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Universalization of electricity supply

Prof. Ignacio J. Pérez-Arriaga
MIT-CEEPR, ESD
IIT-Comillas University

The three gaps in energy access

- The **equity** gap *(the ethical dimension)*

  "It is shameful & unacceptable that today today billions of people lack access to the most basic energy services"

  (International Energy Agency, WEO, Nov-2010)

- The **ambition** gap *(the technical dimension)*

  "The world's poor need more than a token supply of electricity. The goal should be to provide the power necessary to boost productivity and raise living standards"

  (Morgan Bazilian, Roger Pielke, 2013)

- The **opportunity** gap *(the business dimension)*

  "There is another way to look at the challenge: energy access as an opportunity for business"

  ("From gap to opportunity", International Finance Corporation)

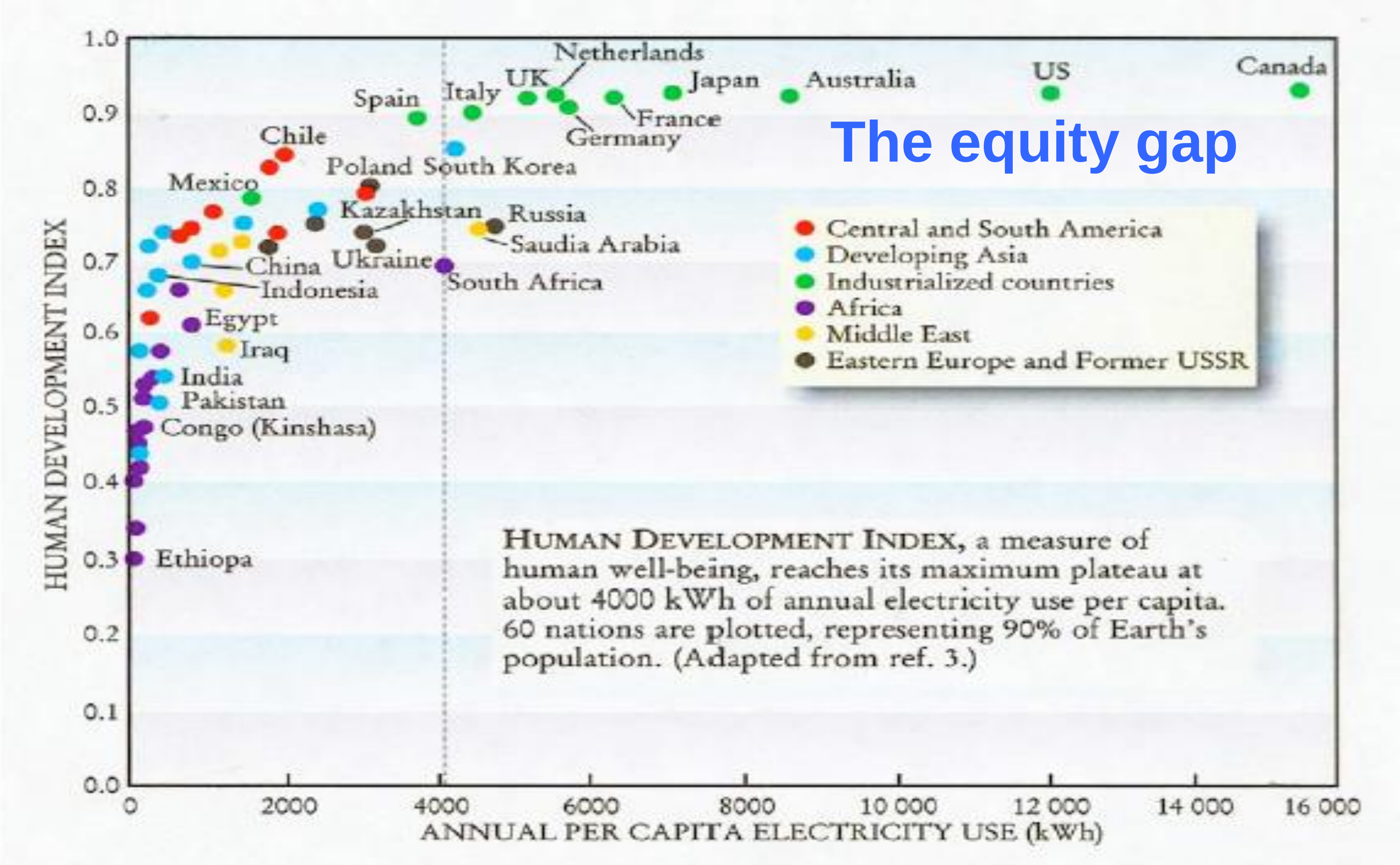


Figure 1.2. Human development index vs. per capita electricity use for selected countries. Taken from S. Benka, *Physics Today* (April 2002), pg 39, and adapted from A. Pasternak, Lawrence Livermore National Laboratory rep. no. UCRL-ID-140773.

Is IEA falling into the ambition gap?

Estimated impacts of universal electricity access according to the IEA *(WEO-2010)***:**

"Achieving universal access by 2030 would **increase global electricity generation by 2.5%**. Demand for **fossil fuels would grow by 0.8%** and **CO2 emissions go up by 0.7%**, both figures being trivial in relation to concerns about energy security or climate change. The prize would be a major contribution to social and economic development and help to avoid 1.5 million premature deaths per year."

"**Adding** 0.003 $/kWh, some **1.8%, to current electricity tariffs in OECD countries** could fully fund the additional investment."

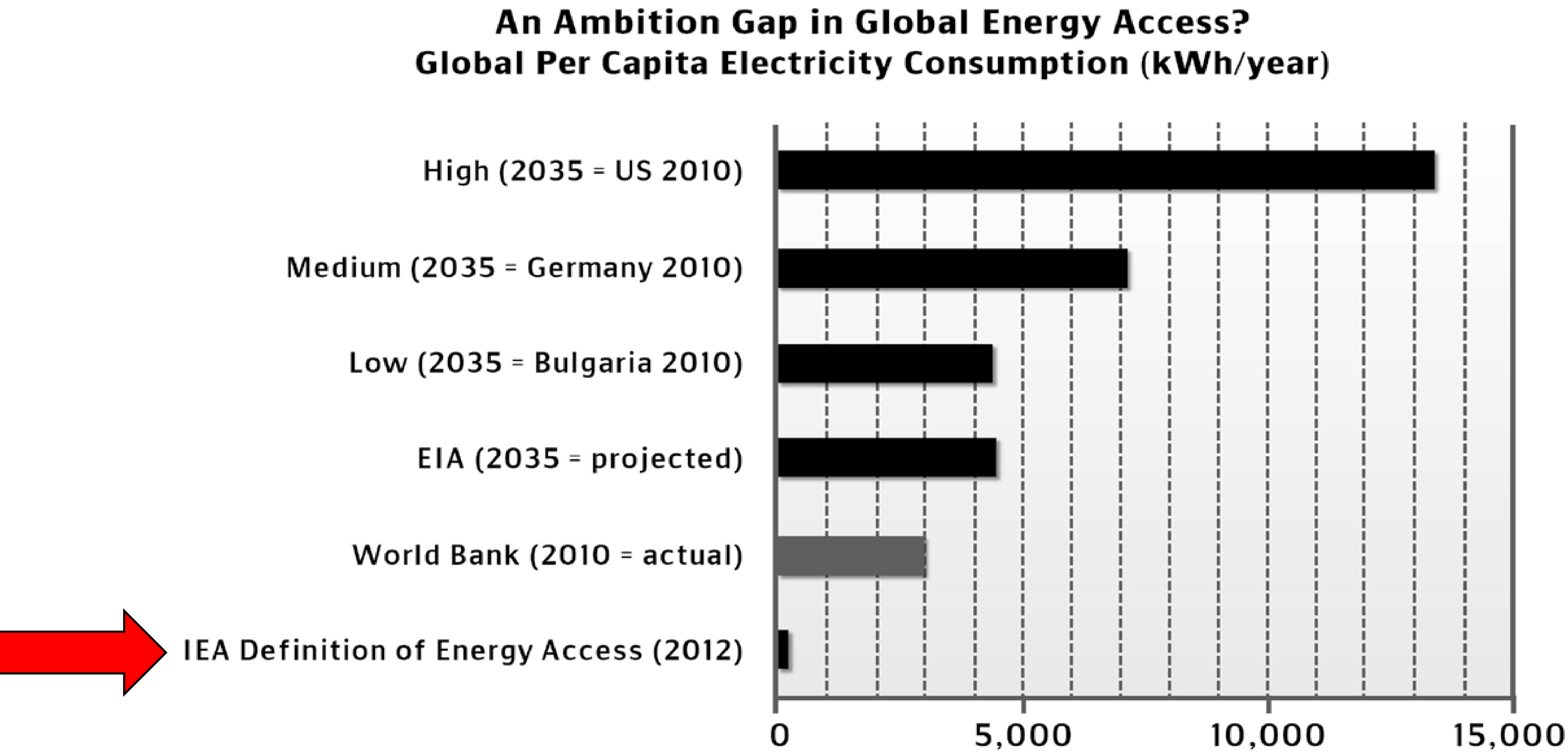


Figure 2: Assumptions of global per capita electricity consumption compared.

