Renewable & Appropriate Energy Laboratory
RAEL

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Transforming Power Systems: Challenges and Solutions

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March 31, 2016

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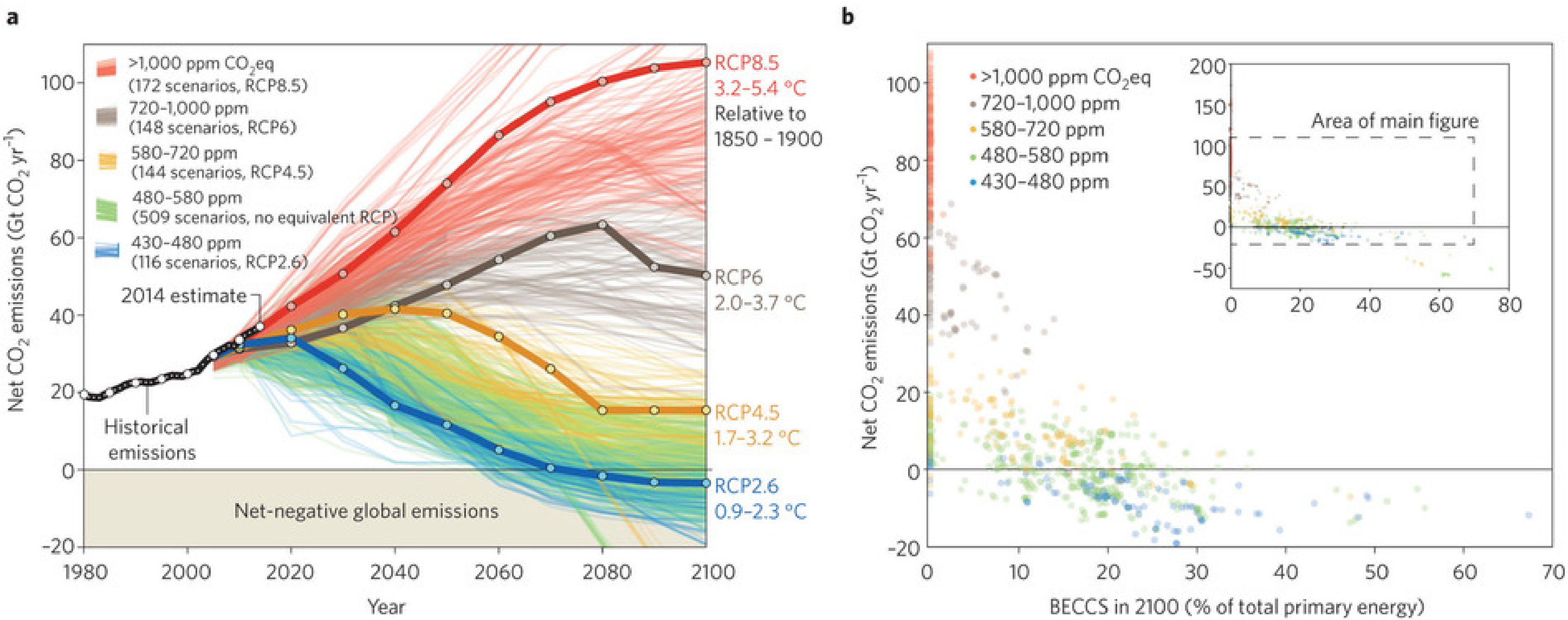
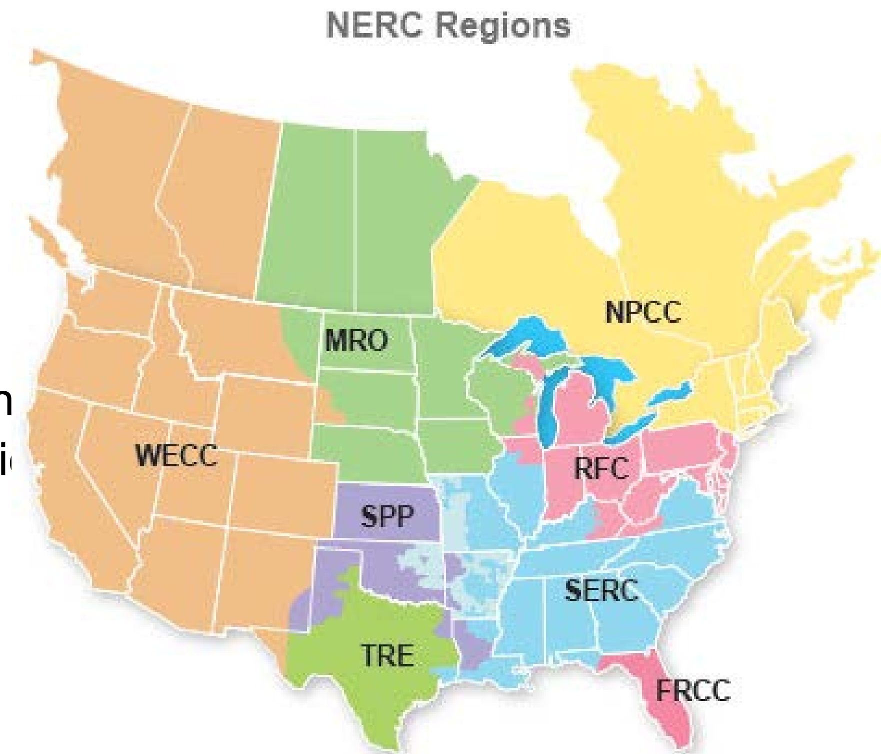
Motivation: The Need for Negative Emissions Options



Fuss et al. (2014)

SWITCH Modeling Platform (Example: WECC)



- Capacity expansion linear program
- Minimizes total power system cost:
  - Generation investment and operation
  - Transmission investment and operati
- Geographic:
  - Western North American Power System (the WECC)
  - 50 load areas
- Temporal:
  - 4 investment periods: 2016-2025 (“2020”); 2026-2035 (“2030”); 2036-2045 (“2040”); 2046-2055 (“2050”);
  - 144 distinct hours simulated per period
    - Dispatch simulated simultaneously with investment decisions

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

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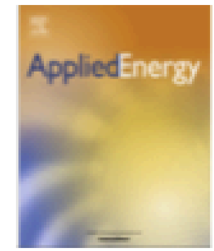

