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GLOBAL POTENTIAL FOR SMALL AND MICRO REACTOR SYSTEMS TO PROVIDE ELECTRICITY ACCESS

Dr. Amy Schweikert
Colorado School of Mines, USA

28 October 2020

Meet the Presenter

Dr. Amy Schweikert is a Research Assistant Professor in Mechanical Engineering at the Colorado School of Mines. She is a Fellow in the Payne Institute for Public Policy and co-appointed in the Nuclear Science Program. Her work focuses broadly in the areas of infrastructure resilience and development. This includes a focus on quantitative risk modeling for infrastructure related to climate change and hazard events. Additionally, her work looks at socio-technical options for energy expansion for underserved areas of the globe, including the role of nuclear energy as a component of the low-carbon energy technology portfolio. She is a graduate of the Santa Fe Institute's Summer School on Complex Systems and hired as a coordinator for the 2019 and 2020 sessions. She has consulting experience with the United Nations, the World Bank and a number of public and private entities. Dr. Schweikert is a Colorado native and holds a Ph.D. in Civil Systems Engineering from the University of Colorado Boulder, a Masters of Science in Civil Systems Engineering and a certificate in Engineering for Developing Communities from University of Colorado Boulder. She completed her undergraduate Bachelor of Arts in International Relations with a focus on Foreign Policy and Security Studies from Boston University.

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Energy Poverty and the Potential of Clean Energy Technologies

The Problem of Energy Poverty

https://www.ibtimes.co.uk/indoor-air-pollution-puts-3-billion-risk-early-death-poor-health-1463906

Really Important

- Health
- Water & Sanitation
- Gender equity
- Education
- *Economic development*
- *Conflict*
- *Governance*

…and lots more

Highly Funded

http://sdg.iisd.org/news/sustainable-energy-finance-update-public-finance-leverages-private-flows-to-renewables/

- JP Morgan [Oct2020]: $200 billion for green business financing, carbon-neutral by 2021[1]
- 2019: $163 billion “Green Bonds” Market
- Single loans > $100 million
- $3 billion for Caribbean Development Bank
- And *lots* more…

1 Benoit, D. JPMorgan Pledges to Push Clients to Align with Paris Climate Agreement. 6 October 2020. Wall Street Journal

Global Attention

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ESMAP
Energy Sector Management Assistance Program

1983
World Bank ESMAP founded (*energy sector management assistance program*)

Millennium Development Goals
2000 - 2015

2010
Clean Energy Ministerial

SE4ALL founded
2011

2012
The International Year of Sustainable Energy for All

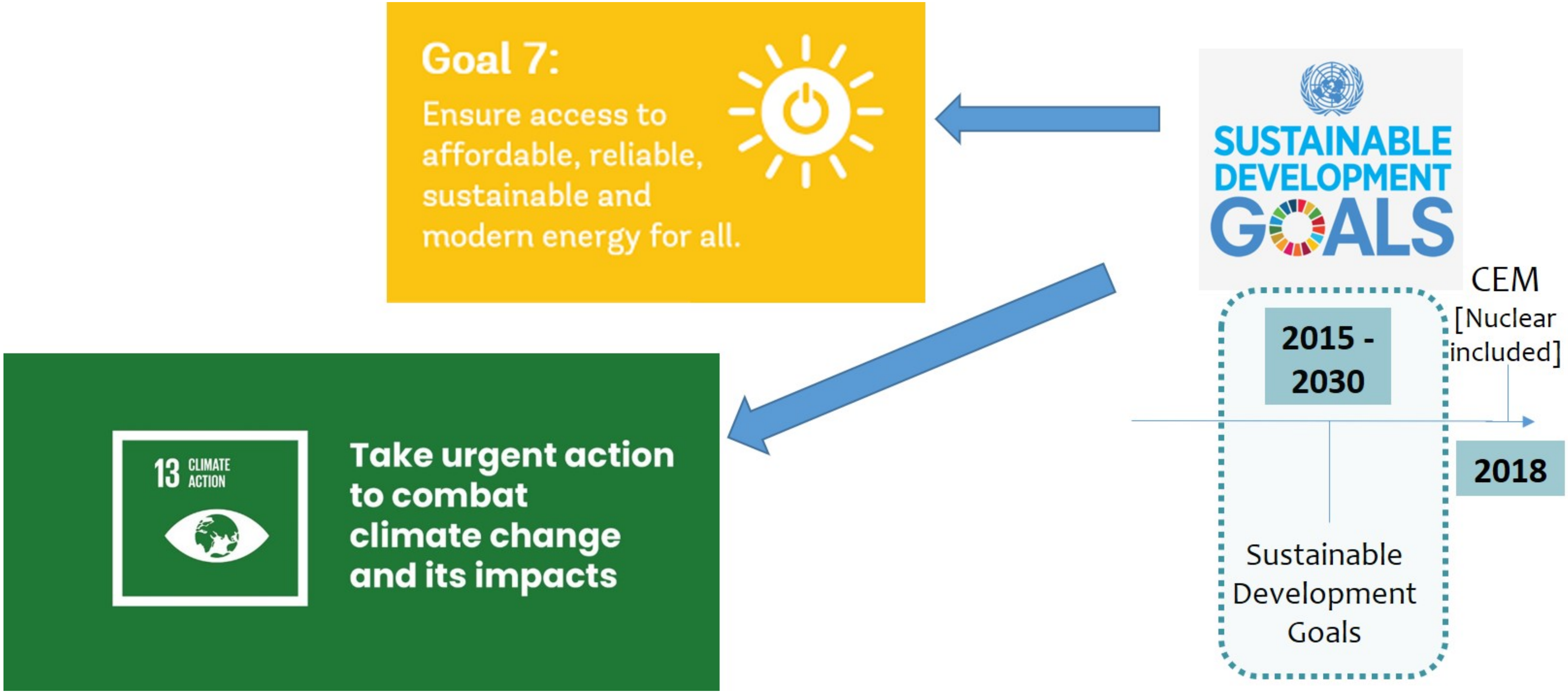
Decade of Sustainable Energy
2014-2024

SUSTAINABLE DEVELOPMENT GOALS

2015 - 2030
Sustainable Development Goals

CEM [Nuclear included]
2018

Global Attention



Where Things Stand

Goal 7:
Ensure access to affordable, reliable, sustainable and modern energy for all.

	OBJECTIVE 1	
	Universal access to modern energy services	
Proxy indicator	Percentage of population with electricity access	Percentage of population with primary reliance on non-solid fuels
Historic reference 1990	76	47
Starting point 2010	83	59
Objective for 2030	100	100

+ 12% → **Past 20 years**

+ 41% → **Next 20 years**

Where Things Stand

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2017:

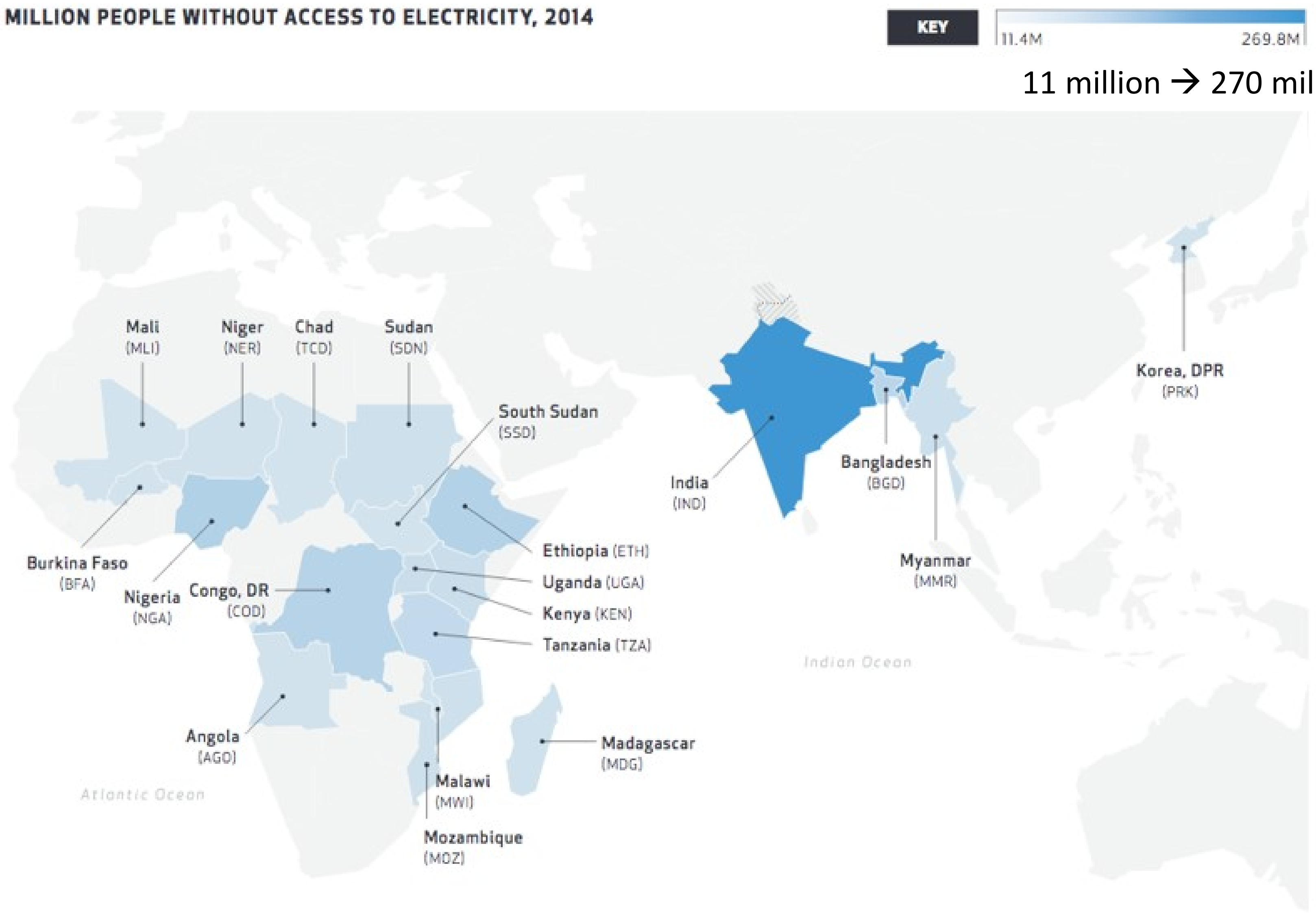
- **1.06 billion** – no electricity
- **3.04 billion** – solid fuels/kerosene

2030 (est.)