Source: Morgan Bazilian & Roger Pielke, "Making Energy Access meaningful", 2013

The problem is even larger than reported

- The official definition of “access to electricity” is misleading
  - In some countries a village is declared “electrified” if a certain % of the households have electricity
  - Having “access” to electricity does not guarantee an effective service: In many rural & periurban areas access lasts for a few hours and not even on a consistent basis.
    - This makes people prefer decentralized solutions that at least guarantee access for a limited number of hours to on-grid unreliable power

The opportunity gap

"While there is broad recognition that lack of access to modern energy has major implications for development, **the energy access gap is increasingly being seen as a market**"

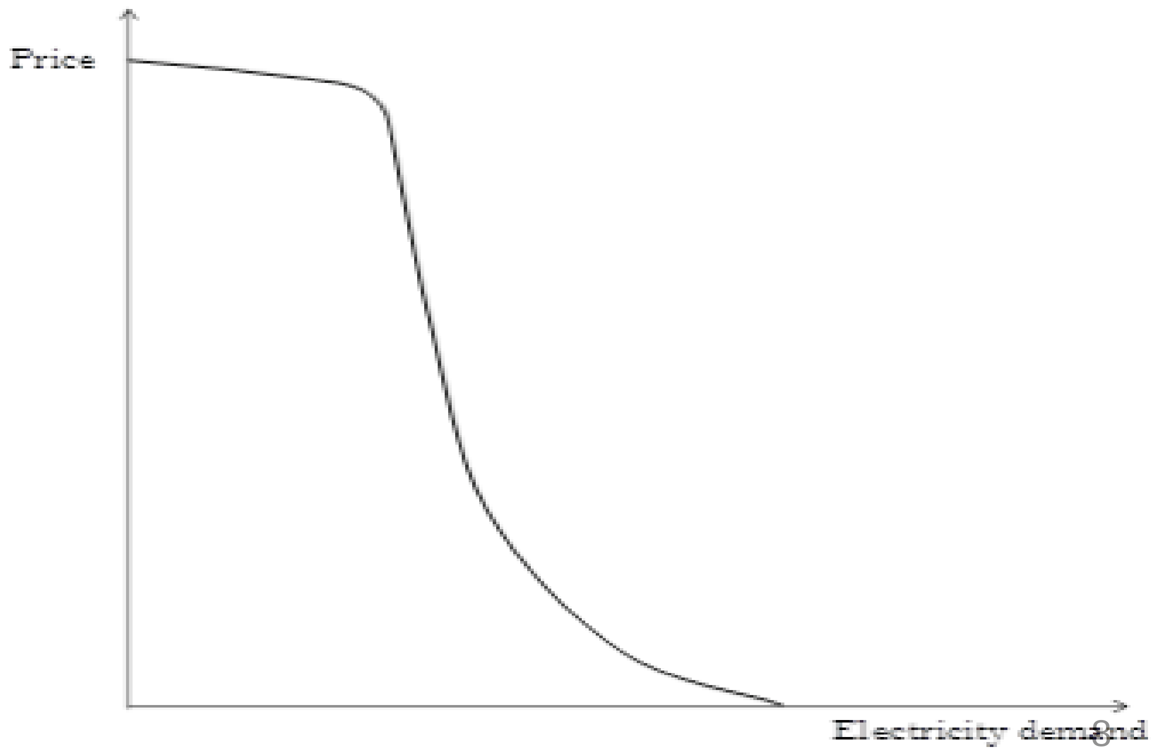
"Each year, **the poor spend $37 billion on poor-quality energy solutions to meet their lighting and cooking needs**. This represents a substantial and largely untapped market for the private sector to deliver better alternatives."

"…an estimated 90 percent of (poor) people already spend so much on kerosene lamps, candles, and disposable batteries to meet their lighting needs that **they could afford to purchase better options**, such as solar lamps. Even more people could afford efficient cookstoves because of the fuel cost savings they offer."

Source: "From gap to opportunity", International Finance Corporation, May 2012

Value of the initial electricity usage

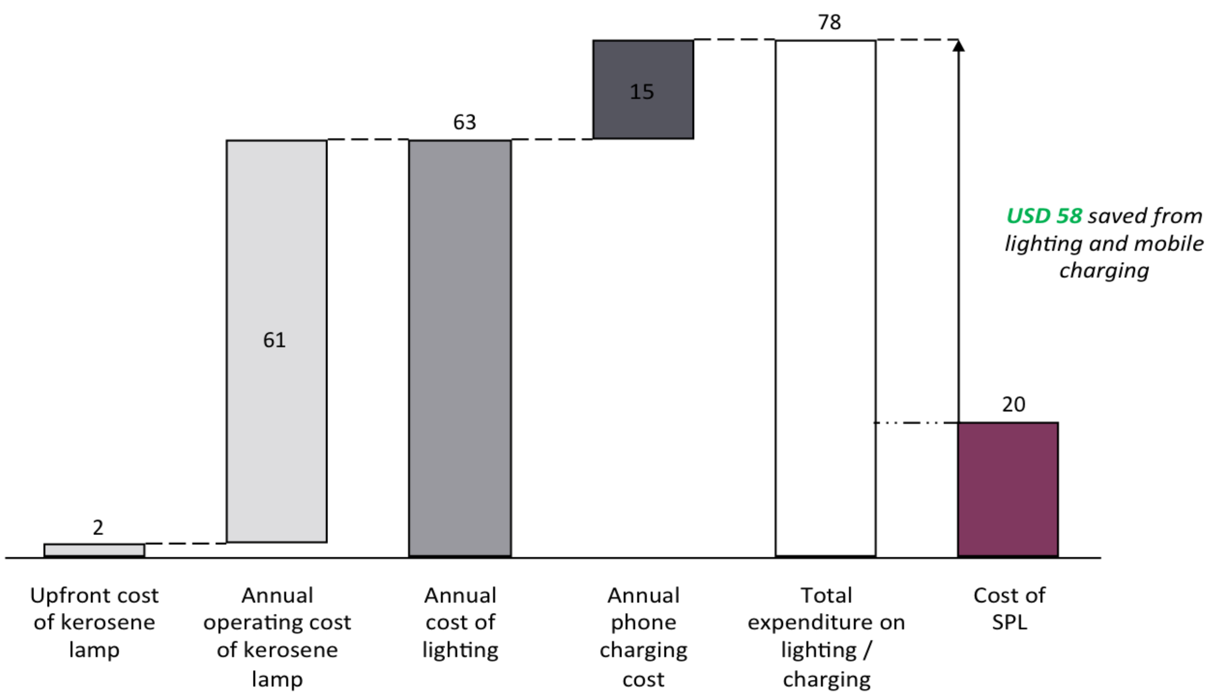
- The initial electricity usage per household, shop or health center is among the most productive electricity usages. Consumers are willing to pay a high price for the most essential electricity services



Example: Solar Power & Light (SPL) products with integrated phone charging are a compelling investment for those with cash

Annual Household expenditure on kerosene and mobile charging vs. expenditure on SPL

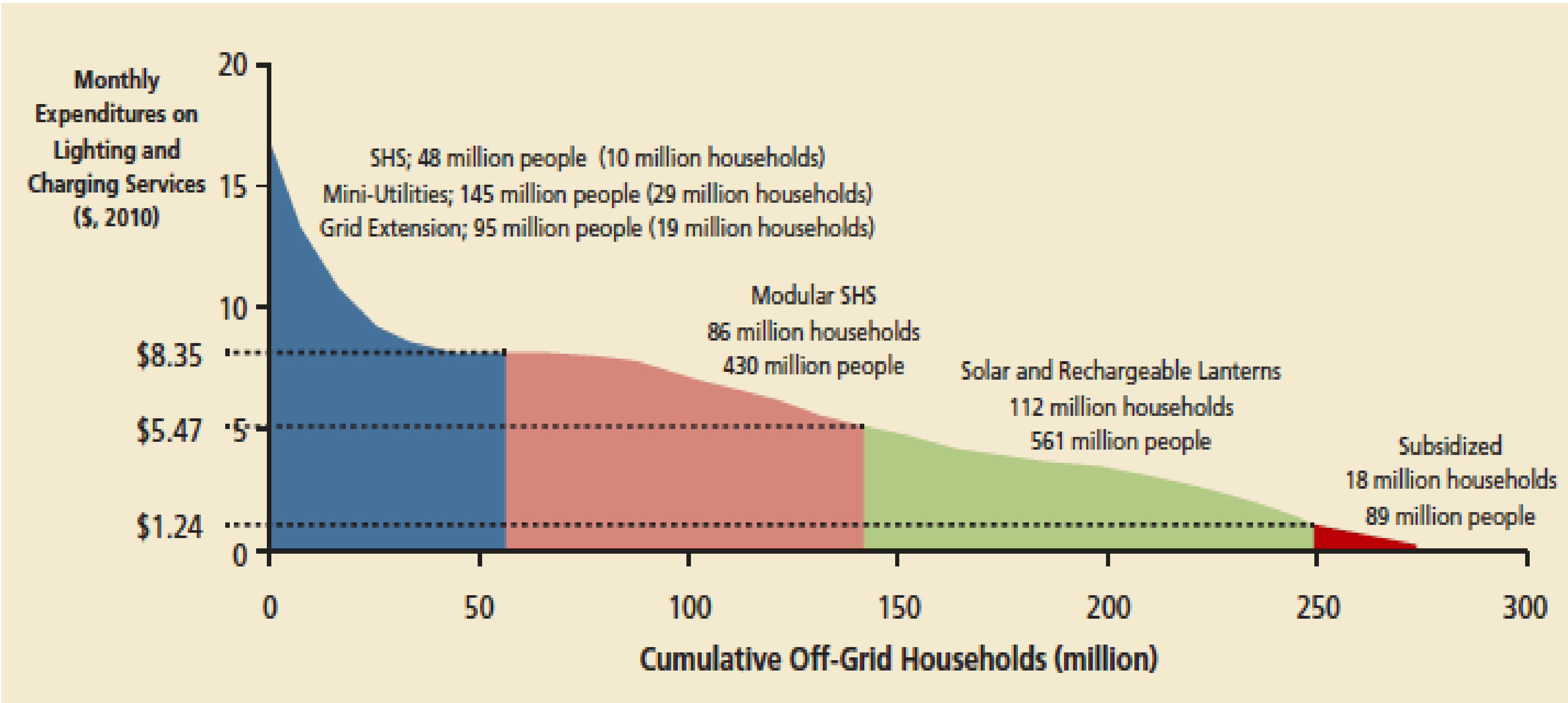
USD, 2012



Kerosene assumptions: Six hours of usage per day of kerosene lamp per day; Average kerosene price of USD X/liter
Mobile charging assumptions: Estimates the charging patterns for the average off grid user (with at least some access to electricity).
SPL assumptions: Median SPL is USD 40, assuming a straight line depreciation in 3 years
Source: GVEP; Internet research, Dalberg Analysis

Figure 1. Comparison of the annual cost of kerosene lighting with the cost of a simple solar lantern with integrated phone charging functionality (World Bank 2012).