Power system balancing for deep decarbonization of the electricity sector

CrossMark

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[b] Energy and Resources Group, University of California, Berkeley, United States
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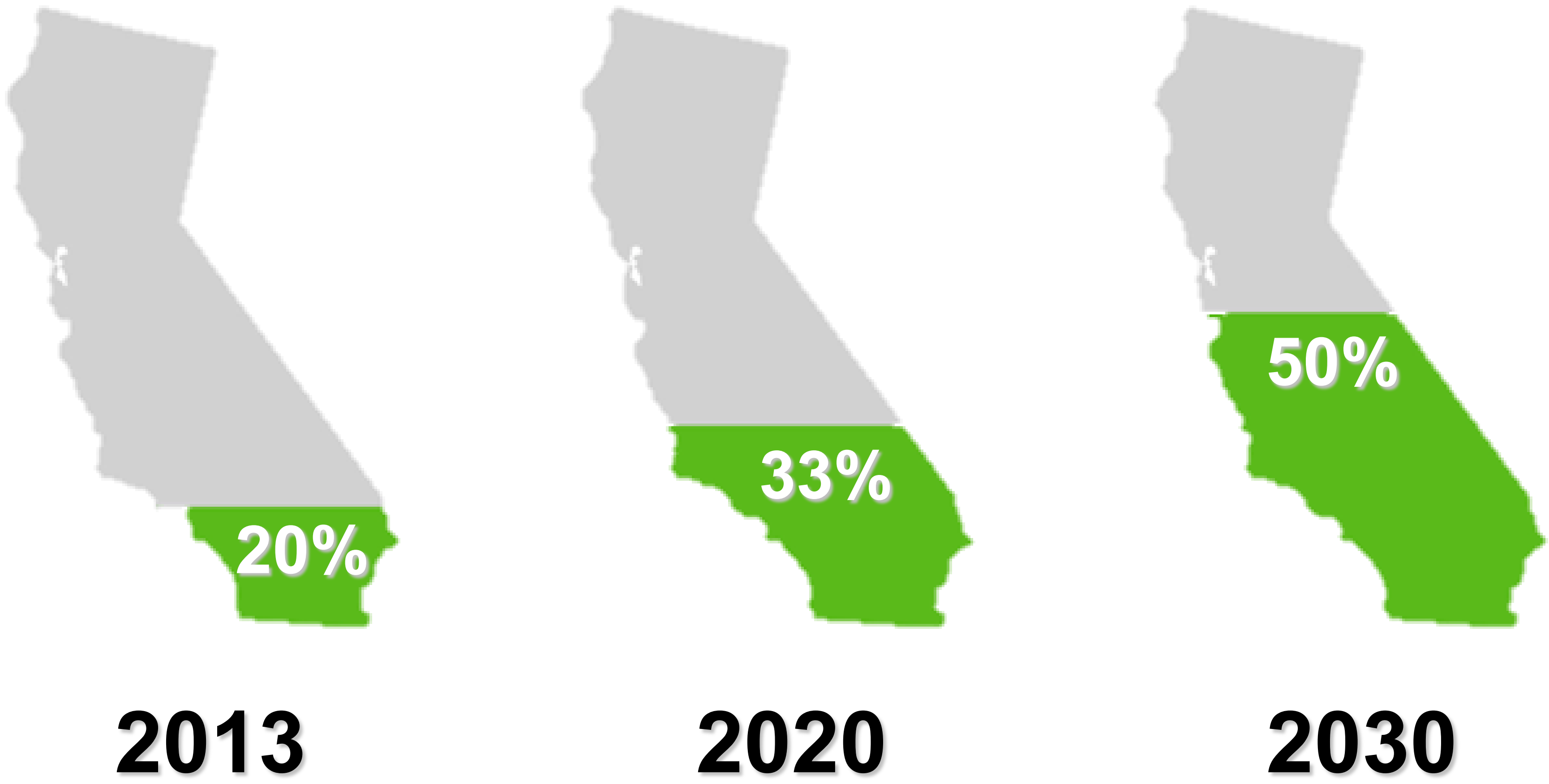
[d] Goldman School of Public Policy, University of California, Berkeley, United States

HIGHLIGHTS

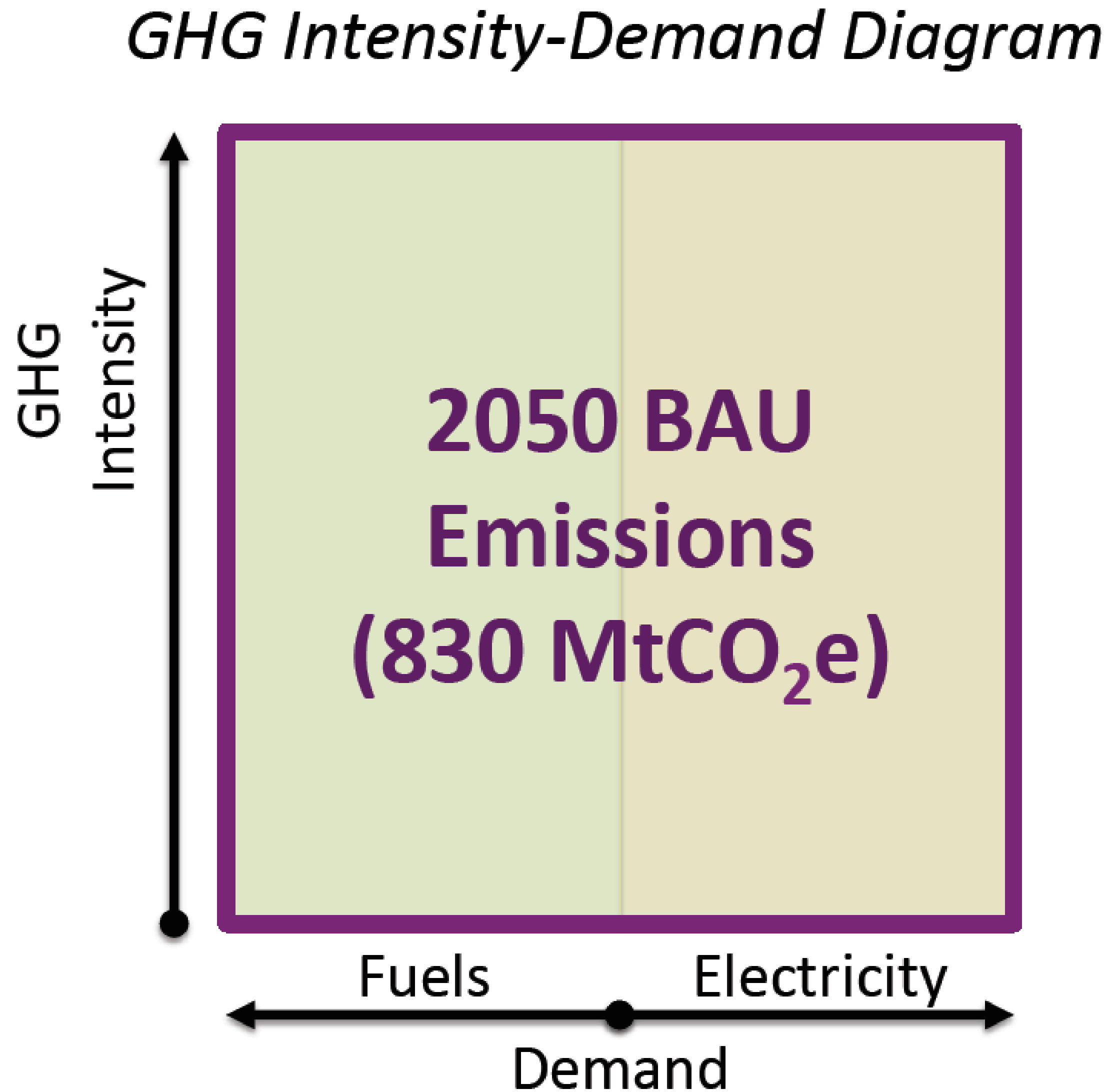
- System balancing needs for deep decarbonization are dependent on technology mix.
- Solar PV deployment is the main driver of battery storage deployment.
- Concentrating solar power with thermal storage is valuable for its dispatchability.
- Wind exhibits seasonal variation, requiring storage with large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