- >500 million – no electricity (Sub-Saharan Africa)

SE4All. “State of Electricity Access Report 2017.” Sustainable Energy for All, 2017. https://www.energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf.

Where Things Stand

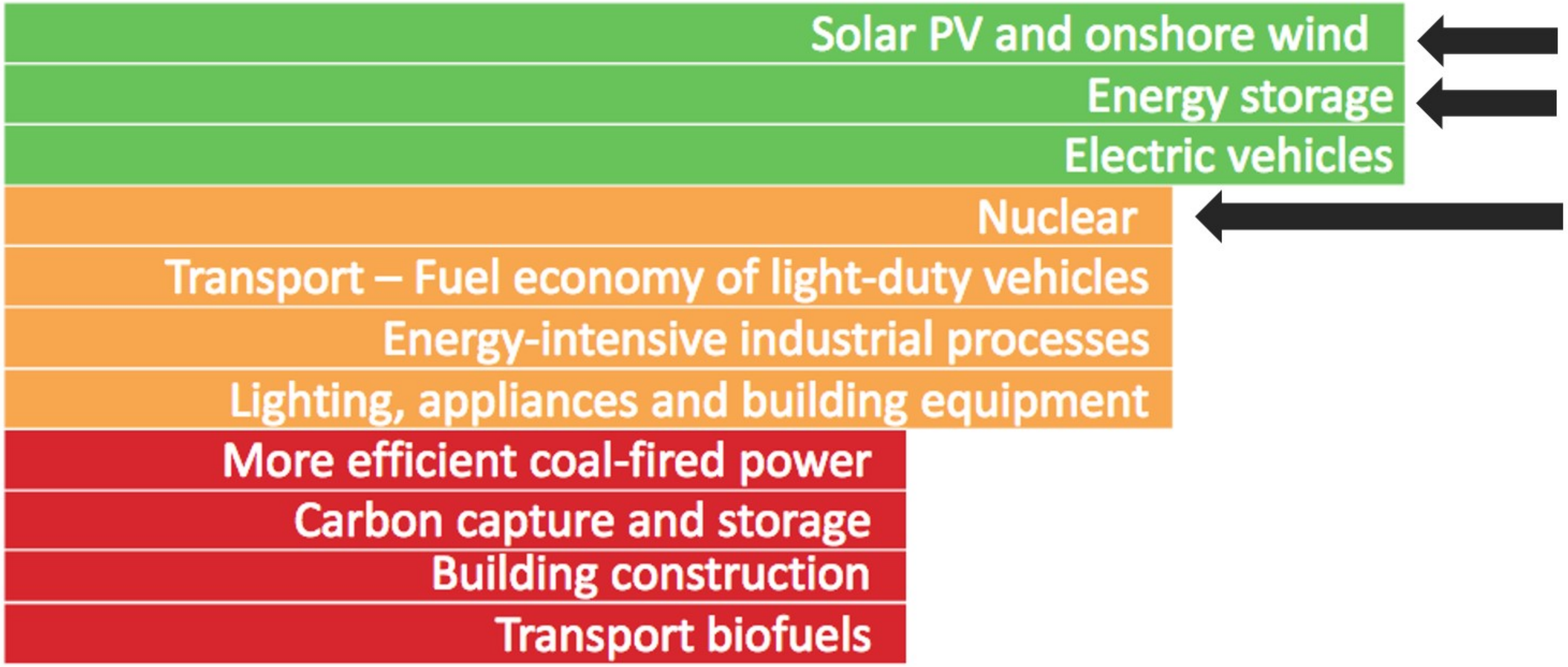


11 million → 270 mil

20 High Impact Countries

- 2/3 of all persons with no access globally

Clean Technology Options



PV with above and below-ground **storage**

Nuclear – **Conventional** and **SMRs**

● Not on track ● Accelerated improvement needed ● On track

Research Question

How can we more accurately understand the market for energy expansion?

What options exist from a technical perspective?

- Clean
- Affordable and Resilient
- Sized appropriately
- Safe
- **Timeline (2030 goals to provide global access)**

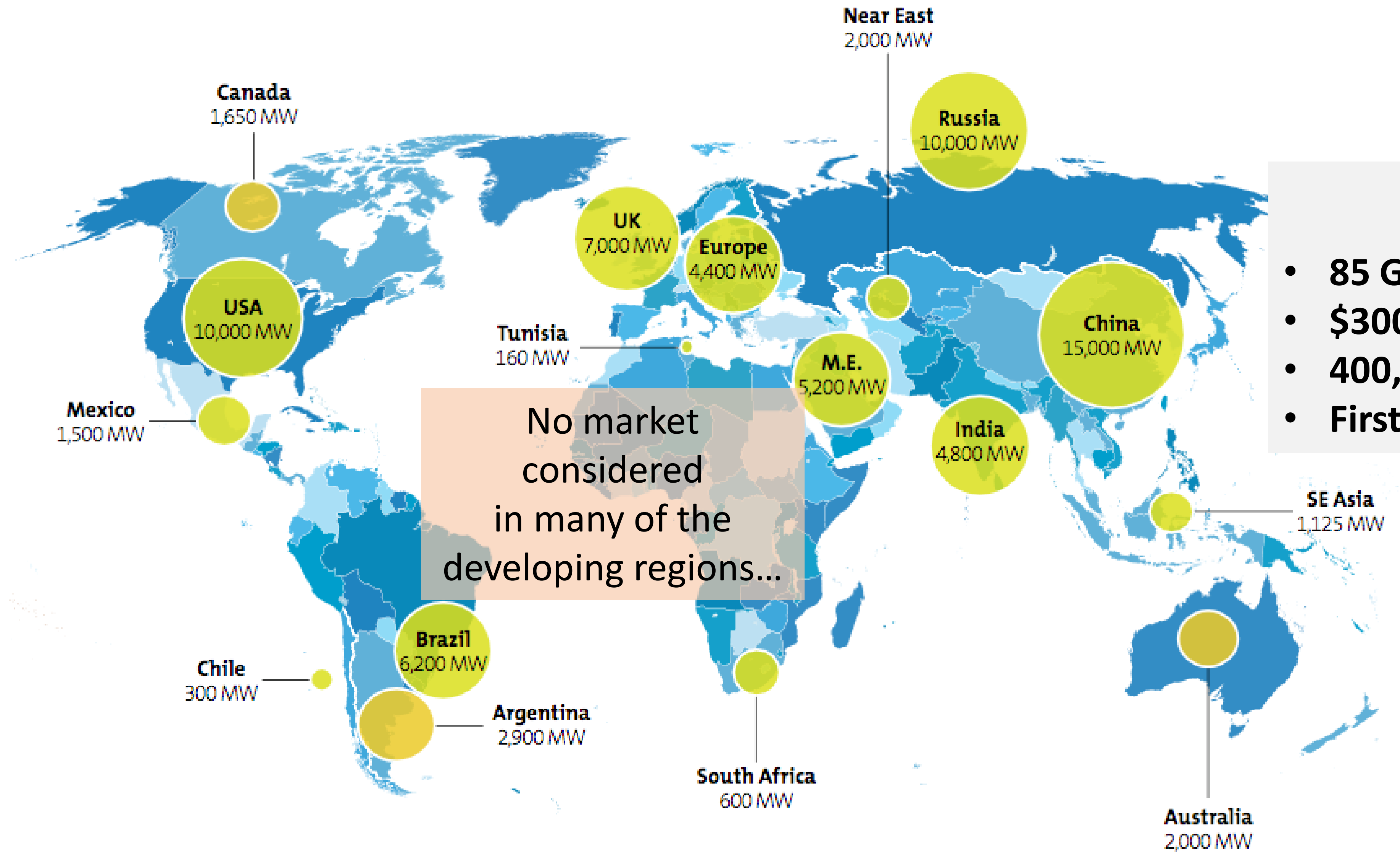
We need data to inform energy investments in next ten years:
Technological lock-in will be significant

DEMAND

Populations Living in Electricity Poverty

How much and where is electricity needed?

Global – "Estimated" Demand



2035 Estimates[1]:

- **85 GW** global demand
- **$300bn** + market size
- **400,000** estimated local jobs
- **First-mover advantage** in exports

1. Rolls-Royce. "Small Modular Reactors: Once in a Lifetime Opportunity for the UK". 2017. https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/nuclear/smr-brochure-july-2017.pdf

