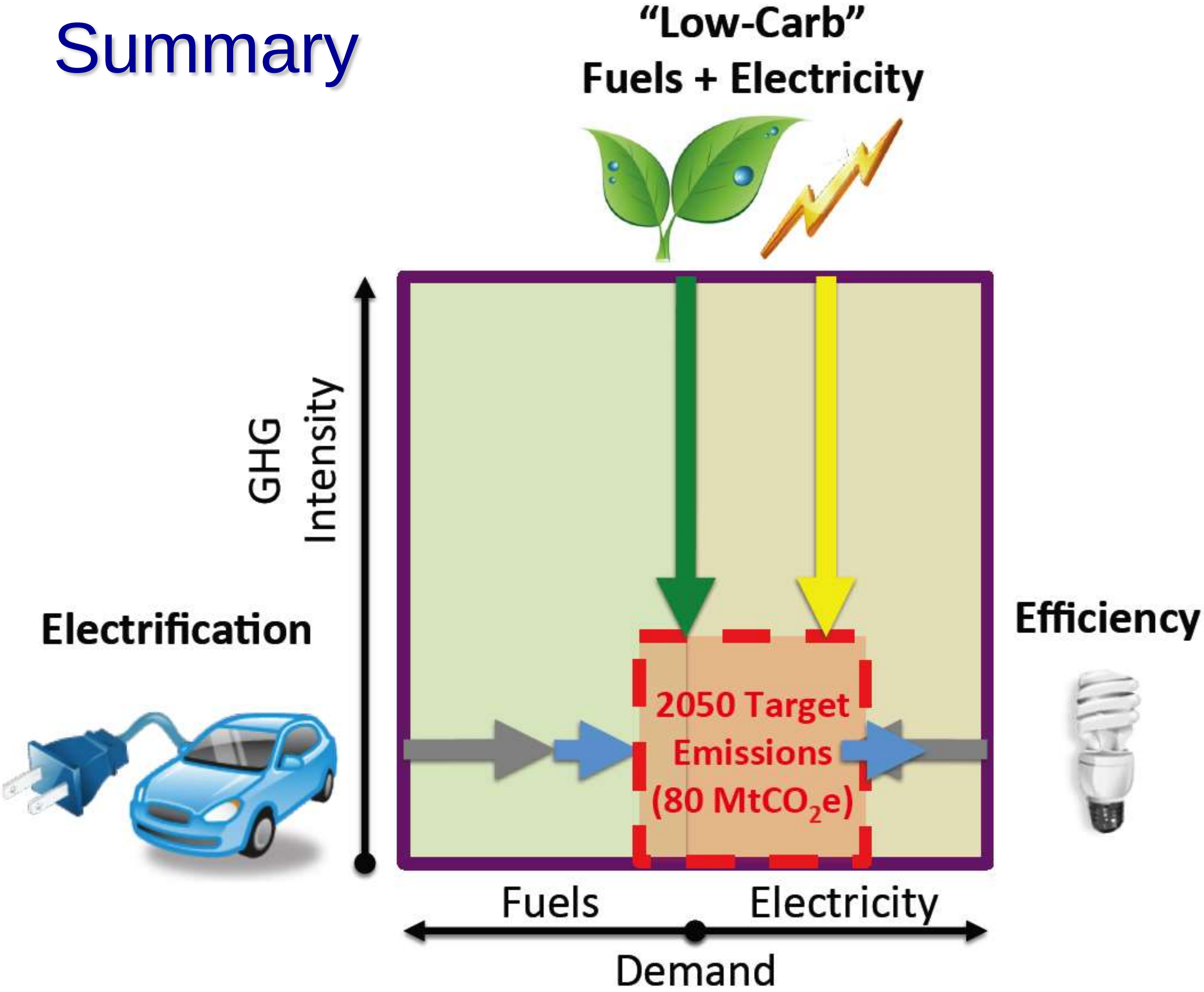
4. “Low-Carb” Fuels + Electric



Summary



Summary



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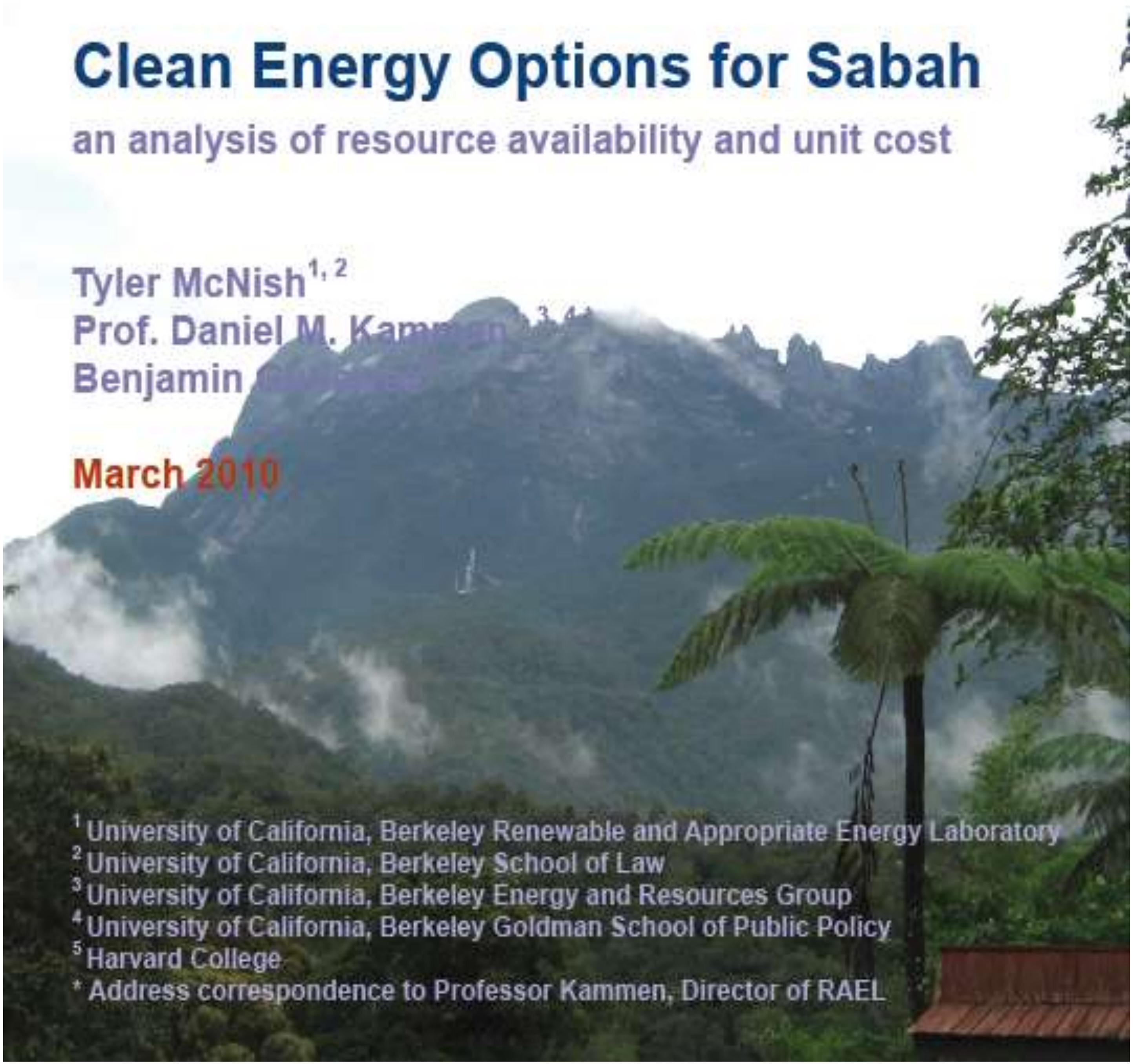


Clean Energy Options for Sabah

an analysis of resource availability and unit cost

Tyler McNish[1, 2]
Prof. Daniel M. Kammen[1, 3, 4*]
Benjamin [illegible]

March 2010

[1] University of California, Berkeley Renewable and Appropriate Energy Laboratory
[2] University of California, Berkeley School of Law
[3] University of California, Berkeley Energy and Resources Group
[4] University of California, Berkeley Goldman School of Public Policy
[5] Harvard College
* Address correspondence to Professor Kammen, Director of RAEL

http://rael.berkeley.edu/node/609

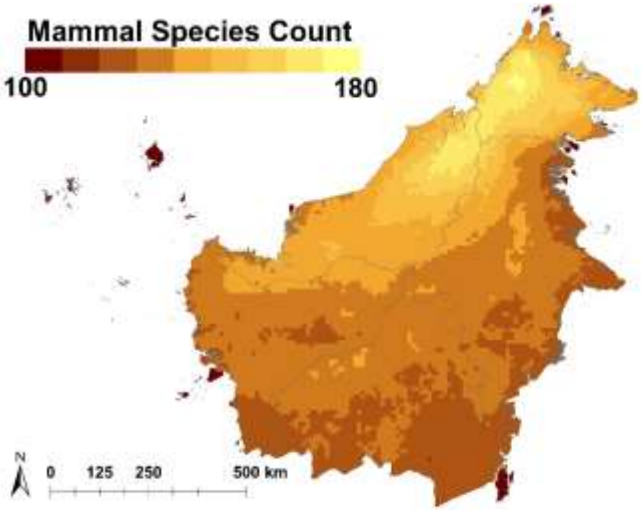
Borneo Says No to Dirty Energy

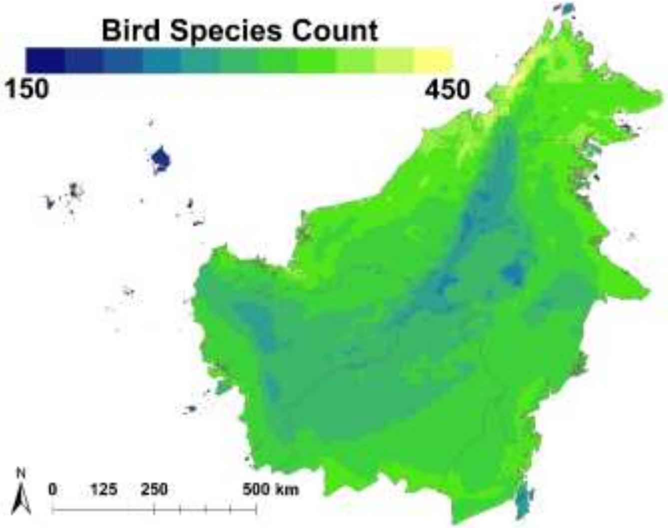
By Jennifer Pinkowski Tuesday, Feb. 22, 2011

TIME Science

Borneo Says No to Dirty Energy

Two-thirds of Bornean Bird, Mammal, Tree and Insect Species may lose habitat forever due to reservoirs





JABATAN PEGUAM BESAR NEGERI SARAWAK
(SARAWAK STATE ATTORNEY-GENERAL'S CHAMBERS)

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WISMA BAPA MALAYSIA,
PETRA JAYA, 93502 KUCHING,
SARAWAK, MALAYSIA.

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Faks: 082-440525/444537
Laman Web: www.sag.sarawak.gov.my

Our Ref. : CS/MYY/001(WS)/5-2015
Date : 15th March, 2016

Your Ref. : Please advice

Messrs Harrison Ngau & Co. Advocates
Lot 1046, 1st Floor,
Shang Garden Commercial Centre,
Jalan Bulan Sabit, 98000 Miri,
Sarawak

By Fax 085-421236 only

Dear Sirs,

Re: In the High Court in Sabah and Sarawak at Miri
Suit No. MYY-21NCvC-1/[illegible]-2015
Plaintiffs : Tama Wing Kalang & 3 Ors
Defendants : Superintendent of Lands and Surveys Miri Division & 2 Ors

We refer to the above matter and "The Land (Native Customary Rights) (No.53) 2014 Direction".

2. We are please to inform you that the above mentioned Direction has been revoked vide "The Land Native Customary Rights (No.2) (Revocation) Direction 2016" published on 18th February, 2016 in the Sarawak Government Gazette under G.N. 569. We forward herewith a copy of the Gazette for your record and further action.

Thank you.

"BERSATU BERUSAHA BERBAKTI"
"AN HONOUR TO SERVE"

[MA XIANG RUI]

Any volunteers? Infecting healthy people to test medicines

Hanging around is cheaper than hovering

Preprints for the life sciences

Science

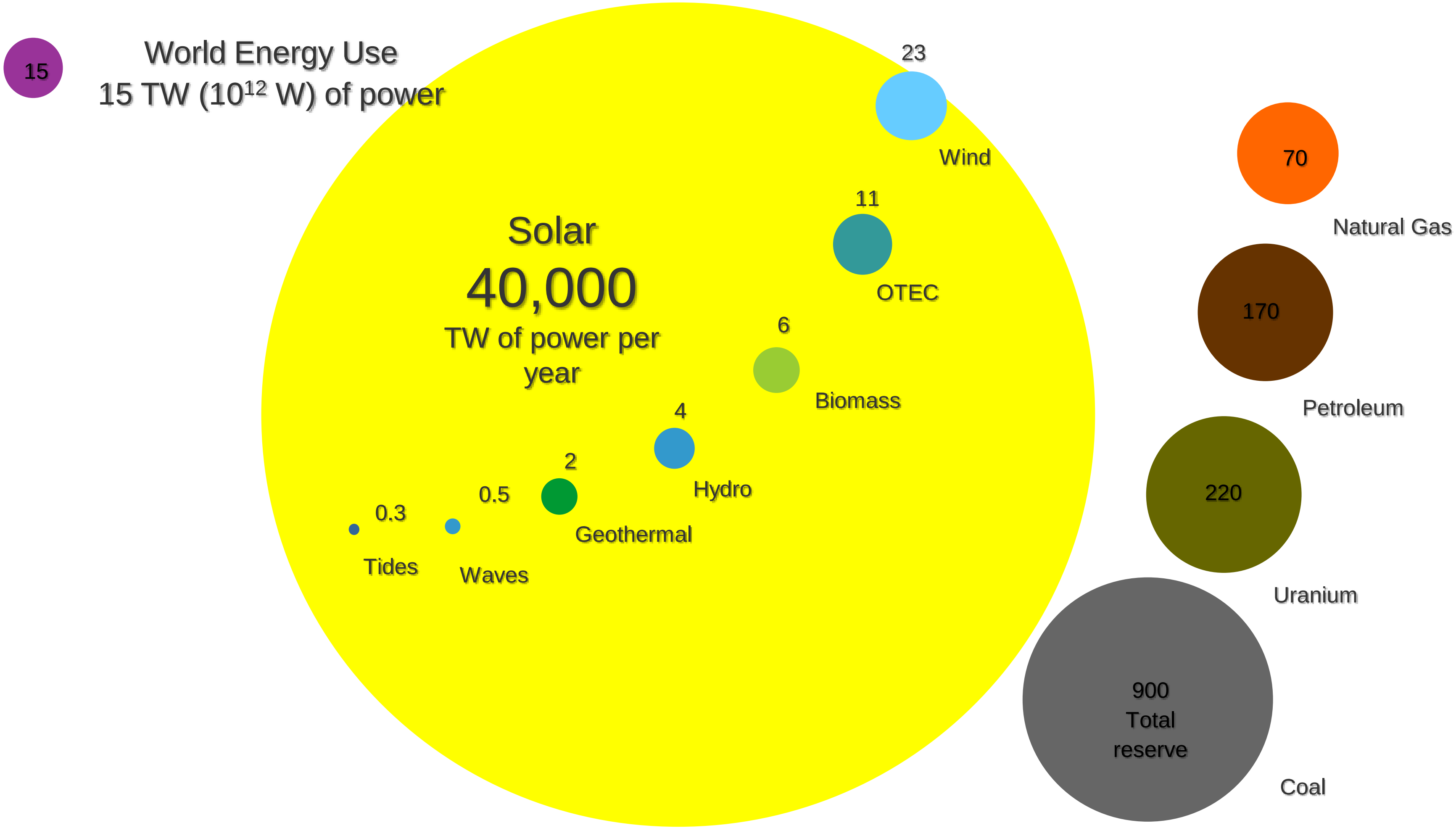
$15
20 MAY 2016
sciencemag.org

AAAS

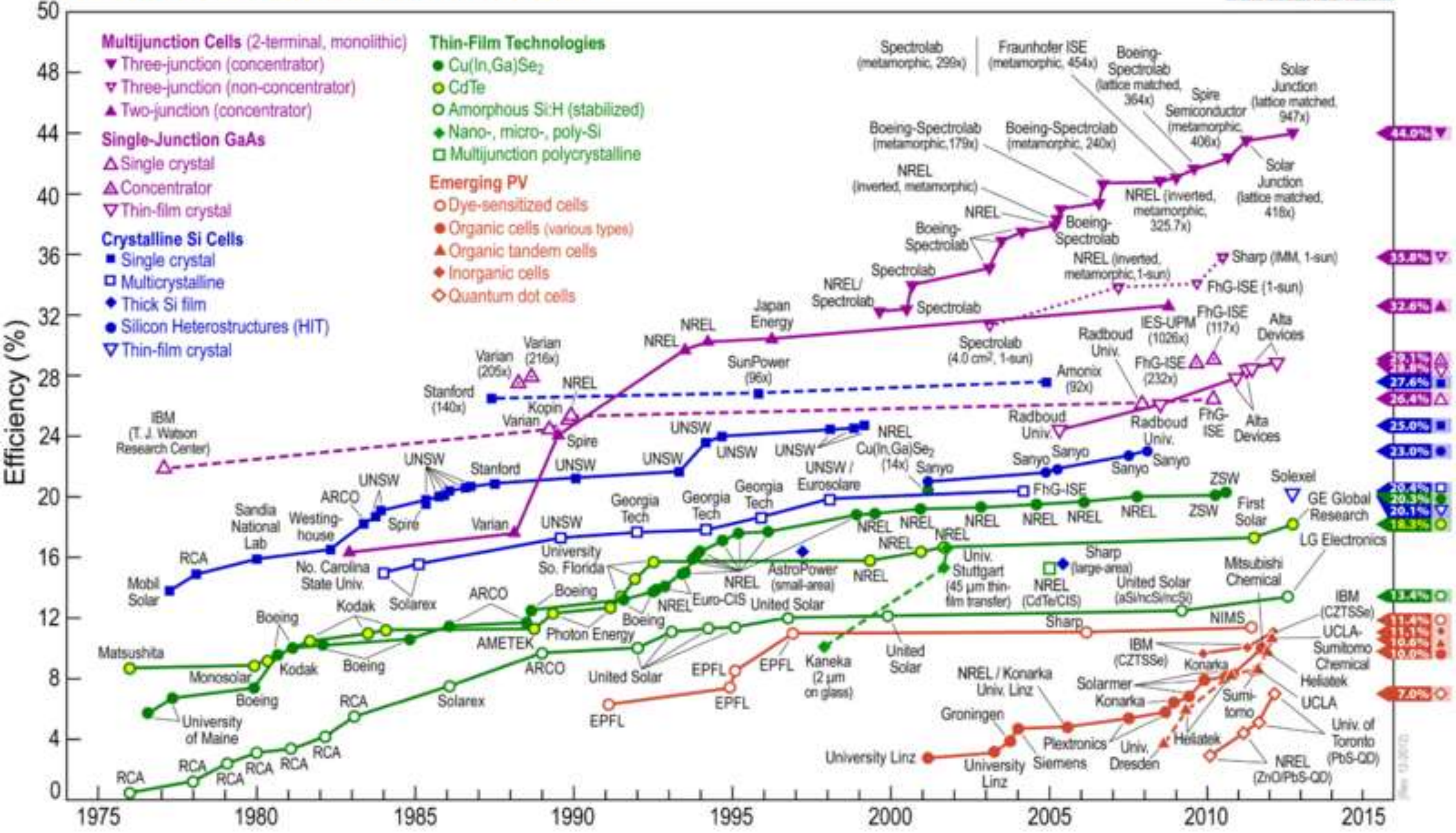
SPECIAL ISSUE

URBAN PLANET

Solar is by Far the Most Abundant



Best Research-Cell Efficiencies



Les objectifs de la transition énergétique

La volonté du Royaume de porter la part des énergies renouvelables

de 42% de puissance installée

Objectif fixé pour 2020

à 52%

A l'horizon 2030

Investissement global dans le secteur énergétique entre 2016 et 2030

Près de 40 milliards de dollars

▶ dont

30 milliards

Pour les projets de production d'électricité de sources renouvelables

Objectif

▶ Réduction de 32% des émissions de gaz à effets de serre (GES) à l'horizon 2030

Le Maroc aura à développer (entre 2016 et 2030)

Une capacité additionnelle de production d'électricité de sources renouvelables d'environ

▶ **10.100 MW**

4.560 MW solaire	4.200 MW éolienne	1.330 MW hydro-électrique

Source: Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement

June 2, 2016: Saeed Mohammed Al Tayer
CEO of Dubai Electricity and Water Authority (DEWA)

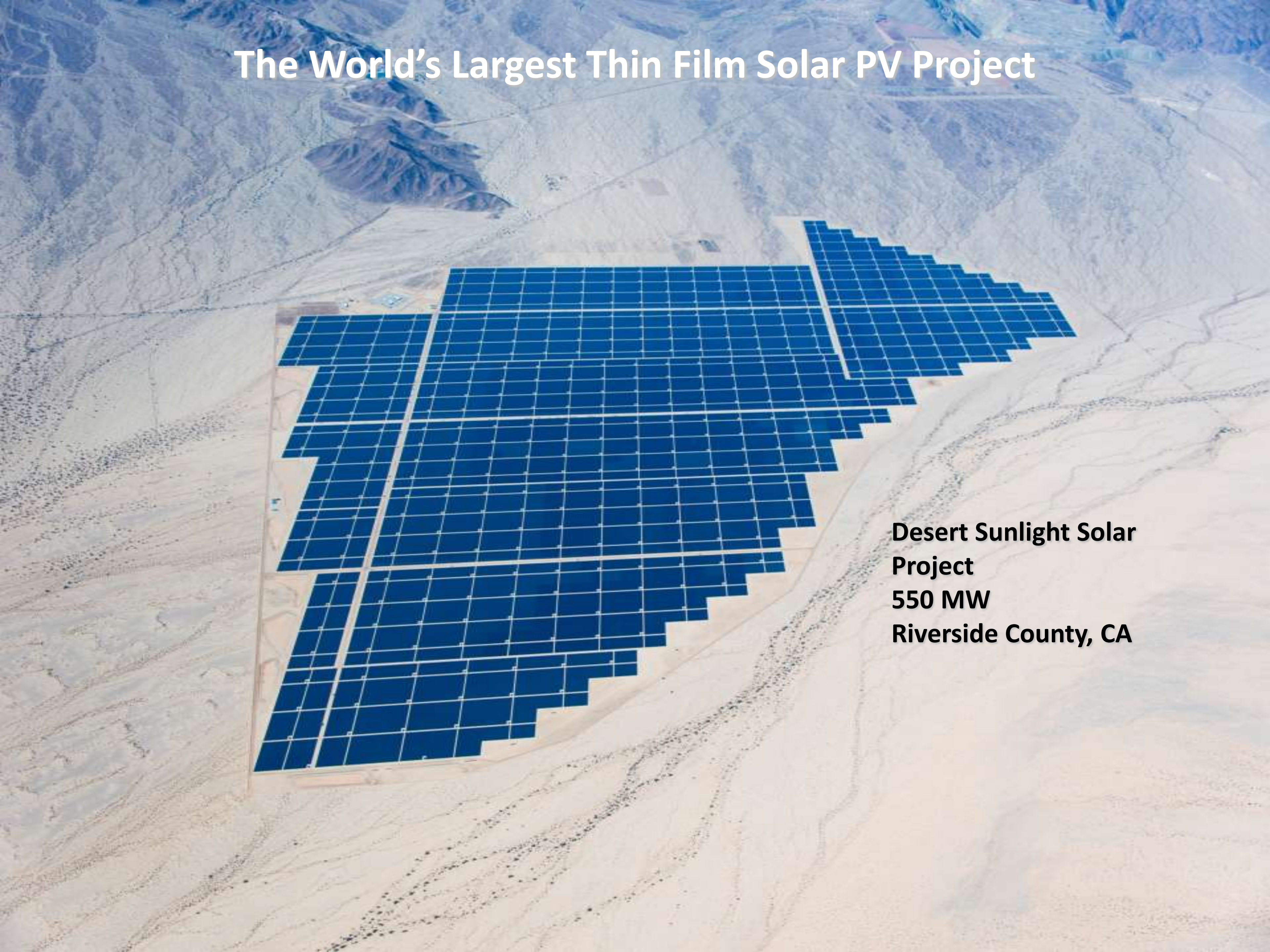
800 MW of solar at 2.99 cents/kWh

Location: Mohammed bin Rashid Al Maktoum Solar Park

Dubai’s goal: lowest carbon footprint of any city in the world

Lancaster, CA: The first city in the US to mandate solar on new construction

The World’s Largest Thin Film Solar PV Project



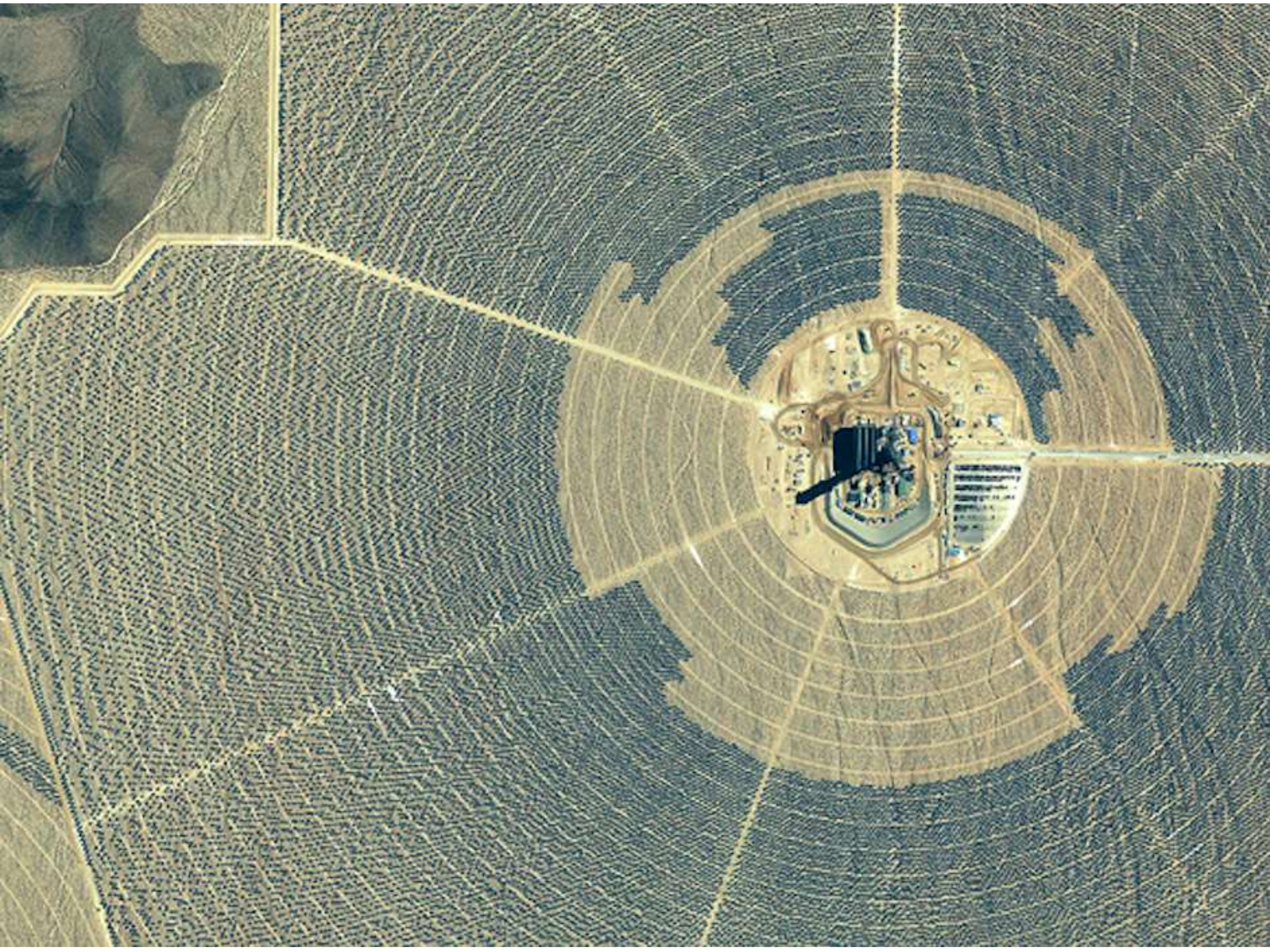
Desert Sunlight Solar Project
550 MW
Riverside County, CA

The World's Largest Silicon PV Project

Solar Star Project
579 MW
Kern County, CA

The World's Largest Solar Thermal Power Plant (Tower)

Ivanpah Solar Thermal Project
393 MW
San Bernardino County, CA



The World’s Largest Solar Thermal Power Plant (Trough)