Addressable market for modern energy products and services



Source: IFC, "From gap to opportunity: Business models for scaling up energy access", May 2012. Figure A.1

Why now?

- Growing markets & associated revenue streams for energy related products & services for the currently underserved segments in developing countries
- Opportunities to create competitive advantage by developing new and affordable energy technologies that reduce emissions and/or improve energy efficiency
- Critical moment to advocate business positions on access to energy at international negotiations:
- Time-limited opportunity to influence rapidly-evolving financing mechanisms discourse to catalyze business action in expanding access to energy

Source: World Business Council on Sustainable Development, WBCSD

Elements for a successful & scalable approach

- **Political commitment** to address the problem
- **Participation** of the concerned communities
- **Viable business model** for the supplier
  - Adequate financing, with an affordable cost for the consumer, made possible by subsidies if required
  - Centered in the provision of a service of prescribed quality

supported by a credible **legal** & **institutional framework**

  - Either a dedicated electrification agency,
  - or a licensed utility-like service provider
  - or decentralized suppliers or cooperatives under light regulation

- Adequate **technical** solutions
- Ensure the **sustainability** of the project

MITei / IIT-Comillas activities on universal energy access*

(*) Presently with funding from the Tata Foundation, Enel Foundation & Iberdrola

A sample of current activities

- Awareness actions
  - e4Dev discussion group at MIT
- Power pools in Africa / Solar generation in Kenya
- Support to scalable & sustainable electrification initiatives
  - Low cost technologies, business models and enabling environment for Universal Access to modern energy service *(Kenya, Peru)*
  - Design & implementation of microgrids for electricity access in India
  - Pilot and business plan for an electrification program of villages in Rwanda using schools as an anchor load

Common to all the on-going projects
Think BIG

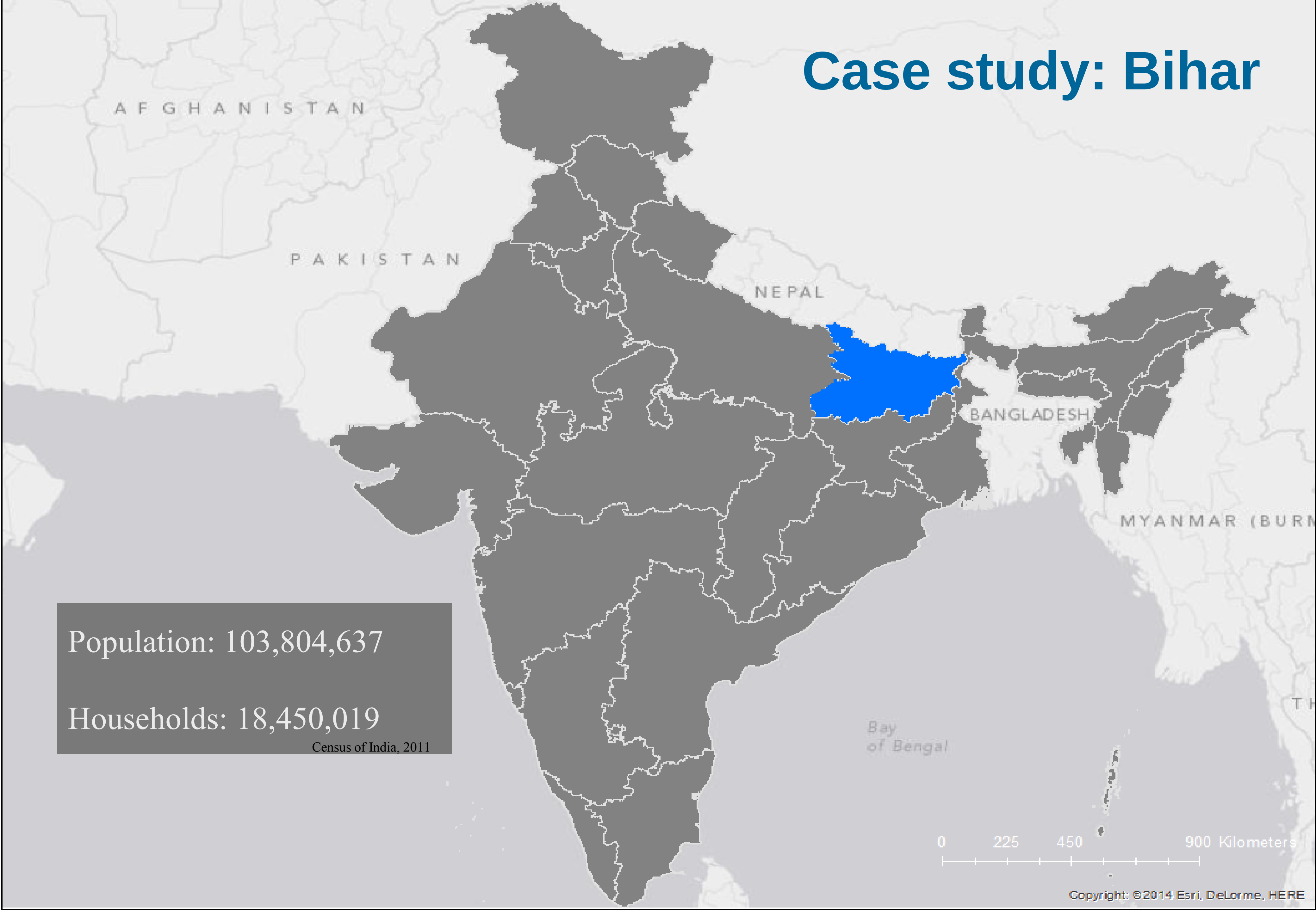
Suite of computer models to drive informed electrification decision making

- Determination of the **location** of electricity demand & characterization of demand
- Assignment of **electrification mode** & design of supply
- Integration into an **electrification plan** & the overall energy system for the country / region

Suite of computer tools
Demand location & characterization

- Start from **satellite imagery**
  - Google Earth, NASA satellite pictures
- **Automated building detection** via machine learning algorithms that minimize the amount of required user input
- Add **layers of information** via GIS techniques to characterize demand & other relevant information for electrification purposes
  - Current electrification level, demand estimation, affordability, distance to existing power lines, energy resources