Binding commitments to renewables



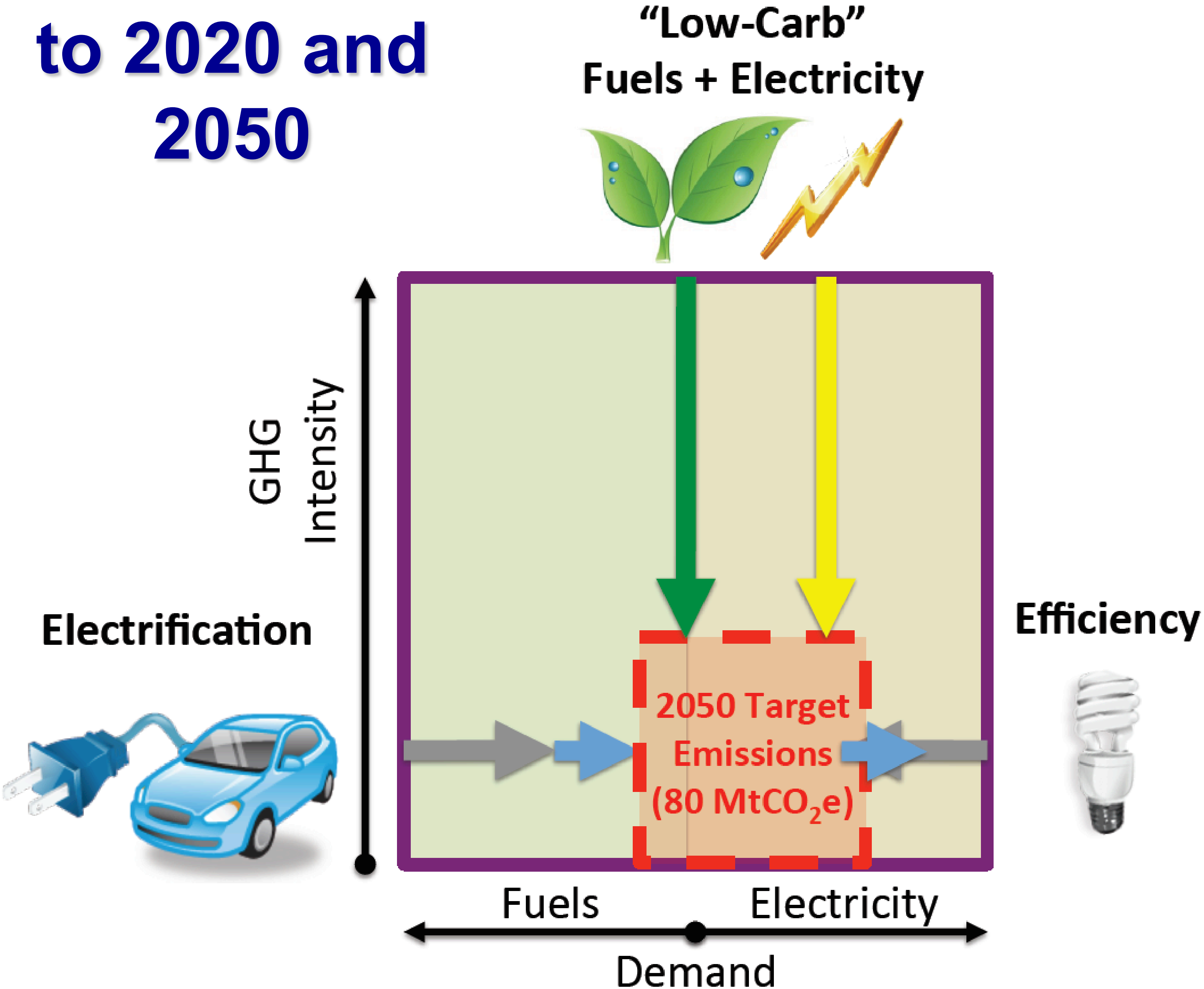
The California Strategy to reduce emissions