Solar Energy Generating System (SEGS)
354 MW
San Bernardino County, CA

The World’s Largest Geothermal Power Plant

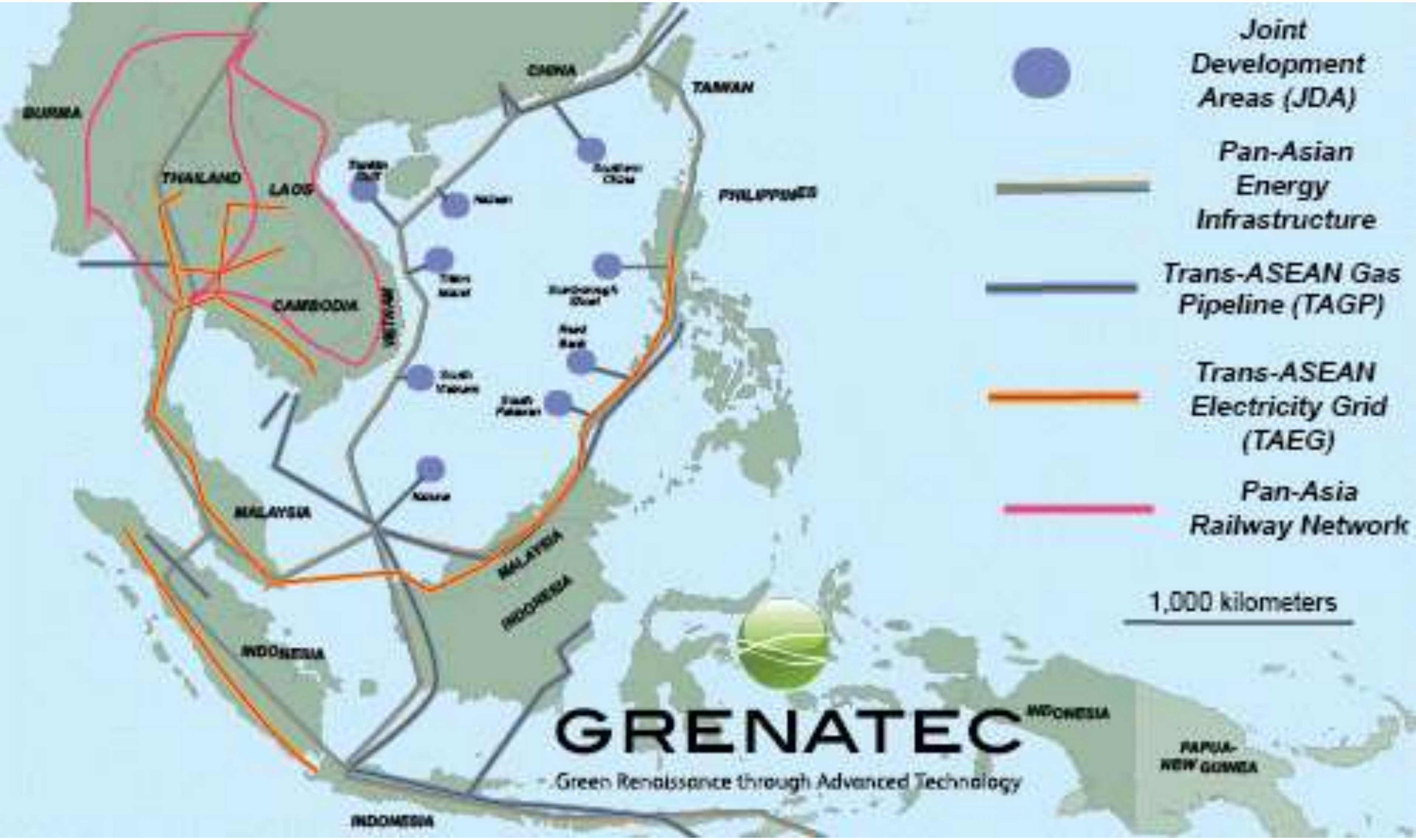
Geysers Geothermal Power Plant
955 MW
Lake County, CA

The World's Largest Iron-Chromium Flow Battery

EnerVault Iron-Chromium Technology
1 MW-hr capacity at 250 kW (4 hour duration)
Turlock, CA

The World's Largest Wind Project

Alta Wind Energy Center
1550 MW
Kern County, CA



GRENATEC

Green Renaissance through Advanced Technology

Largest Manufacturing Operation in CA is now Electric Vehicles

Automation is allowing "on-shoring" of manufacturing processes back from Asia

Tesla Factory - Fremont, CA

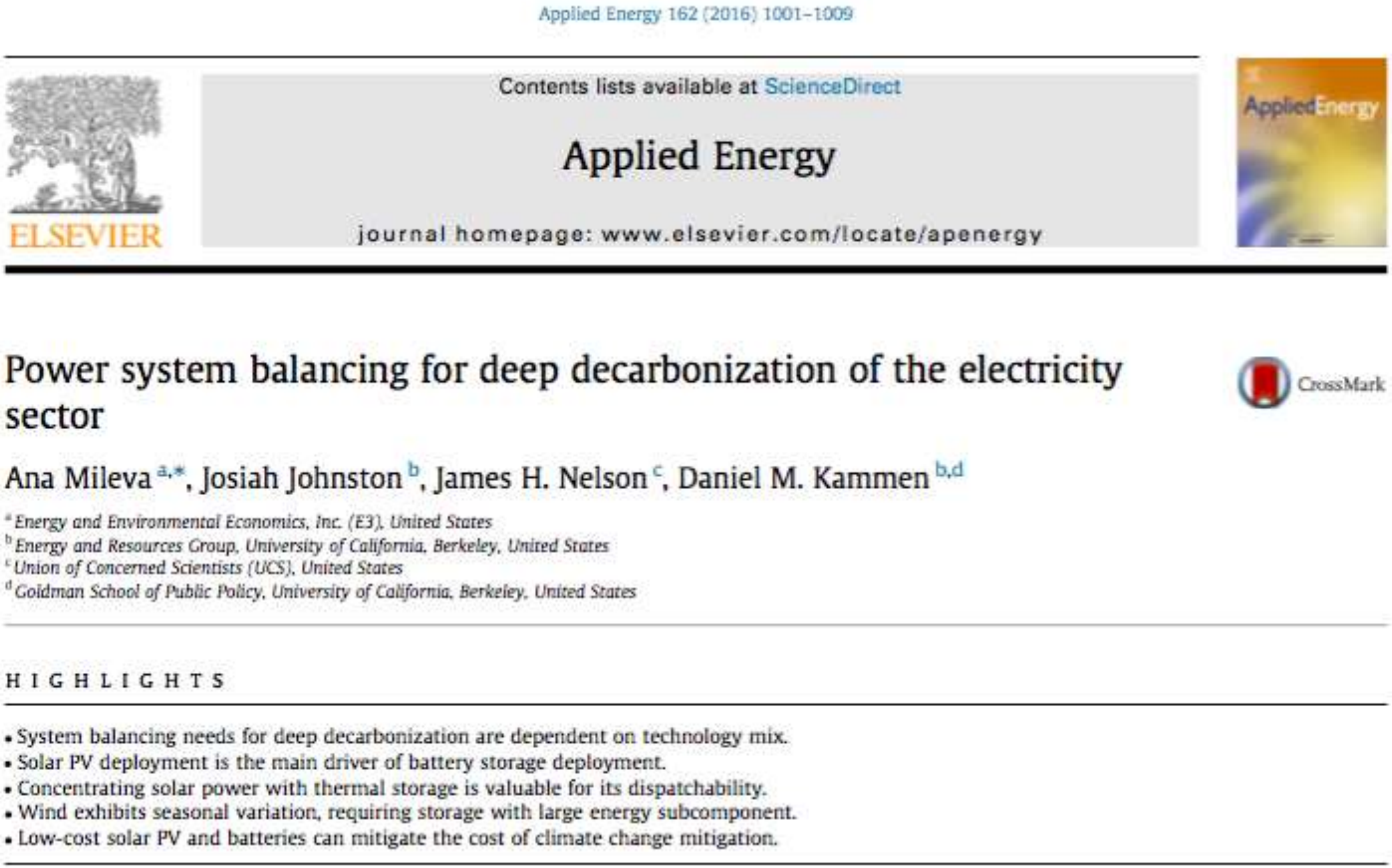
Over 3,000 workers now working at the Tesla Factory

Fastest production car ever: 0–60 in 2.5* sec.

The fine print: At $144,000 the Model S P100D with Ludicrous mode is the third fastest accelerating production car ever produced, with a 0-60 mph time of 2.5* seconds. However, both the LaFerrari and the Porsche 918 Spyder were limited $1 million dollar cars and cannot be bought new. Those cars are small two seaters with very little luggage space, the pure electric, all-wheel drive Model S P100D has four doors, seats 5.

Tesla Model 3: $35,000 in 2017

http://rael.berkeley.edu/switch



Applied Energy 162 (2016) 1001–1009

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Power system balancing for deep decarbonization of the electricity sector

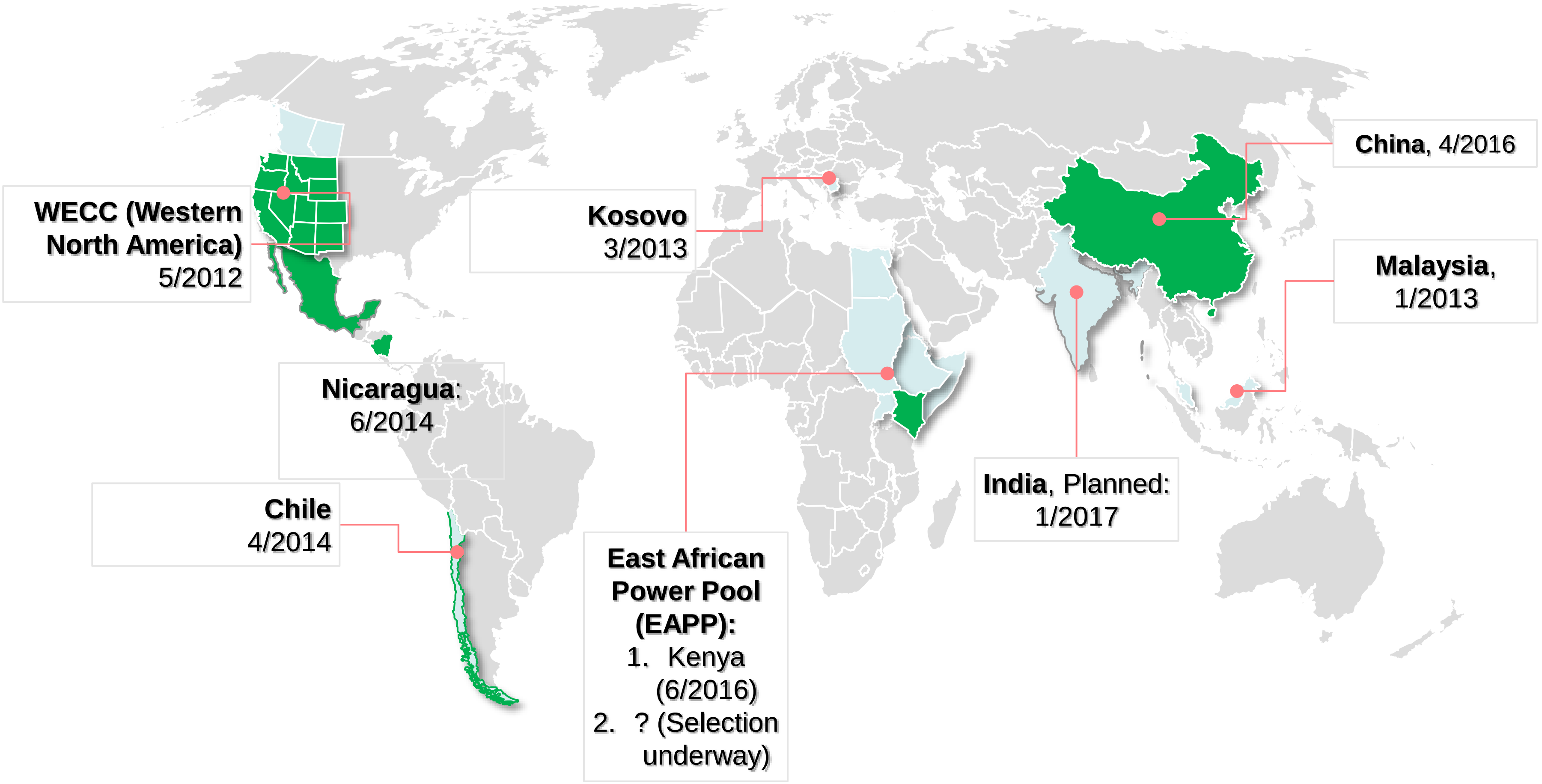
Ana Mileva [a,*], Josiah Johnston [b], James H. Nelson [c], Daniel M. Kammen [b,d]

[a] *Energy and Environmental Economics, Inc. (E3), United States*
[b] *Energy and Resources Group, University of California, Berkeley, United States*
[c] *Union of Concerned Scientists (UCS), United States*
[d] *Goldman School of Public Policy, University of California, Berkeley, United States*

HIGHLIGHTS

- System balancing needs for deep decarbonization are dependent on technology mix.
- Solar PV deployment is the main driver of battery storage deployment.
- Concentrating solar power with thermal storage is valuable for its dispatchability.
- Wind exhibits seasonal variation, requiring storage with large energy subcomponent.
- Low-cost solar PV and batteries can mitigate the cost of climate change mitigation.

Power System Models http://rael.berkeley/edu/project/SWITCH



WECC (Western North America)
5/2012

Kosovo
3/2013

China, 4/2016

Malaysia,
1/2013

Nicaragua:
6/2014

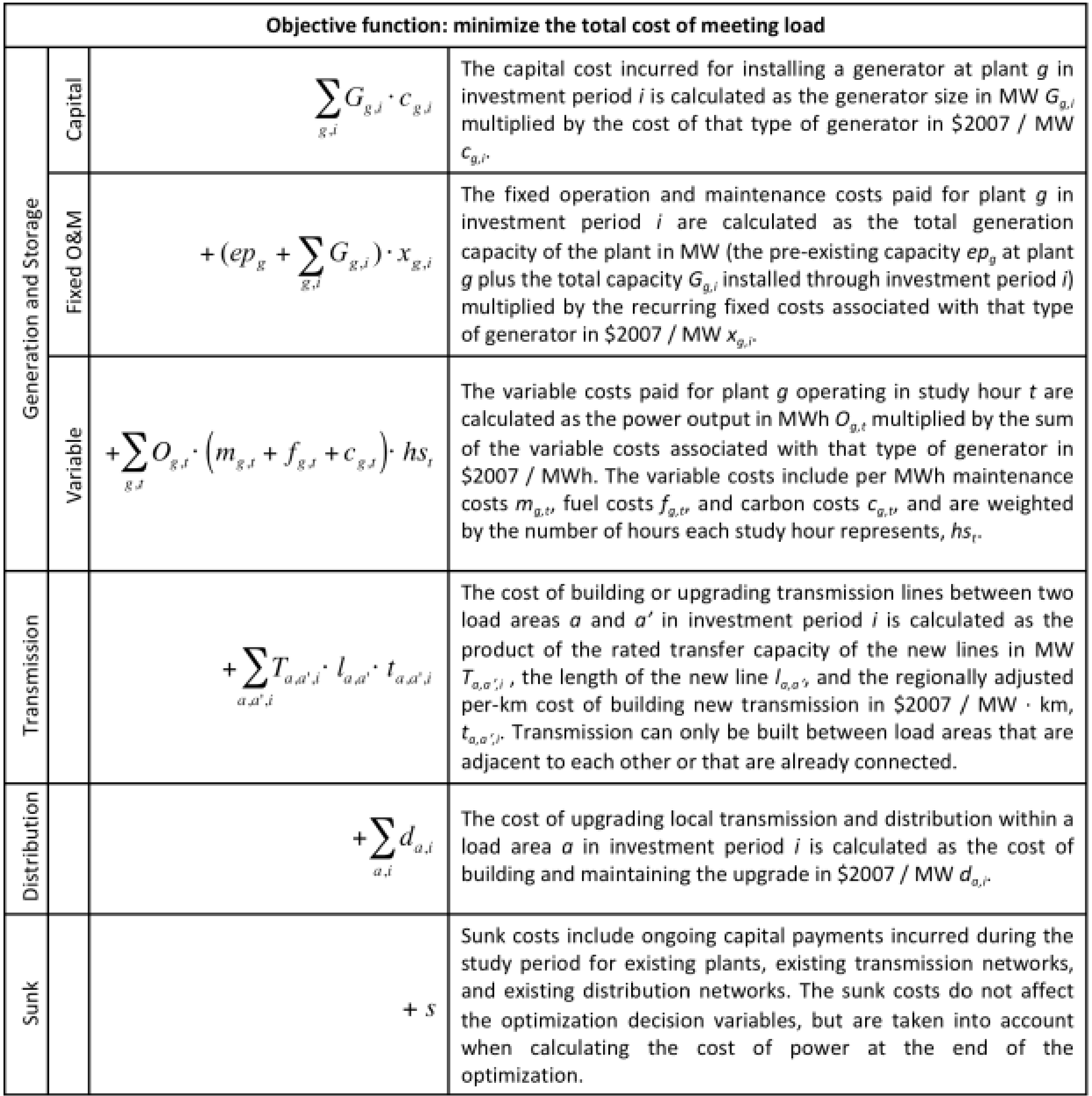
Chile
4/2014

East African Power Pool (EAPP):

1. Kenya (6/2016)
2. ? (Selection underway)

India, Planned:
1/2017

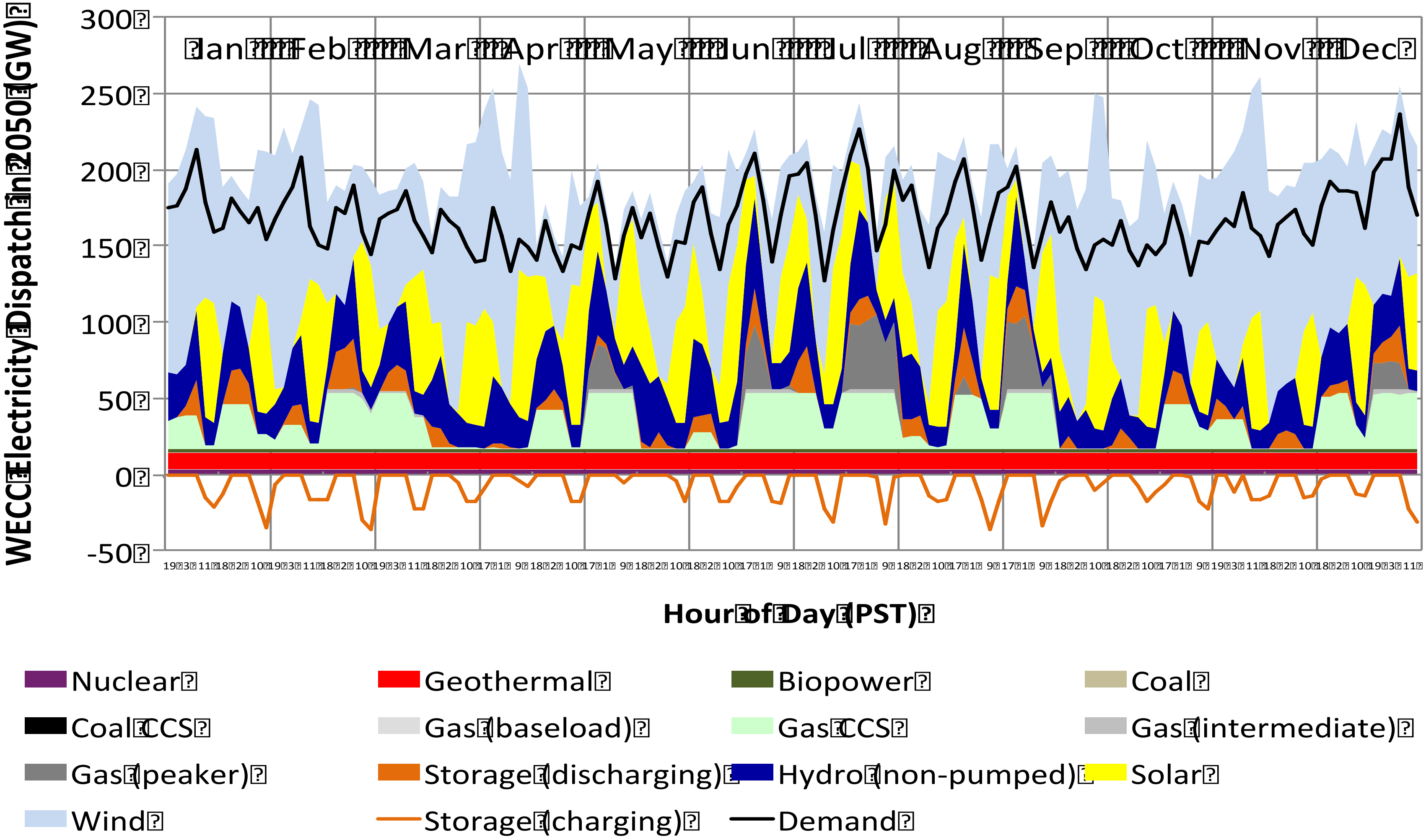
Linear Program Around Least Cost



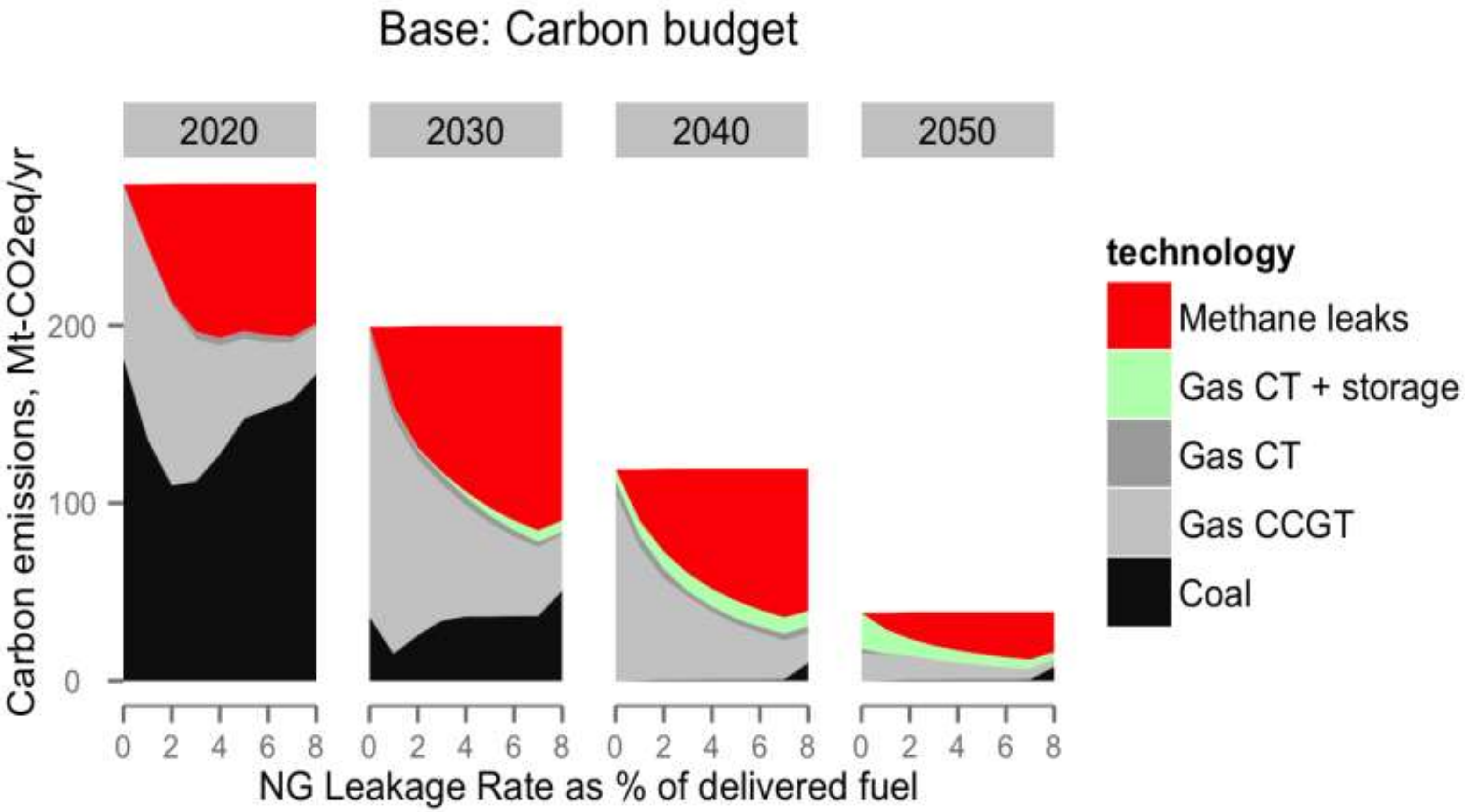
Objective function: minimize the total cost of meeting load			
Generation and Storage	Capital	$\sum_{g,i} G_{g,i} \cdot c_{g,i}$	The capital cost incurred for installing a generator at plant *g* in investment period *i* is calculated as the generator size in MW $G_{g,i}$ multiplied by the cost of that type of generator in \$2007 / MW $c_{g,i}$.
	Fixed O&M	$+(ep_g + \sum_{g,i} G_{g,i}) \cdot x_{g,i}$	The fixed operation and maintenance costs paid for plant *g* in investment period *i* are calculated as the total generation capacity of the plant in MW (the pre-existing capacity ep_g at plant *g* plus the total capacity $G_{g,i}$ installed through investment period *i*) multiplied by the recurring fixed costs associated with that type of generator in \$2007 / MW $x_{g,i}$.
	Variable	$+\sum_{g,t} O_{g,t} \cdot \left(m_{g,t} + f_{g,t} + c_{g,t}\right) \cdot hs_t$	The variable costs paid for plant *g* operating in study hour *t* are calculated as the power output in MWh $O_{g,t}$ multiplied by the sum of the variable costs associated with that type of generator in \$2007 / MWh. The variable costs include per MWh maintenance costs $m_{g,t}$, fuel costs $f_{g,t}$, and carbon costs $c_{g,t}$, and are weighted by the number of hours each study hour represents, hs_t.
Transmission		$+\sum_{a,a',i} T_{a,a',i} \cdot l_{a,a'} \cdot t_{a,a',i}$	The cost of building or upgrading transmission lines between two load areas *a* and *a'* in investment period *i* is calculated as the product of the rated transfer capacity of the new lines in MW $T_{a,a',i}$, the length of the new line $l_{a,a'}$, and the regionally adjusted per-km cost of building new transmission in \$2007 / MW · km, $t_{a,a',i}$. Transmission can only be built between load areas that are adjacent to each other or that are already connected.
Distribution		$+\sum_{a,i} d_{a,i}$	The cost of upgrading local transmission and distribution within a load area *a* in investment period *i* is calculated as the cost of building and maintaining the upgrade in \$2007 / MW $d_{a,i}$.
Sunk		$+ s$	Sunk costs include ongoing capital payments incurred during the study period for existing plants, existing transmission networks, and existing distribution networks. The sunk costs do not affect the optimization decision variables, but are taken into account when calculating the cost of power at the end of the optimization.