Case study: Bihar

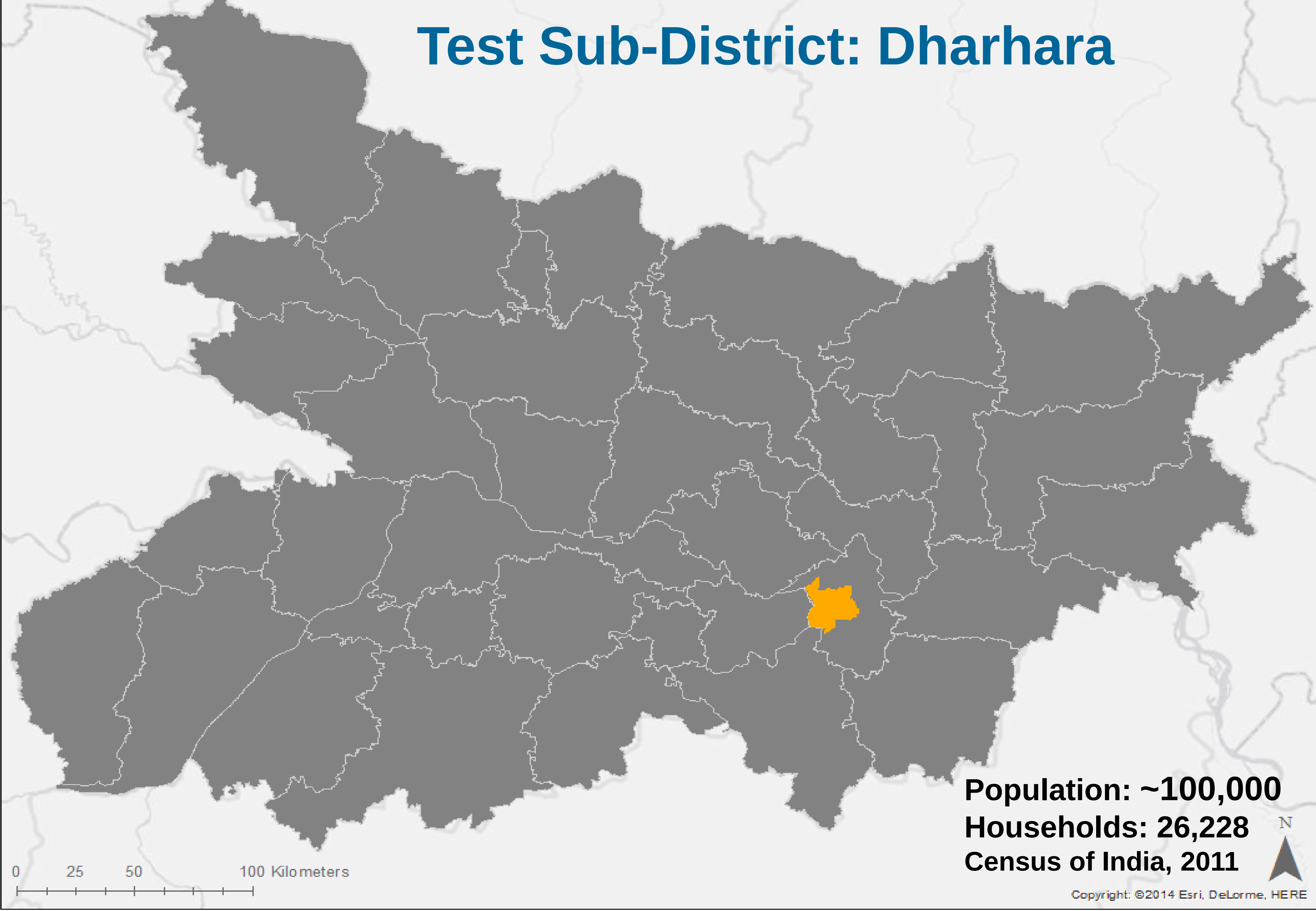


Population: 103,804,637

Households: 18,450,019

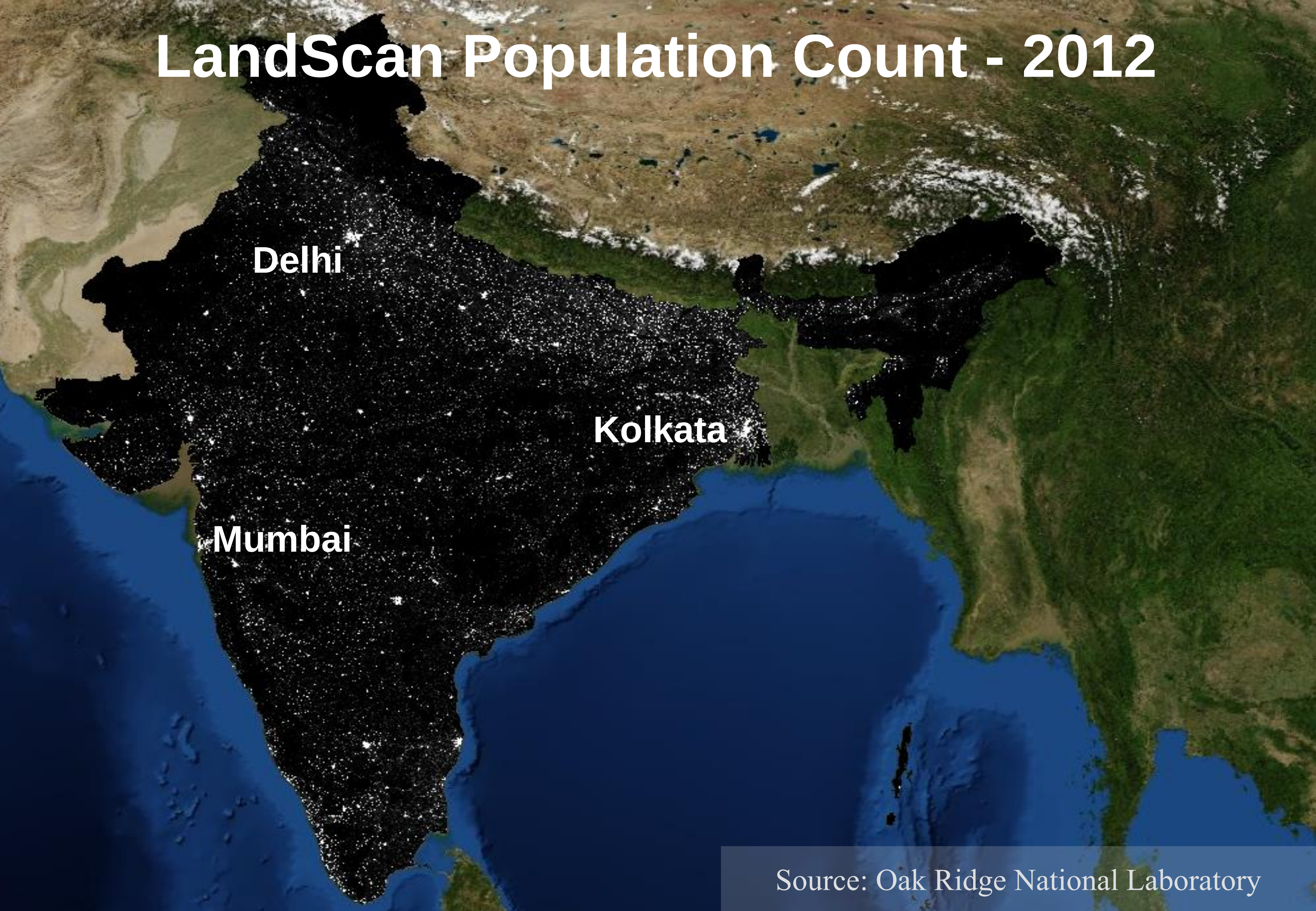
Census of India, 2011

Test Sub-District: Dharhara

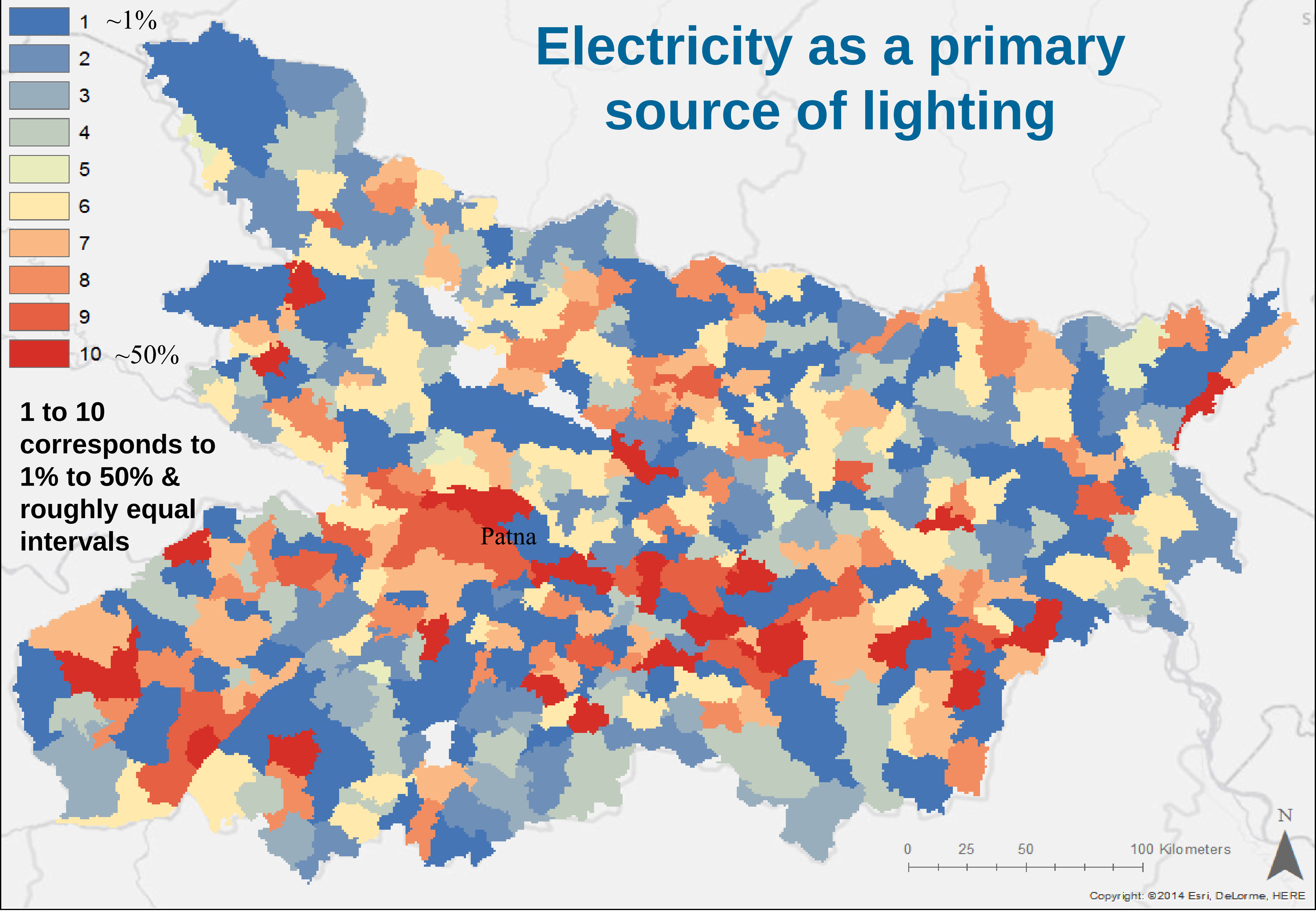


Population: ~100,000
Households: 26,228
Census of India, 2011

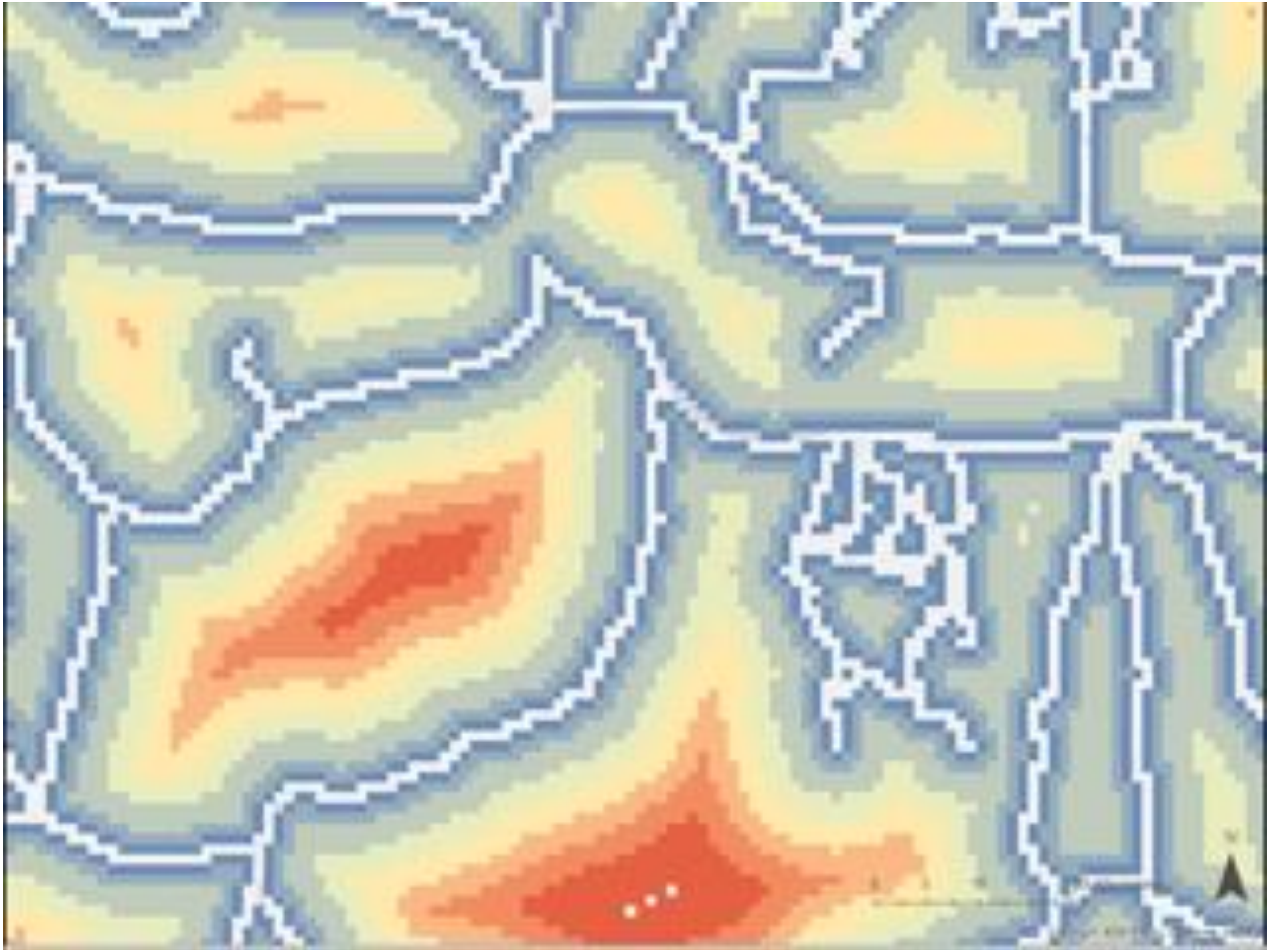
		Variable	Unit	Proxy	Source	Data Type
Population	**LandScan 2012**	Population	km x km	Household Points	ORNL	Raster
	Census of India, 2011	Electricity Access, Households, Appliances	Sub-district	Electricity Access, Demand	Government of India	Tabular
	Dharhara Household Points, 2014	Individual building locations	buildings	N/A	Extract from Google Earth Satellite Imagery	Point/shp
Environment	**Topography**	Terrain	km x km	N/A	G-TOPO	Raster
Infrastructure	**Highways**	Roads	Meters	Grid	Open Street Maps	Line
	Night Time Lights DMSP	Average light brightness (1-63)	km x km	Grid, Electricity Consumption	NASA	Raster