First: -20% by 2020



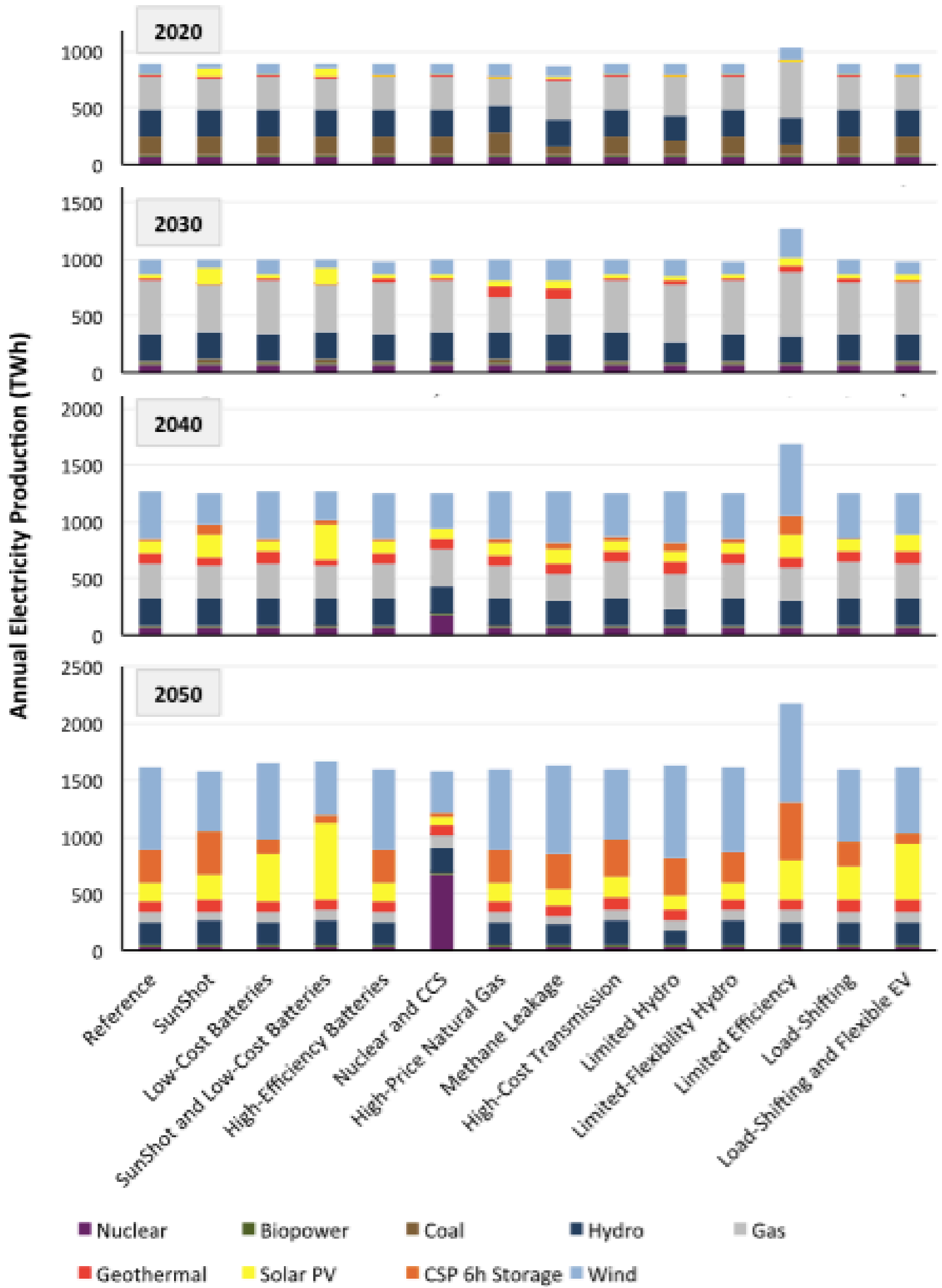
Then: -90% by 2050

to 2020 and 2050



Linear Program Around Least Cost

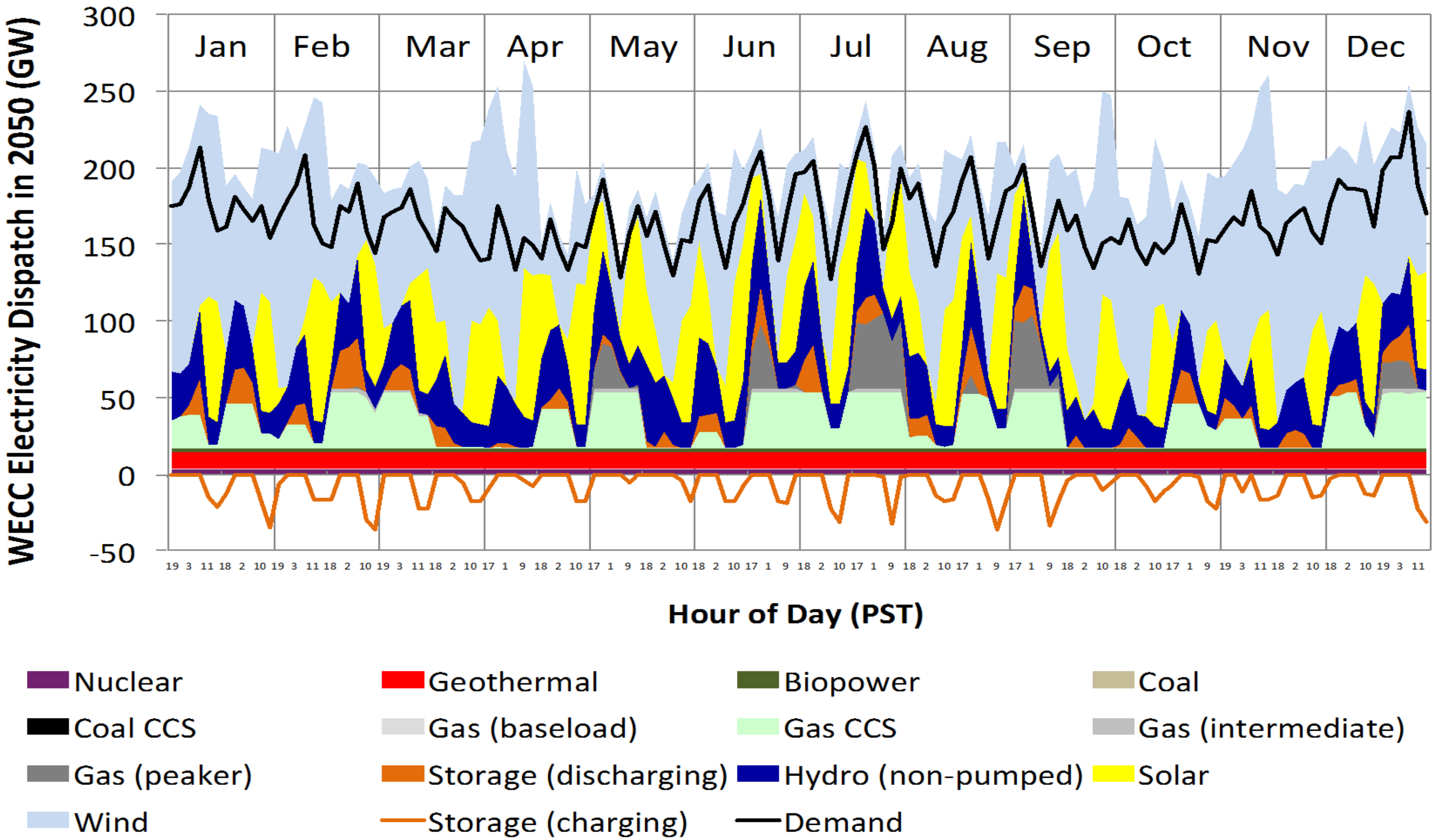
Objective function: minimize the total cost of meeting load			
Generation and Storage	Capital	$\sum_{g,i} G_{g,i} \cdot c_{g,i}$	The capital cost incurred for installing a generator at plant *g* in investment period *i* is calculated as the generator size in MW $G_{g,i}$ multiplied by the cost of that 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.