Dispatch in 2050: Flexibility and variable renewables dominate

- Storage almost exclusively moves solar to the night
- Geothermal only remaining substantial baseload



Fugitive Emissions: WECC



Environmental Science & Technology

Policy Analysis

pubs.acs.org/est

SWITCH-China: A Systems Approach to Decarbonizing China's Power System

Gang He,*,†,‡,§ Anne-Perrine Avrin,‡,§ James H. Nelson,⊥ Josiah Johnston,‡,§ Ana Mileva,⊥ Jianwei Tian,# and Daniel M. Kammen*,‡,§,∥

[†] Department of Technology and Society, College of Engineering and Applied Sciences, Stony Brook University, Stony Brook, New York 11794, United States

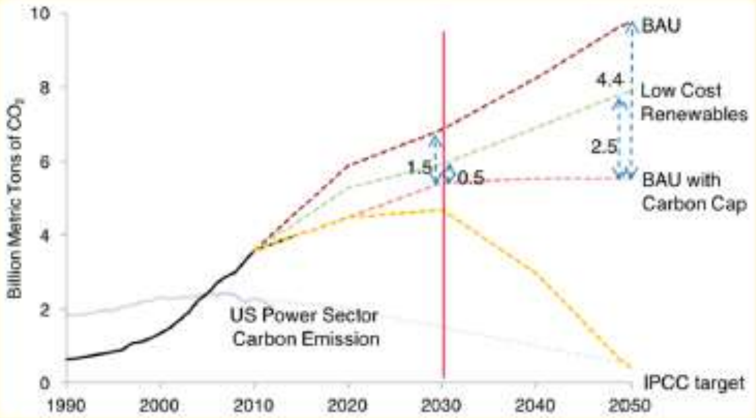
[‡] Renewable and Appropriate Energy Laboratory, [§] Energy and Resources Group, and [∥] Goldman School of Public Policy, University of California, Berkeley, California 94720, United States

[⊥] Energy and Environmental Economics, Inc. (E3), San Francisco, California 94104, United States

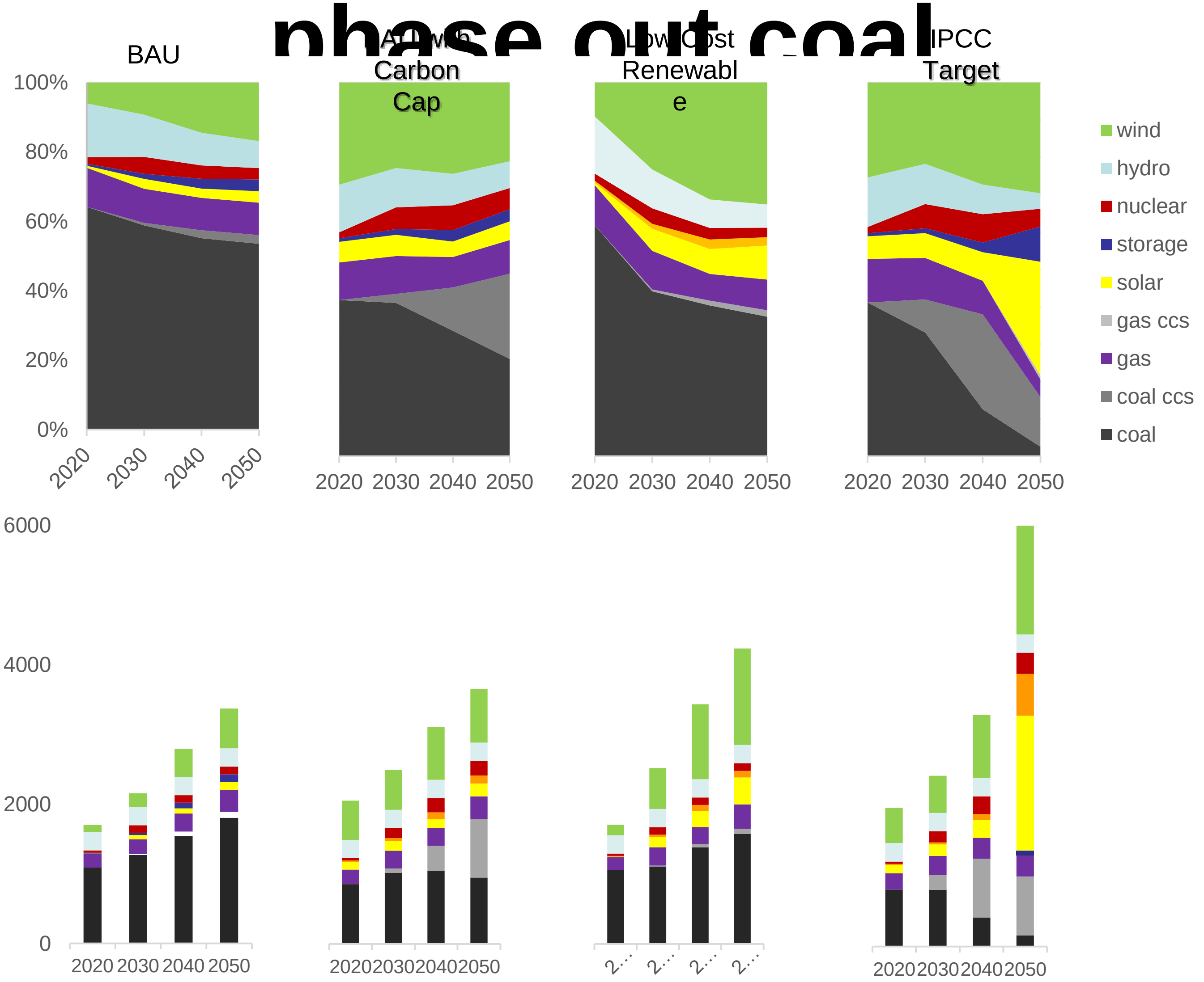
[#] China National Institute of Standardization, Beijing 100191, P.R. China

Supporting Information

ABSTRACT: We present an integrated model, SWITCH-China, of the Chinese power sector with which to analyze the economic and technological implications of a medium to long-term decarbonization scenario while accounting for very-short-term renewable variability. On the basis of the model and assumptions used, we find that the announced 2030 carbon peak can be achieved with a carbon price of ~\$40/tCO$_2$. Current trends in renewable energy price reductions alone are insufficient to replace coal; however, an 80% carbon emission reduction by 2050 is achievable in the Intergovernmental Panel on Climate Change Target Scenario with an optimal electricity mix in 2050 including nuclear (14%), wind (23%), solar (27%), hydro (6%), gas (1%), coal (3%), and carbon capture and sequestration coal energy (26%). The co-benefits of carbon-price strategy would offset 22% to 42% of the increased electricity costs if the true cost of coal and the social cost of carbon are incorporated. In such a scenario, aggressive attention to research and both technological and financial innovation mechanisms are crucial to enabling the transition at a reasonable cost, along with strong carbon policies.

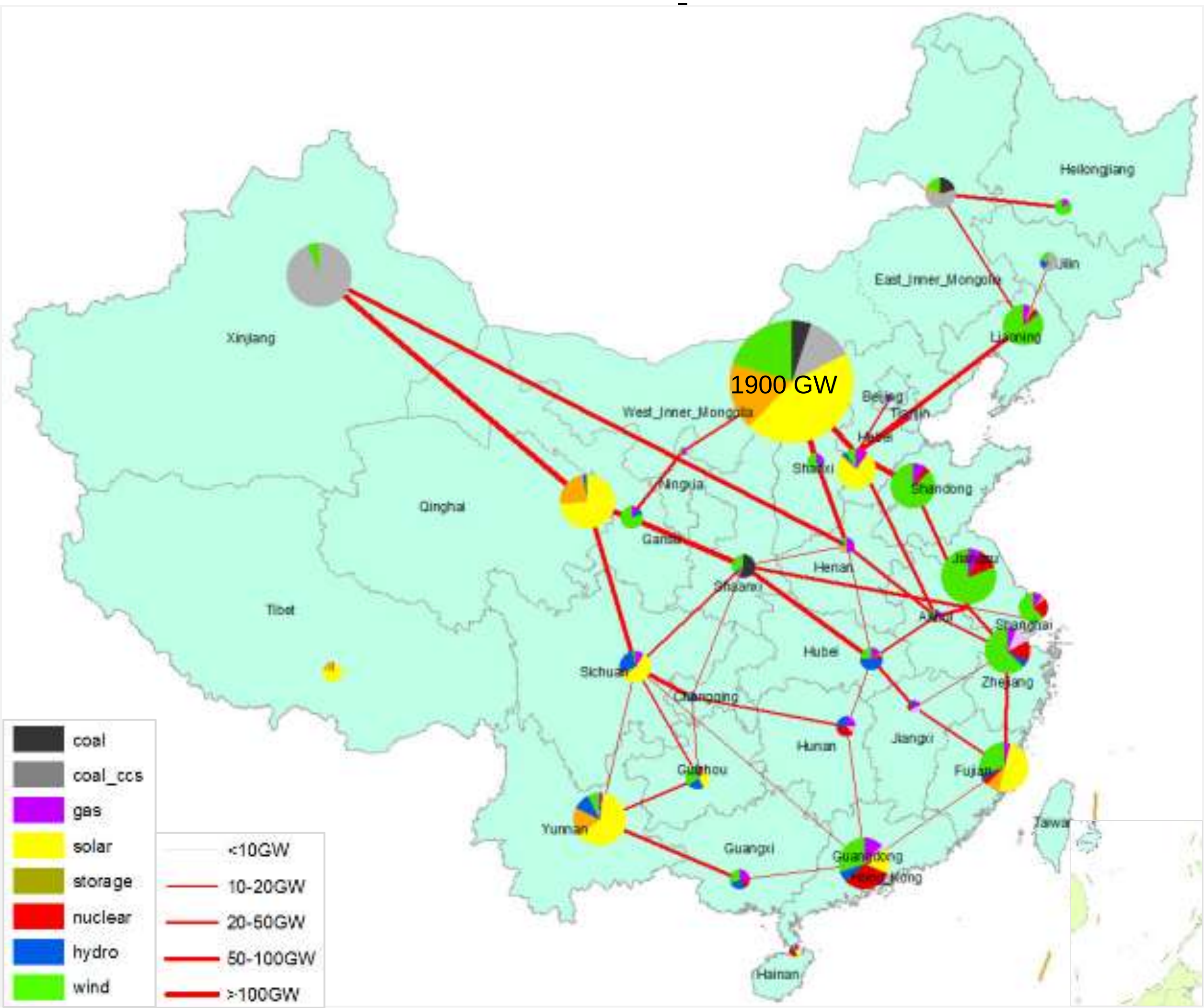


Aggressive wind and solar learning curve is not enough to phase out coal



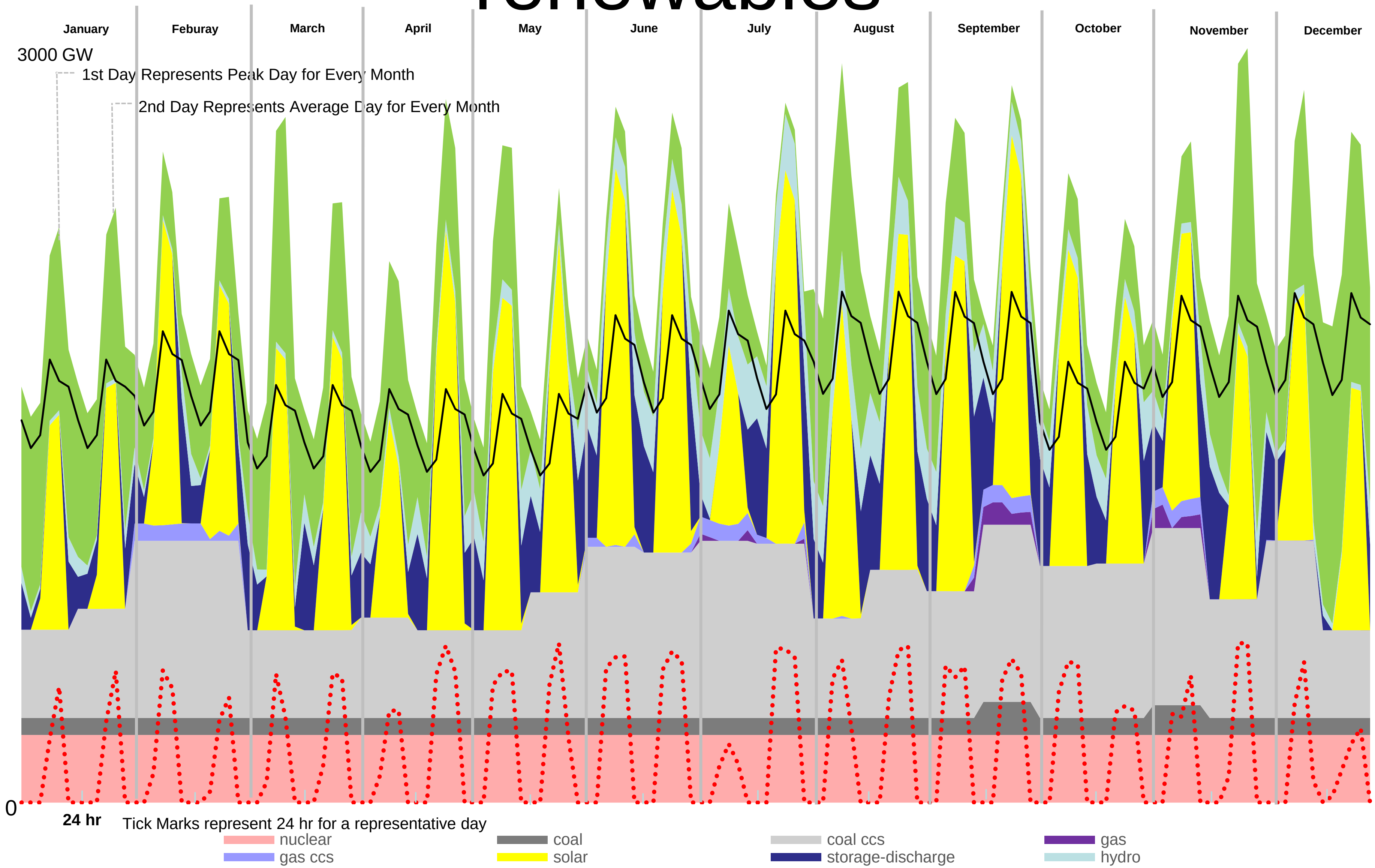
Source: He, Avrin, Nelson, Johnston, Mileva, Tian, and Kammen, 2015.

Transmission brings more renewables online, but also cheap



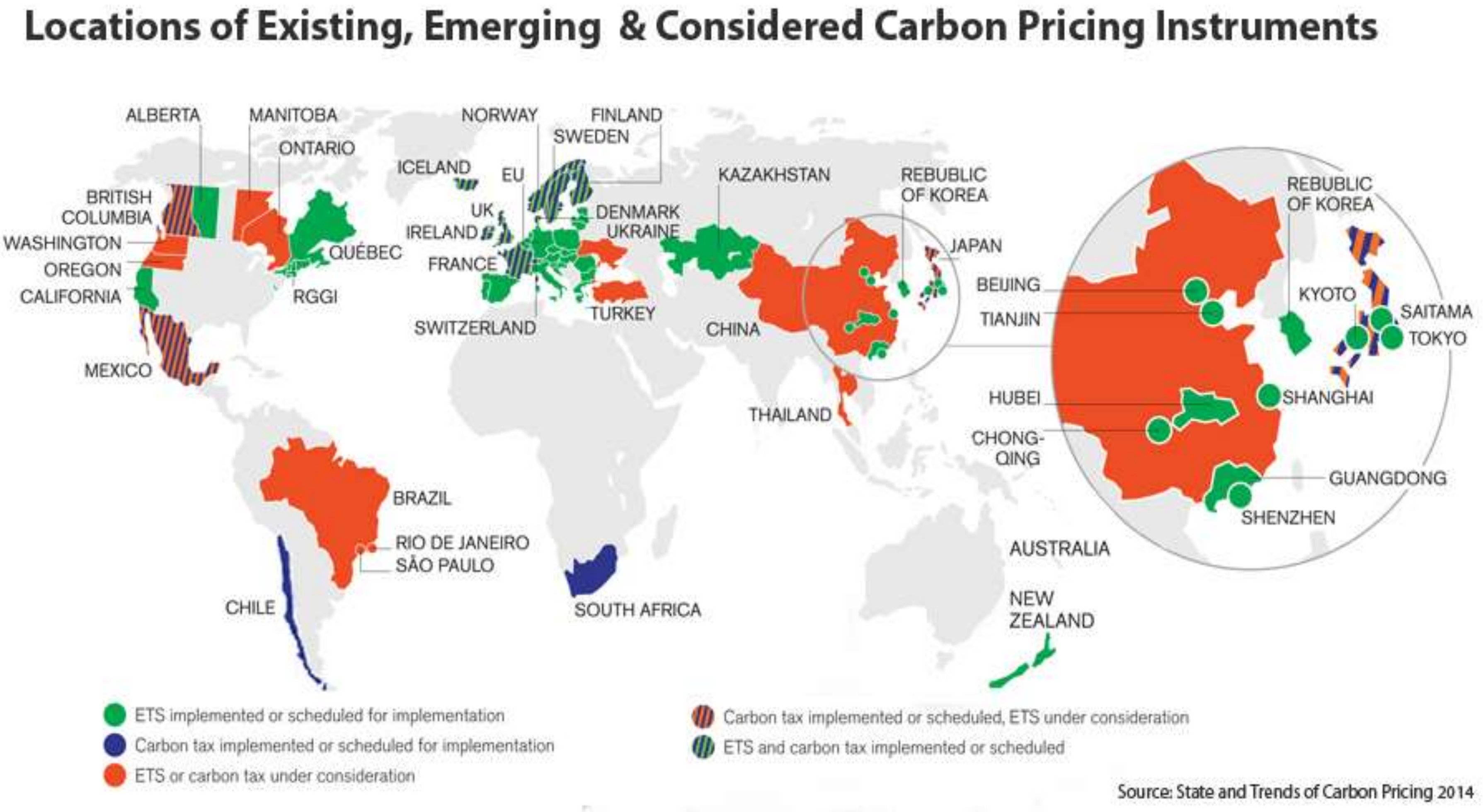
Source: He, Avrin, Nelson, Johnston, Mileva, Tian, and Kammen, 2015.

China: dispatch challenge for coal and renewables



Source: He, Avrin, Nelson, Johnston, Mileva, Tian, and Kamme

Pricing Carbon in operation today

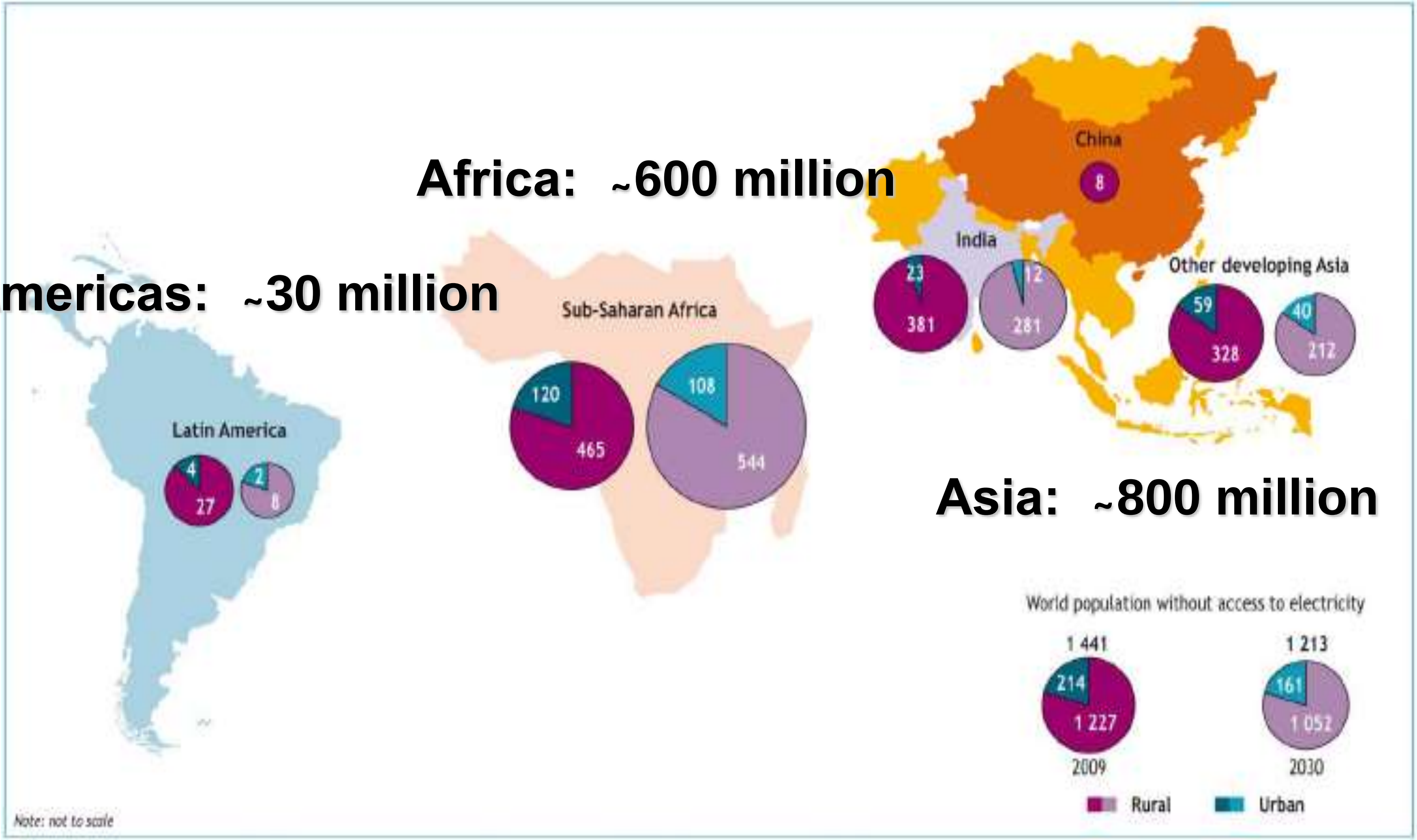


Locations of Existing, Emerging & Considered Carbon Pricing Instruments

Source: State and Trends of Carbon Pricing 2014

Figure from World Bank report, 2014

Unelectrified People (and fuel based lighting users) in Asia is Even Higher than in Africa



Africa: ~600 million

Americas: ~30 million

Asia: ~800 million

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Source: IEA, 2010 World Energy Outlook

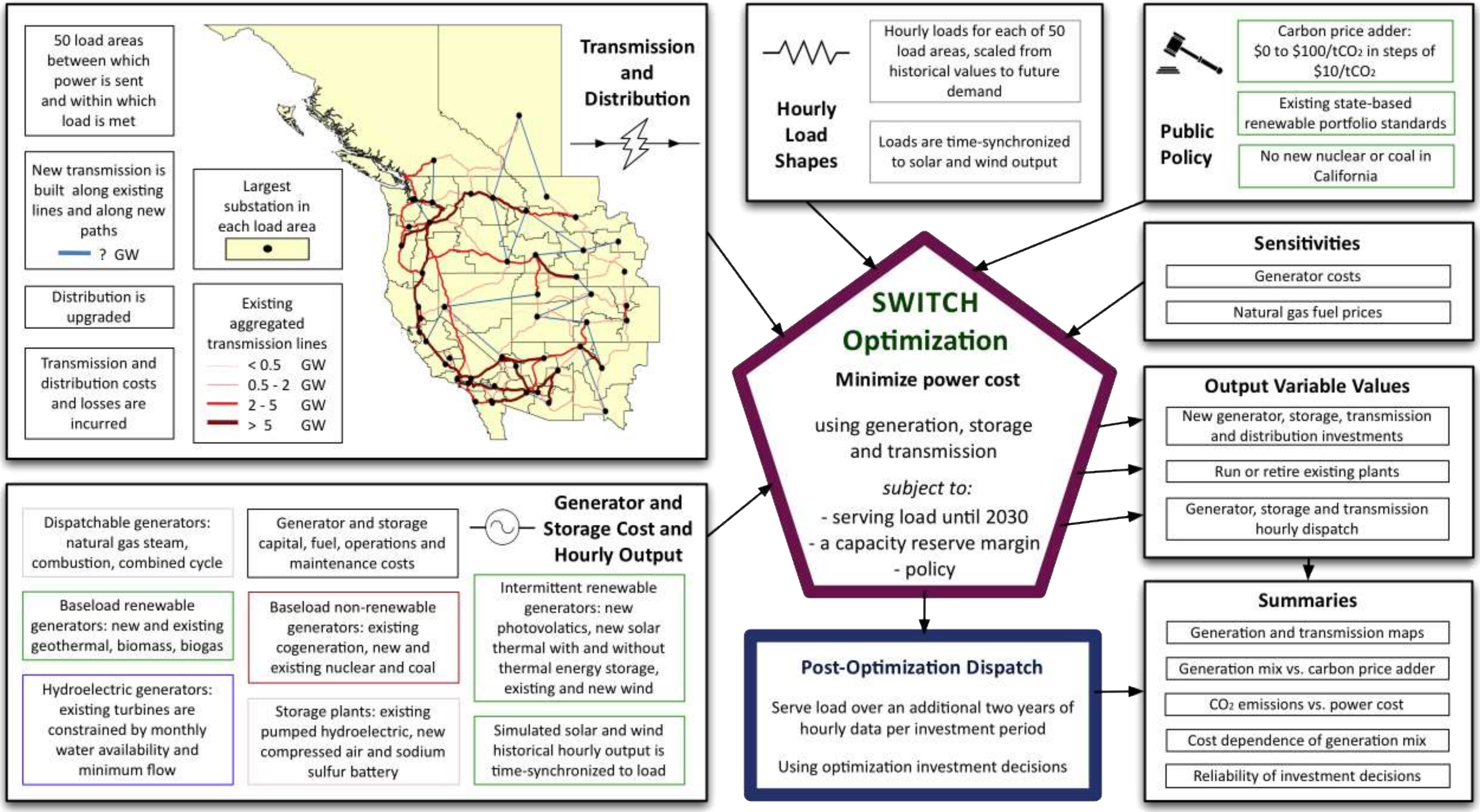
Technological and Entrepreneurial Opportunity: Lighting Africa

VOLATILE EXPENSIVE ENERGY

An investment in solar energy for international humanitarian operations in South Sudan can offer significant economic savings. In can also build longer-term energy infrastructure to support peace and reconstruction in South Sudan, one of the least electrified countries in the world as a result of decades of conflict and under-development.

The Civil War has decimated local infrastructure, forcing the population into costly and unsustainable relief camps

The SWITCH-WECC Model



Transmission and Distribution

50 load areas between which power is sent and within which load is met

New transmission is built along existing lines and along new paths

? GW

Largest substation in each load area

●

Distribution is upgraded

Existing aggregated transmission lines

< 0.5 GW

0.5 - 2 GW

2 - 5 GW

> 5 GW

Transmission and distribution costs and losses are incurred

Hourly Load Shapes

Hourly loads for each of 50 load areas, scaled from historical values to future demand

Loads are time-synchronized to solar and wind output

Public Policy

Carbon price adder: \$0 to \$100/tCO₂ in steps of \$10/tCO₂

Existing state-based renewable portfolio standards

No new nuclear or coal in California

Sensitivities

Generator costs

Natural gas fuel prices

SWITCH Optimization

Minimize power cost

using generation, storage and transmission

subject to:

- serving load until 2030
- a capacity reserve margin
- policy

Output Variable Values

New generator, storage, transmission and distribution investments

Run or retire existing plants

Generator, storage and transmission hourly dispatch

Summaries

Generation and transmission maps

Generation mix vs. carbon price adder

CO₂ emissions vs. power cost

Cost dependence of generation mix

Reliability of investment decisions

Generator and Storage Cost and Hourly Output

Dispatchable generators: natural gas steam, combustion, combined cycle

Generator and storage capital, fuel, operations and maintenance costs

Baseload renewable generators: new and existing geothermal, biomass, biogas

Baseload non-renewable generators: existing cogeneration, new and existing nuclear and coal

Intermittent renewable generators: new photovolatics, new solar thermal with and without thermal energy storage, existing and new wind

Hydroelectric generators: existing turbines are constrained by monthly water availability and minimum flow

Storage plants: existing pumped hydroelectric, new compressed air and sodium sulfur battery

Simulated solar and wind historical hourly output is time-synchronized to load

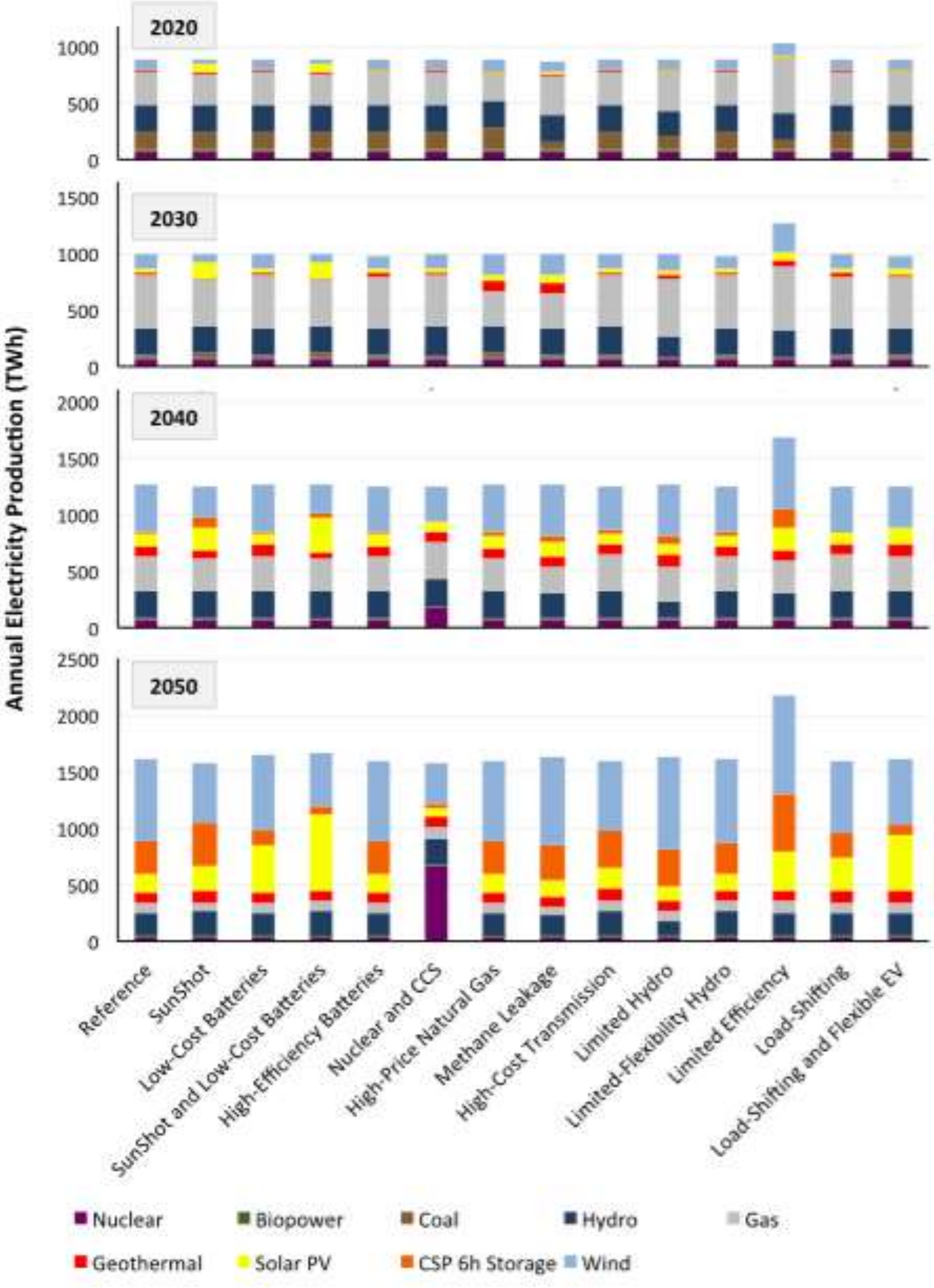
Post-Optimization Dispatch

Serve load over an additional two years of hourly data per investment period

Using optimization investment decisions

Optimization and data framework of the western North American SWITCH model.