Resources	**PV Watts**	Solar Insolation	10km X 10km		NREL	Tabular
	International Fuel Prices, 2009	Diesel Prices	rupees/liter	Price/region		
Grid Connection	**Accesibility Database**	Distance from Cities		Multiplier for Diesel costs	Joint Research Center	
	GIS Processing	Distance from Grid		Cost of Grid Connection		
Survey	**NSS 66th, 2009-2010**	Appliance ownership, MPCE	household in sample	Demand		
	IHDS, 2004-2005	Urban/rural income distribution	household in sample		Univ of Md/Nat'l Council of Applied Econ Research	Tabular


LandScan Population Count - 2012
Delhi
Kolkata
Mumbai
Source: Oak Ridge National Laboratory

Electricity as a primary source of lighting



Distance from roads

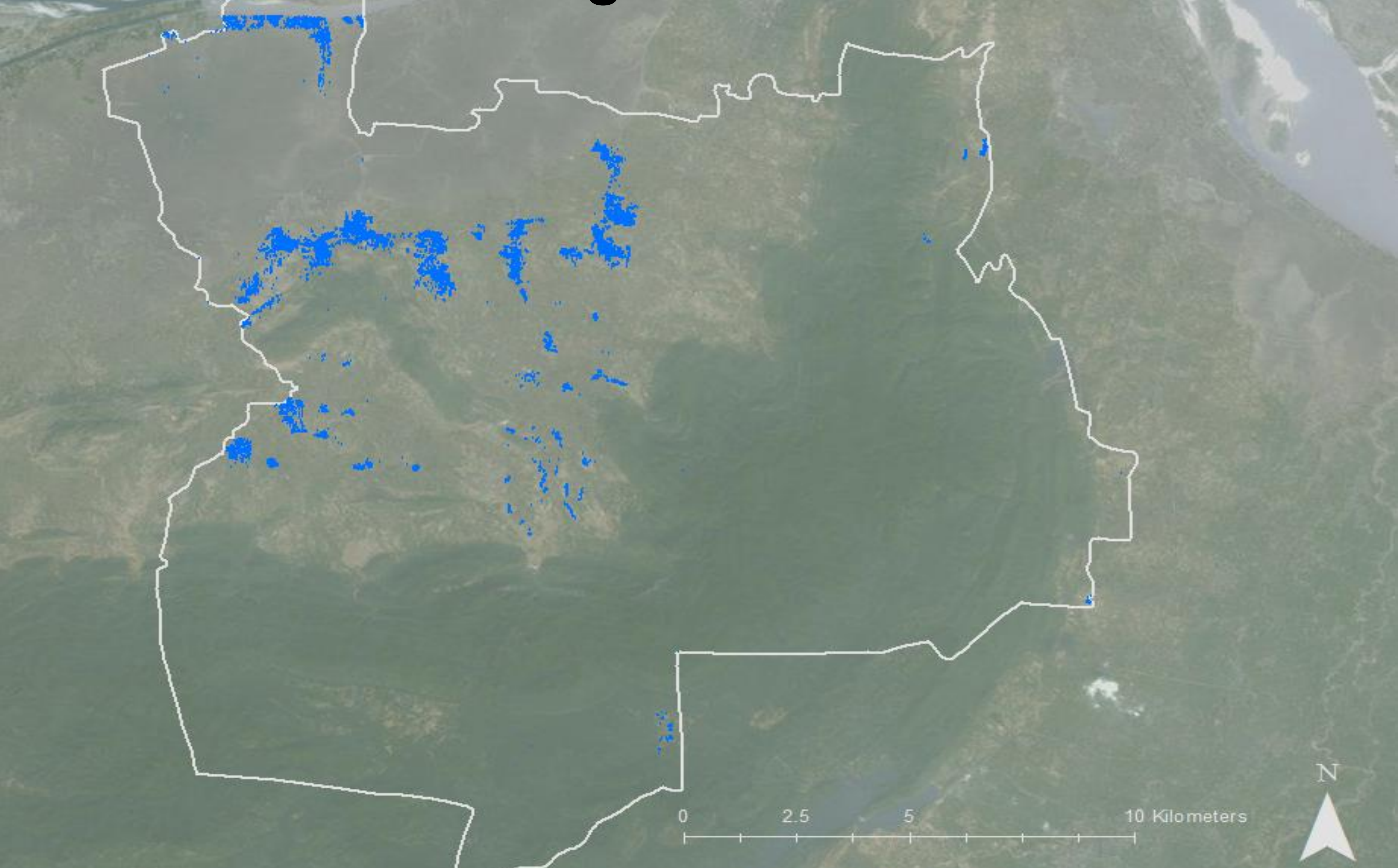


Suite of computer tools
Electrification mode & supply design

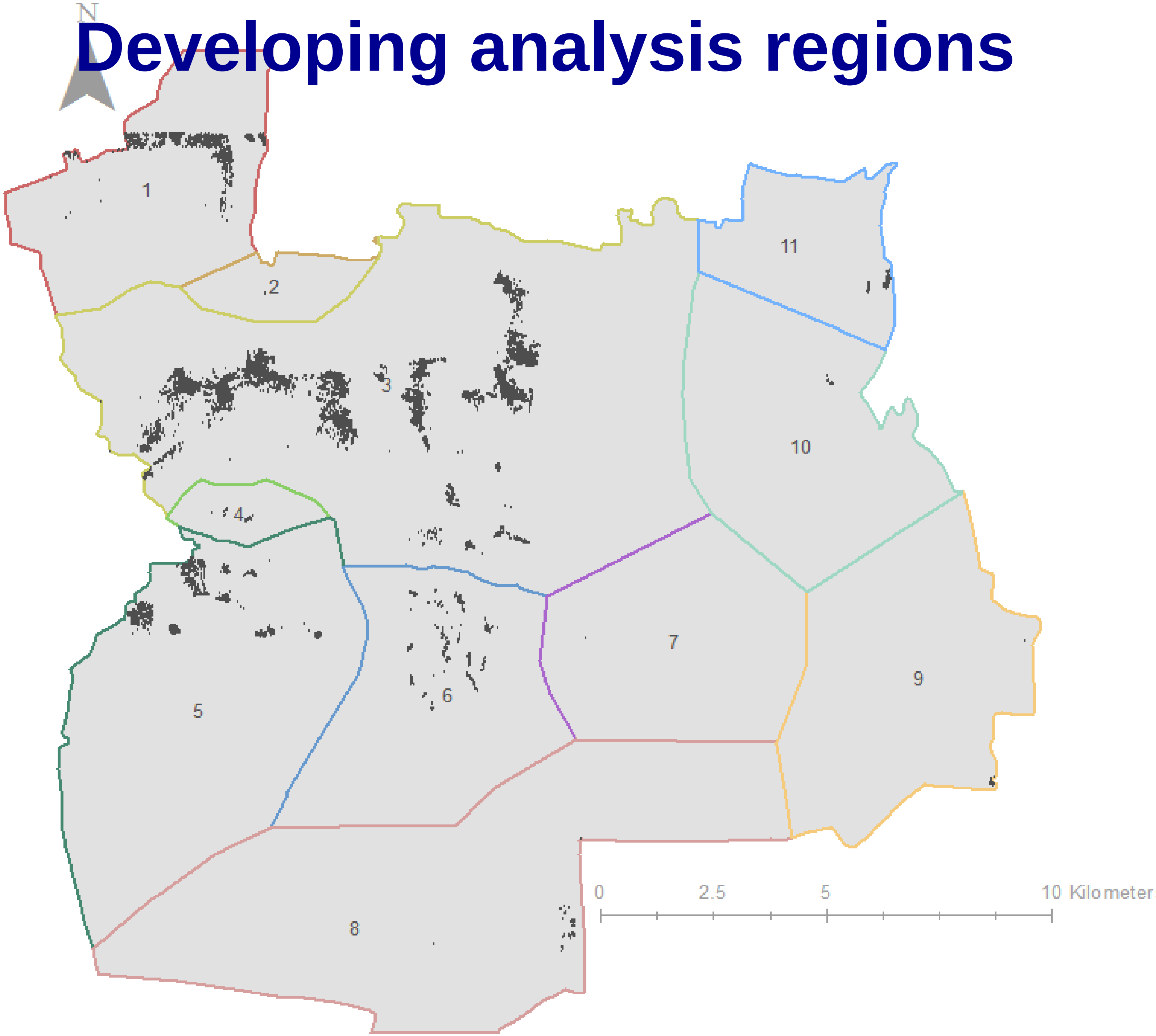
Reference Electrification Model (REM)