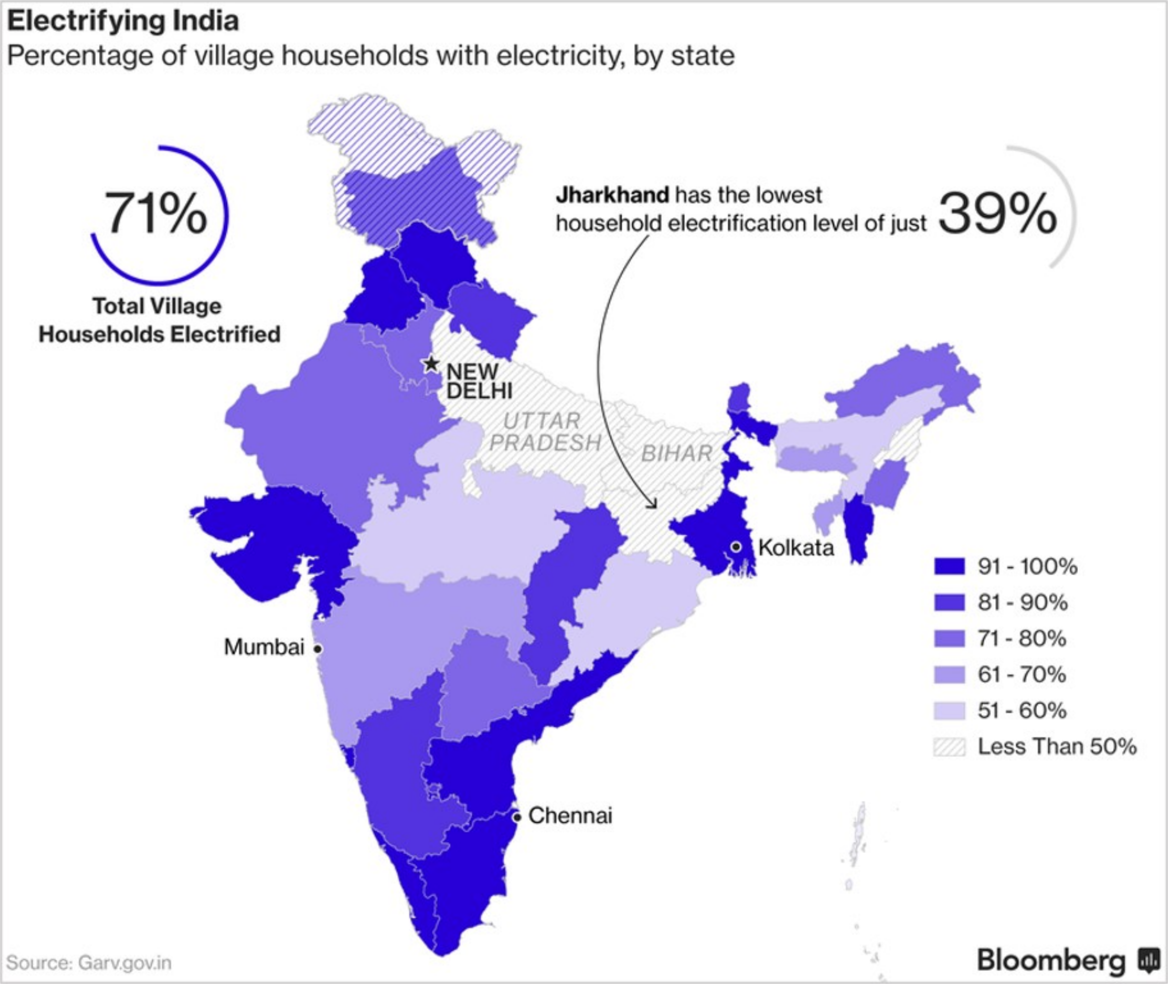
Populations Living in Electricity Poverty

SE4All – 1.06 billion / 3.04 billion

- *Resolution*: State level analysis
- *Source*: Relies heavily on country reporting

State-level assessment is still pretty coarse

Example: State-level analysis



https://www.bloomberg.com/news/features/2017-01-24/living-in-the-dark-240-million-indians-have-no-electricity

The World at Night

Populations Living in Electricity Poverty

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Satellite Imagery –

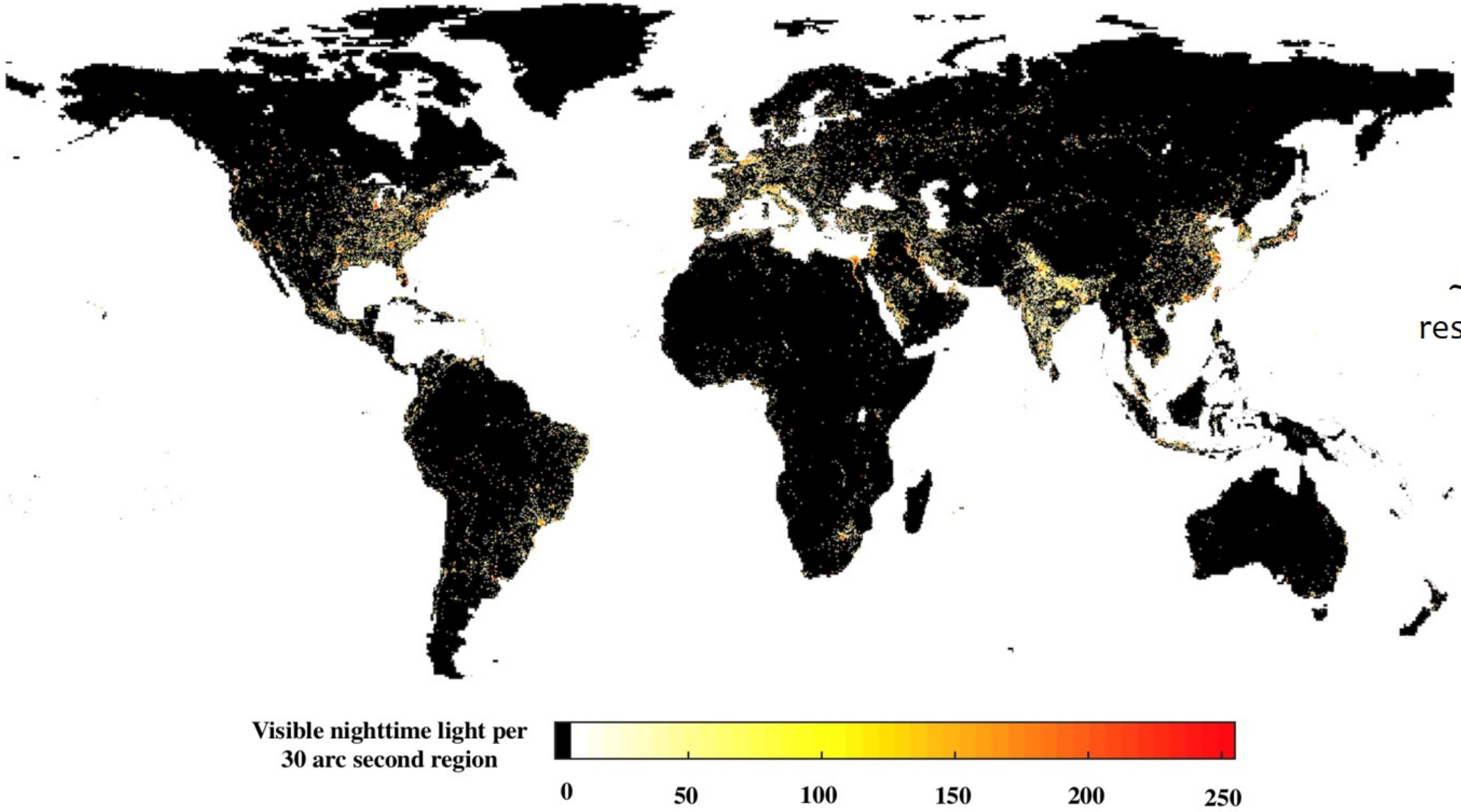
- *Resolution*: ~1 km^2
- *Used for*:
  - Human Development Index
  - Income inequality
  - Infrastructure development
  - Lots more

- *Source*: satellite data
- *Includes*:
  - Nighttime light
  - Population

Example: Nighttime Lights (30 arcsecond)

https://www.cnn.com/2017/04/13/asia/india-nasa-satellite-night-trnd/index.html

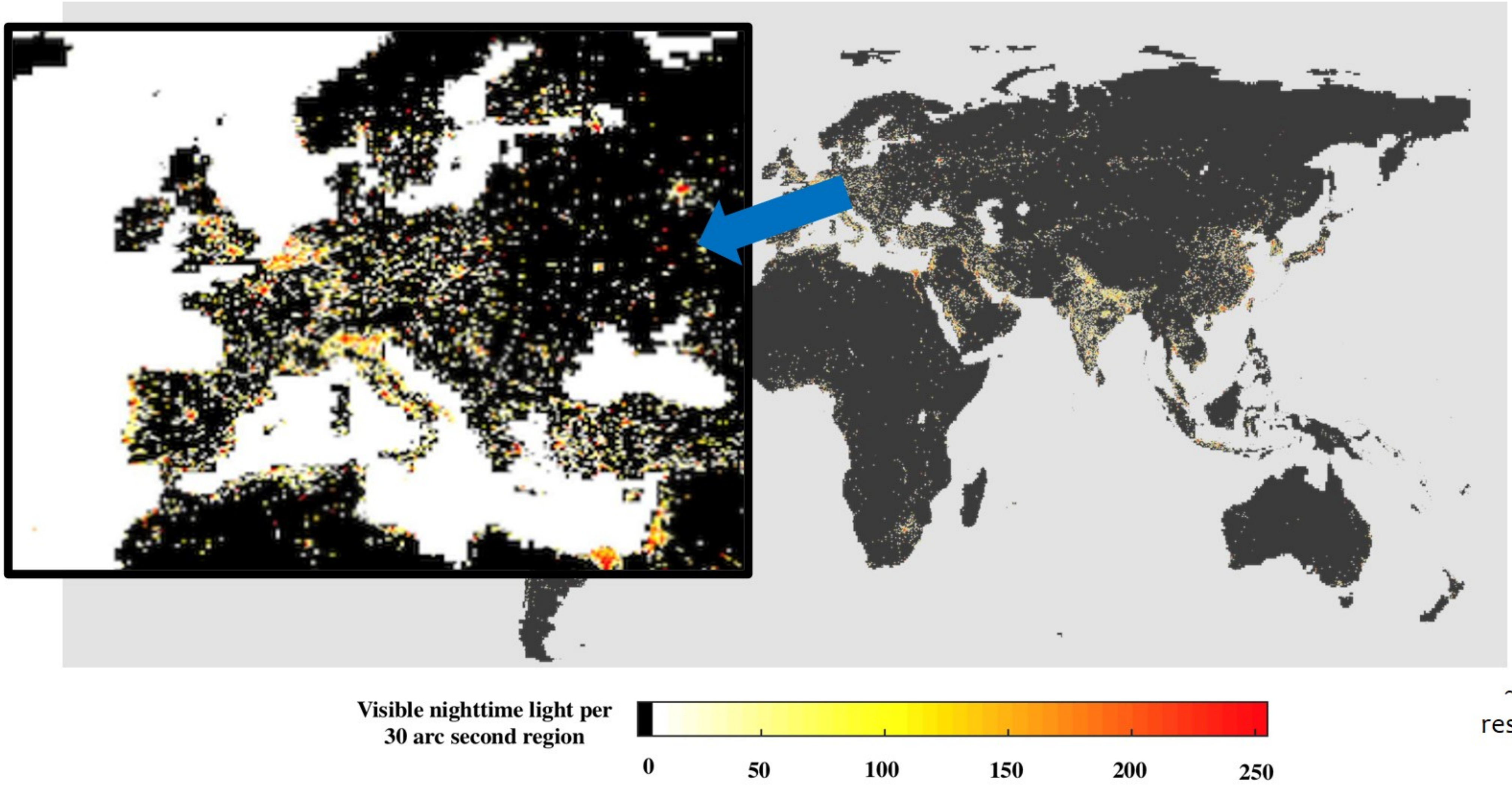
Visible Nighttime Light (Annual Composite, 2016)