http://rael.berkeley.edu/switch


2020
2030
2040
2050
Annual Electricity Production (TWh)
0
500
1000
1500
2000
2500
Reference
SunShot
Low-Cost Batteries
SunShot and Low-Cost Batteries
High-Efficiency Batteries
Nuclear and CCS
High-Price Natural Gas
Methane Leakage
High-Cost Transmission
Limited Hydro
Limited-Flexibility Hydro
Limited Efficiency
Load-Shifting
Load-Shifting and Flexible EV
Nuclear
Biopower
Coal
Hydro
Gas
Geothermal
Solar PV
CSP 6h Storage
Wind

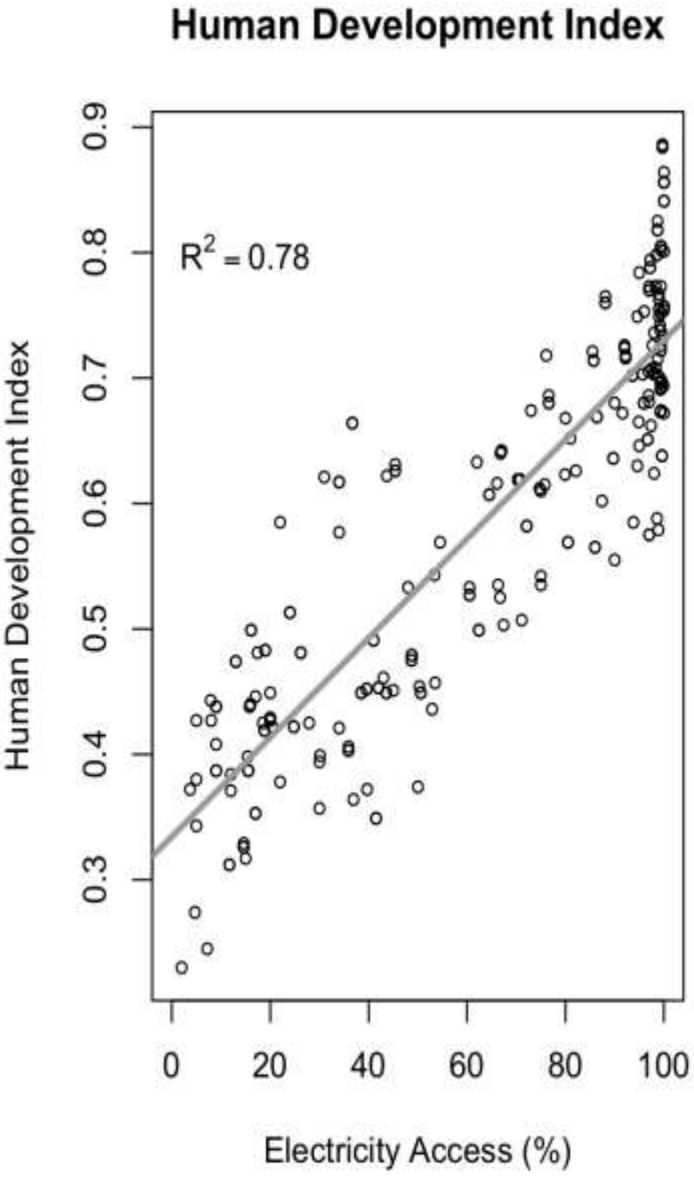
Overview:

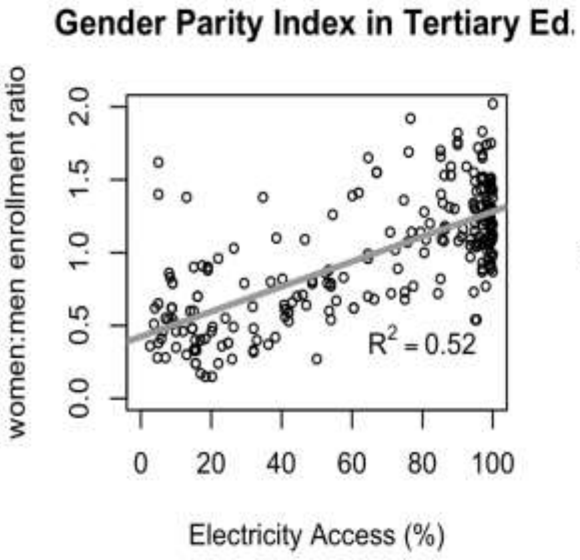
- Introduction to the Renewable and Appropriate Energy Laboratory (RAEL) - a unique think/do tank

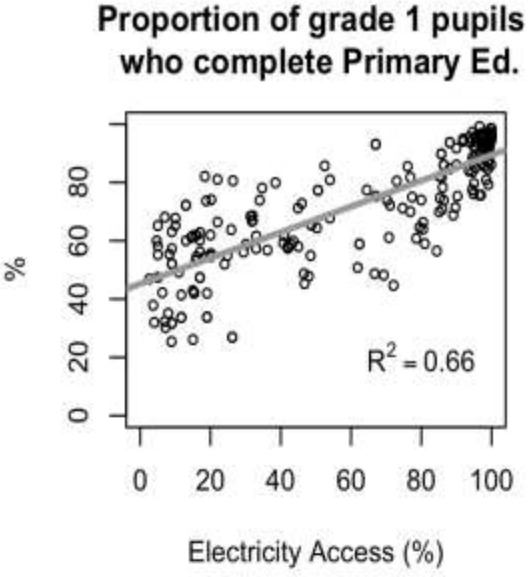
- From Problem Statement to Solutions Science for Climate Change

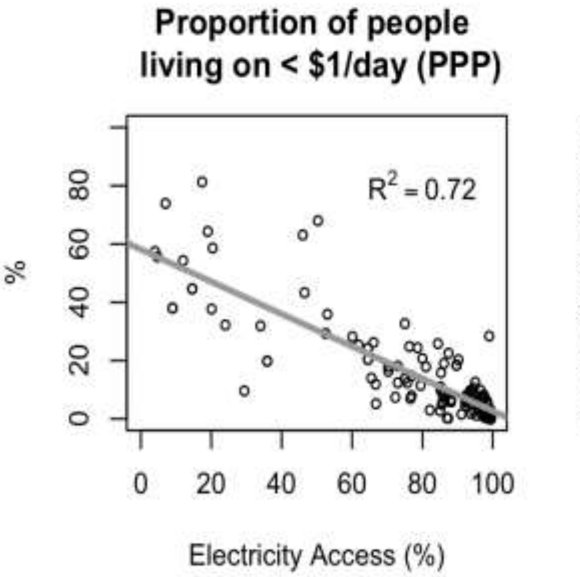
- An Opportunity for Partnership

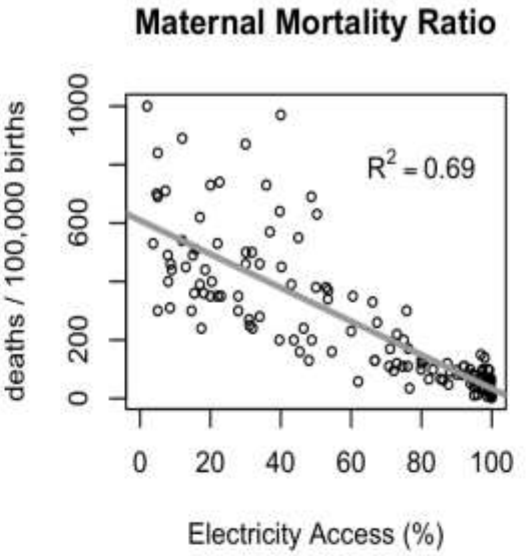
Quantitative Assessments: Energy and Human Development
Sustainable Energy for All (UN)


Human Development Index


Gender Parity Index in Tertiary Ed.


Proportion of grade 1 pupils who complete Primary Ed.


Proportion of people living on < $1/day (PPP)


Maternal Mortality Ratio

Alstone, Gershenson & Kammen, Nature Climate Change

Fuel Based Lighting:
Displacing the Incumbent in Low-Income Areas

Fuel Based Lighting : Expensive, Unhealthy, and Inefficient

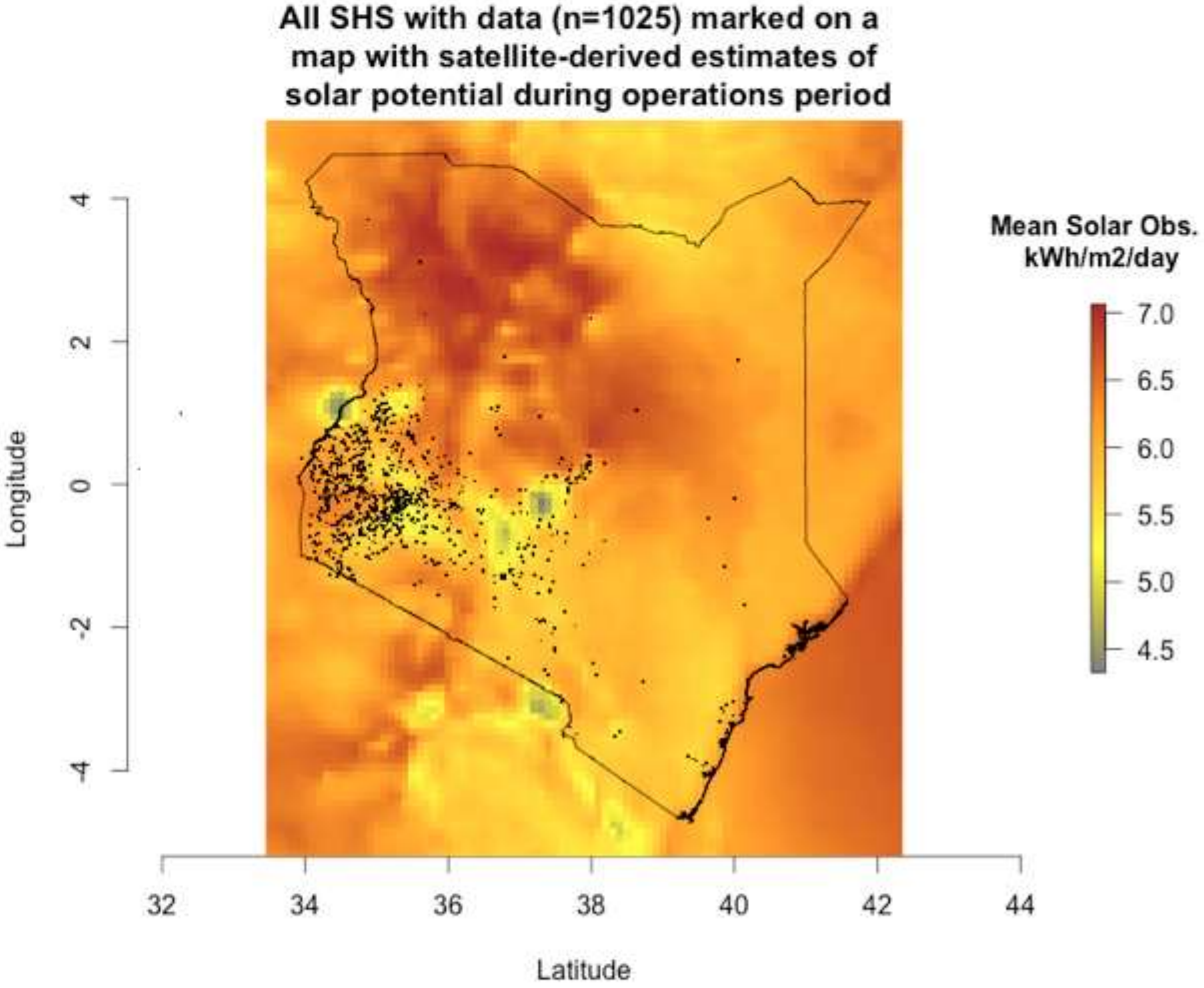
Photo by Peter Alstone

Photo by Peter Alstone

Photo by Evan Mills

Kerosene for lighting is a $25 billion per year industry globally (source: UNEP, 2013)

Low cost solar powered home energy products are transforming rural energy access in developing nations

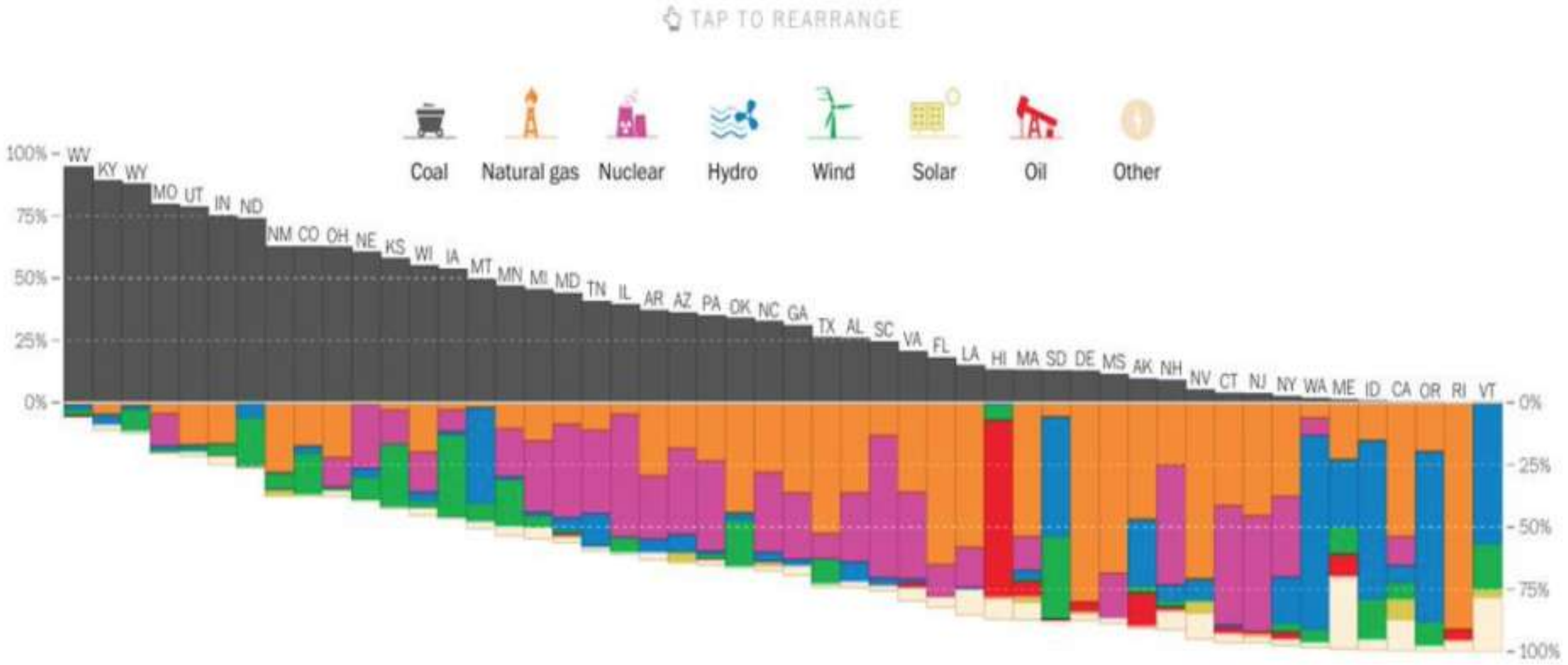


All SHS with data (n=1025) marked on a map with satellite-derived estimates of solar potential during operations period

Next Wave of Off-grid products

Electricity generation by power source, January to May 2015

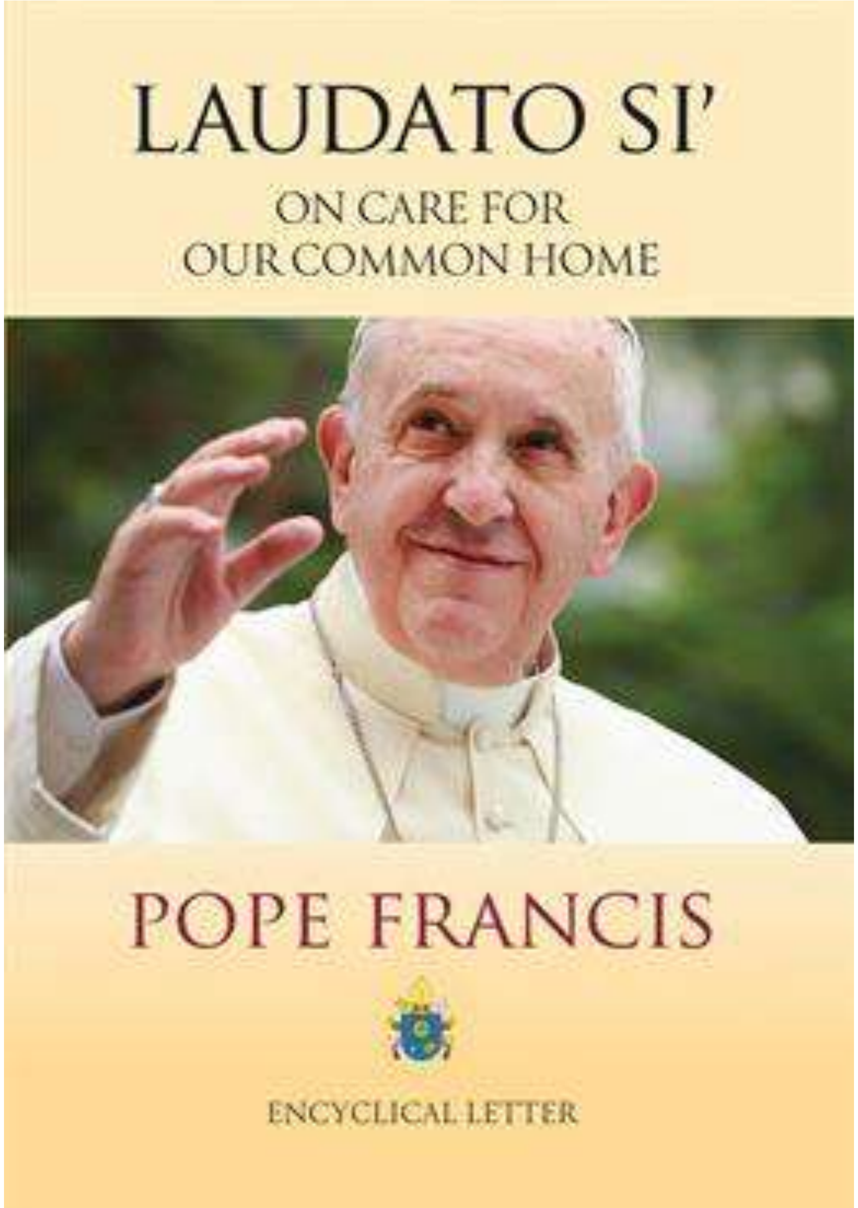
Local electric utilities take advantage of the power sources most accessible to them: coal mines, dammed rivers, new supplies of natural gas or nuclear plants to generate the bulk of the nation's electricity. This shows the source of electricity generation in each state in 2015.



East African Rift Valley is currently the world's most active geothermal development zone

- 10MW test well at Olkaria field in Hell's Gate National Park, Kenya
- KenGen's first plant commissioned in 1985 (45MW) – now over 300MW at Olkaria

Laudato Si
Encyclical Letter on Care for our Common Home



LAUDATO SI'

ON CARE FOR
OUR COMMON HOME

POPE FRANCIS

ENCYCLICAL LETTER

Islamic Declaration on Climate Change

20 August 2015 (http://Islamicclimatedeclaration.org)

- We affirm that –

- God created the Earth in perfect equilibrium *(mīzān)*;
- By His immense mercy we have been given fertile land, fresh air, clean water and all the good things on Earth that makes our lives here viable and delightful;
- The Earth functions in natural seasonal rhythms and cycles: a climate in which living beings – including humans – thrive;
- The present climate change catastrophe is a result of the human disruption of this balance –

وَالسَّمَاءَ رَفَعَهَا وَوَضَعَ الْمِيزَانَ

أَلاَّ تَطْغَوْا فِي الْمِيزَانِ

وَأَقِيمُوا الْوَزْنَ بِالْقِسْطِ وَلا تُخْسِرُوا الْمِيزَانَ

وَالأَرْضَ وَضَعَهَا لِلْأَنَامِ

Islamic Declaration on Climate Change

20 August 2015 (http://Islamicclimatedeclaration.org)

The Muslim leaders called on the people of all nations and their leaders to:

- Phase out greenhouse gas emissions as soon as possible in order to stabilize greenhouse gas concentrations in the atmosphere
- Commit themselves to 100 % renewable energy and/or a zero emissions strategy as early as possible.
- They specifically called on richer nations and oil-producing states to lead the way in phasing out their greenhouse gas emissions as early as possible and no later than the middle of the century.

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ELECTRICITY is cheaper than gasoline

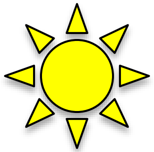
… even using photovoltaics

Conventional 25 mpg: $\dfrac{\$3.50 / \text{gal}}{25 \text{ miles/gal}} = 14¢ / \text{mile}$

Hybrid 45 mpg: $\dfrac{\$3.50 / \text{gal}}{45 \text{ miles/gal}} = 7.8¢ / \text{mile}$

Electric 3.5 miles/kWh: $\dfrac{12¢ / \text{kWh}}{3.5 \text{ miles/kWh}} = 3.4 ¢/\text{m}$

off peak it is ≈ 6¢

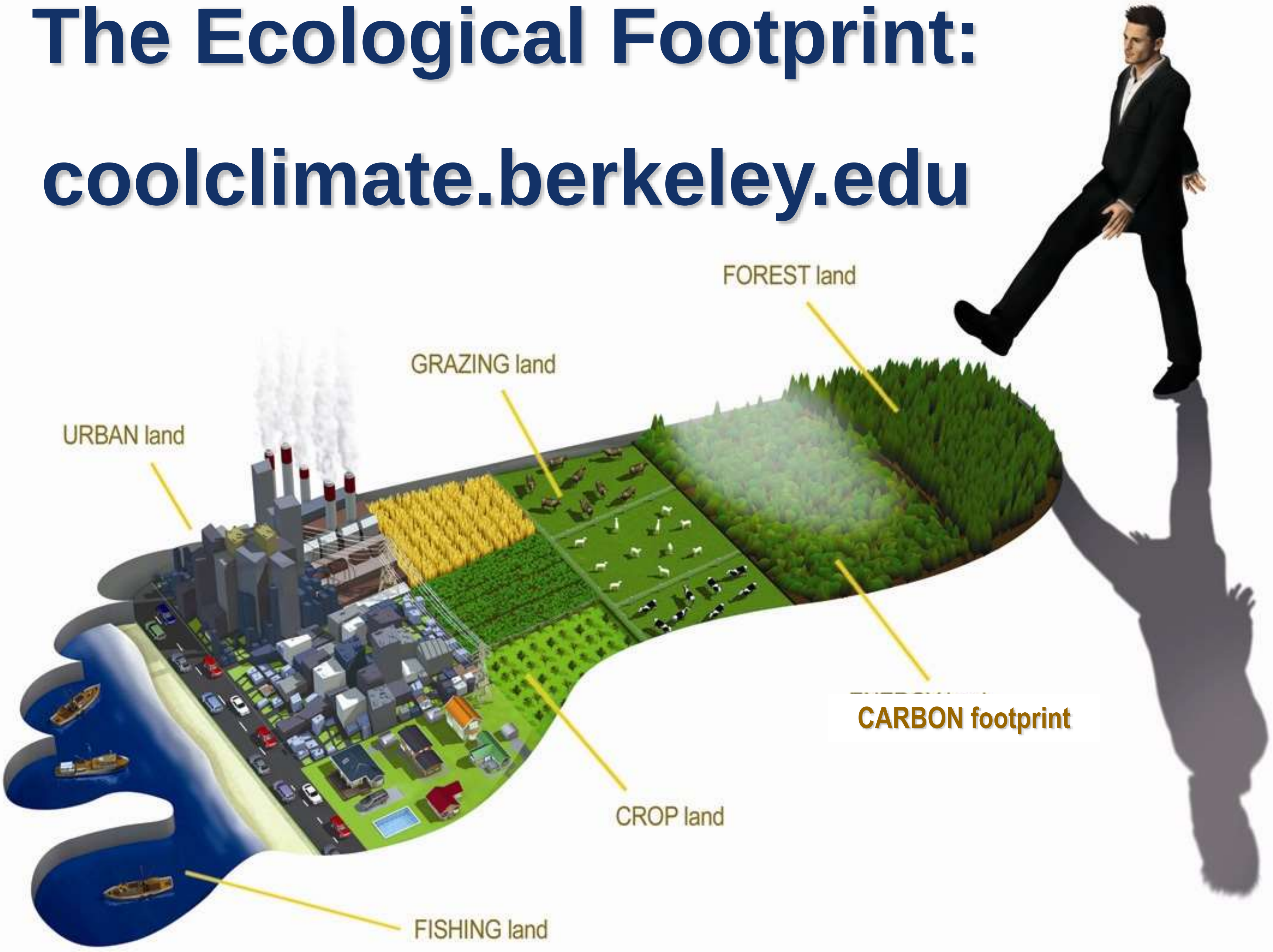


Photovoltaics: $\dfrac{\$0.13 / \text{kWh}}{3.5 \text{ miles/kWh}} = 3.7 ¢ / \text{mile}$

$4/Wdc,stc (after 30% tax credit), 5.5 hr/day, 0.75 de-rating, 5% loan, 34% MTB

The Ecological Footprint:

coolclimate.berkeley.edu



TAKE ACTION TO KEEP THE PLANET COOL

WELCOME TO COOLCALIFORNIA.org, our goal is to provide resources to all Californians in order to reduce their environmental impact and take action to stop climate change. Realizing local governments, businesses, schools and individuals have different needs, we have customized pages for each audience. Click the tabs above to find:

- Money saving actions and best practices
- Financial incentives for actions and projects
- Carbon footprint and greenhouse gas emissions calculation tools
- Case studies and Success stories
- Educational resources

So, come on, be "cool" and check out the resources on CoolCalifornia.org today!

Popular content

- Calculator
- Household Actions
- About Us
- Small Biz Actions
- Small Business Award Program

Recent Case Studies

- Diamond D General Engineering
  Heavy civil general engineering construction company...
- The Living Christmas Company

CoolCalifornia

Stay informed on our latest news!