- Split the study area into separate analysis regions
- Split the analysis regions into electrically independent clusters
  - Connected to the main grid, off-grid microgrids or stand alone systems
- Design the electricity supply & the network layout for each cluster
  - Determine the supply attributes (cost, environmental impact, quality of service)
    - Different runs for various electrification levels (for interaction with the MASTER model)

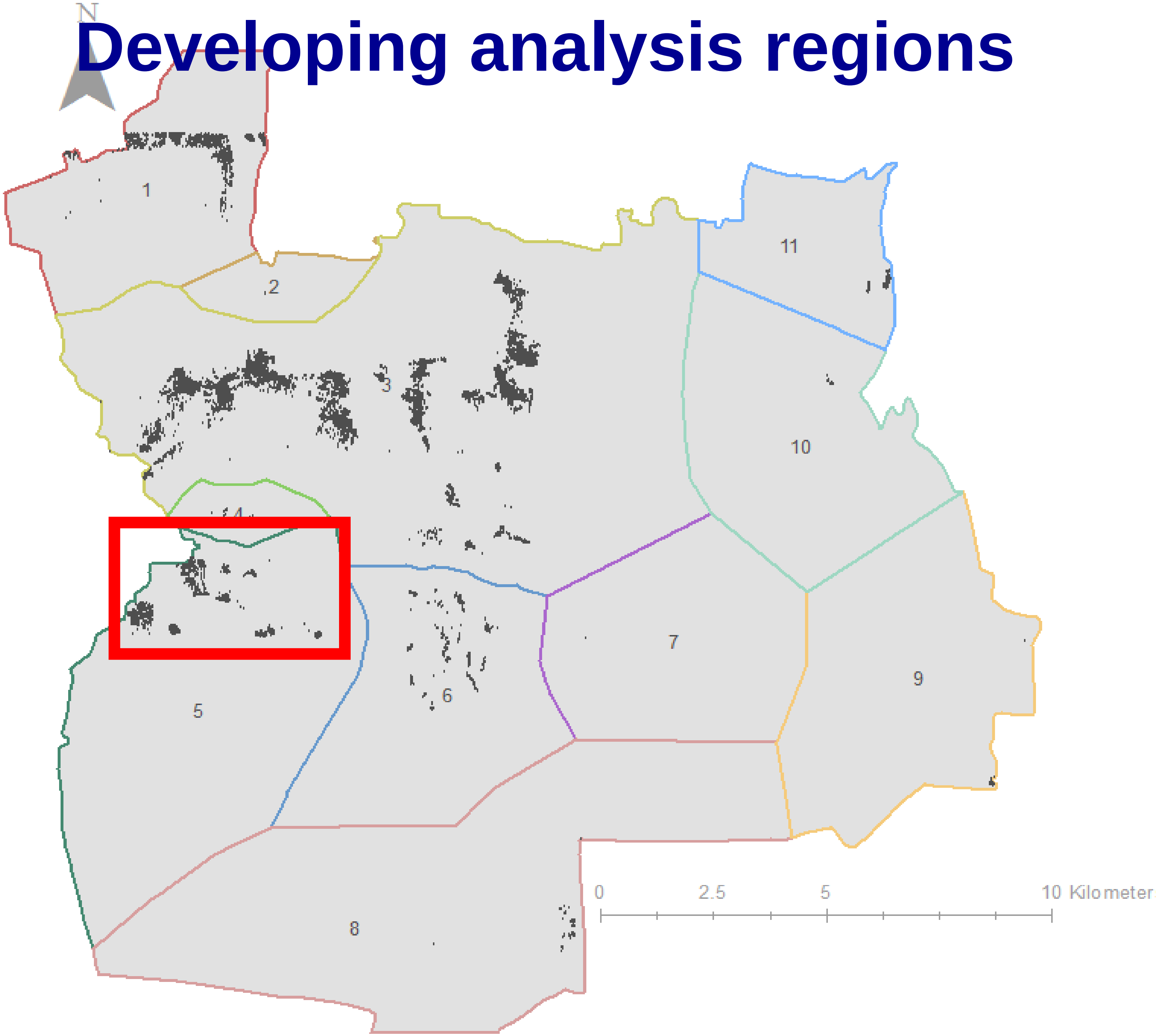
Buildings in Dharhara



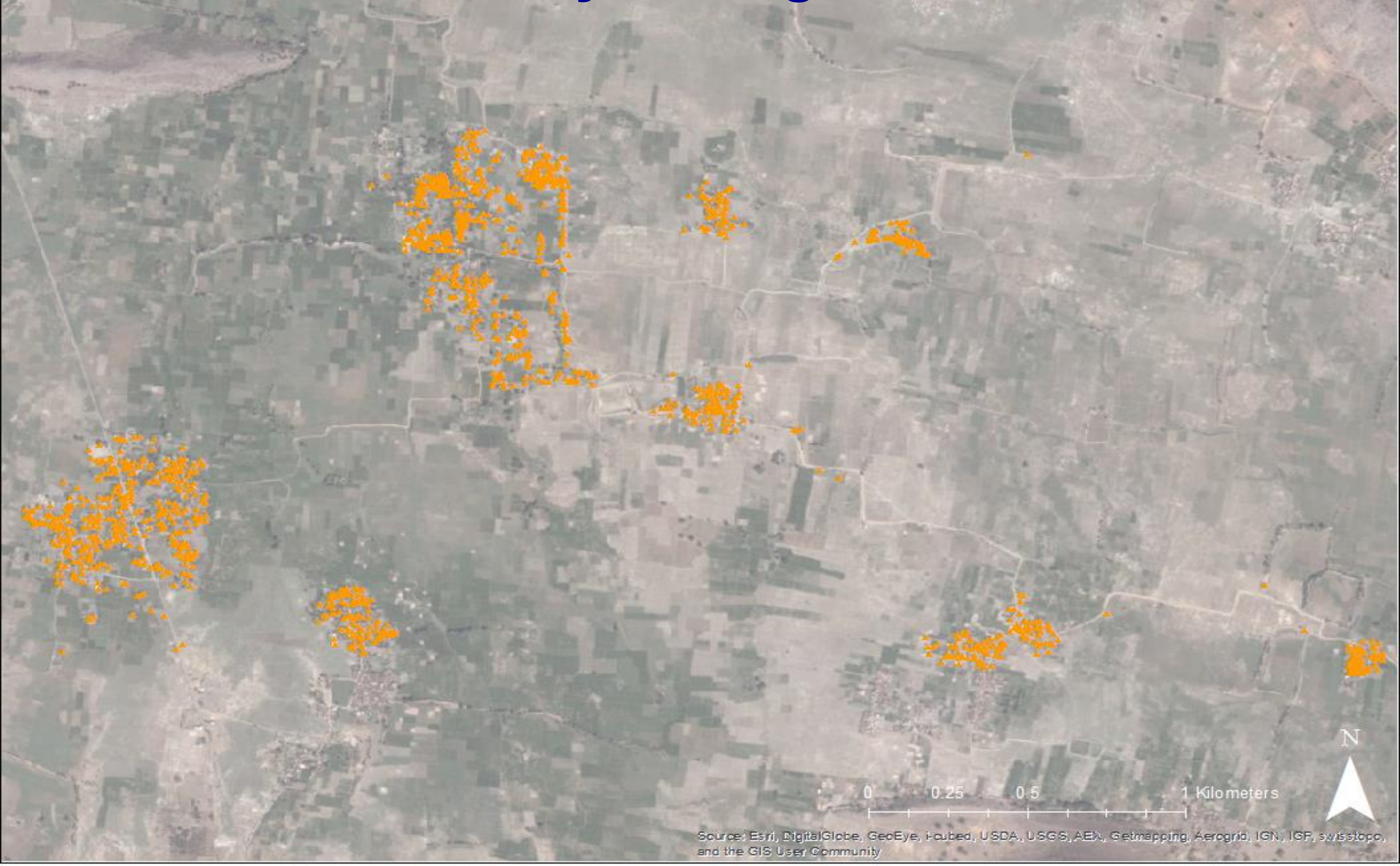