~ 1 km
resolution

Schweikert, A., Osborne, A. Stoll, B., Duncan, I., Deinert, M. "A Global Assessment of Resources Available to Address Electricity Poverty using Photovoltaics and Energy Storage" 2018. *In Review*

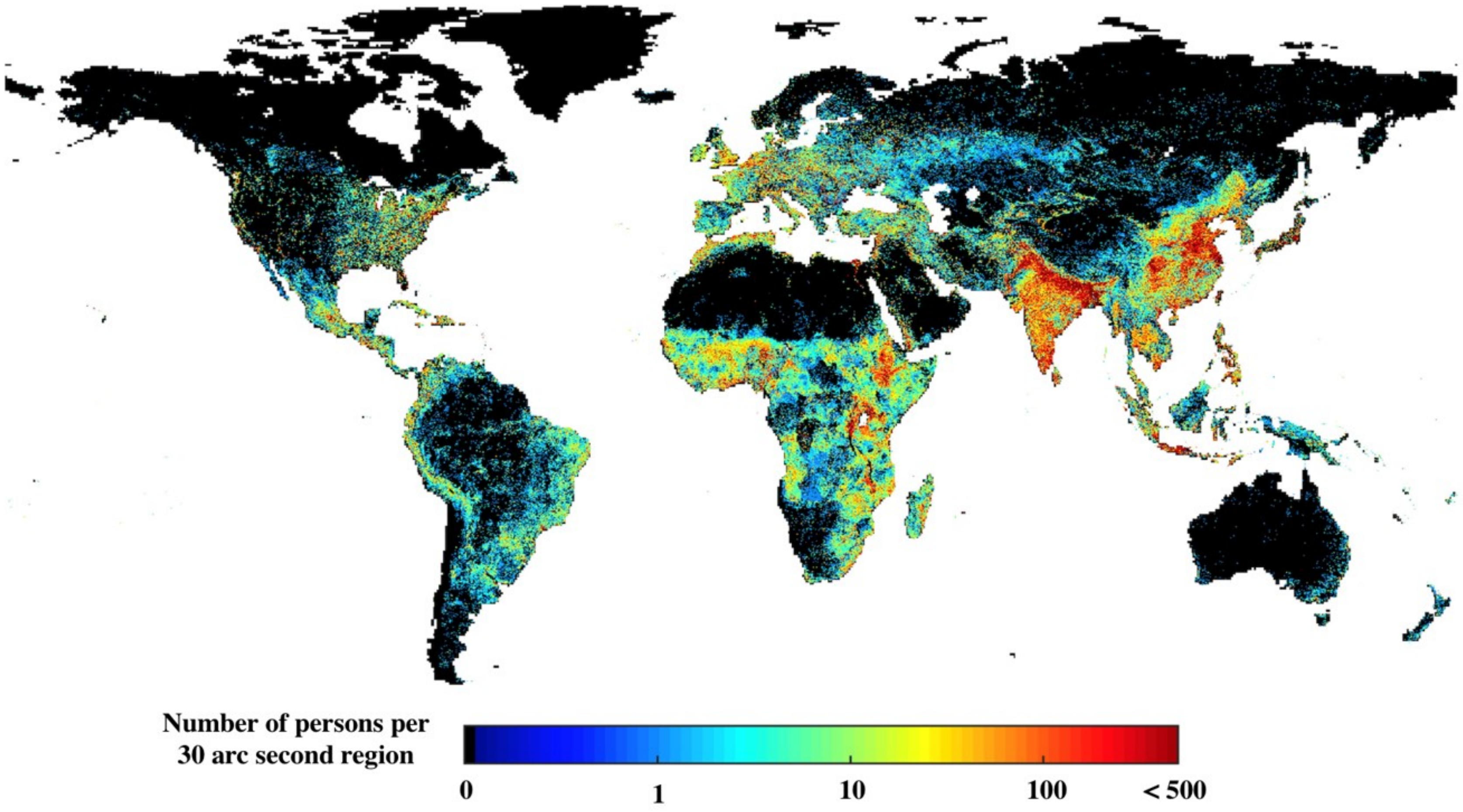
Visible Nighttime Light (Annual Composite, 2016)



~ 1 km resolution

Schweikert, A., Osborne, A. Stoll, B., Duncan, I., Deinert, M. "A Global Assessment of Resources Available to Address Electricity Poverty using Photovoltaics and Energy Storage" 2018. *In Review*

Ambient Population (Annual Average, 2016)



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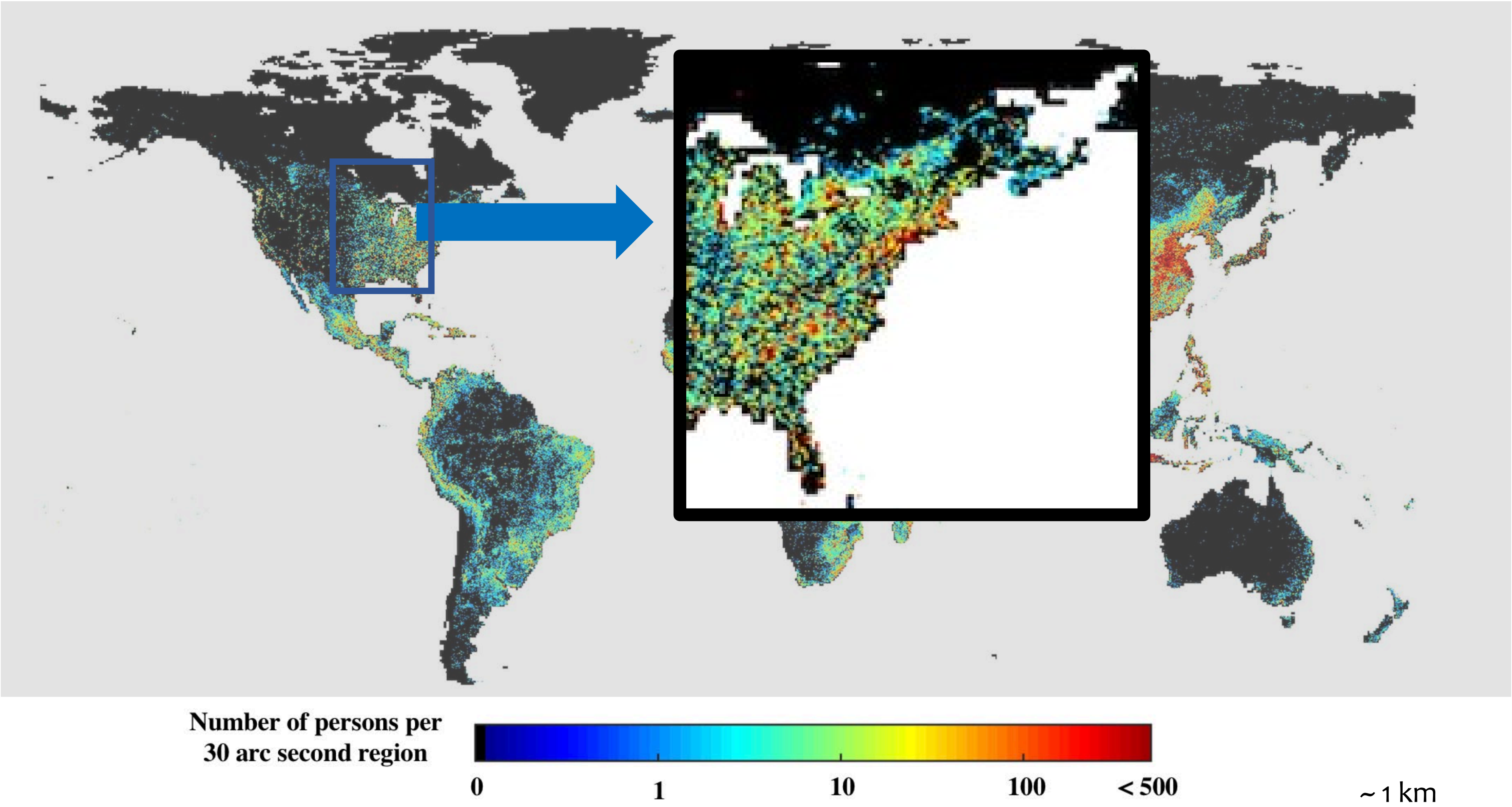
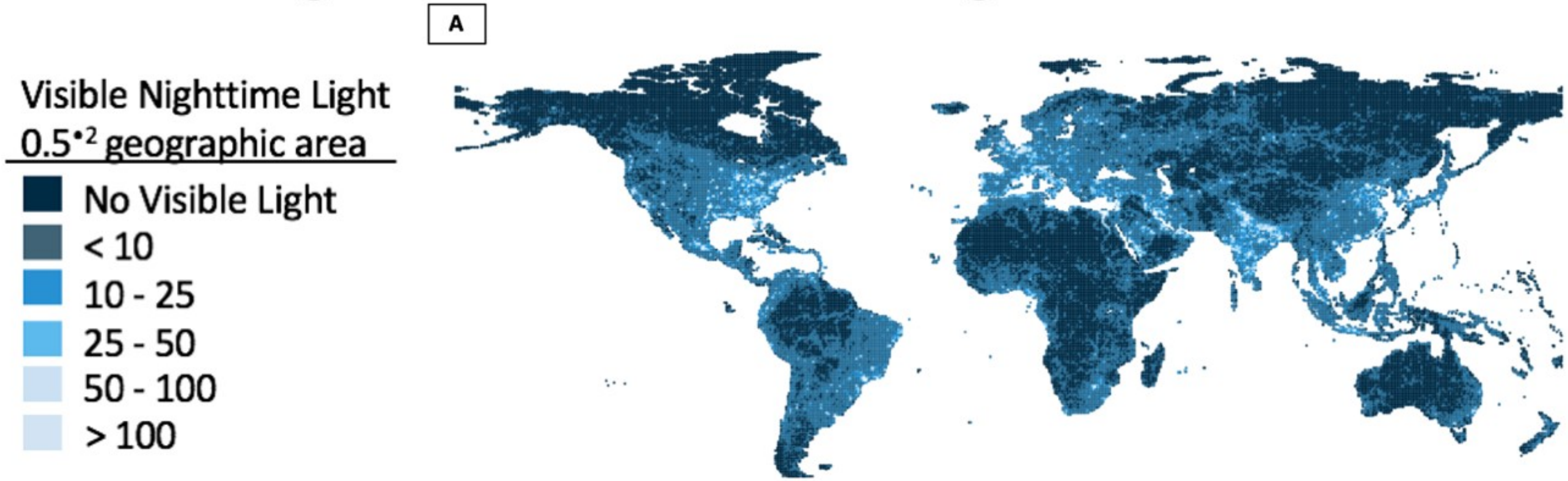
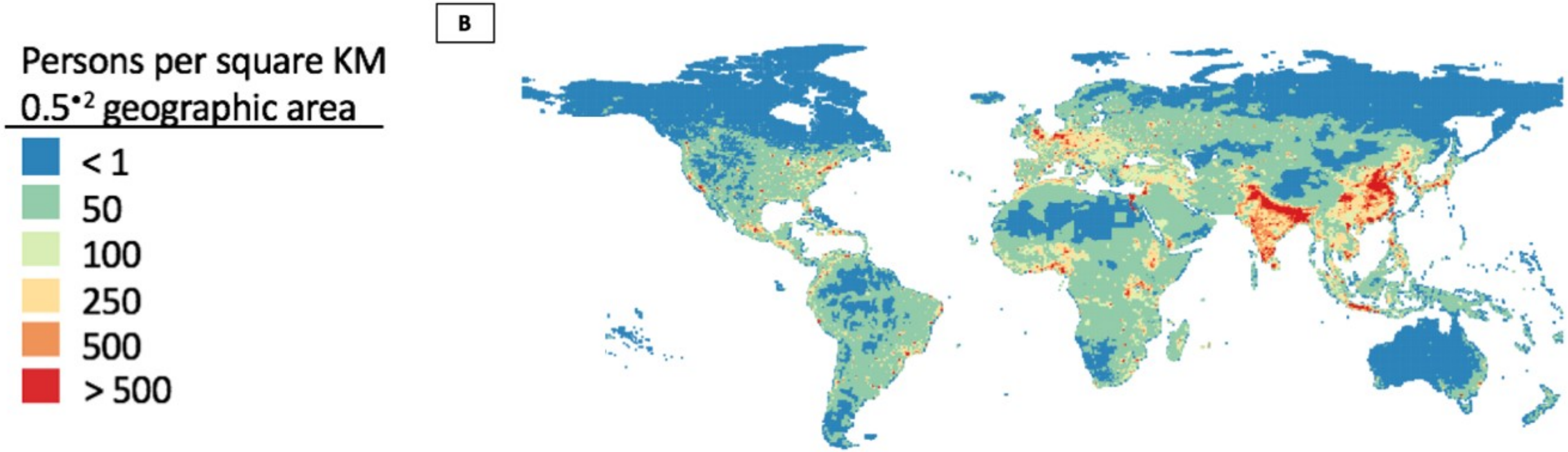