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○ Unsubscribe

Carbon Footprint Summary (tons CO_2e / year)

Transportation	14
Housing	2
Food	6
Goods	7
Services	7
Total	36

🟩 Footprint ▨ Offsets ▢ Pledged reductions

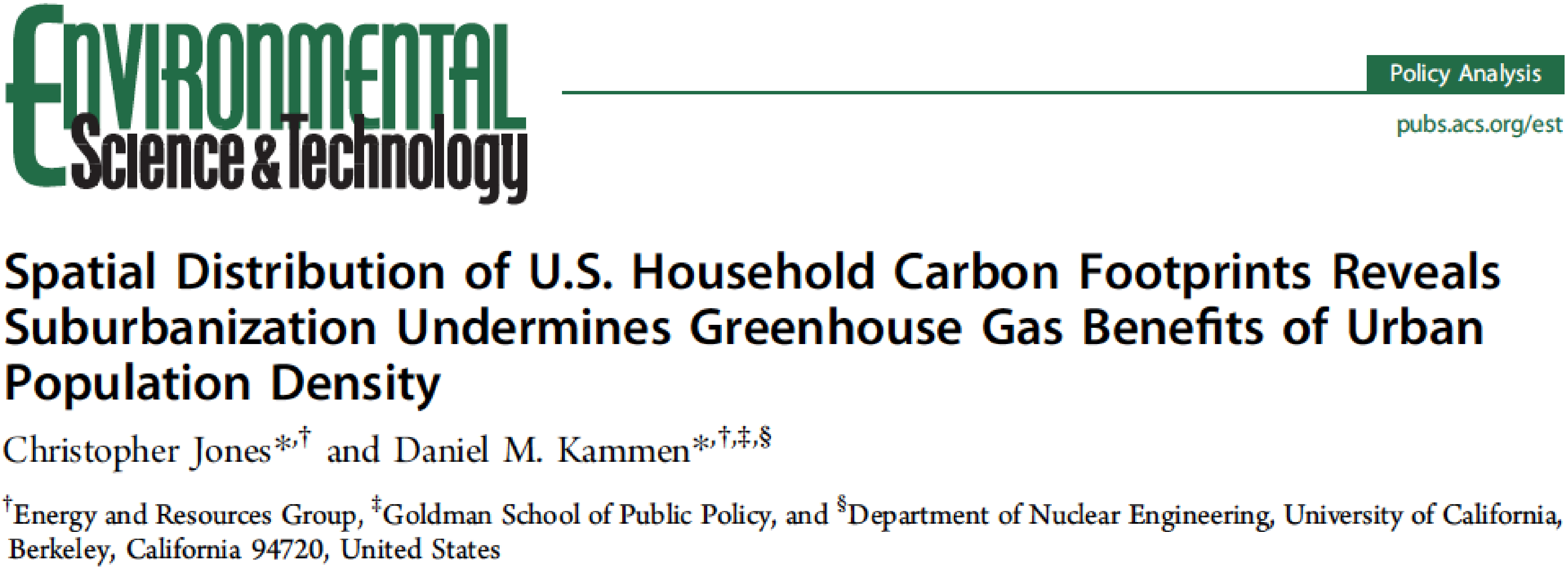
Climate Action Plan Summary

MY CURRENT FOOTPRINT	41	100%
Pledged reductions	5	12%
Offsets	0	0%
MY NEW FOOTPRINT	36	88%
financial savings per yr	$2223	
10 year net savings	$20321	
Payback	0.9	

1) Click view / hide 2) Pledge 3) Save

☐ Assumptions
☐ Pledge all

		mt CO2e/yr reduced	$ / yr saved	10 year net savings
✓	Buy a More Efficient Vehicle	1.86	$500	$3000
✓	Telecommute to Work	1.07	$528	$5280
	Ride my Bike	0.58	$156	$1560
	Take Public Transportation	0.47	$156	$1560
	Practice Eco-Driving	0.93	$249	$2490
	Maintain my Vehicles	0.71	$190	$1900
	Reduce Air Travel	0.45	$100	$1000
	Offset Remaining Transportation Footprint	13.07	$-261	$-2610
✓	Switch to CFLs	0.18	$63	$721
	Turn Down Thermostat in Winter	0.52	$95	$950
	Turn up Thermostat in Summer	0.15	$54	$540
	Choose an Energy Star Refrigerator	0.05	$17	$140
	Dry your Clothes on the Line	0.22	$75	$750
	Purchase Green Electricity	0	$0	$0



Environmental Science & Technology

Policy Analysis

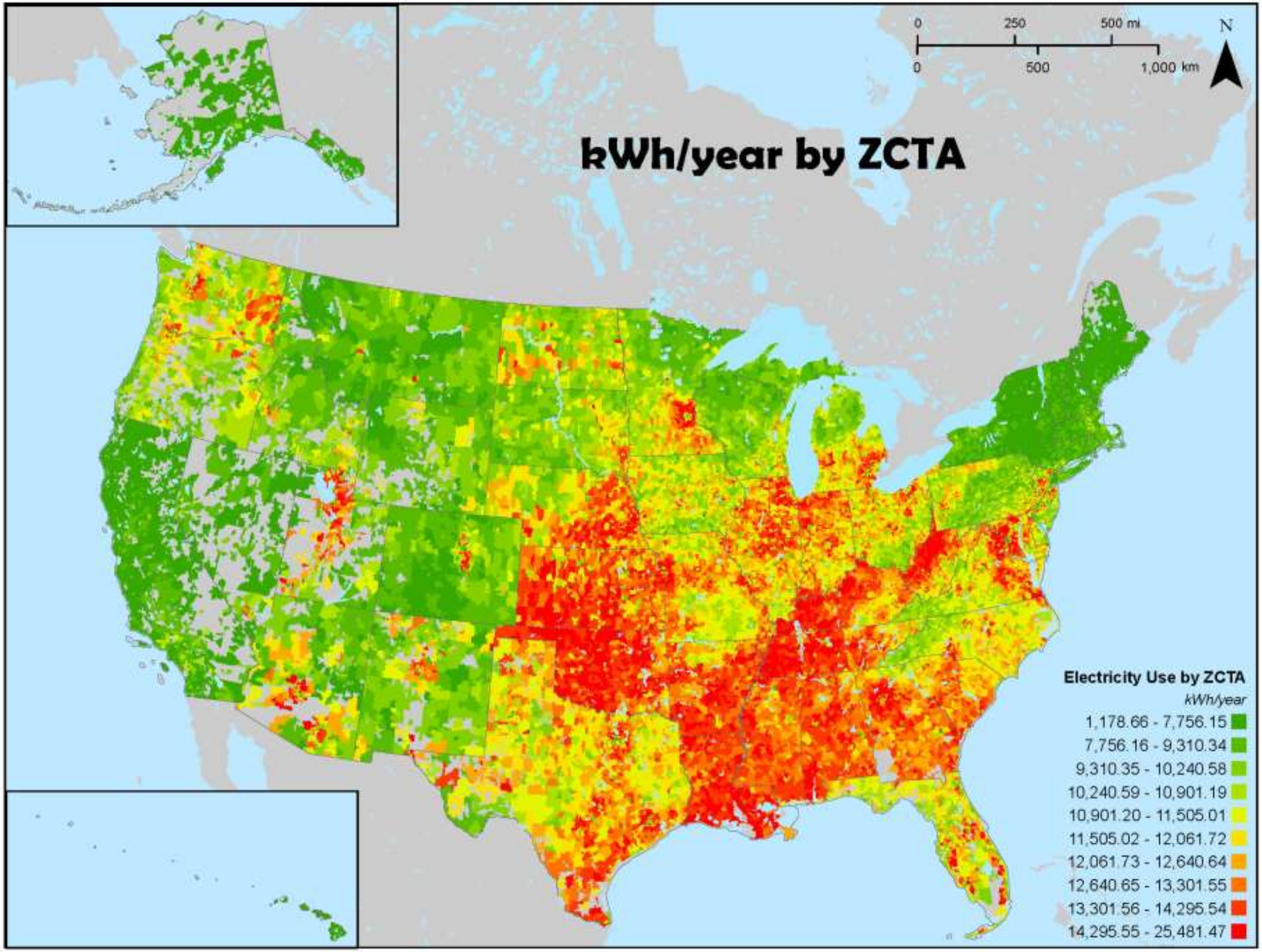
pubs.acs.org/est

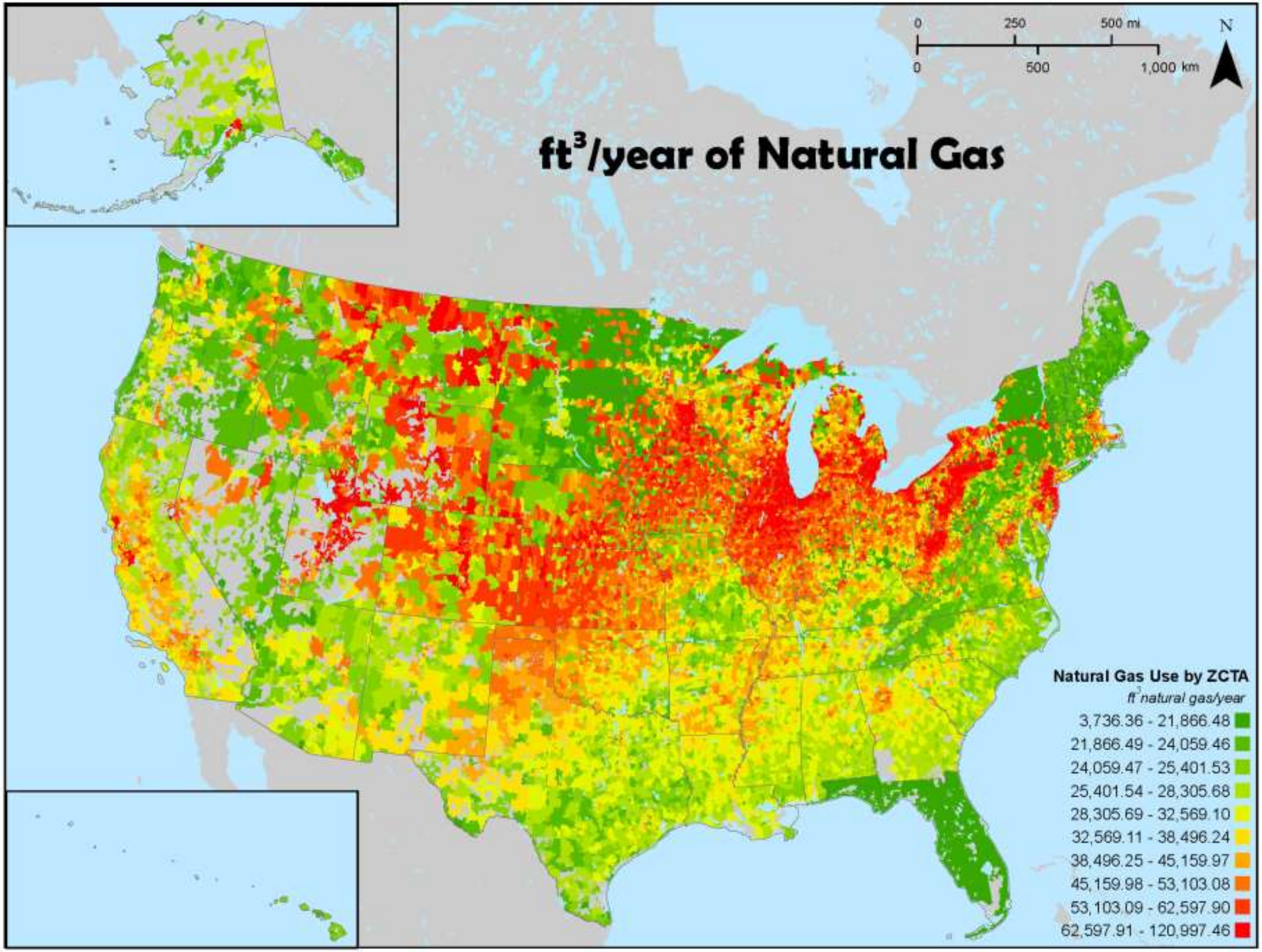
Spatial Distribution of U.S. Household Carbon Footprints Reveals Suburbanization Undermines Greenhouse Gas Benefits of Urban Population Density

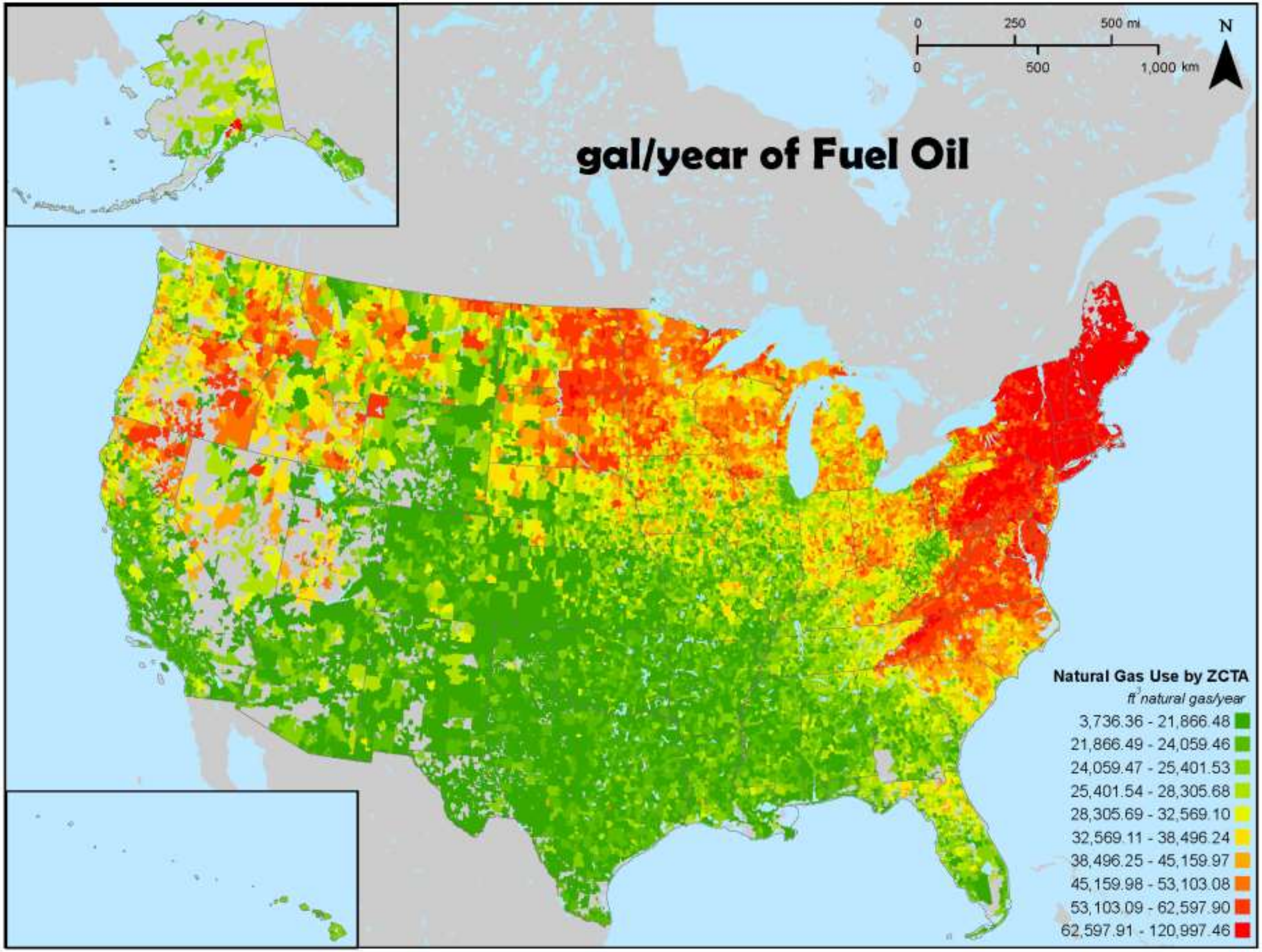
Christopher Jones*,[†] and Daniel M. Kammen*,[†,‡,§]

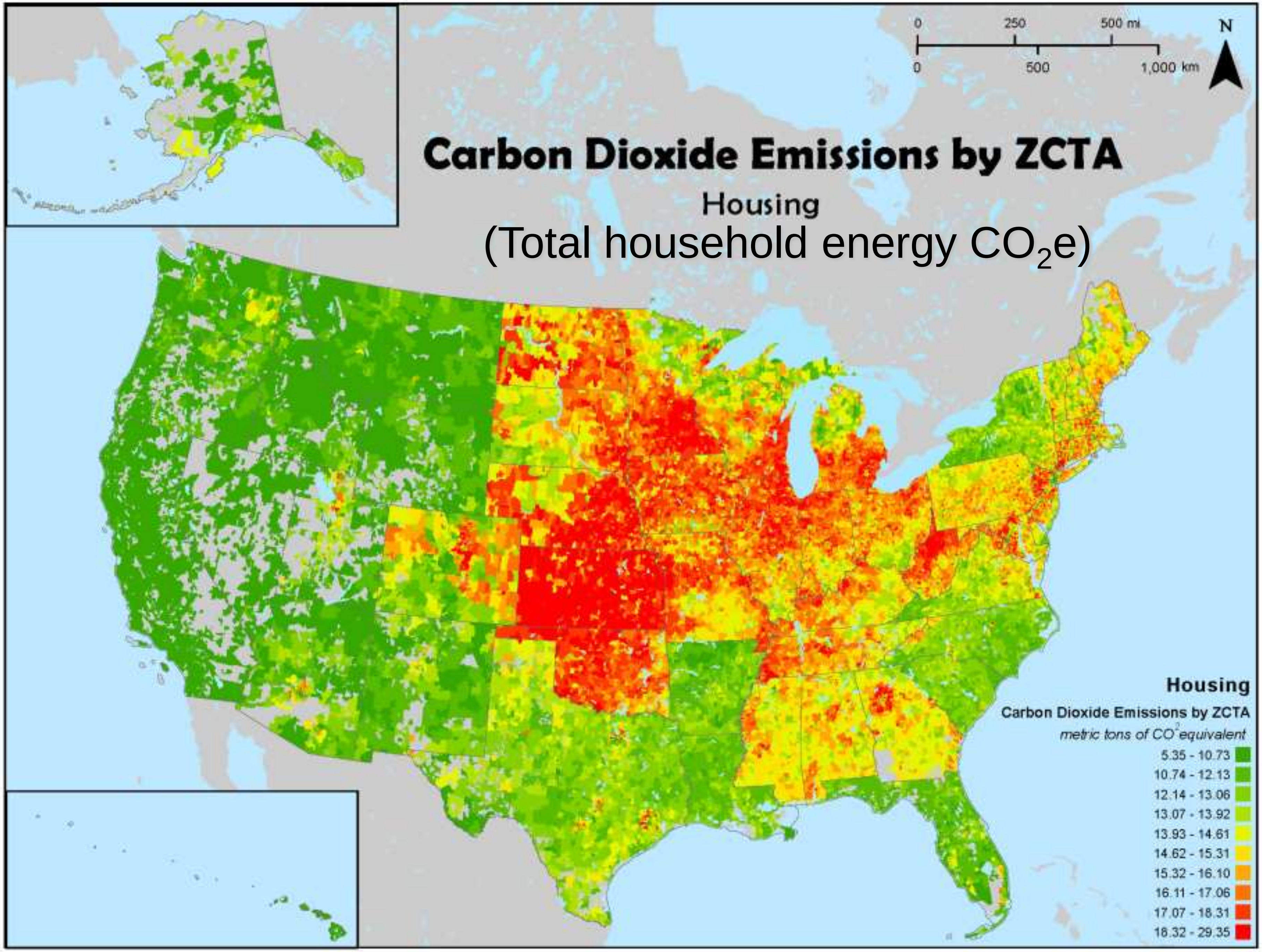
[†]Energy and Resources Group, [‡]Goldman School of Public Policy, and [§]Department of Nuclear Engineering, University of California, Berkeley, California 94720, United States

http://coolclimate.berkeley.edu/maps

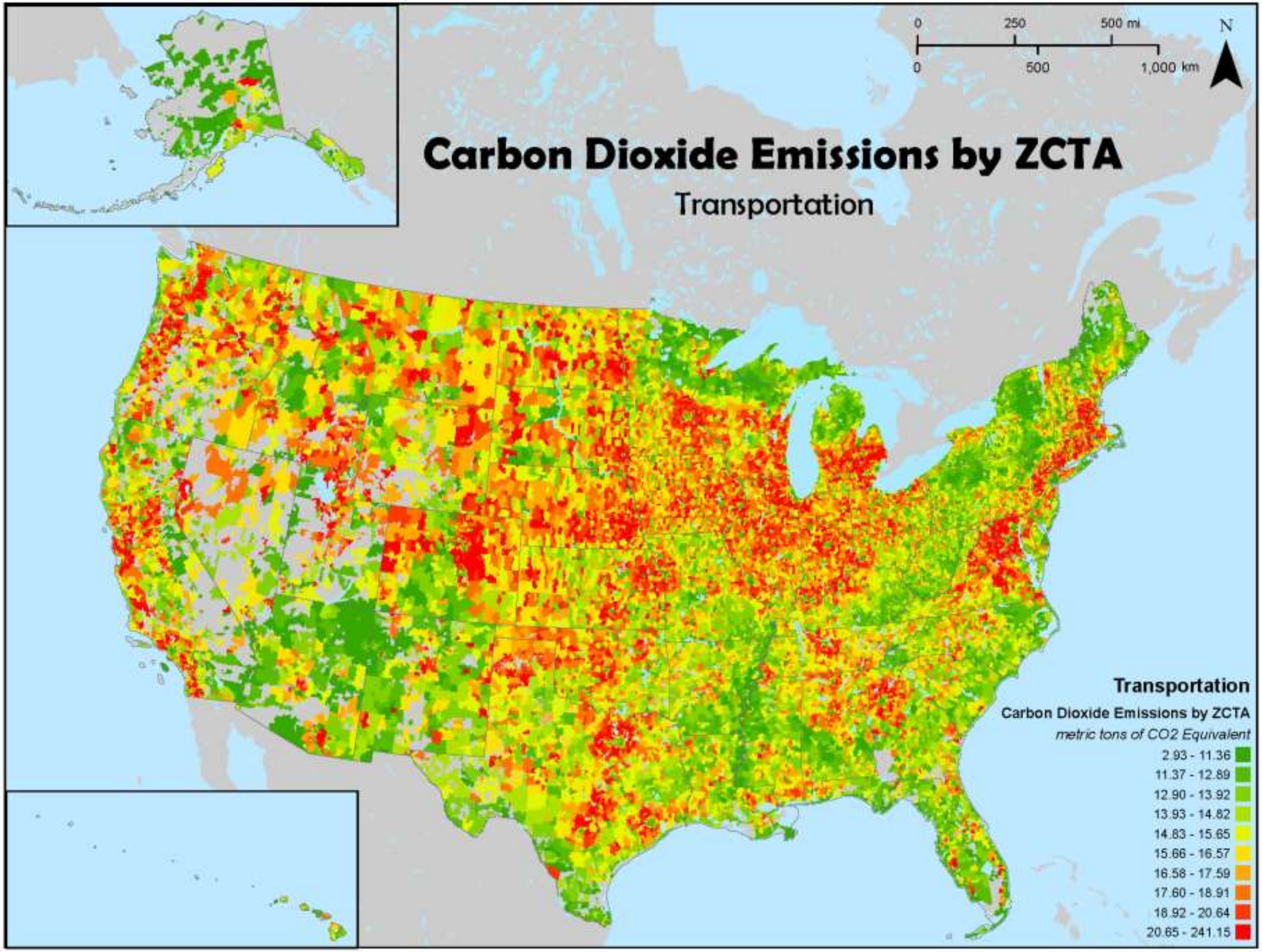

kWh/year by ZCTA
0
250
500 mi
0
500
1,000 km
N
Electricity Use by ZCTA
kWh/year
1,178.66 - 7,756.15
7,756.16 - 9,310.34
9,310.35 - 10,240.58
10,240.59 - 10,901.19
10,901.20 - 11,505.01
11,505.02 - 12,061.72
12,061.73 - 12,640.64
12,640.65 - 13,301.55
13,301.56 - 14,295.54
14,295.55 - 25,481.47


ft^3/year of Natural Gas
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft^3 natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46


gal/year of Fuel Oil
0
250
500 mi
0
500
1,000 km
N
Natural Gas Use by ZCTA
ft^3 natural gas/year
3,736.36 - 21,866.48
21,866.49 - 24,059.46
24,059.47 - 25,401.53
25,401.54 - 28,305.68
28,305.69 - 32,569.10
32,569.11 - 38,496.24
38,496.25 - 45,159.97
45,159.98 - 53,103.08
53,103.09 - 62,597.90
62,597.91 - 120,997.46

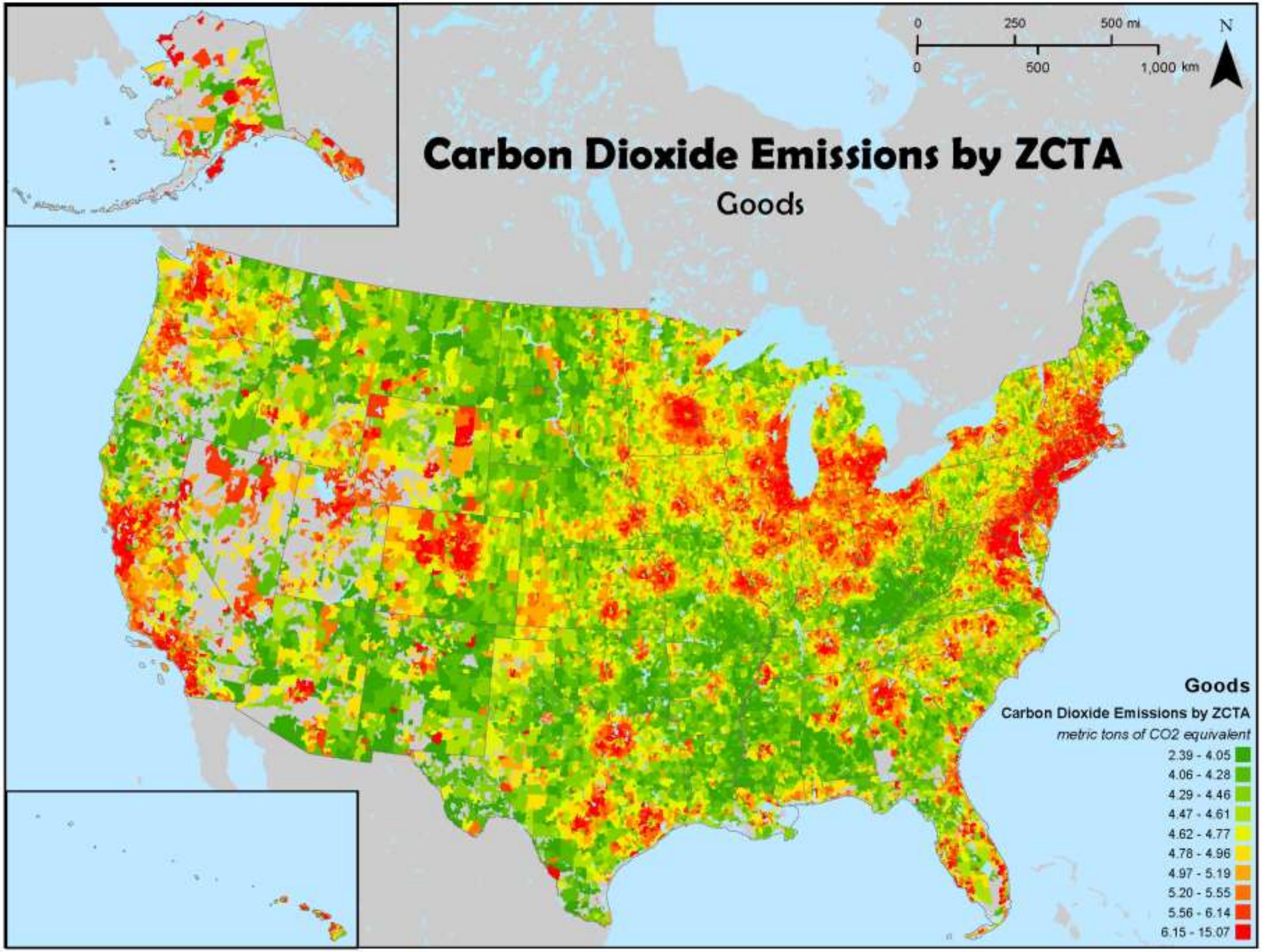


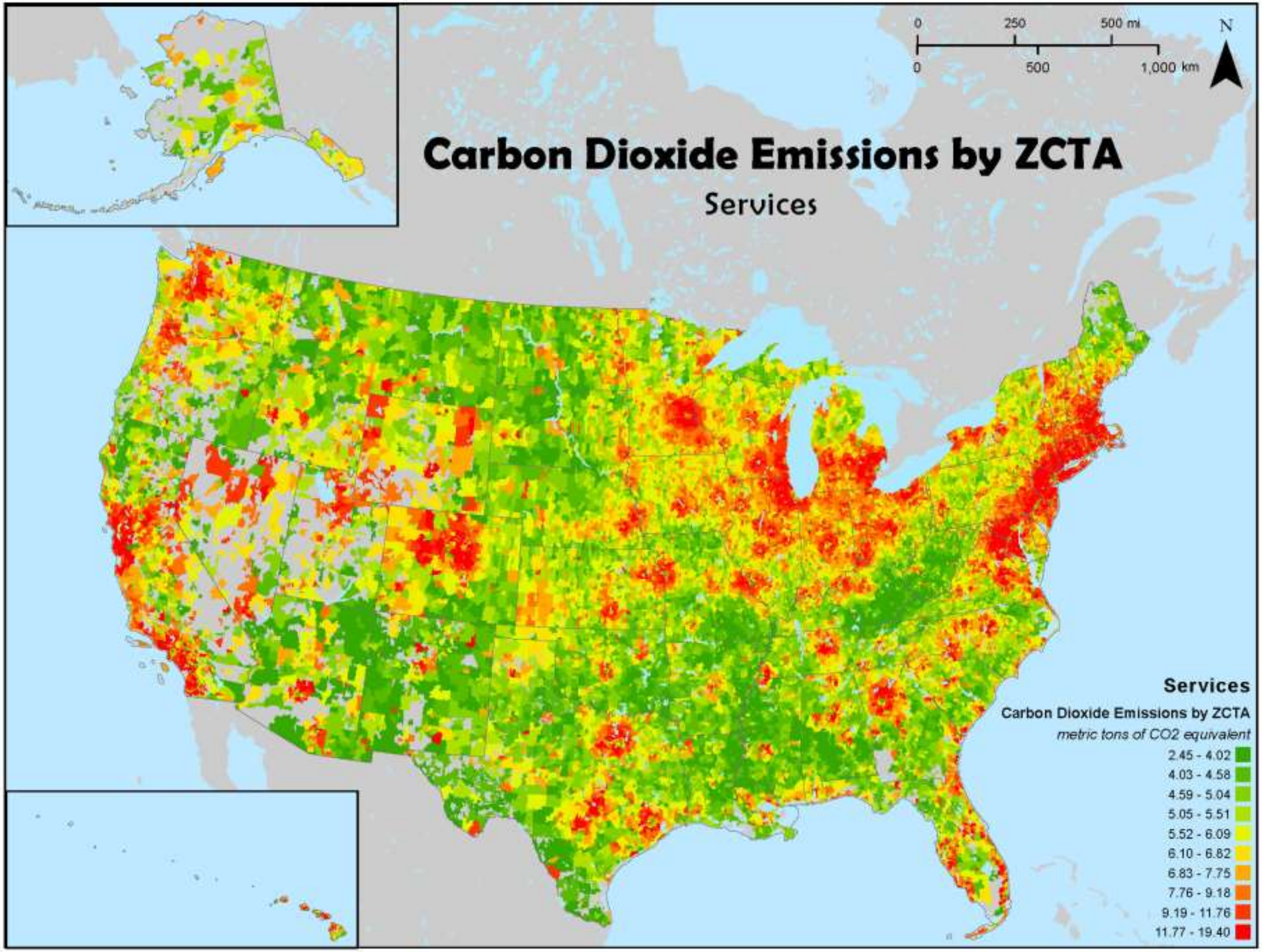
(Total household energy CO_2e)