Annual Electricity Production (TWh)
2020
2030
2040
2050
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

Dispatch in 2050: Flexibility and variable renewables dominate

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



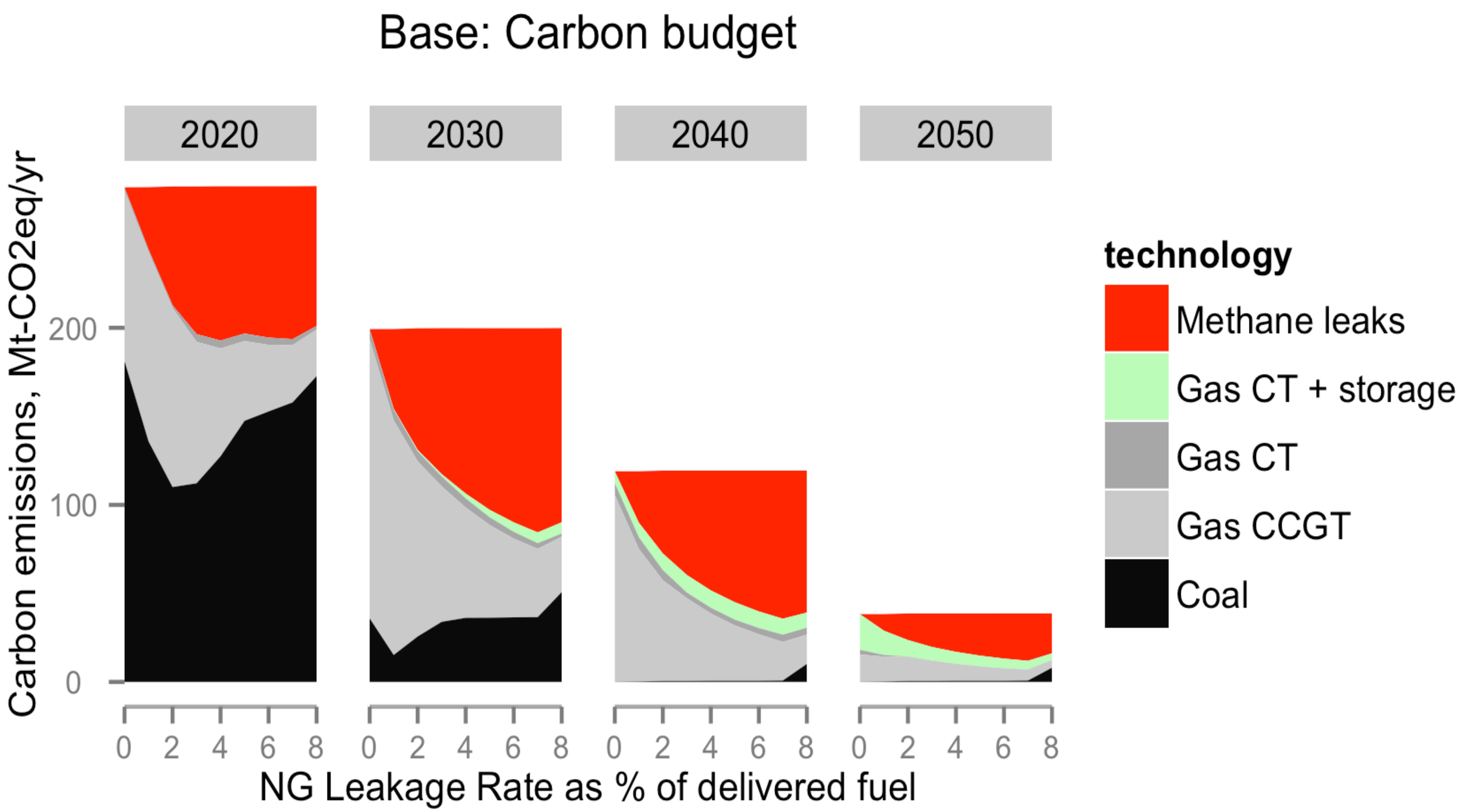
CA Leads in New Solar Home Construction

Zero Energy Community
Rocklin, CA

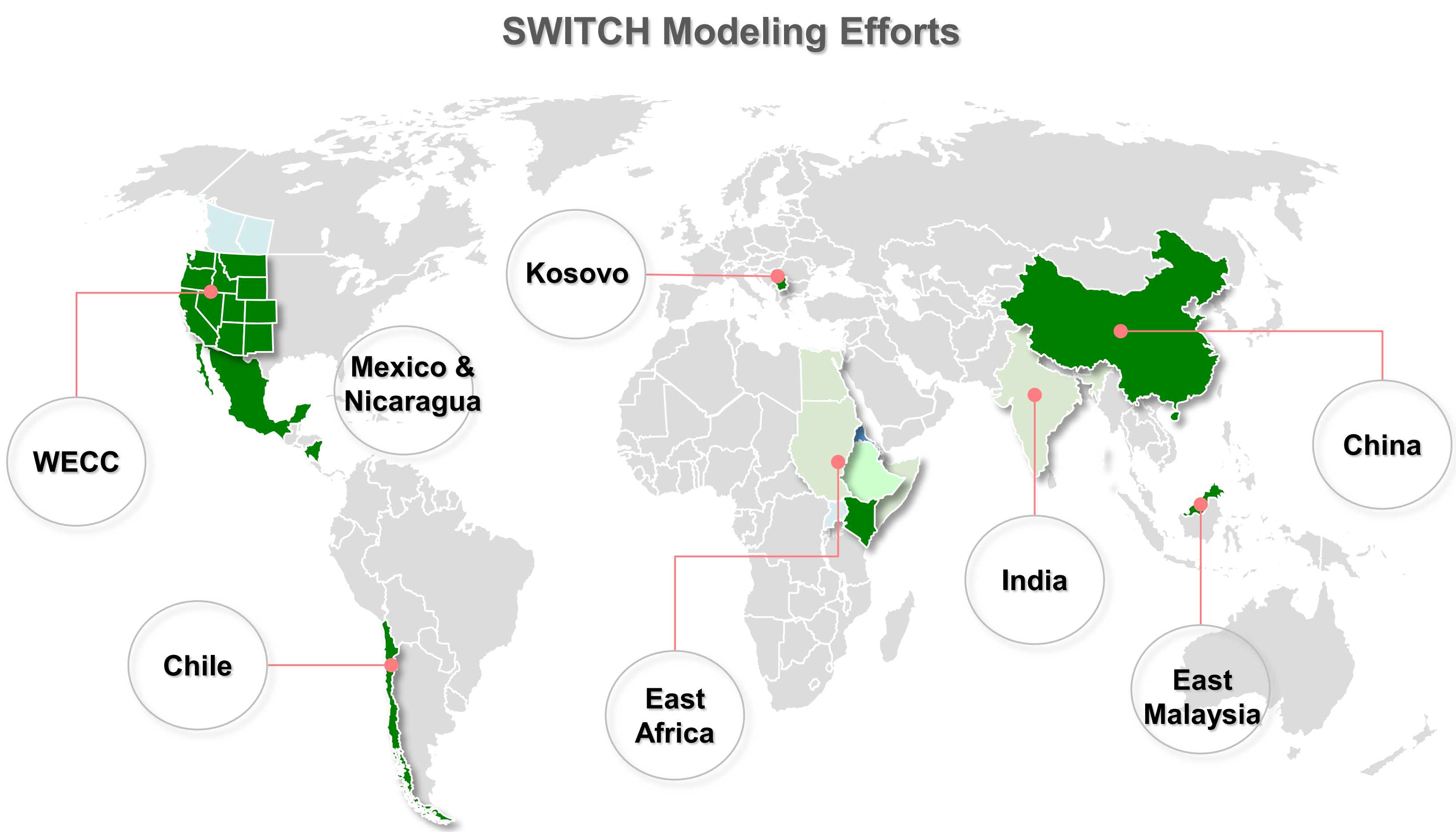
27% of New Homes in Southern CA Being Built with Solar