~ 1 km
resolution

Visible Light and Population



~ 50 km² resolution



~ 50 km² resolution

Persons with no visible nighttime light

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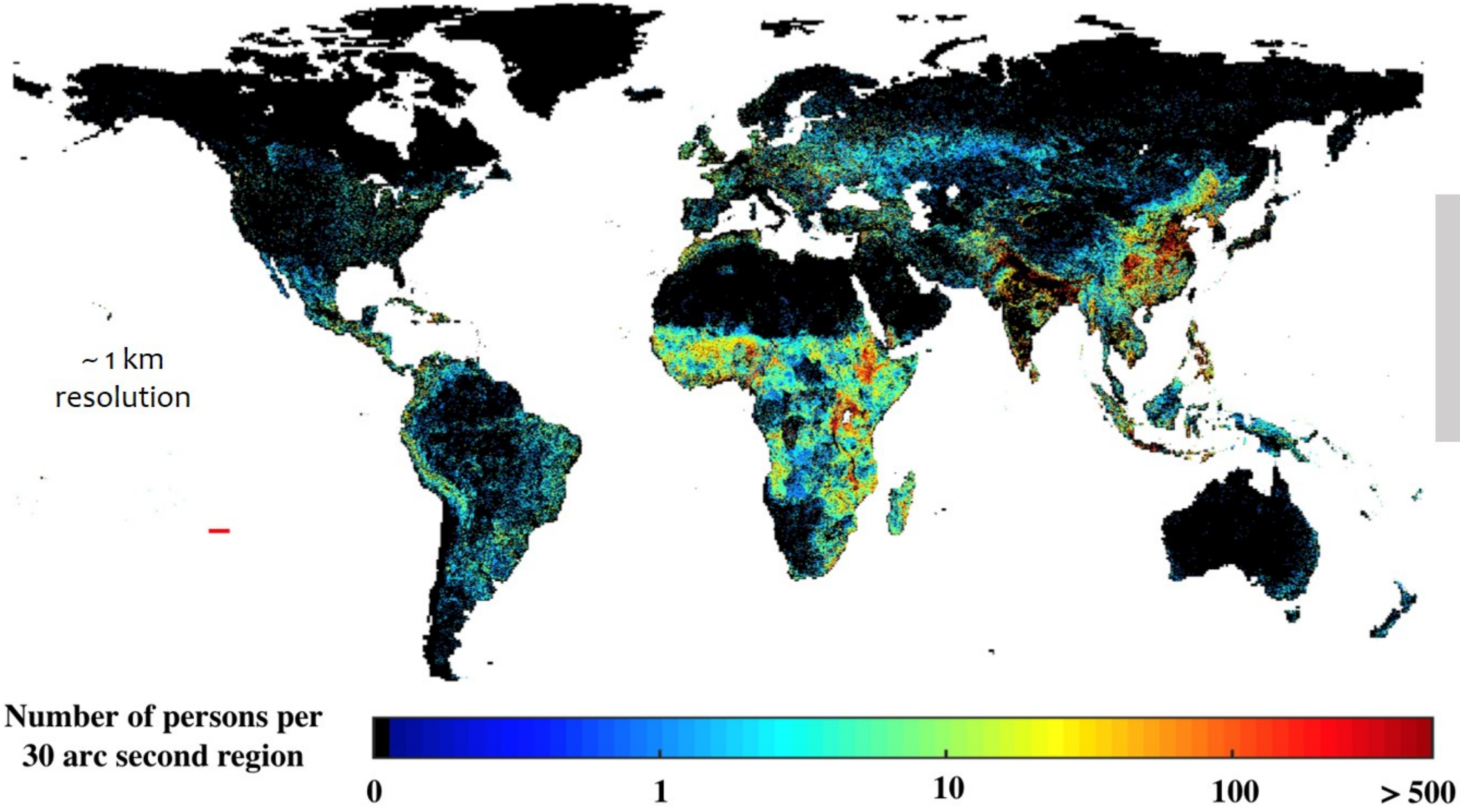

Est. Electricity Poverty:

1.75 billion people

Schweikert, A., Osborne, A. Stoll, B., Duncan, I., Deinert, M. "A Global Assessment of Resources Available to Address Electricity Poverty using Photovoltaics and Energy Storage" 2018. *In Review*

Meeting Electricity Demand

TIER 0	TIER 1	TIER 2
	Task lighting AND Phone charging	General lighting AND Phone Charging AND Television AND Fan (if needed)

TIER 5
Tier 2 AND Any very high-power appliances

Multi-tier Matrix for Measuring Household Electricity Consumption

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Annual consumption levels, in kWhs		≥4.5	≥73	≥365	≥1,250	≥3,000
Daily consumption levels, in Whs		≥12	≥200	≥1,000	≥3,425	≥8,219