Carbon Dioxide Emissions by ZCTA

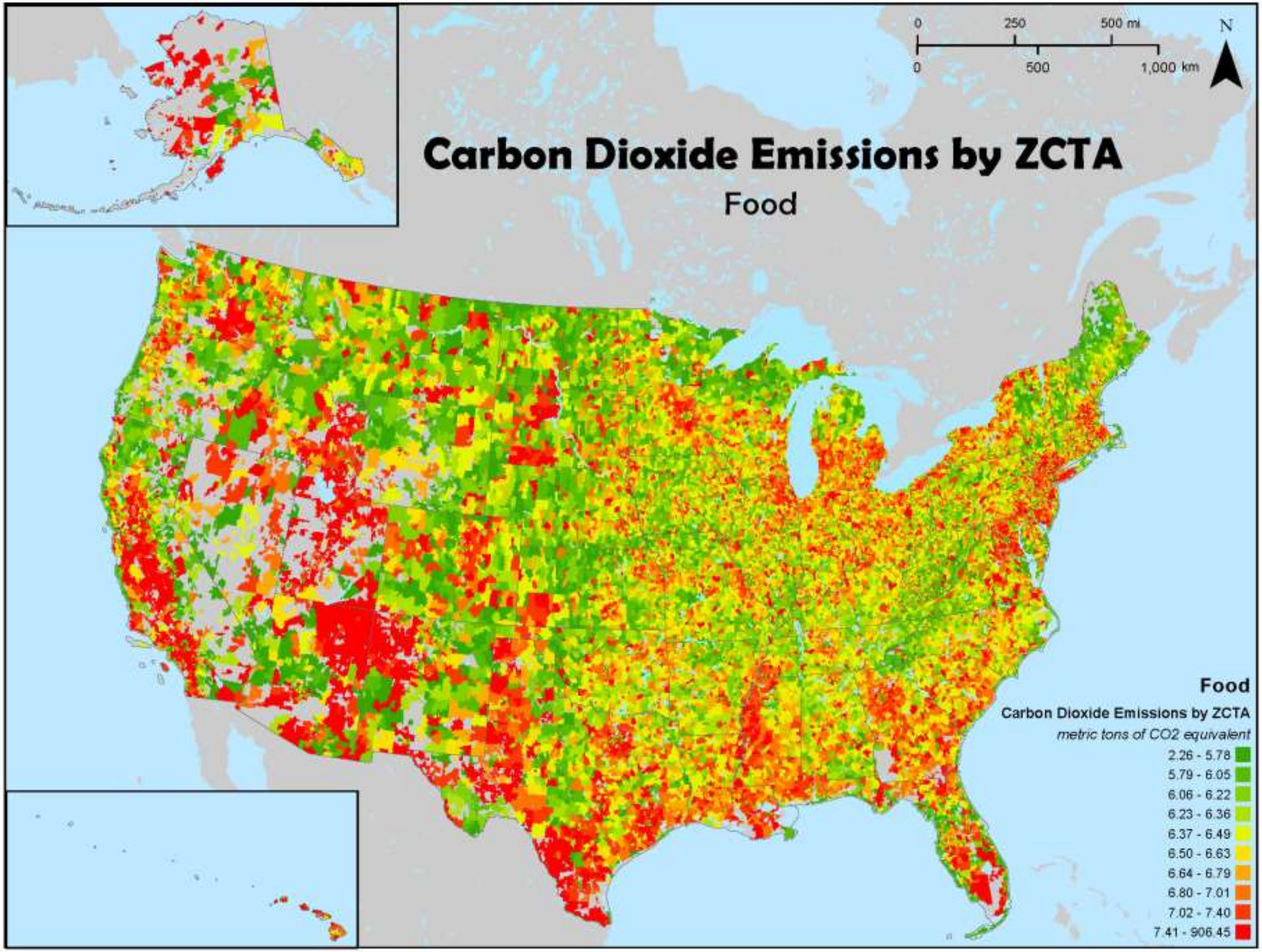
Transportation

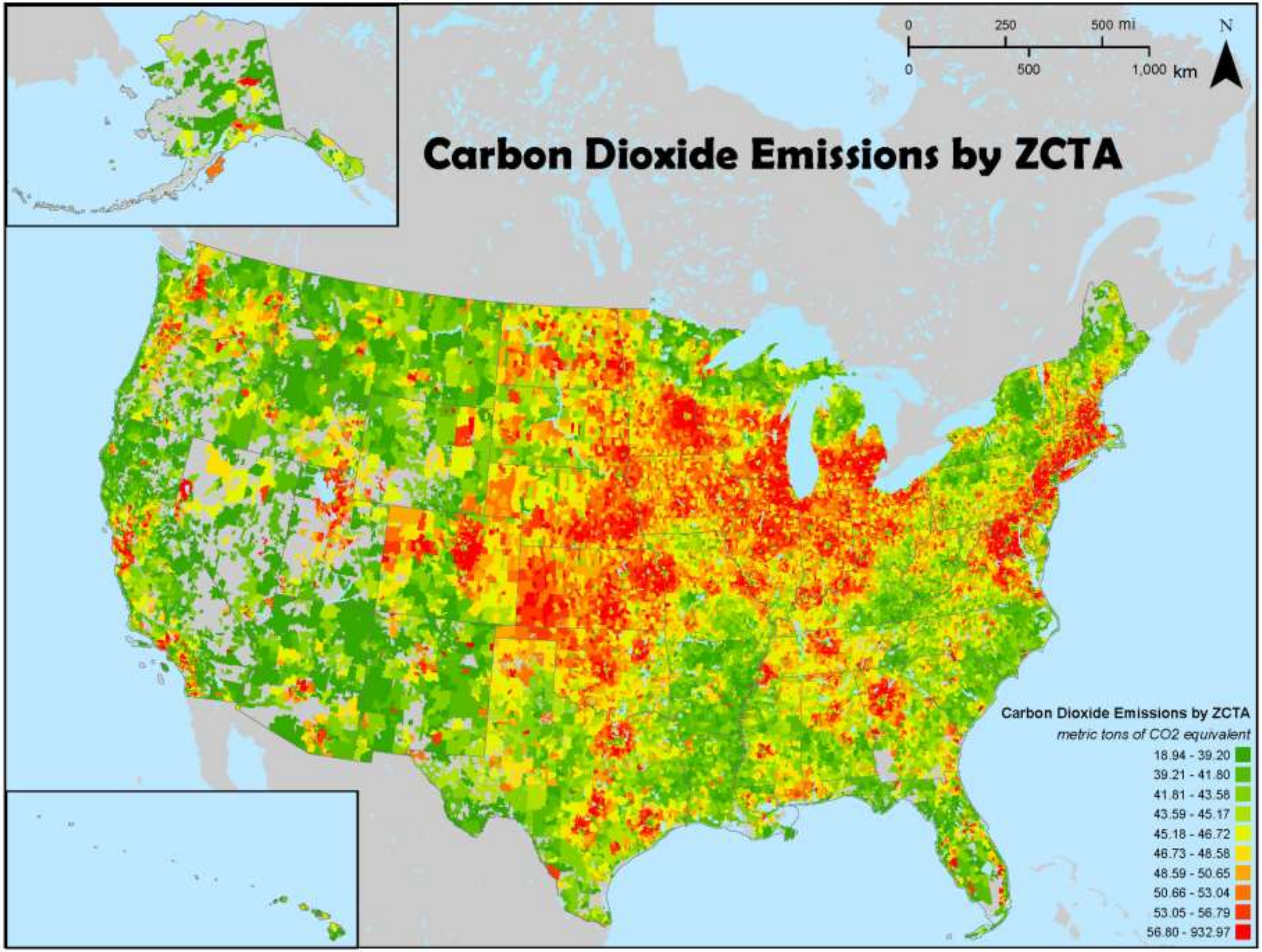

Carbon Dioxide Emissions by ZCTA
Goods
0
250
500 mi
0
500
1,000 km
N
Goods
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
2.39 - 4.05
4.06 - 4.28
4.29 - 4.46
4.47 - 4.61
4.62 - 4.77
4.78 - 4.96
4.97 - 5.19
5.20 - 5.55
5.56 - 6.14
6.15 - 15.07



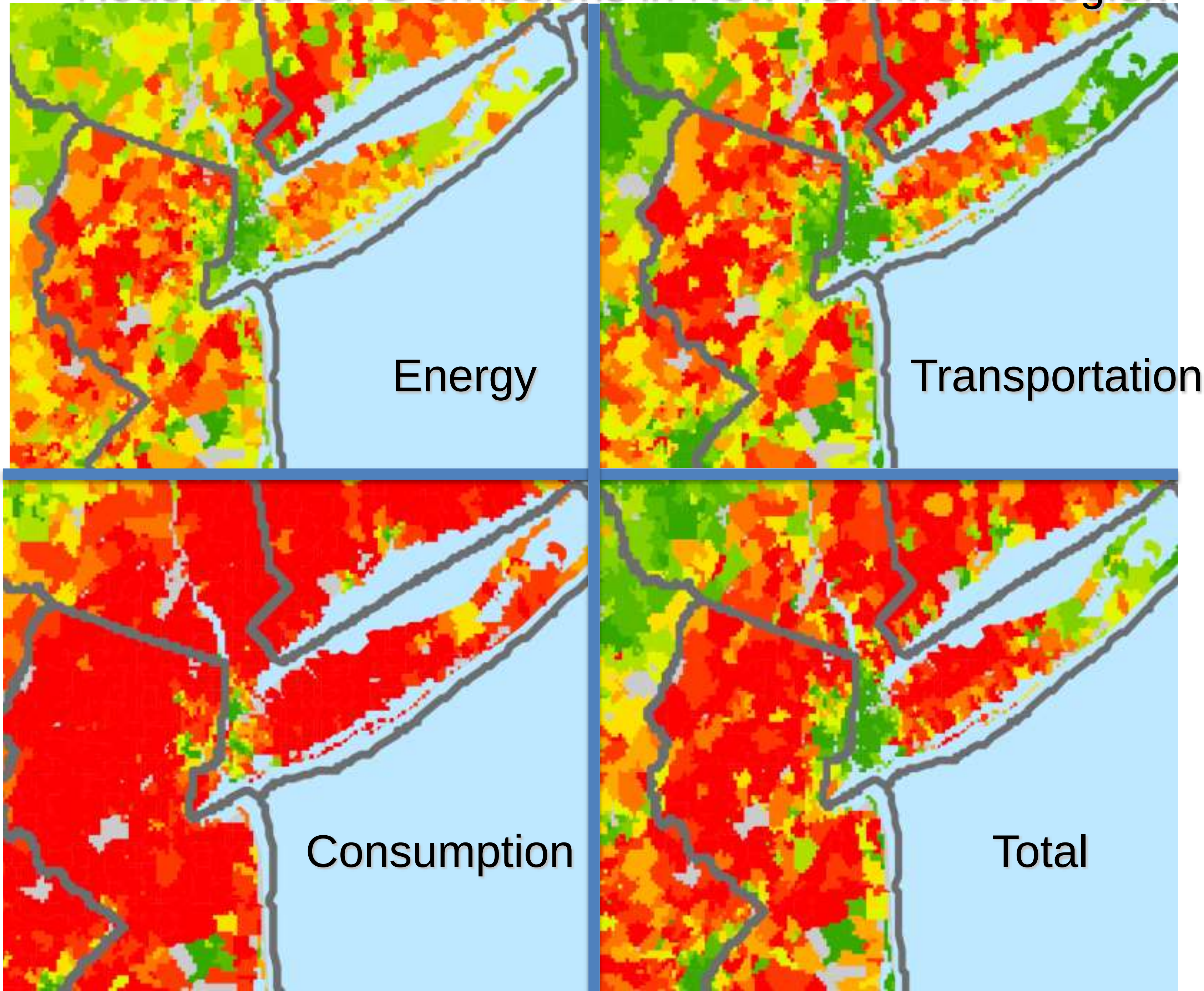
Carbon Dioxide Emissions by ZCTA

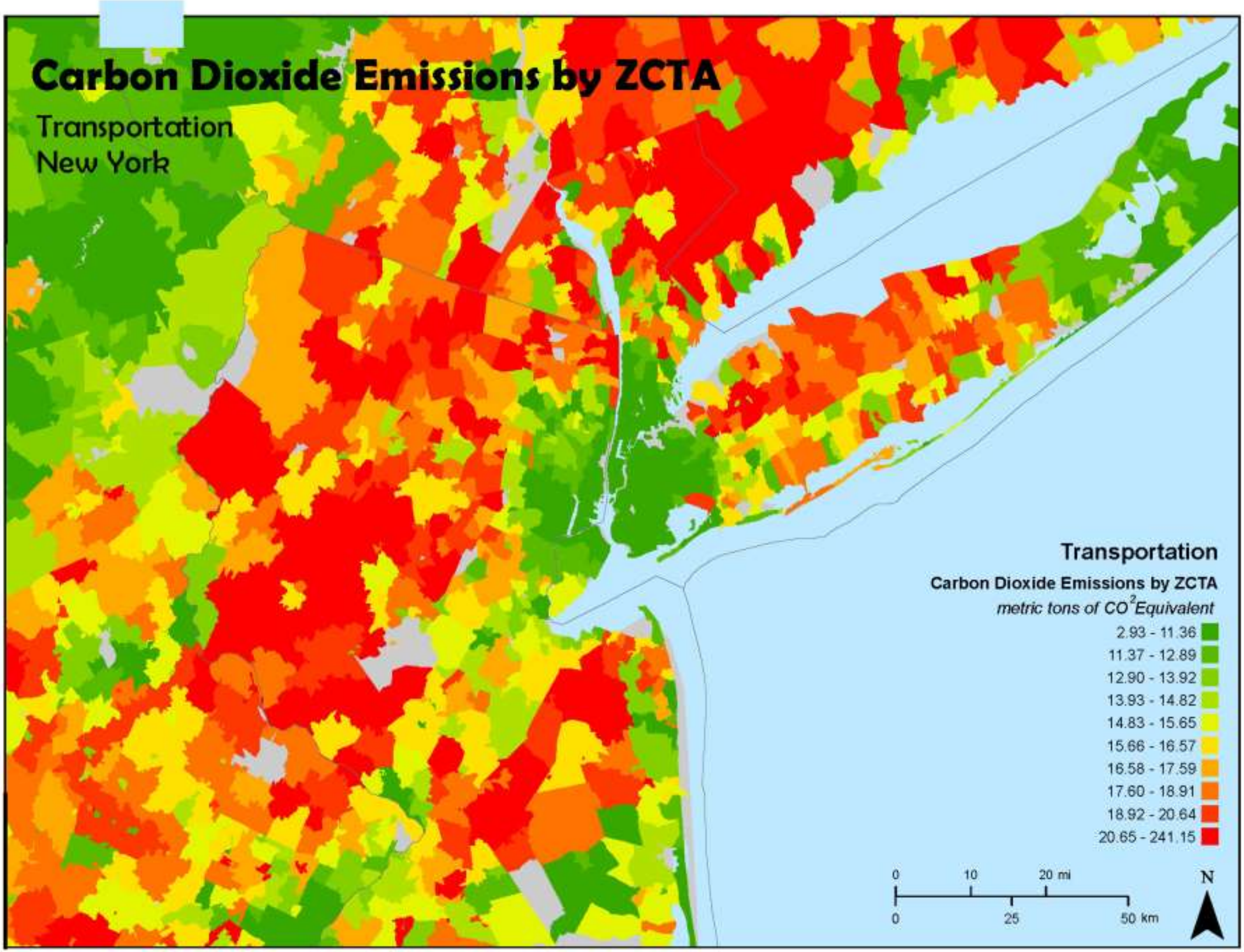
Services


Carbon Dioxide Emissions by ZCTA
Food
0
250
500 mi
0
500
1,000 km
N
Food
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
2.26 - 5.78
5.79 - 6.05
6.06 - 6.22
6.23 - 6.36
6.37 - 6.49
6.50 - 6.63
6.64 - 6.79
6.80 - 7.01
7.02 - 7.40
7.41 - 906.45


Carbon Dioxide Emissions by ZCTA
0
250
500 mi
0
500
1,000 km
N
Carbon Dioxide Emissions by ZCTA
metric tons of CO2 equivalent
18.94 - 39.20
39.21 - 41.80
41.81 - 43.58
43.59 - 45.17
45.18 - 46.72
46.73 - 48.58
48.59 - 50.65
50.66 - 53.04
53.05 - 56.79
56.80 - 932.97

Household GHG emissions in New York Metro Region

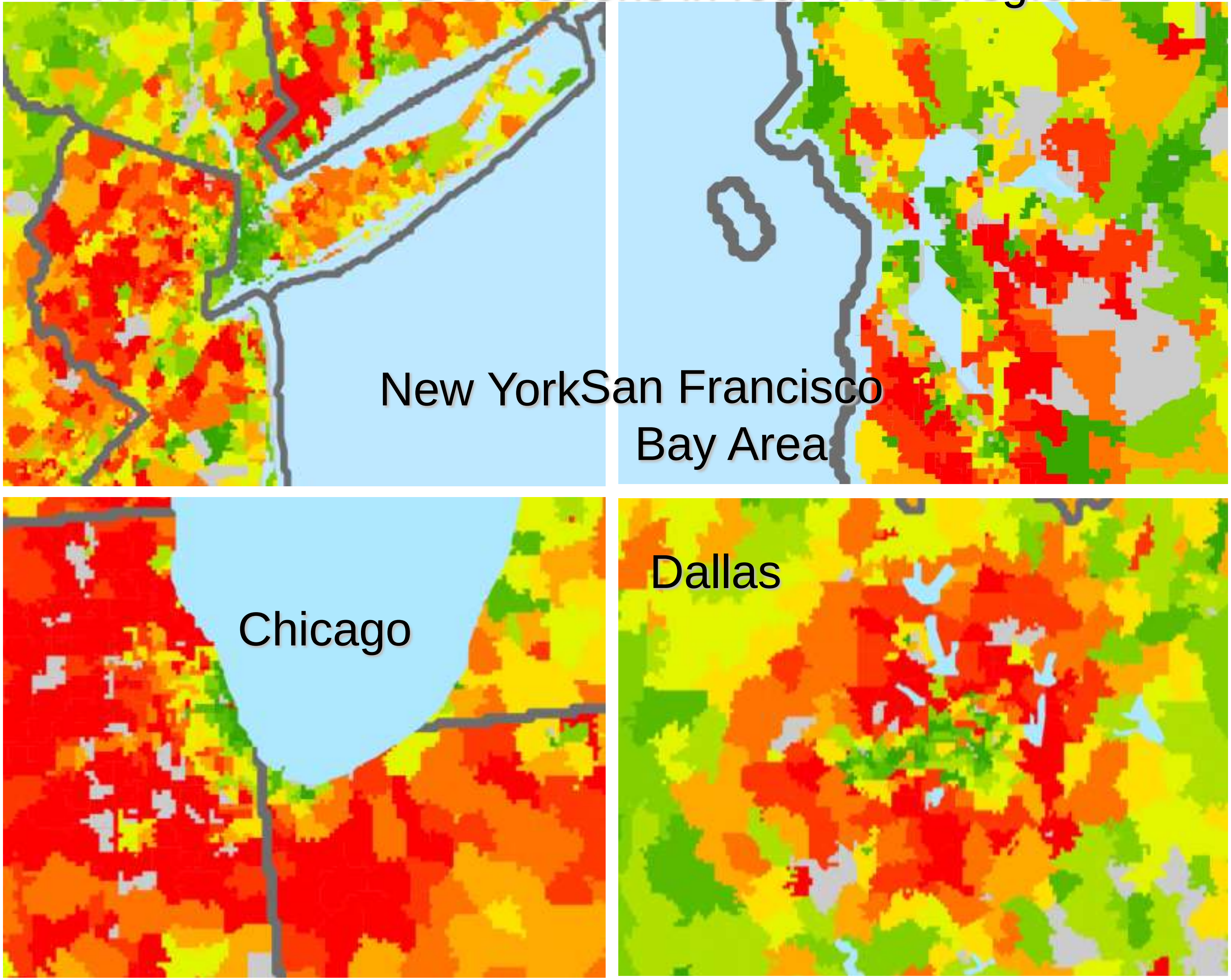




Carbon Dioxide Emissions by ZCTA

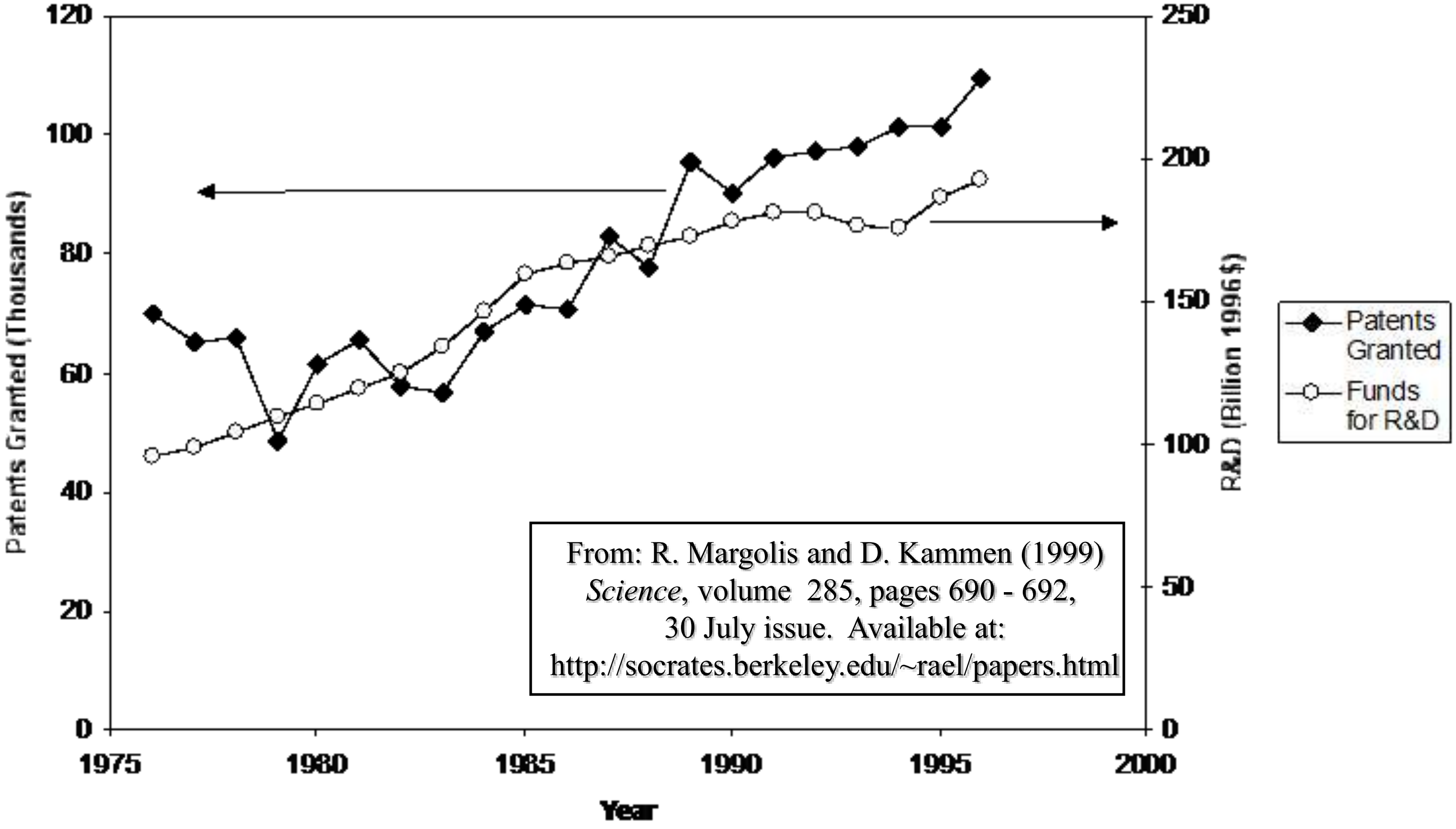
Transportation
New York

Household GHG emissions in four metro regions



Federal R&D Policy Can be Effective

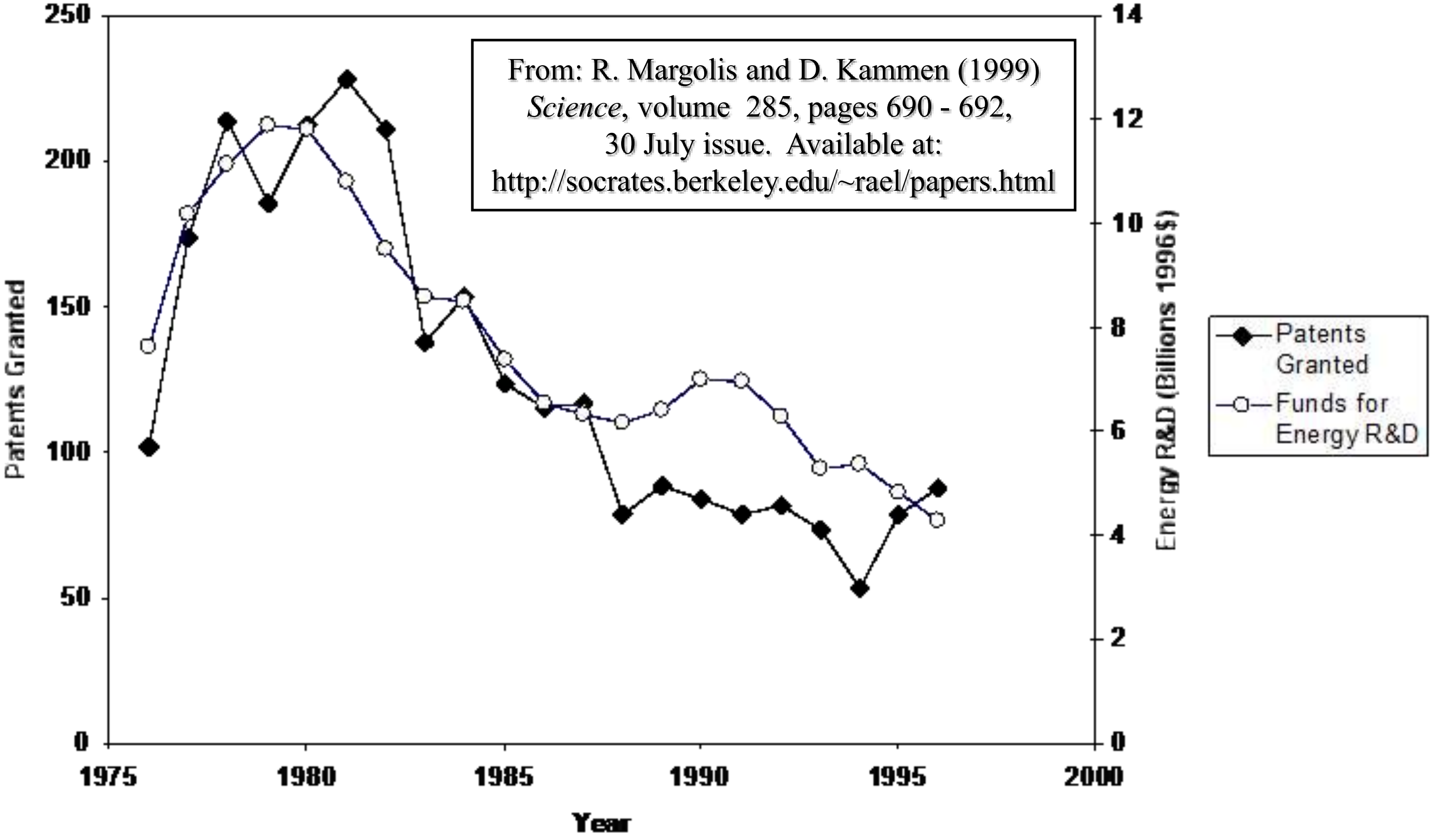
Figure 1. Total U.S. patents granted and total U.S. investments in R&D.