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

Fugitive Emissions: WECC

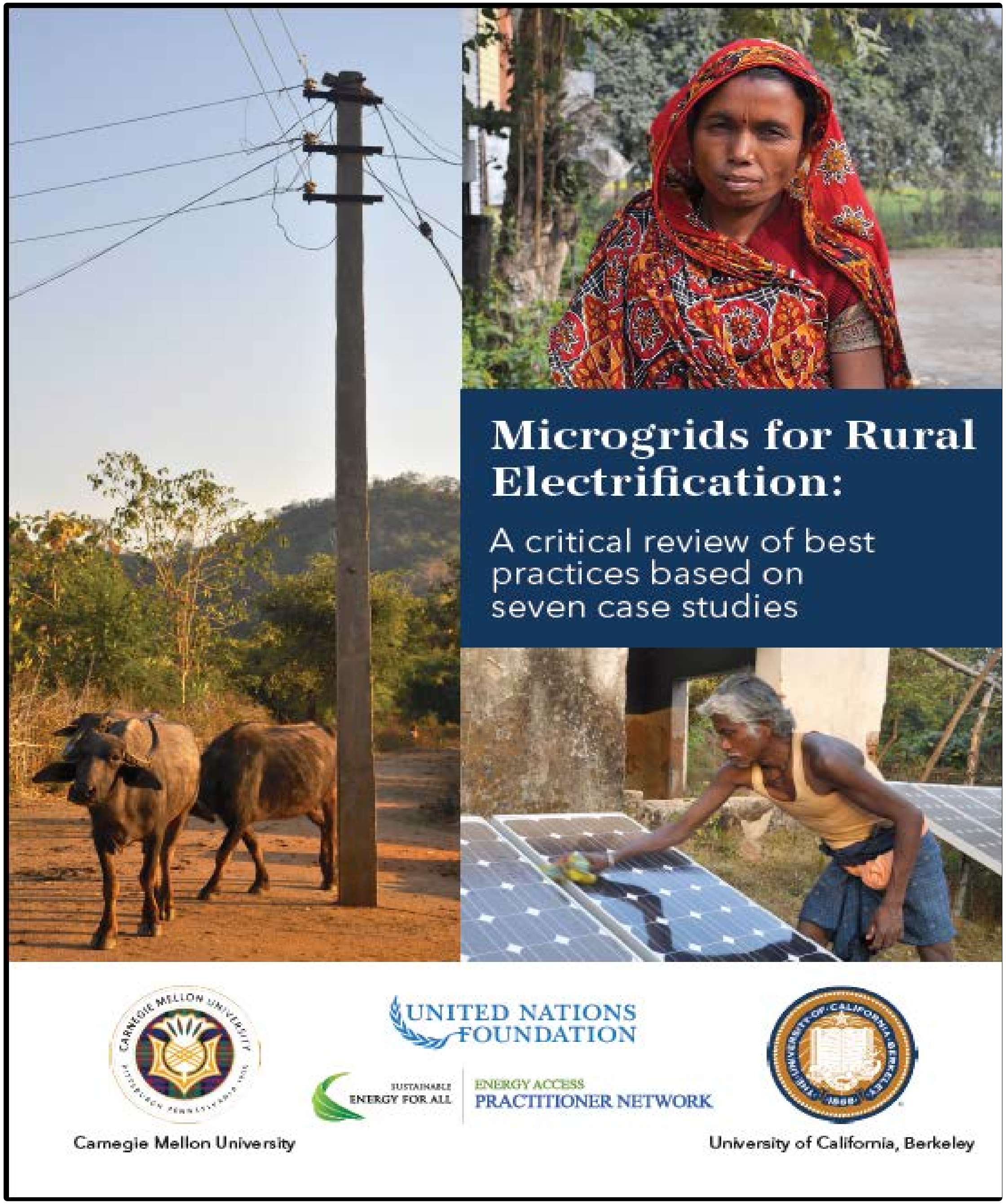


Modeling the Clean Energy Transition
2° (and lower) Scenarios



https://rael.berkeley.edu/project/switch-a-modeling-tool-for-the-electricity-sector/

Lessons disseminated to new micro-grid developers

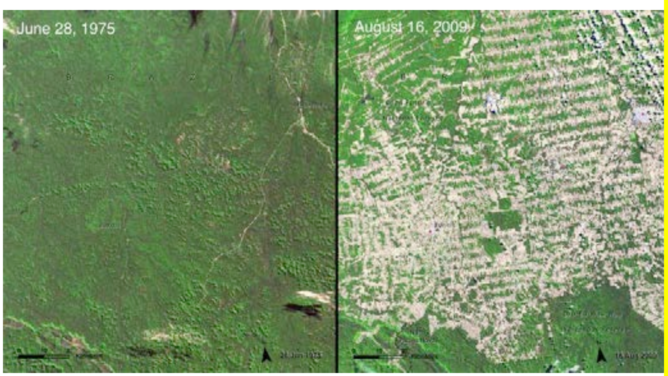


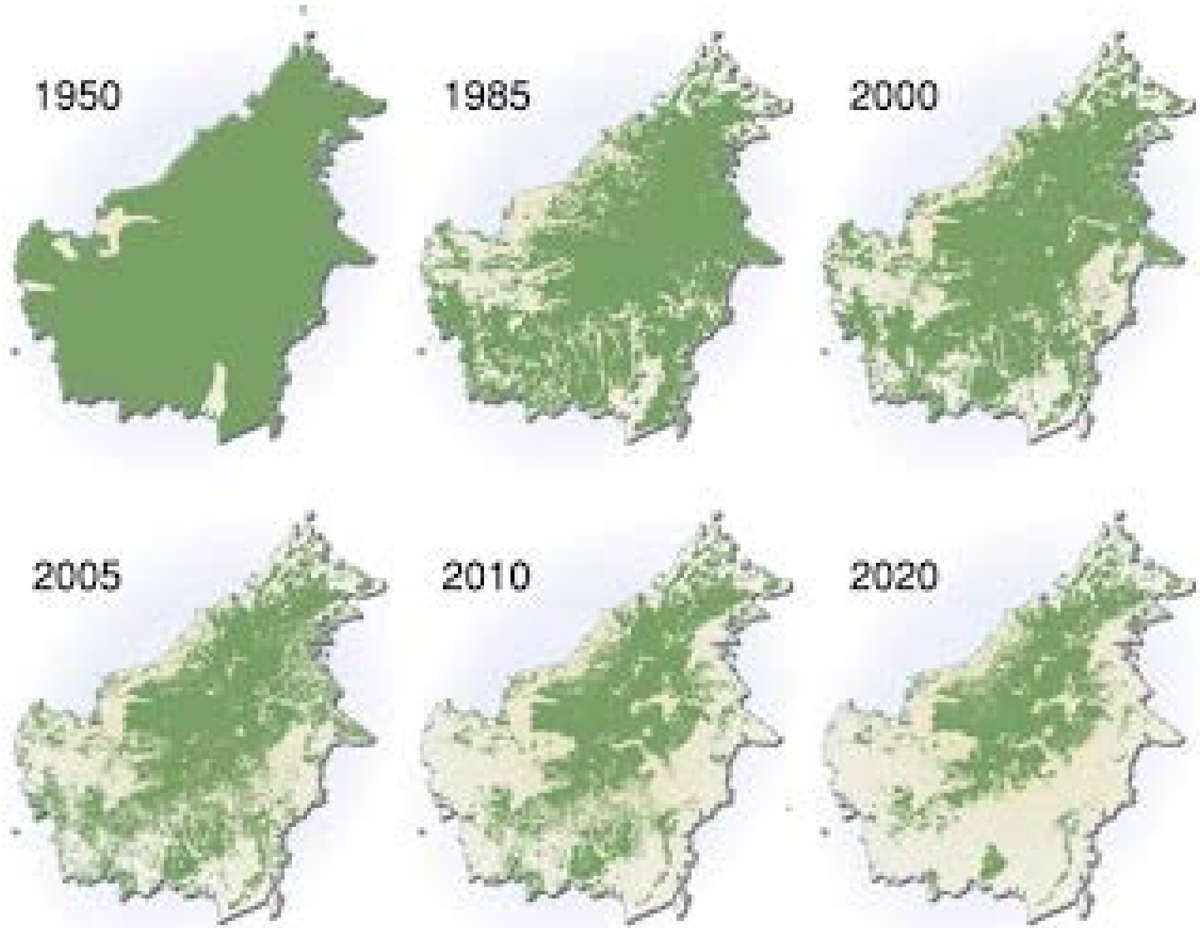
http://energyaccess.org/images/content/files/MicrogridsReportFINAL_high.pdf

Charting and Locally Addressing Tropical Deforestation
http://www.globalforestwatch.org

Amazonian Deforestation and cattle grazing

Amazonian Deforestation





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Our Ref. : CS/MYY/001(WS)/3-2015 Date : 15th March, 2016

Your Ref. : Please advice

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By Fax 085-421236 only

Dear Sirs,

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

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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.