Meeting Electricity Demand

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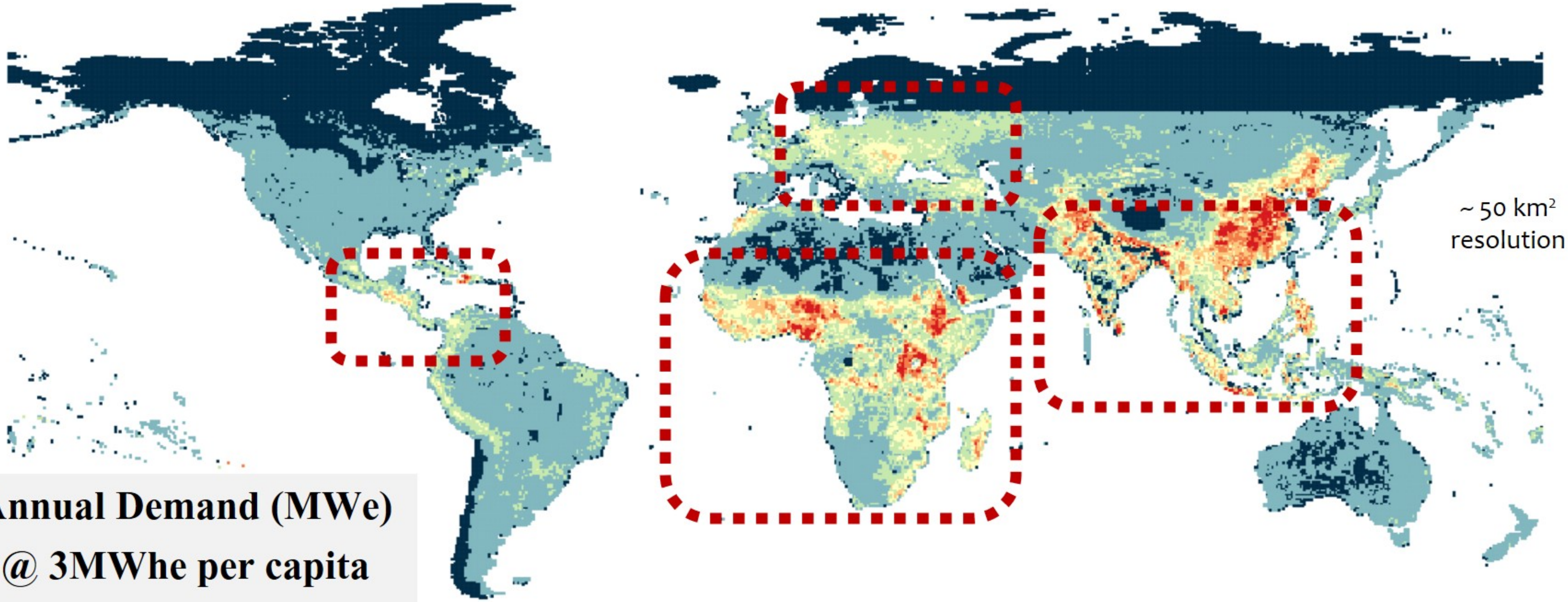


Annual Demand (MWe)
@ 3MWhe per capita

System size required to meet population electricity needs (MWe, Peak Watts, 0.85 capacity factor)
Per 0.5°^{2} geographic area

Schweikert, A., Osborne, A. Stoll, B., Duncan, I., Deinert, M. "A Global Assessment of Resources Available to Address Electricity Poverty using Photovoltaics and Energy Storage" 2018. *In Review*

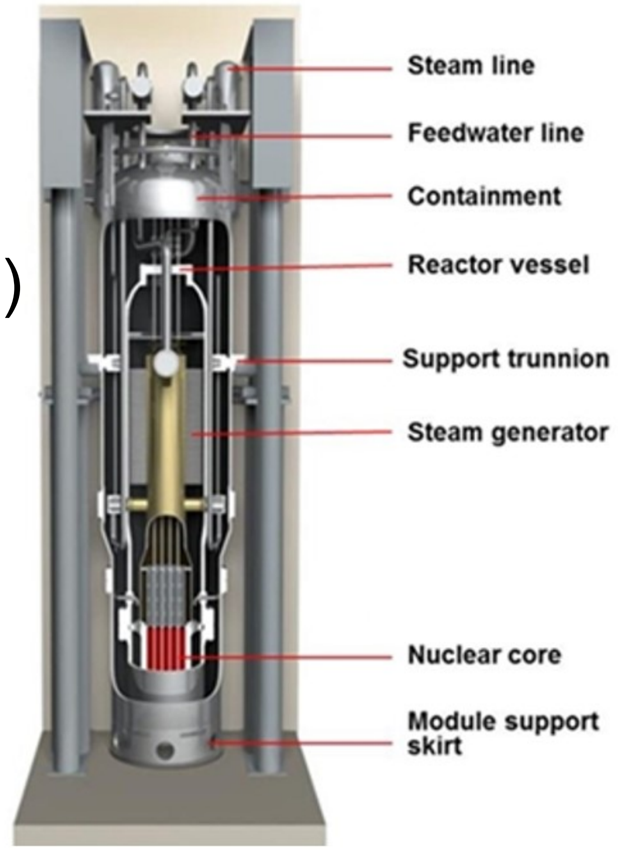
Small Modular Reactors

Small - <300 MWt

- NuScale (200MWt / 60MWe)
- ARC-100 (260 MWt / 50-100 MWe)

Micro – ~1-20 MWt

- Oklo (2 MWt)
- Deinert group (10 MWt)



https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html

FEASIBILITY

Resilience, Size, Cost and Safety

How does SMR/MMR technologies address these challenges?

Resilience: Generation Facilities

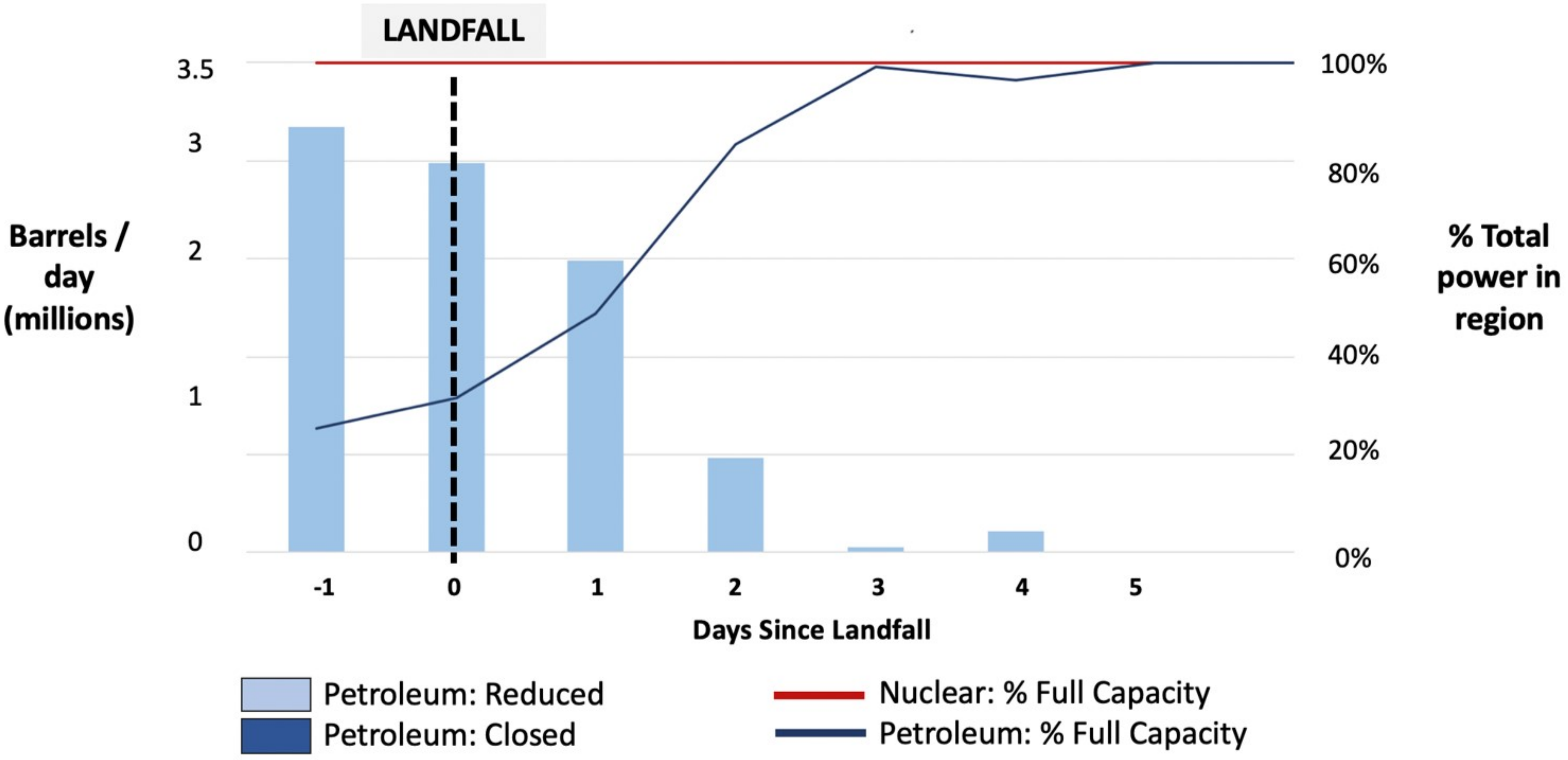
Nuclear is resistant to most natural hazard events by design

https://www.reddit.com/r/solar/comments/73g0li/large_solar_panel_array_destroyed_by_hurricanes/

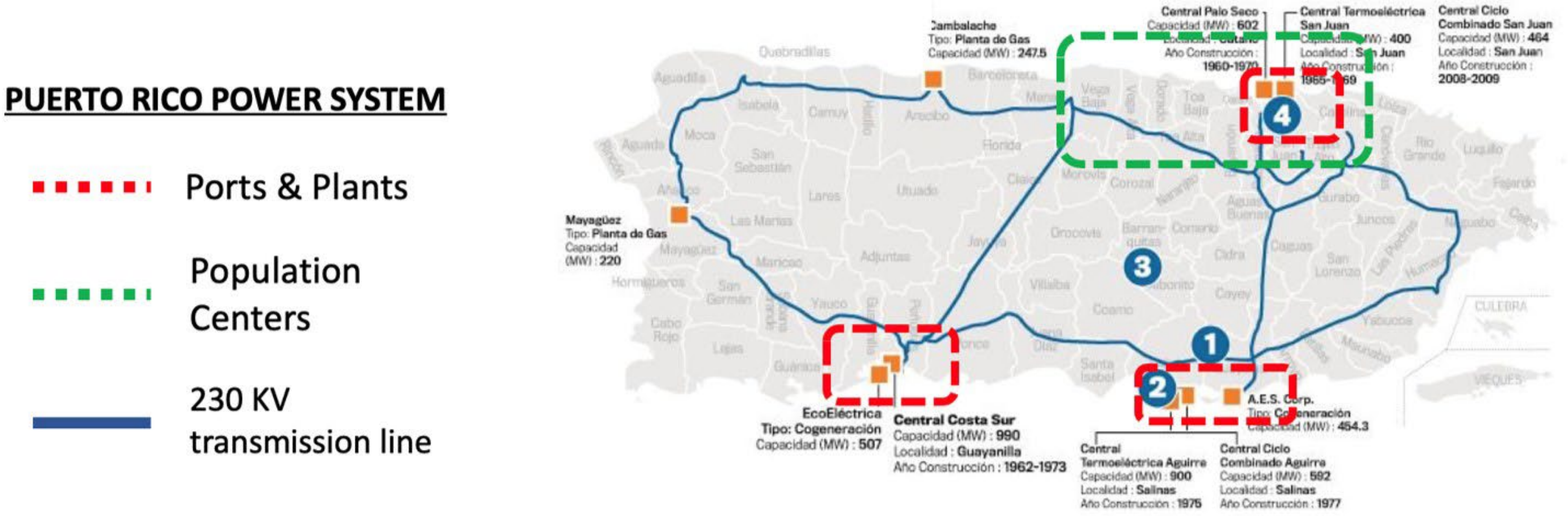
https://www.bizjournals.com/charlotte/news/2018/09/21/duke-energy-shuts-down-inundated-sutton-plant-as.html#g/442010/1