From: R. Margolis and D. Kammen (1999) *Science*, volume 285, pages 690 - 692, 30 July issue. Available at: http://socrates.berkeley.edu/~rael/papers.html

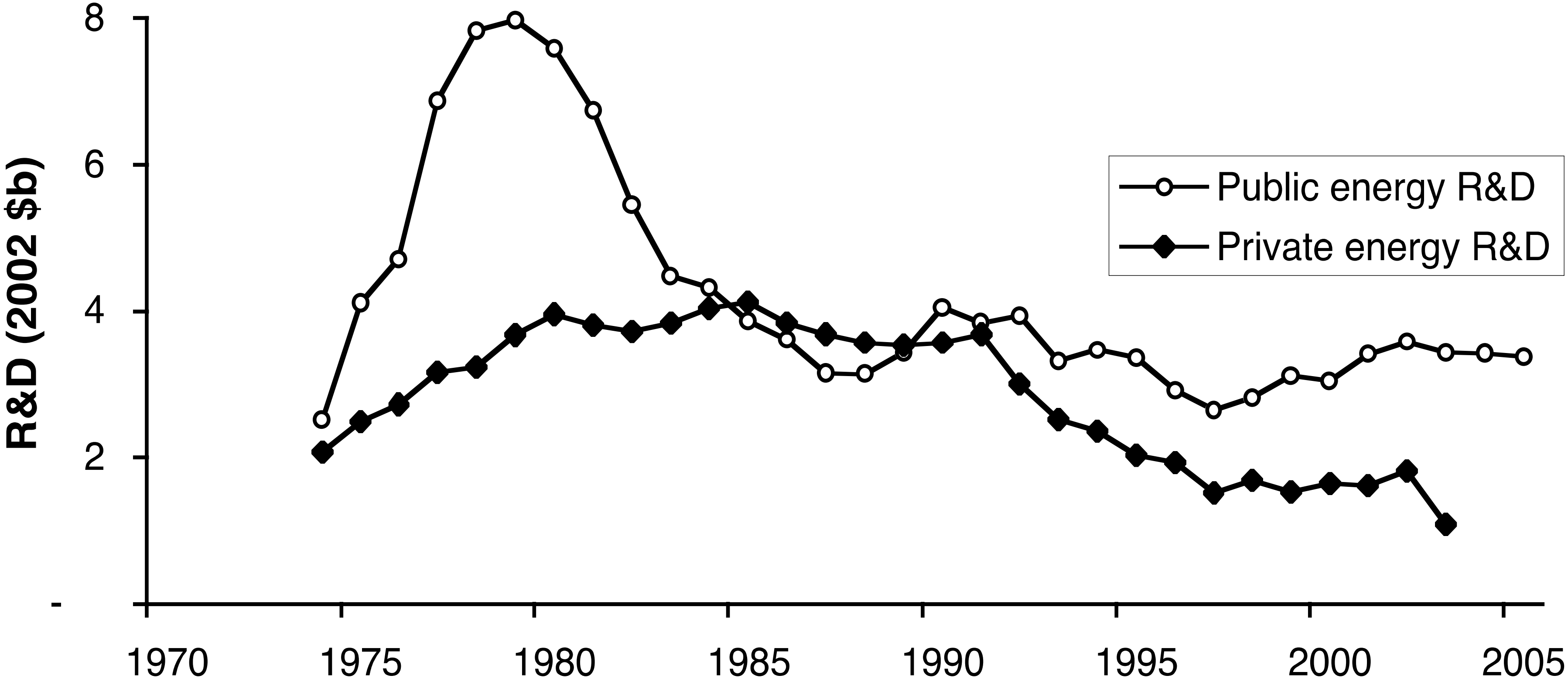
Lack of Federal R&D policy… leads to lack of support for energy options

Figure 2. U.S. energy technology patents and total U.S. energy R&D.



From: R. Margolis and D. Kammen (1999) *Science*, volume 285, pages 690 - 692, 30 July issue. Available at: http://socrates.berkeley.edu/~rael/papers.html

If you think US public sector energy R&D funding is doing poorly …



Kammen & Nemet (2005)

What, you don't read the North Borneo Post?

HOME THE BORNEO POST Sunday, March 21, 2010 A5

Biomass can replace coal – Professor

By Sandra Sokial

KOTA KINABALU: Palm oil mill waste, or commonly known as biomass, can feasibly be used to replace coal as a source of energy in Sabah.

Dr Daniel M Kammen, a professor of energy at the University of California, Berkeley, disclosed this in his talk during a forum on Energy Options for Sabah here yesterday.

He said biomass presented an attractive electricity supply option and should continue to receive support from the government and utilities.

Kammen, who carried out a study on clean energy options for Sabah, said that biomass waste projects were cost competitive compared with coal, adding that it also solved two environmental problems at once.

"One is the problem of disposing of potentially hazardous mill waste in open ponds and landfills and the problem of supplying Sabah's energy demand," he said.

Several oil palm mills in Sabah have already adopted the project and a number of national incentives are aimed to stimulate further investments.

Kammen said based on the 2008 palm oil industry production statistics and conservative growth estimates, they calculated that 700MW of theoretical baseload capacity was economically feasible and logistically achievable via a four-project per-year ramp-up programme. "We recommend that Sabah support this project," he said.

During the study, Kammen, Tyler McNish and Benjamin Gutierrez also carried out a research on other energy options such as hydropower, solar, wind, geothermal and demand-side energy efficiency.

He also recommended phasing out fossil-fuel subsidies that distort energy markets and the 10MW limit on investment under the small renewable energy power programme be repealed.

"There should be continued research and outreach efforts targeted at increasing the quantity of grid-connected electricity available from palm oil mills besides recognising renewable energy status as a premium product.

"It is also important to continue studying the feasibility of renewable investments at known geothermal, wind and environmentally-sound micro hydro sites," he said.

In addition to this, Kammen said the continuation and extension of Malaysia's existing solar promotion programmes should be continued, and supplement these efforts by launching a state-level solar energy commission.

Another speaker, Adrian Lasimbang of the Pacos Trust, believes that Sabah should be a role model and spearhead the development of renewable energy (RE) in Malaysia.

Also touching on biomass as another option to electricity supply, he said there were over 110 oil palm mills in Sabah, and were mainly located in the east coast of the state.

"With such numbers, there is abundance of biomass waste which could be used for power supply thus reducing the electricity shortage faced by the people in the east coast of Sabah.

"We have initiated several projects in several villages to utilise agro-based waste as alternative to power supply. It helps to generate jobs for the villagers and other support services, such as transportation," he said.

About 400 people attended the forum which was organised by Green Surf.

Adrian Lasimbang

Dr Daniel M Kammen

The public participating in the question-and-answer session with the experts during the forum yesterday.

Integrating these systems tools with civil society-industry dialog

TIME
Science

Borneo Says No to Dirty Energy
By Jennifer Pinkowski Tuesday, Feb. 22, 2011

Daniel Kammen of the University of California, Berkeley, who directed an energy and environmental-impact study commissioned by a coalition of green groups, which was used widely in the discussions of Sabah's energy options. "It is a turning point that should bring deserved praise and partnerships to Malaysia at the upcoming climate conference in Durban, South Africa,"

http://www.time.com/time/health/article/0,8599,2052627,00.html#ixzz1lvOeiiyz

Resource Assessments

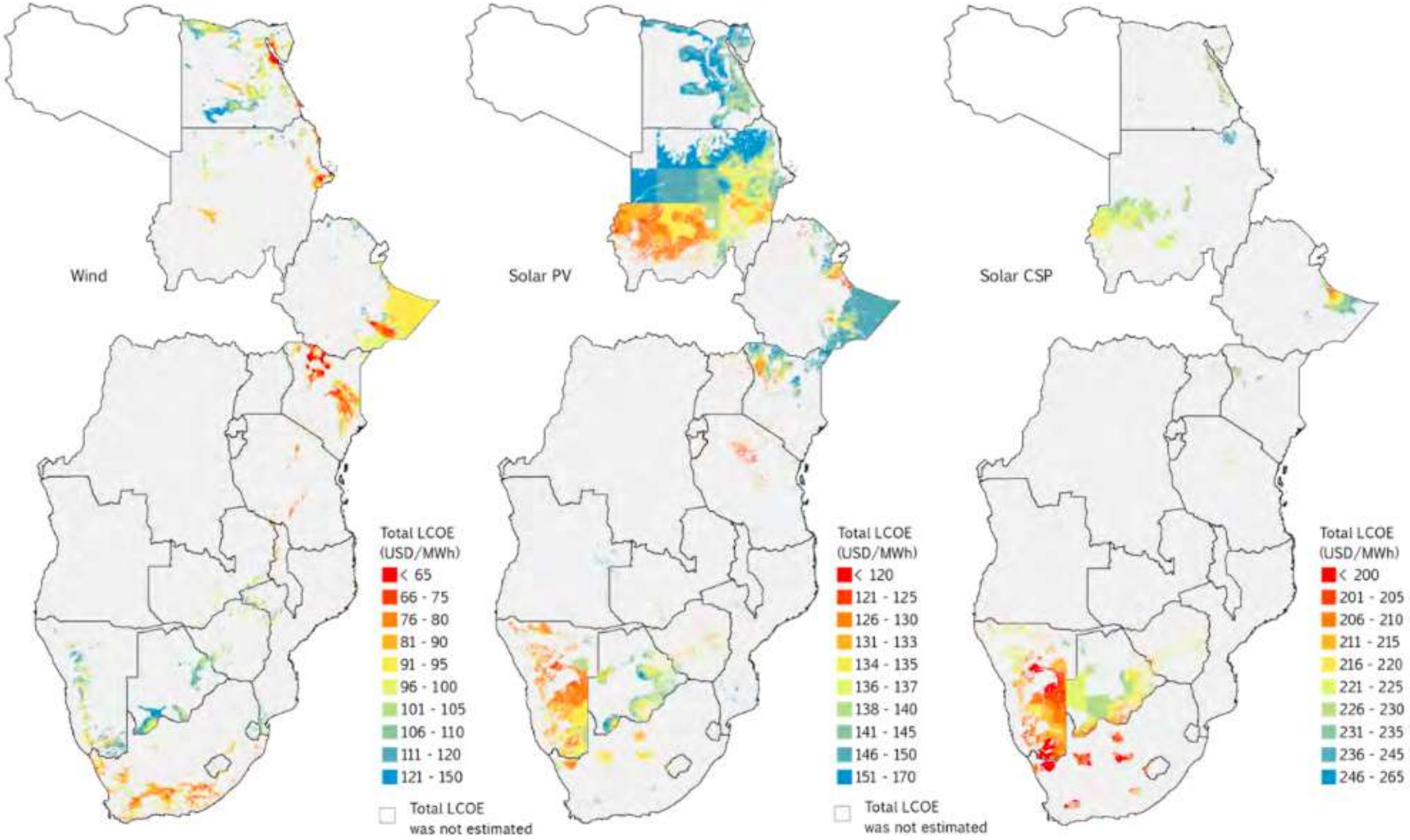


FIGURE 1: Average total levelized cost of electricity (LCOE) of wind (A), solar PV (B), and solar CSP (C) zones estimated using resource quality, distance to the nearest transmission line or substation, and distance to the nearest road.

Outline:

1. Climate science: The 2 degree mandate agreed to in Paris

2. What tools do we have? [Technology]

3. The climate-development nexus
    1. The energy access crisis
    2. Land and people

4. **Your mission:**
   create a national strategy for energy and development for the 2016 climate meeting in Morocco

5. Compare the options

Outline:

1. Climate science: The 2 degree mandate agreed to in Paris

2. What tools do we have?

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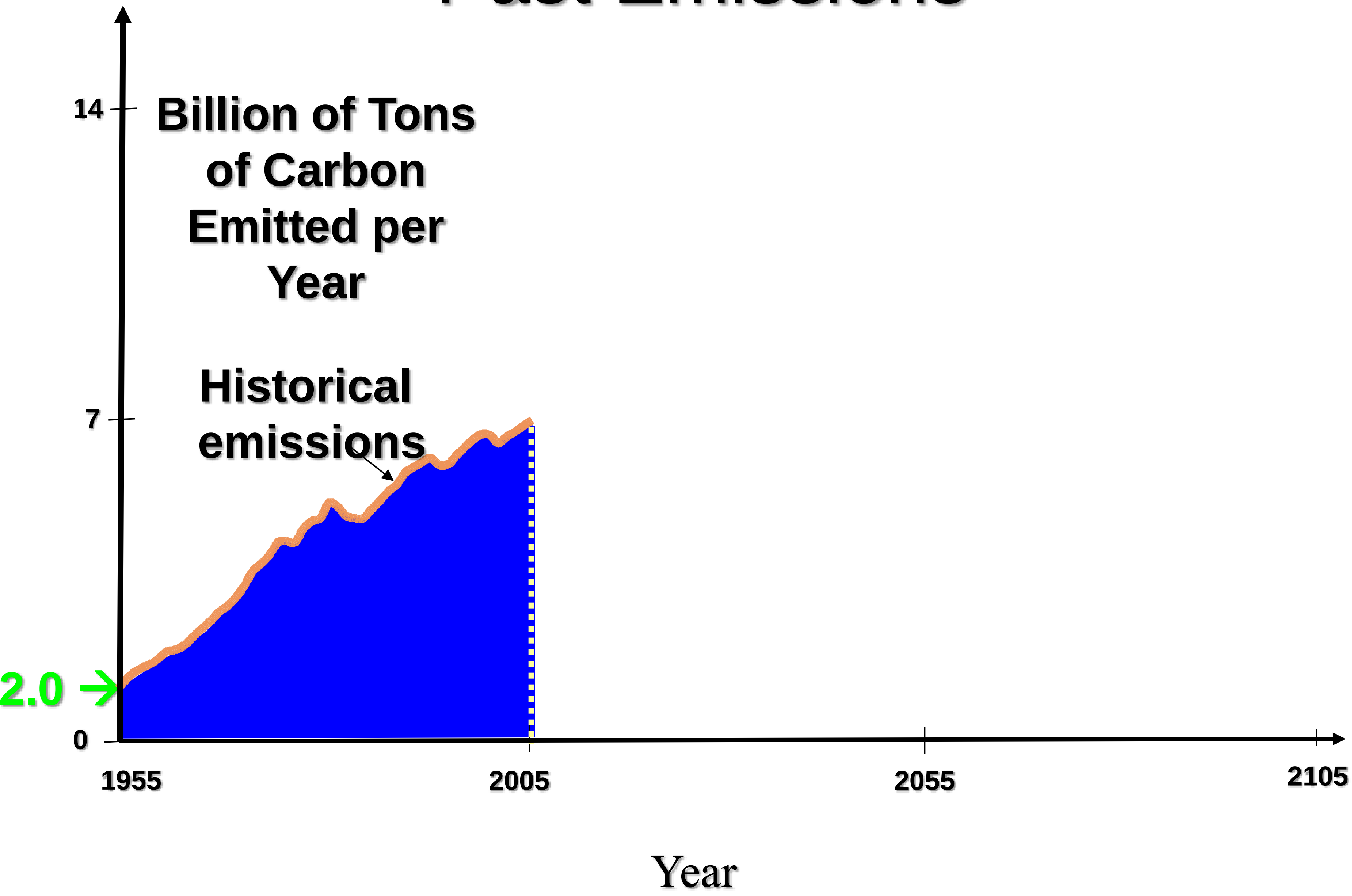
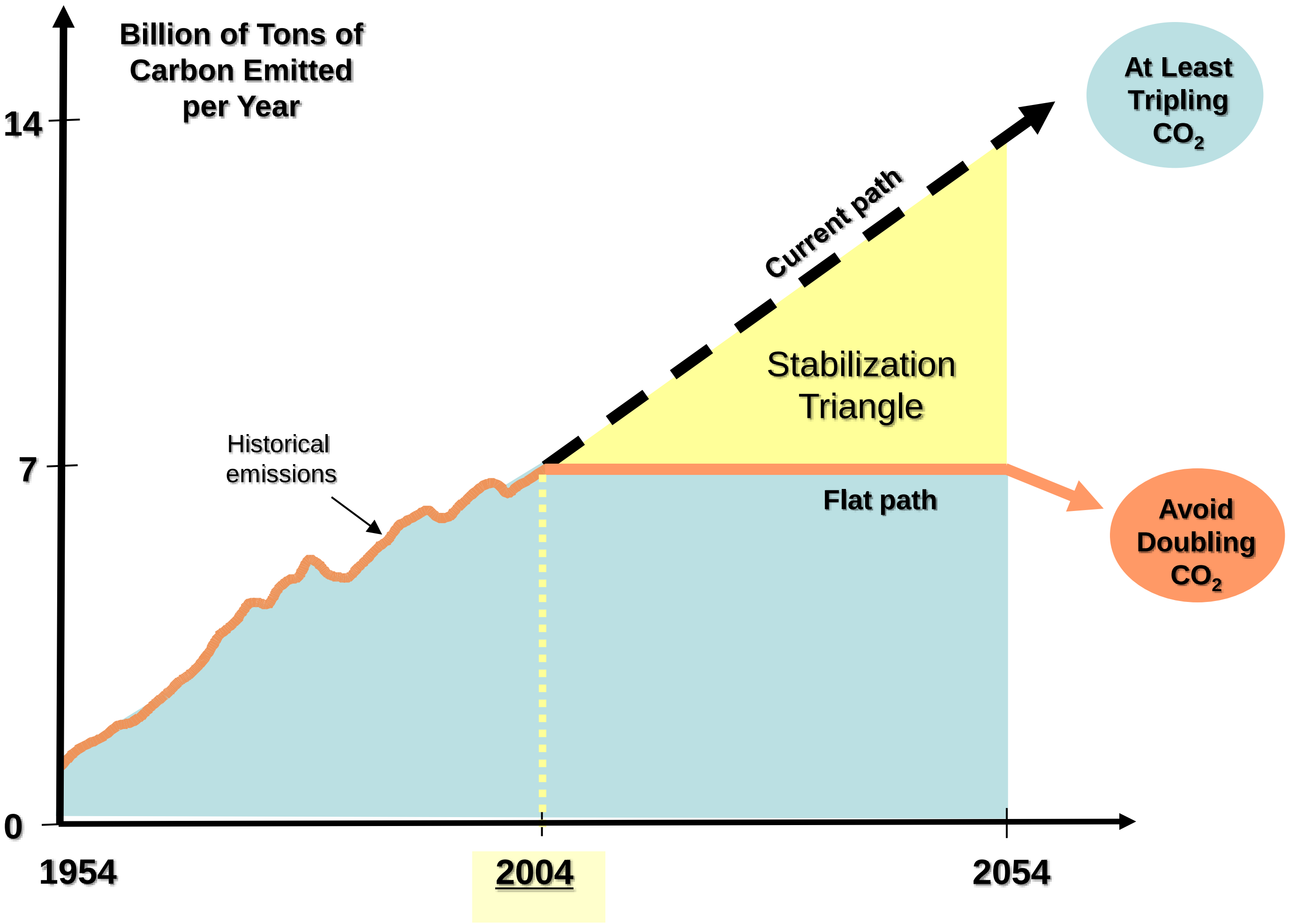
    1. The energy access crisis
    2. Land and people

4. **Your mission:**
   create a national strategy for energy and development for the 2016 climate meeting in Morocco

5. Compare the options

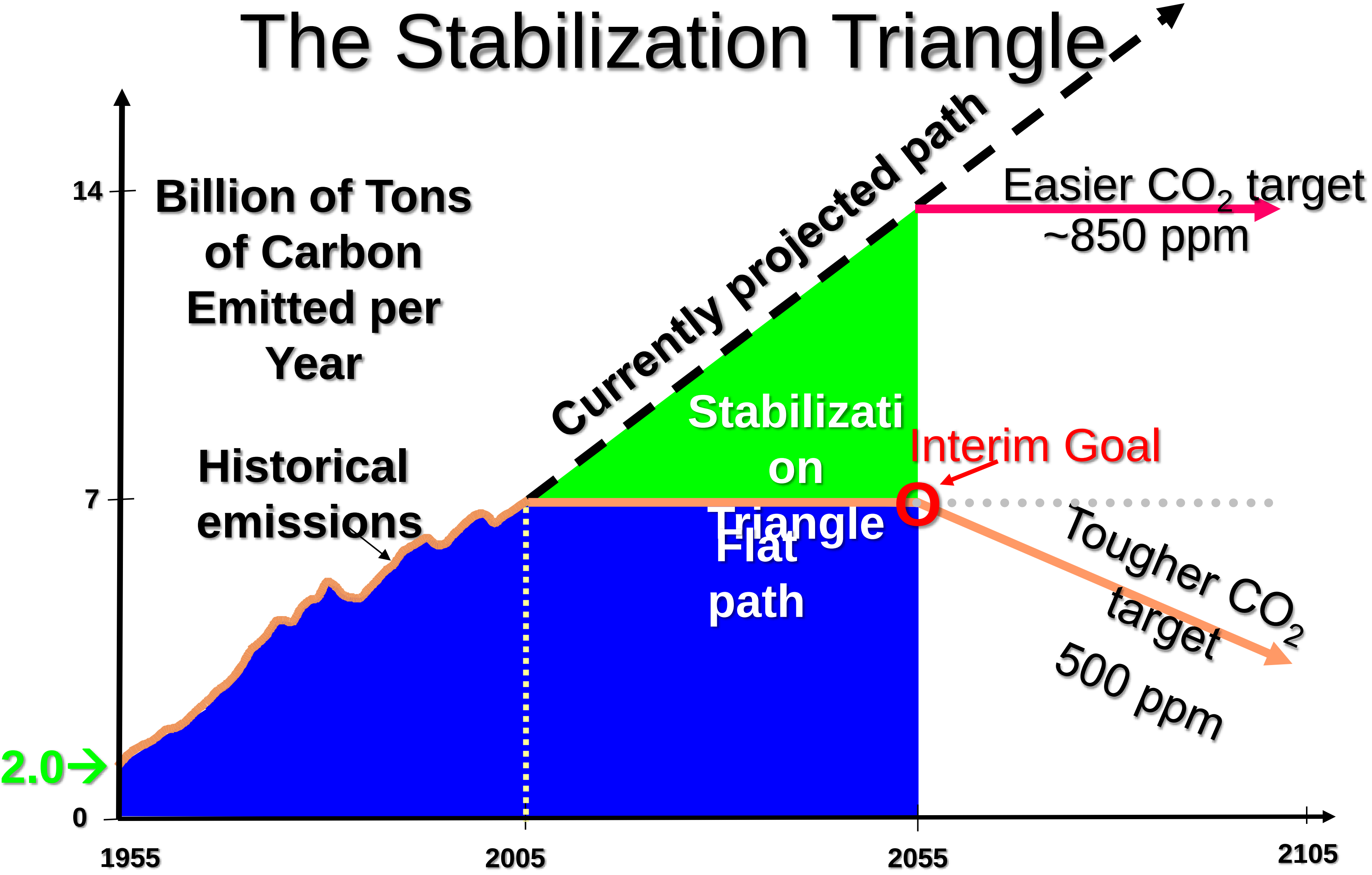
Past Emissions



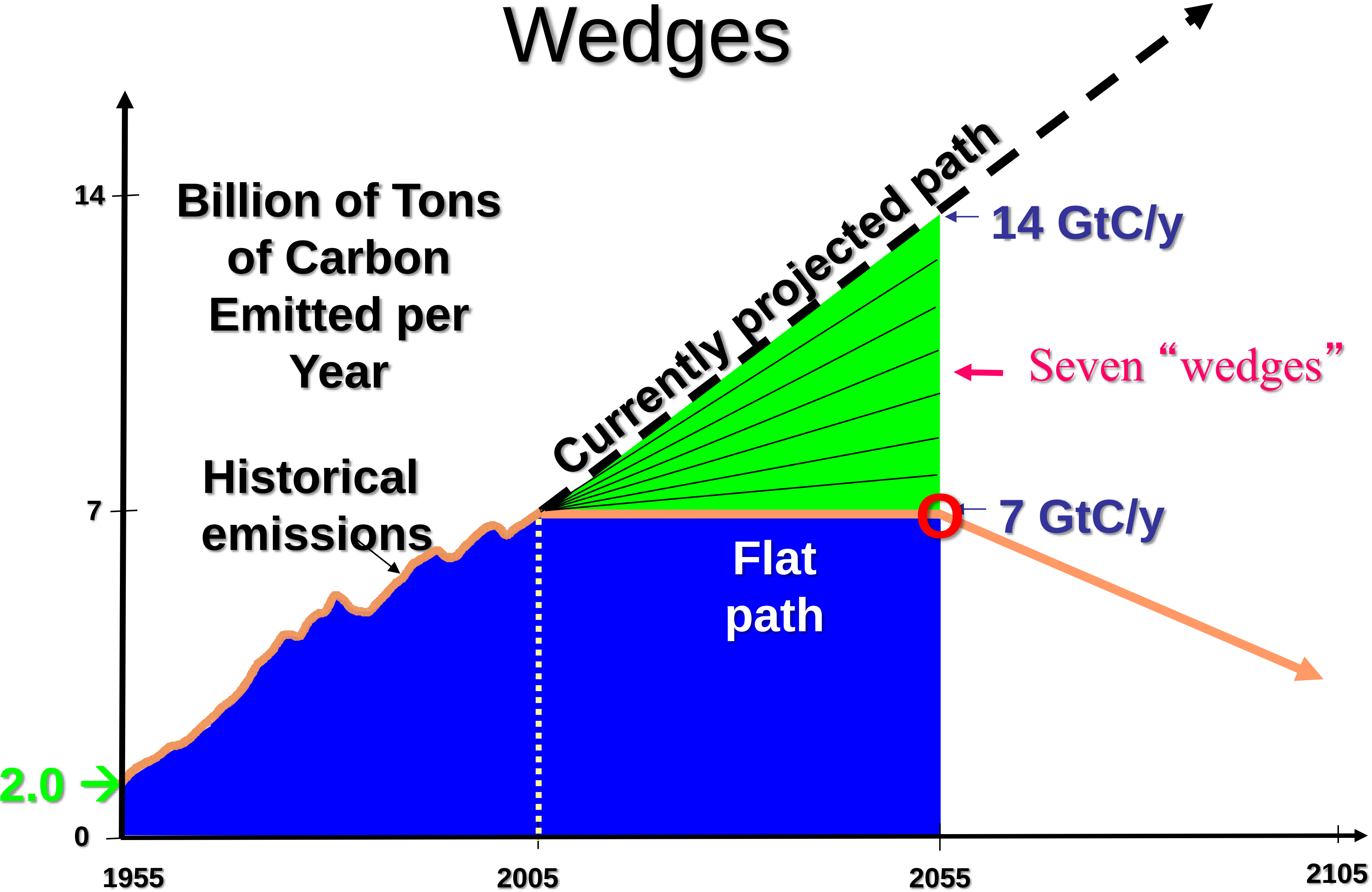


What does it mean to 'solve the carbon and climate problem' over the next 50 years?

The Stabilization Triangle

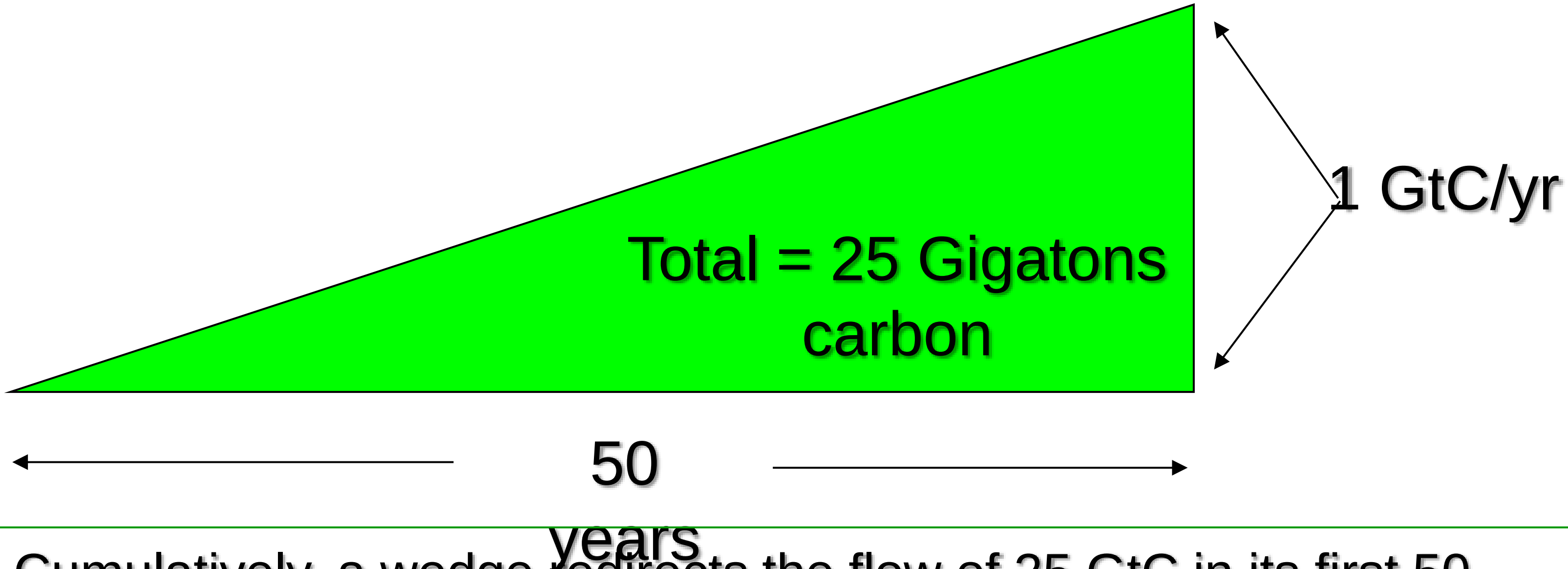


Wedges


14
7
0
2.0 →
Billion of Tons of Carbon Emitted per Year
Historical emissions
Currently projected path
14 GtC/y
Seven "wedges"
7 GtC/y
O
Flat path
1955
2005
2055
2105

What is a “Wedge”?