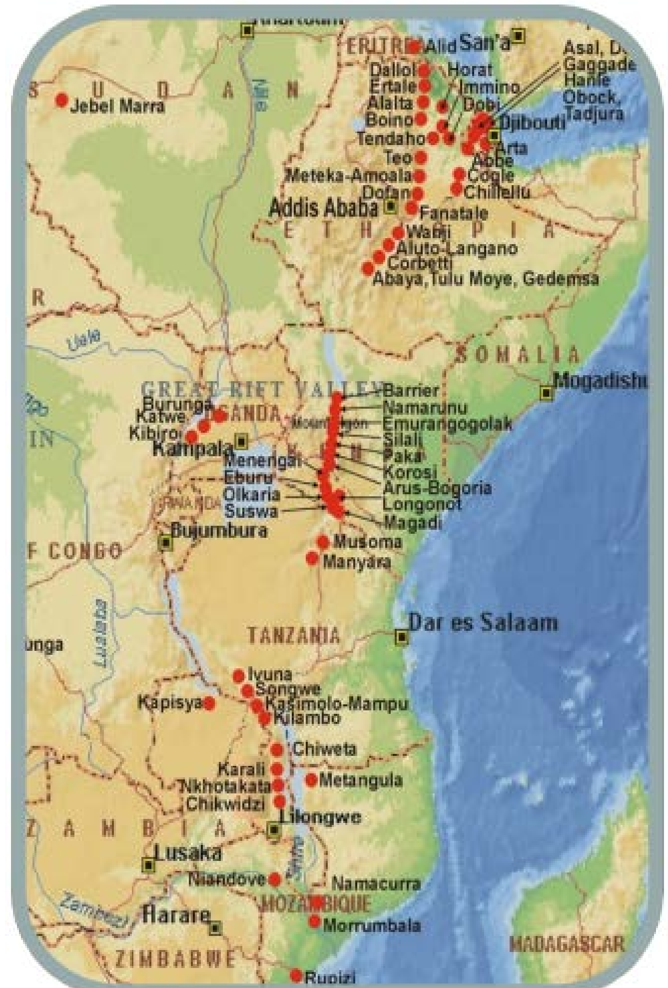
Thank you.

"BERSATU BERUSAHA BERBAKTI"
"AN HONOUR TO SERVE"

[MA XIANG RUI]

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



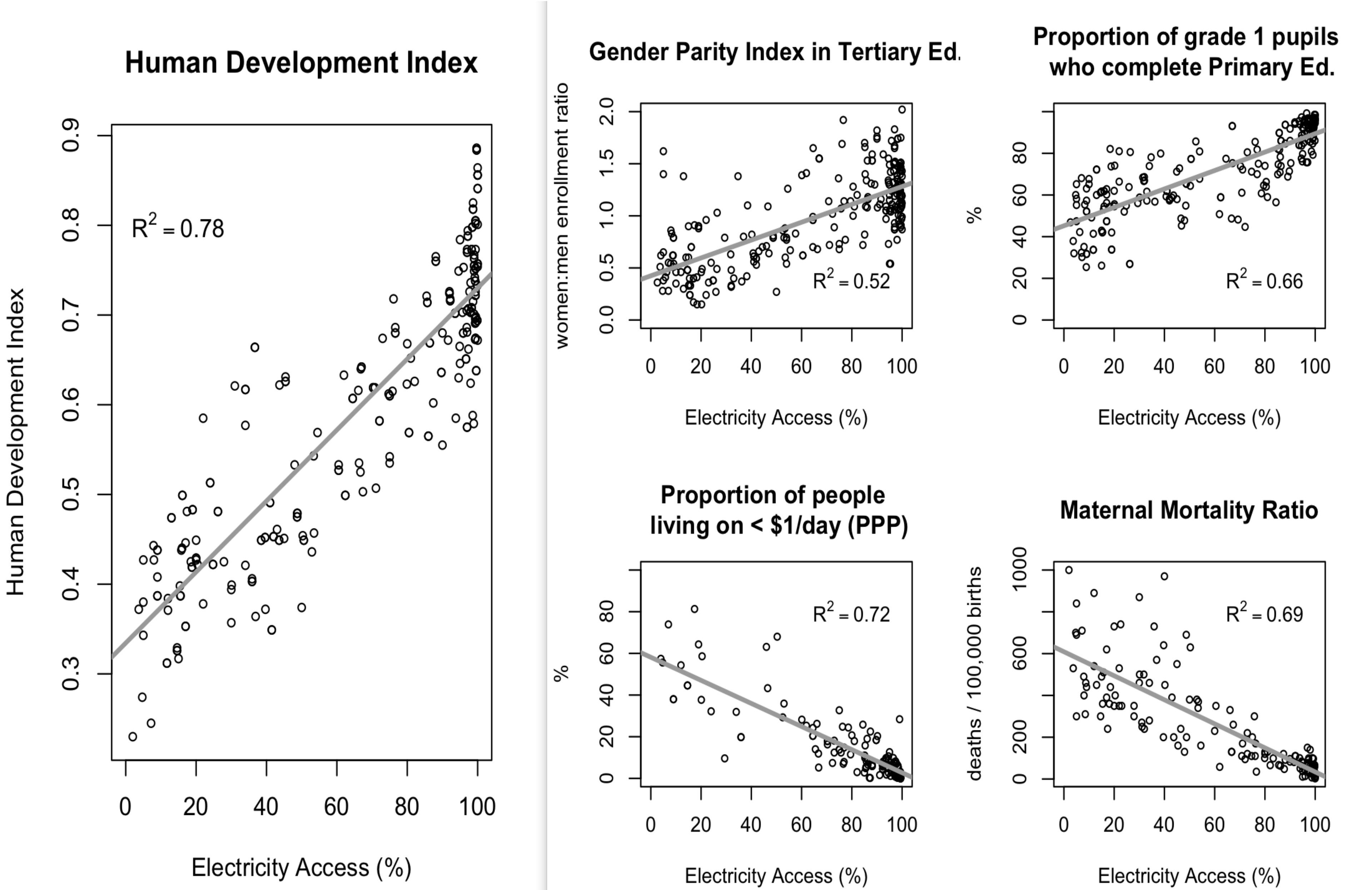
Ngong Hill Wind Farm: Kenya
& Lake Turkana Wind, largest in Africa

World's Most Active Geothermal Development Zone:
Olkaria, Kenya (in Hell's Gate National Park)

Left: 10 MW generation test well

700MW total capacity installed at Olkaria,

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



Alstone, Gershenson & Kammen, Nature Climate Change


Portable lantern uses
OK 363

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