Coal
Oil-fired (petroleum)
Natural gas
Nuclear power
Solar photovoltaic
Diesel generators
Geothermal
Hydroelectric
Wind

Resilience: Harvey's Impact on Petroleum and Nuclear



Resilience: Hurricane Irma and Maria: Puerto Rico



Island states present unique challenges:

- Diversity of providers, operations matter
- Supply chain of fuel is critical (port closures – dependent on oil imports)

Graphic modified from: https://www.elnuevodia.com/noticias/locales/nota/todoloquenecesitassabersobreelapagon-2243737/?TB_iframe=true

Resilience: Transmission and Distribution

No matter how power is generated, it must be delivered to end users

Smaller generators allow for more distributed grids

Resilience: Fuel and Maintenance Supply Chains

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Fuel supply chains rely on ports, roads, pipelines and other infrastructure

On-demand fuel sources are vulnerable to disruptions caused by hazards

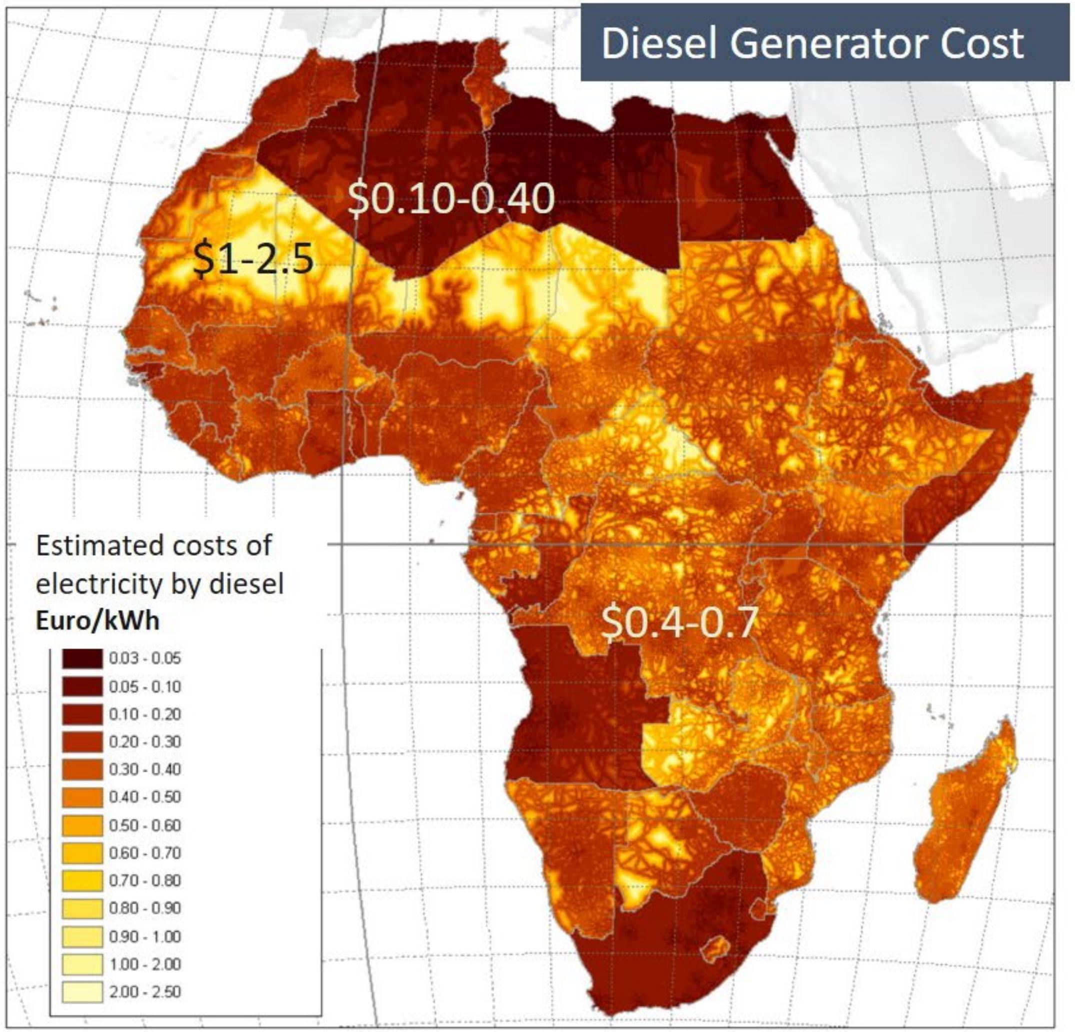
FEASIBILITY

Resilience, **Size, Cost**, and Safety

How does SMR/MMR technologies address these challenges?

Costs: Regional Comparison to Other Technologies

- Considering costs in context
- Size, especially in remote (non-grid) areas is an important market for SMR/MMR technology



S. Szabó, K. Bodis, T. Huld, I. Pinedo-Pascua, U. Tromboni, and M. Moner-Girona, "Energy options in rural Africa: solar and diesel distributed systems vs. grid extension," Joint Research Centre, European Commission, 2010.

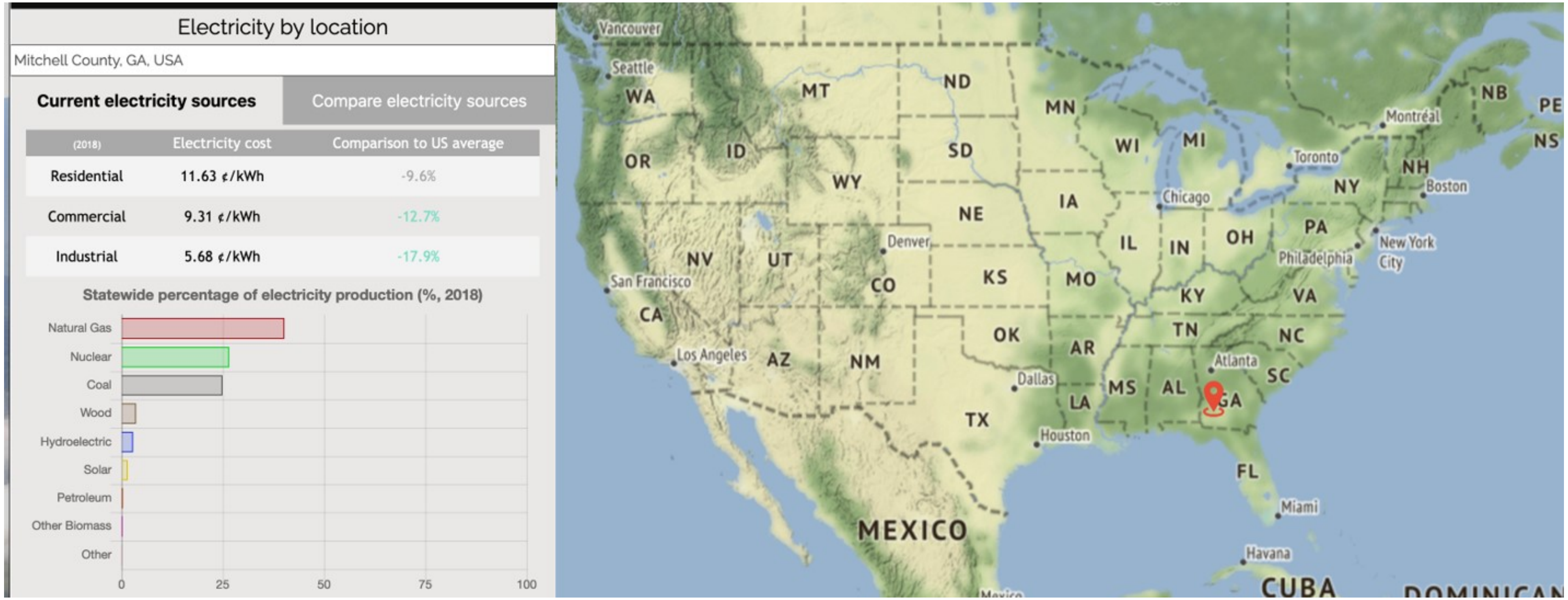
Costs: Transition Risk

- The risk to companies, banks, portfolios, etc. related to clean energy and emissions
- Operationalized in numerous banking organization, insurers, investors and governments
  - 16 global banks partnering with UNEP-FI Task Force on Climate-Related Financial Disclosures[1]
- U.S. Commodity Futures Trading Commission, 2020: Recommendation #1 is a carbon tax[2]

[1] United Nations Environmental Prograame, Finance Initiative - https://www.unepfi.org/climate-change/tcfd/