A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A “solution” to the CO_2 problem should provide at least one wedge.

Wedges #1 - #8 (out of 15)

	Option	**Effort by 2054 for one wedge, relative to 14 GtC/year BAU**	**Comments, issues**
Energy Efficiency and Conservation	Economy-wide carbon-intensity reduction (emissions/$GDP)	Increase reduction by additional 0.15% per year (e.g., increase U.S. goal of reduction of 1.96% per year to 2.11% per year)	Can be tuned by carbon policy
	1. Efficient vehicles	Increase fuel economy for 2 billion cars from 30 to 60 mpg	Car size, power
	2. Reduced use of vehicles	Decrease car travel for 2 billion 30-mpg cars from 10,000 to 5,000 miles per year	Urban design, mass transit, telecommuting
	3. Efficient buildings	Cut carbon emissions by one-fourth in buildings and appliances projected for 2054	Weak incentives
	4. Efficient baseload coal plants	Produce twice today's coal power output at 60% instead of 40% efficiency (compared with 32% today)	Advanced high-temperature materials
Fuel shift	**5.** Gas baseload power for coal baseload power	Replace 1400 GW 50%-efficient coal plants with gas plants (4 times the current production of gas-based power)	Competing demands for natural gas
CO_2 Capture and Storage (CCS)	**6.** Capture CO_2 at baseload power plant	Introduce CCS at 800 GW coal or 1600 GW natural gas (compared with 1060 GW coal in 1999)	Technology already in use for H_2 production
	7. Capture CO_2 at H_2 plant	Introduce CCS at plants producing 250 MtH_2/year from coal or 500 MtH_2/year from natural gas (compared with 40 MtH_2/year today from all sources)	H_2 safety, infrastructure
	8. Capture CO_2 at coal-to-synfuels plant	Introduce CCS at synfuels plants producing 30 million barrels per day from coal (200 times Sasol), if half of feedstock carbon is available for capture	Increased CO_2 emissions, if synfuels are produced *without* CCS
	Geological storage	Create 3500 Sleipners	Durable storage, successful permitting

Wedges #9 - #15 (out of 15)

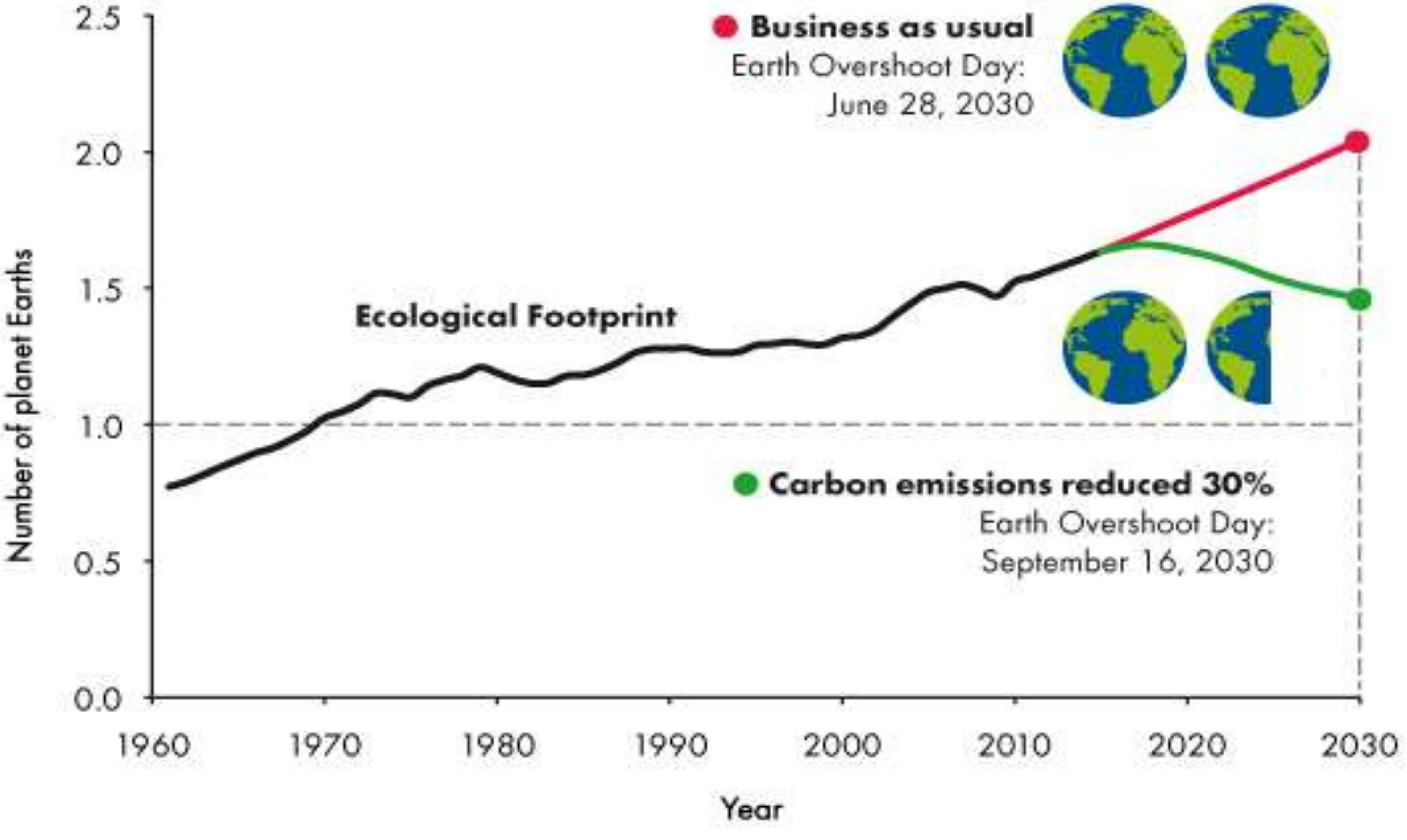
	Option	**Effort by 2054 for one wedge, relative to 14 GtC/year BAU**	**Comments, issues**
Nuclear Fission	**9.** Nuclear power for coal power	Add 700 GW (twice the current capacity)	Nuclear proliferation, terrorism, waste
Renewable Electricity and Fuels	**10.** Wind power for coal power	Add 2 million 1-MW-peak windmills (50 times the current capacity) “occupying” 30x10^6 ha, on land or off shore	Multiple uses of land because windmills are widely spaced
	11. PV power for coal power	Add 2000 GW-peak PV (700 times the current capacity) on 2x10^6 ha	PV production cost
	12. Wind H_2 in fuel-cell car for gasoline in hybrid car	Add 4 million 1-MW-peak windmills (100 times the current capacity)	H_2 safety, infrastructure
	13. Biomass fuel for fossil fuel	Add 100 times the current Brazil or U.S. ethanol production, with the use of 250 x10^6 ha (1/6 of world cropland)	Biodiversity, competing land use
Forests and Agricultural Soils	**14.** Reduced deforestation, plus reforestation, afforestation and new plantations.	Decrease tropical deforestation to zero instead of 0.5 GtC/year, and establish 300 Mha of new tree plantations (twice the current rate)	Land demands of agriculture, benefits to biodiversity from reduced deforestation
	15. Conservation tillage	Apply to all cropland (10 times the current usage)	Reversibility, verification

Question:

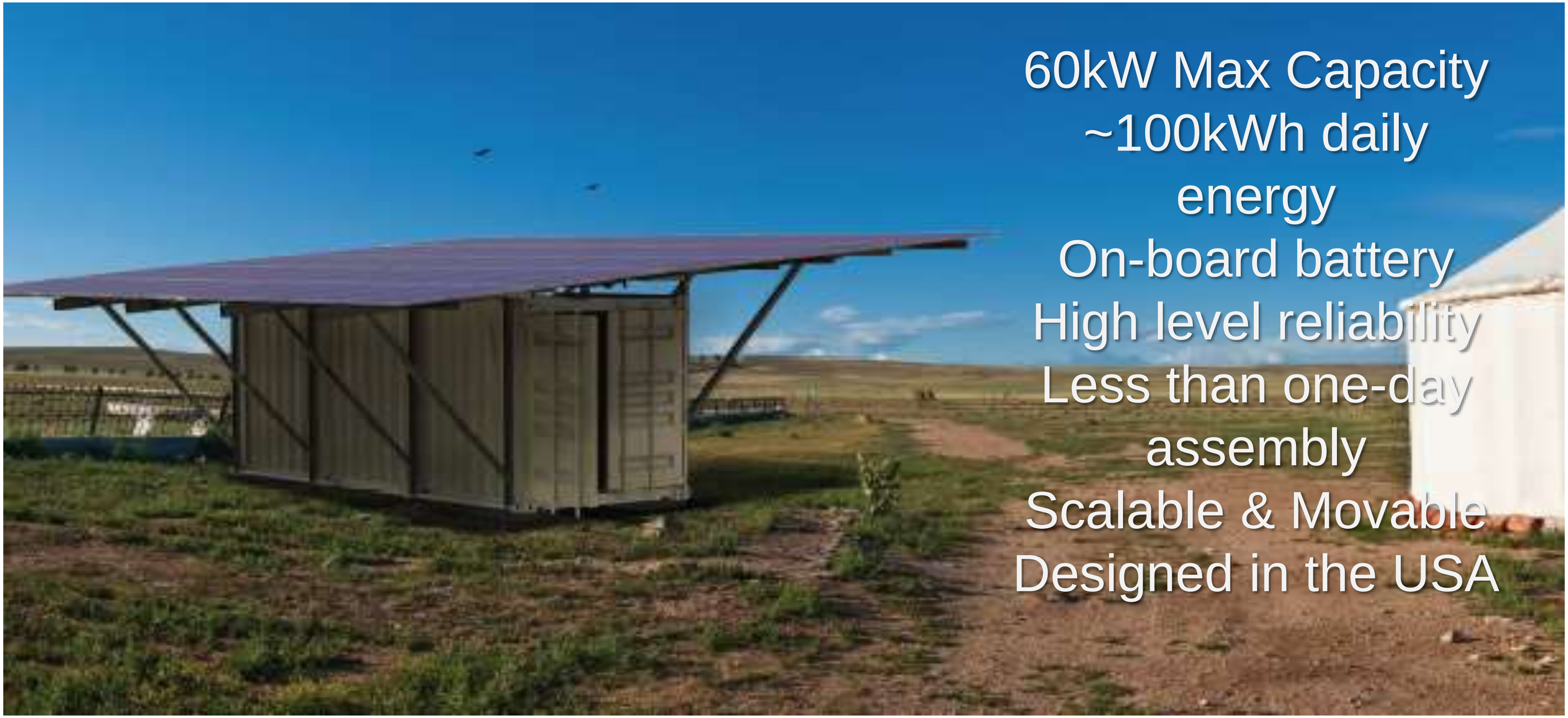
What do you recommend your country advocate for or commit to do at COP22 in Morocco, in November 2016?

Extra:

How many Earths does it take to support humanity?



Solar Power Hub



60kW Max Capacity

~100kWh daily energy

On-board battery

High level reliability

Less than one-day assembly

Scalable & Movable

Designed in the USA

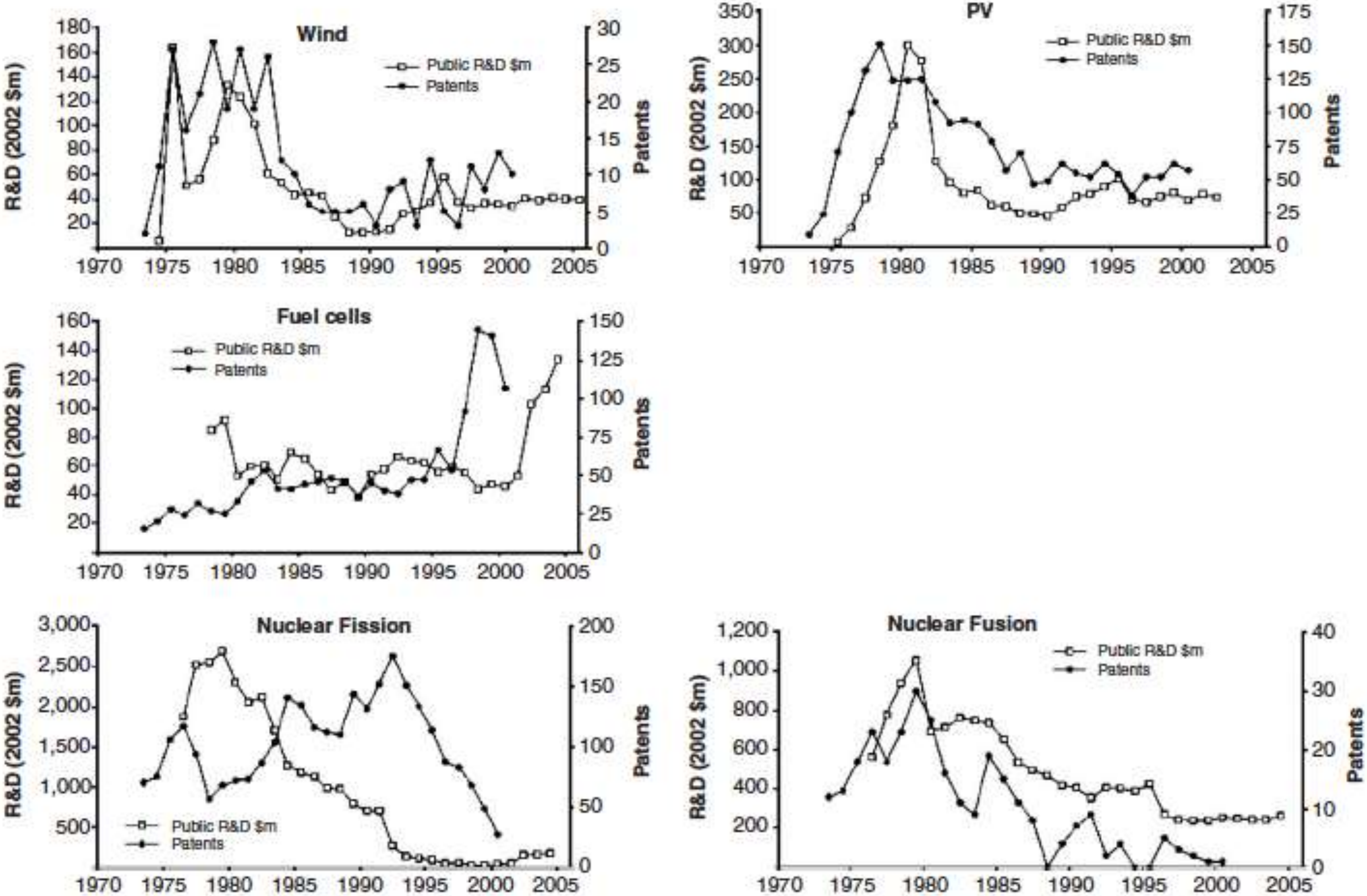
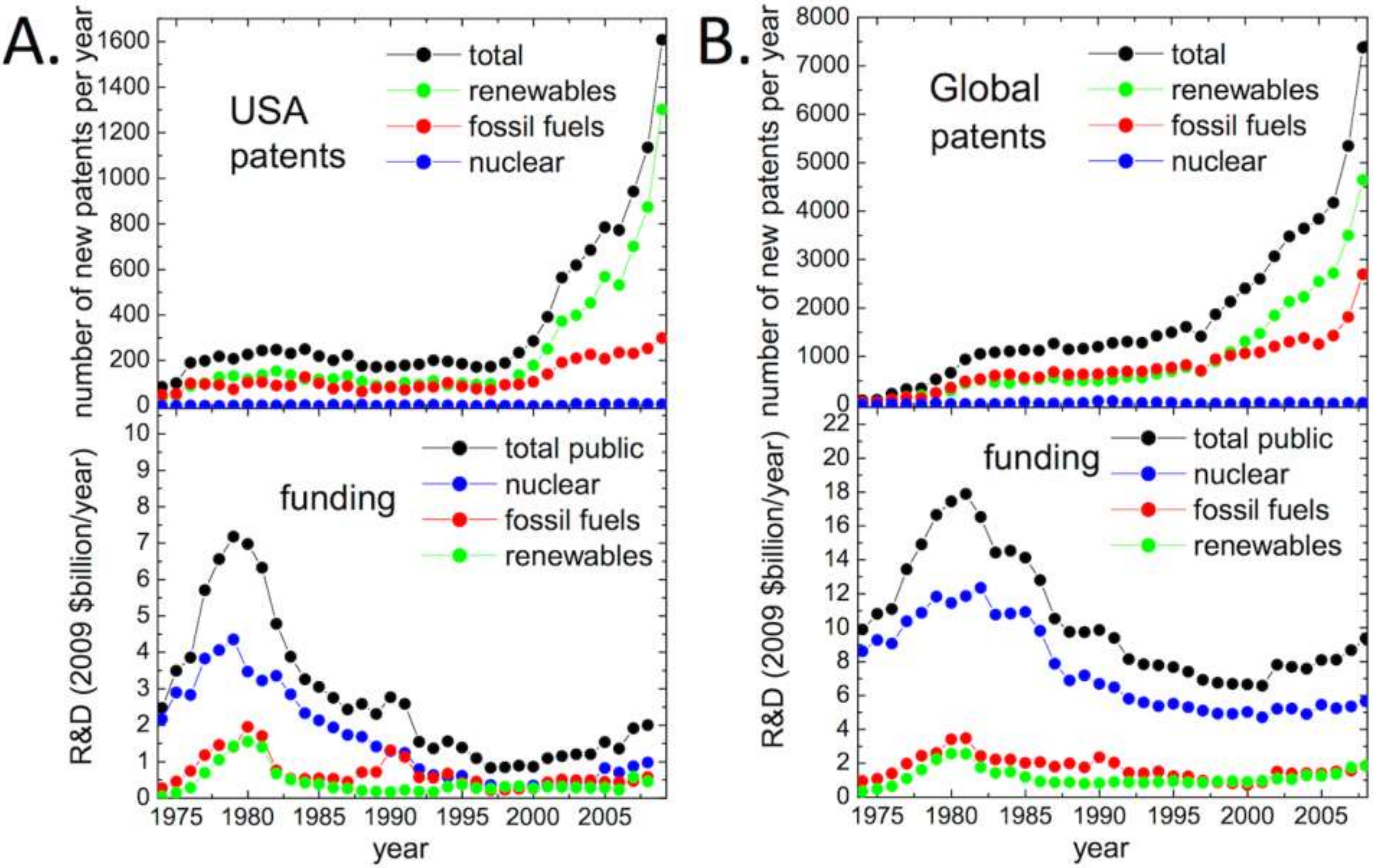


Fig. 7. Patenting and federal R&D. Patenting is strongly correlated with federal R&D. To provide comparisons with U.S. R&D funding, foreign patents are excluded. The data include granted patents in the U.S. patent system filed by U.S. inventors only. Patents are dated by their year of application to remove the effects of the lag between application and approval. This lag averages 2 years.

Nemet and Kammen, 2007



Trancik, et al, PLoS, 2014

What my laboratory does: but not our mission today

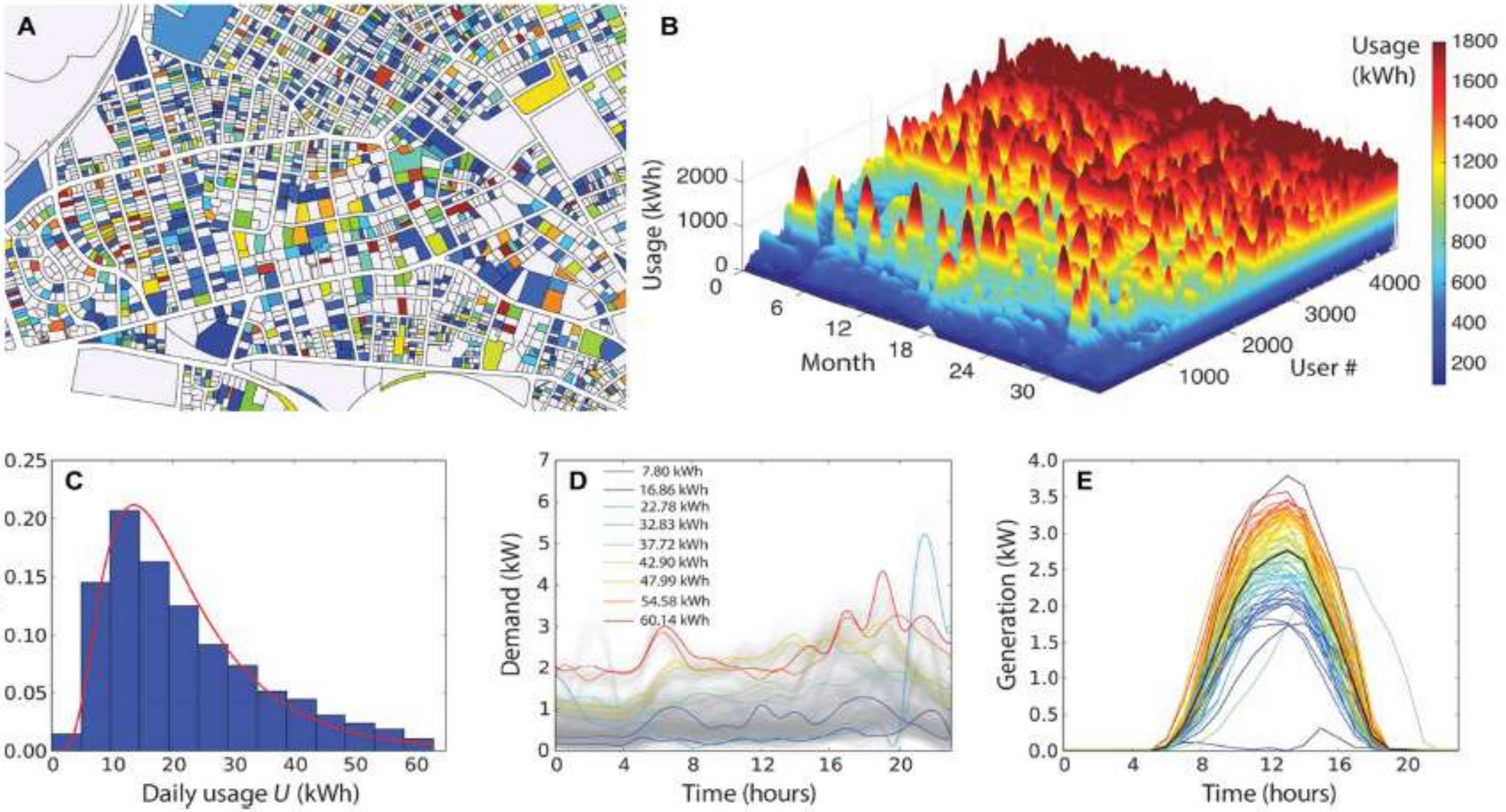
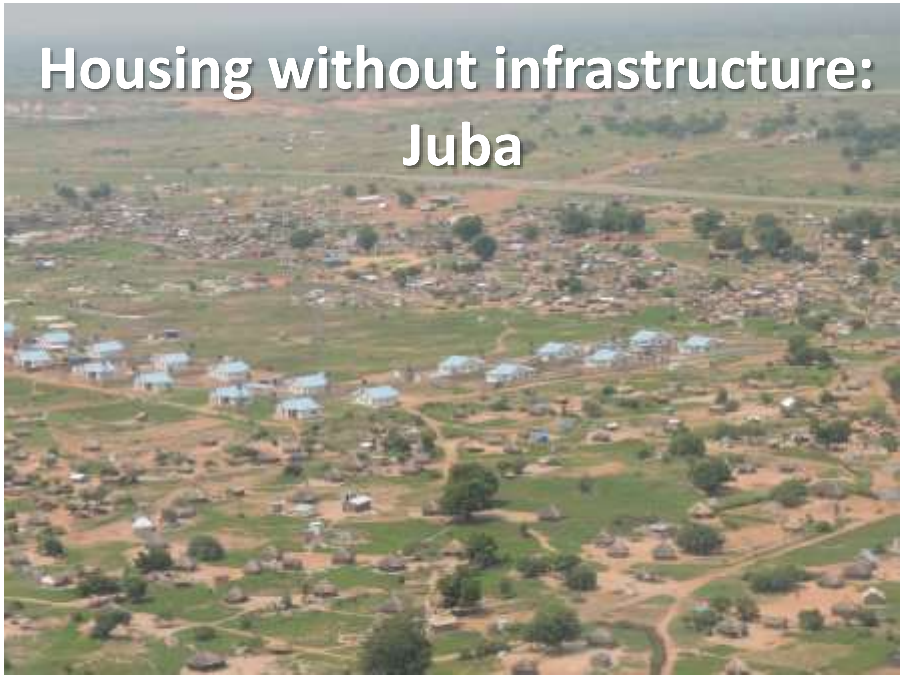


Fig. 1. Temporal patterns of electric energy demand. (**A**) Map of a portion of Cambridge, MA. The colors represent the monthly electricity consumption. (**B**) Monthly electricity consumption of 4683 users over the course of 3 years. (**C**) Distribution of the daily consumption for an average day in July. The solid red curve denotes the lognormal fit. (**D**) Hourly demand profiles for a typical day in July, with representative daily curves marked with colors and respective daily consumption values. (**E**) Hourly solar generation profiles for typical residential-size installations.

Halu, et al., 2016, *Science Advances*

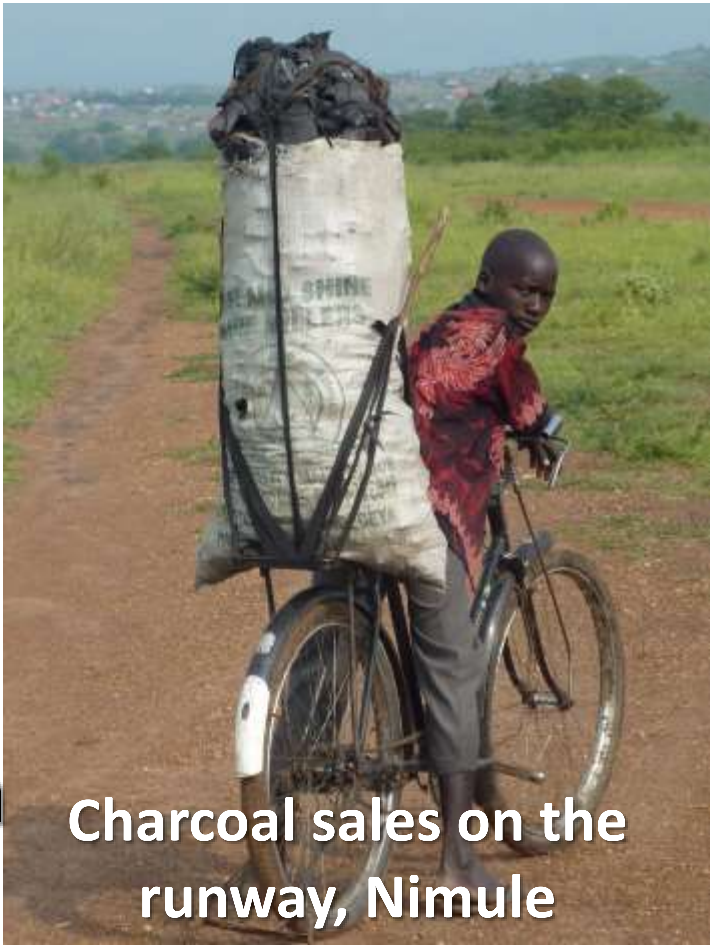
Basic Energy Resources Amidst Regional Conflict



Housing without infrastructure: Juba

Solar kiosks

South Sudan



Charcoal sales on the runway, Nimule