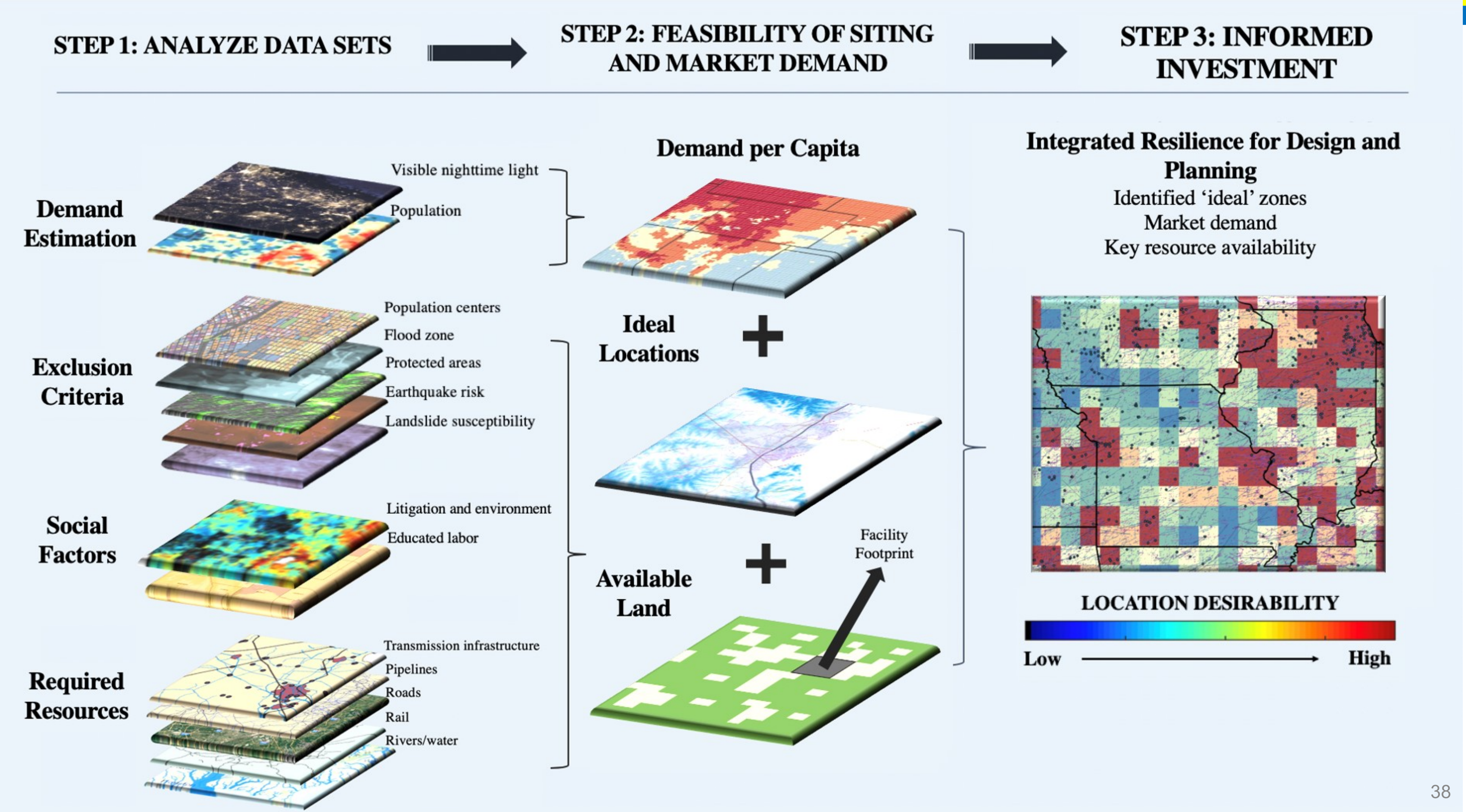
[2] Behnam and Litterman, “Managing Climate Risk in the U.S. Financial System” Report of the Climate-Related Market Risk Subcommittee, Market Risk Advisory Committee of the U.S. Commodity Futures Trading Commission. Sep. 2020

Technology	LCOE, Current [$/kWhe]	Direct CO_2 Cost [$/kWhe]	LCOE, CO_2 Tax [$/kWhe]
Natural Gas	$0.0453	$0.0096	$0.0549
Nuclear PWR	$0.0547	$0.00	$0.0547
Coal	$0.0658	$0.0226	$0.0884
Solar	$0.1071	$0.00	$0.1071
Nuclear SMR [NuScale]	$0.0421	$0.00	$0.0421



ANALYSIS

How can we put all of this together?


STEP 1: ANALYZE DATA SETS
STEP 2: FEASIBILITY OF SITING AND MARKET DEMAND
STEP 3: INFORMED INVESTMENT
Demand Estimation
Visible nighttime light
Population
Exclusion Criteria
Population centers
Flood zone
Protected areas
Earthquake risk
Landslide susceptibility
Social Factors
Litigation and environment
Educated labor
Required Resources
Transmission infrastructure
Pipelines
Roads
Rail
Rivers/water
Demand per Capita
Ideal Locations
Available Land
Facility Footprint
Integrated Resilience for Design and Planning
Identified 'ideal' zones
Market demand
Key resource availability
LOCATION DESIRABILITY
Low
High

International Site Screening

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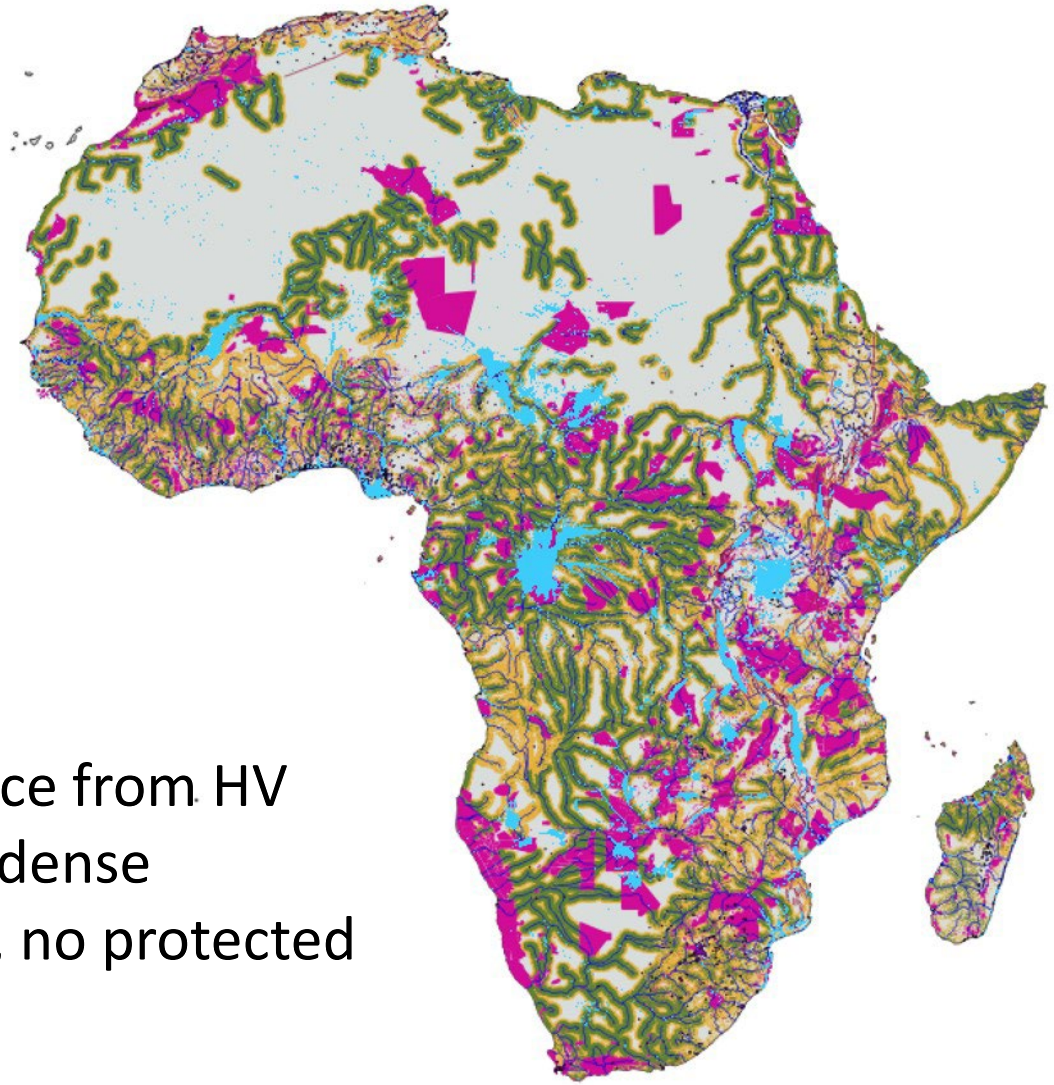
<u>Nuclear Siting</u>

- Ideal for siting
- Acceptable for siting
- Population centers
- Active fault zone
- Water
- Not suitable land



"Ideal" and "Acceptable" Criteria: Distance from HV Transmission and water source, outside dense population centers, no seismic fault line, no protected environmental regions

The Potential – Annual Market Size

	Market Size (GWh)	Market Size - USD (at: 10.84 cents/kWhe*)
Tier 5 Access 3 MWhe	5.25 million GWh	$ 569 billion
US Access 10.8 MWhe	18.9 million GWh	$2.05 trillion

1.75 billion persons *currently living in* Electricity Poverty

* Lowest Cost US Region, *West South Central*, Residential US July 2018

Final Considerations

- At an equivalent energy use per capita of 3.6 MWe and a capacity factor of 0.85, an expansion of electricity production of just over 1,000 GWe is needed globally
  - Huge initial market potential
  - 2030 Technological lock-in matters
- Regulatory infrastructure, security considerations and educated workforce is critical to include
- Size matters
  - In many regions, smaller is better and more resilient
  - Reliability is important (***collaboration*** vs. ***competition*** with other low-carbon options)


Questions?

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Upcoming Webinars

19 November 2020	Neutrino and Gen IV Reactor Systems	Prof. Jonathan Link, Virginia Tech, USA
17 December 2020	Development of Multiple-Particle Positron Emission Particle Tracking for Flow Measurement	Dr. Cody Wiggins, University of Tennessee, USA
28 January	MOX Fuel for Advanced Reactors	Dr. Nathalie Chauvin, CEA, France