Developing analysis regions



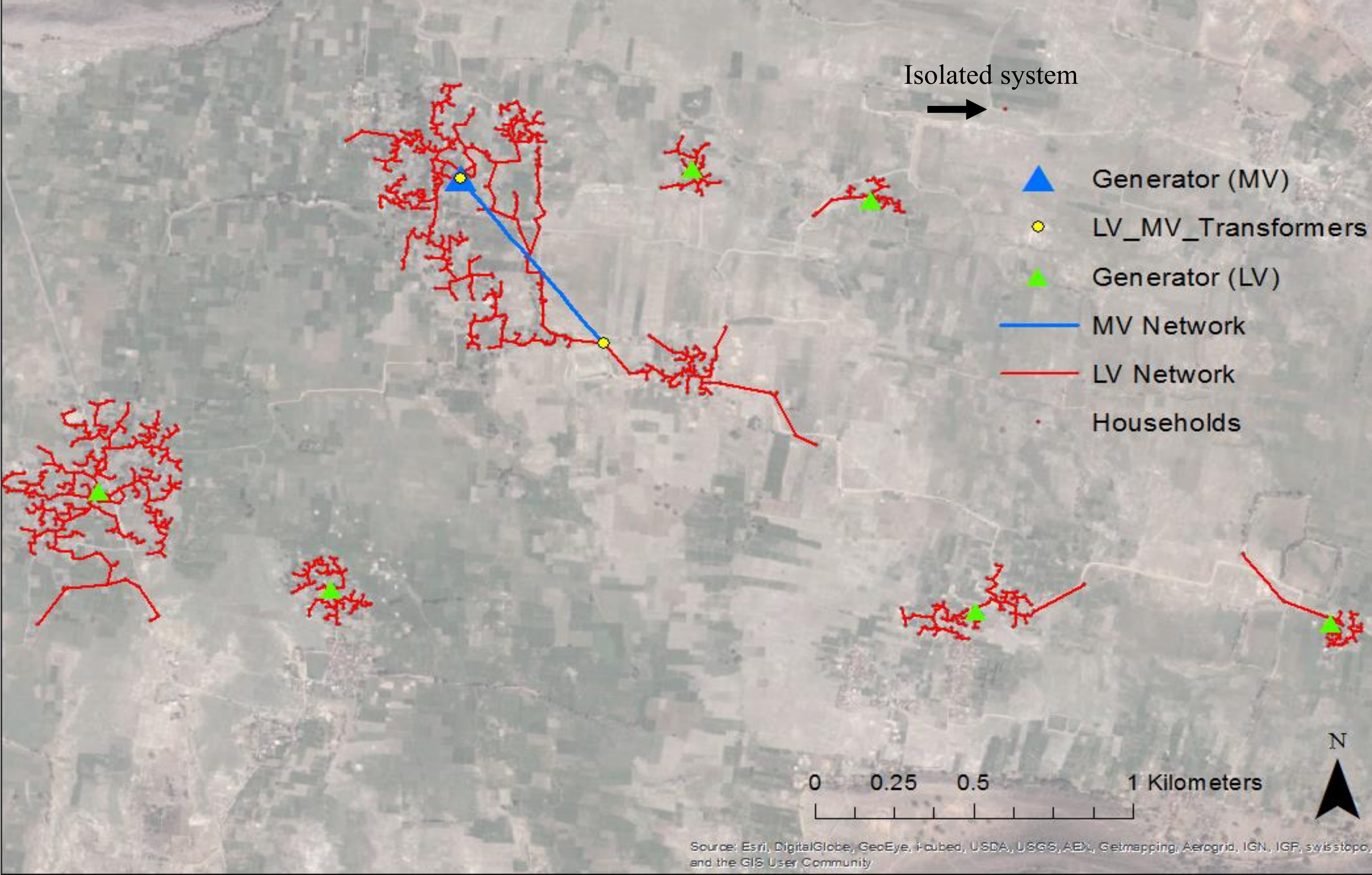
Developing analysis regions



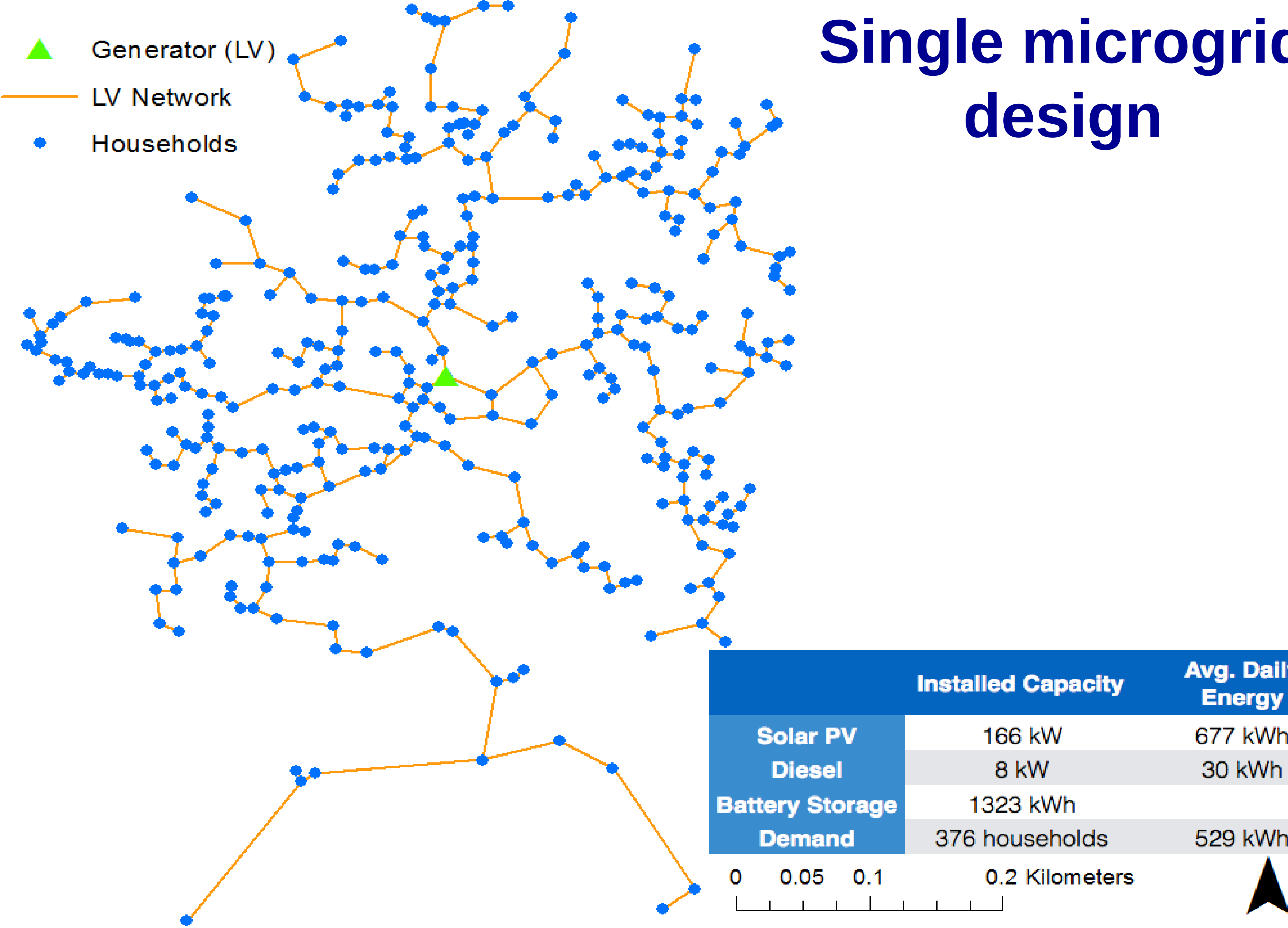
Analysis region 5



Network results

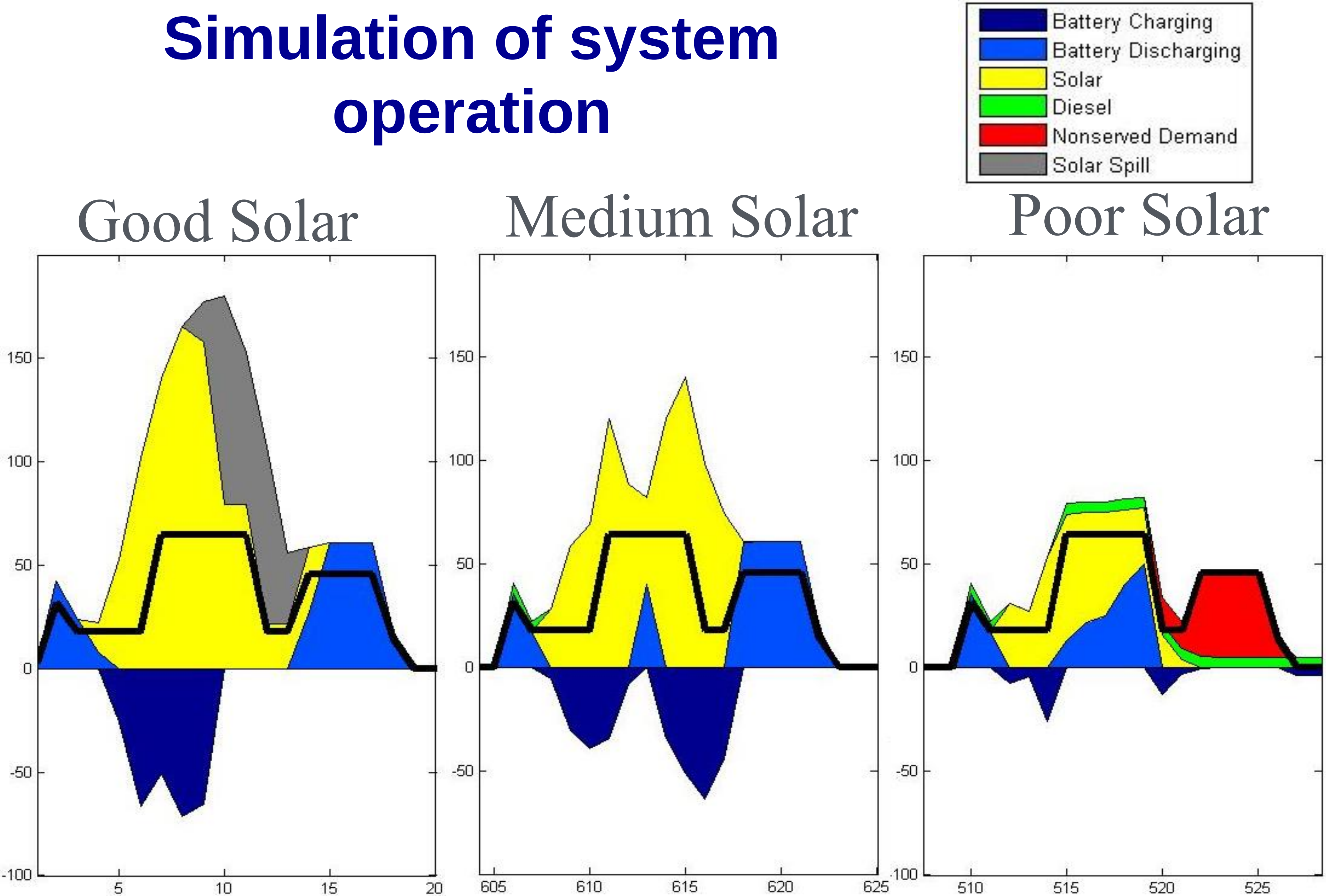


Single microgrid design

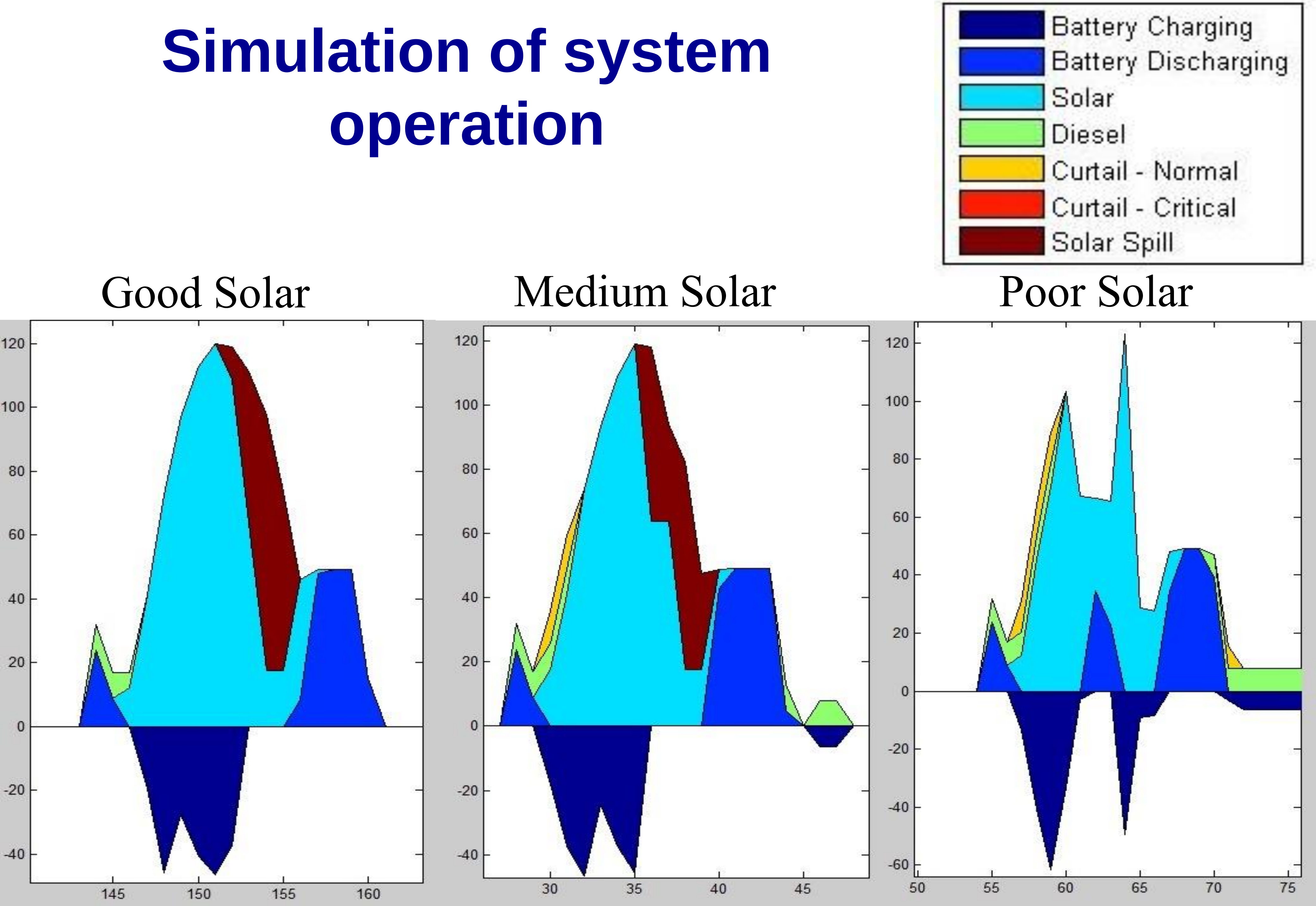


	Installed Capacity	Avg. Daily Energy
Solar PV	166 kW	677 kWh
Diesel	8 kW	30 kWh
Battery Storage	1323 kWh	
Demand	376 households	529 kWh

Simulation of system operation



Simulation of system operation



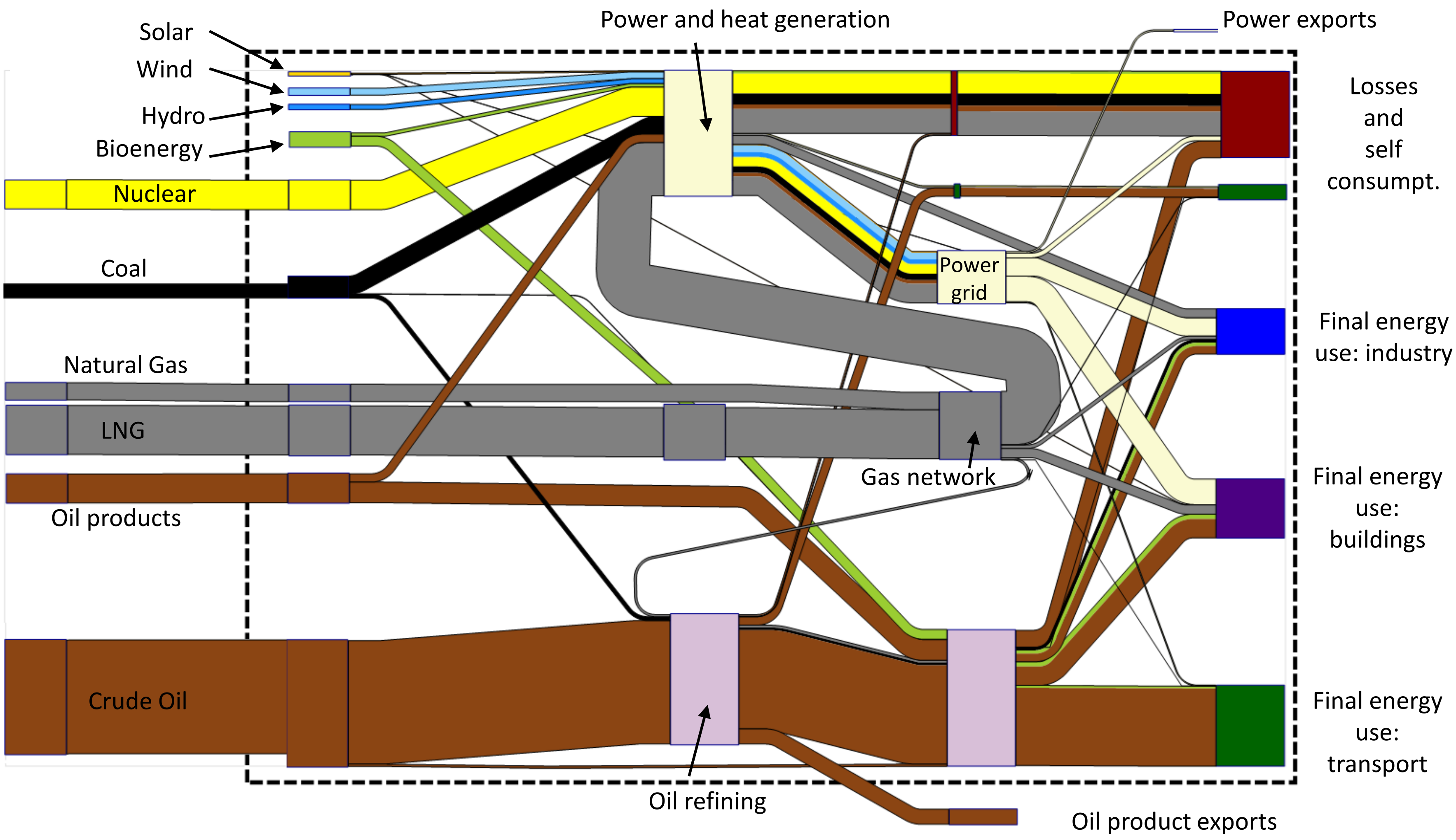
Electrification planning

MASTER4all*

- Optimizes the on-grid & off-grid supply of electricity services jointly with the rest of the delivery of energy services
  - Modern access to heating & cooking has been explicitly included in the model
  - Optimization can be subject to budget constraints, electrification targets & planner priorities
  - MASTER4all can optimize over a diversity of electrification options whose characteristics have been previously computed by the REM model

(*) *Model for the Analysis of Sustainable Energy Roadmaps for all*

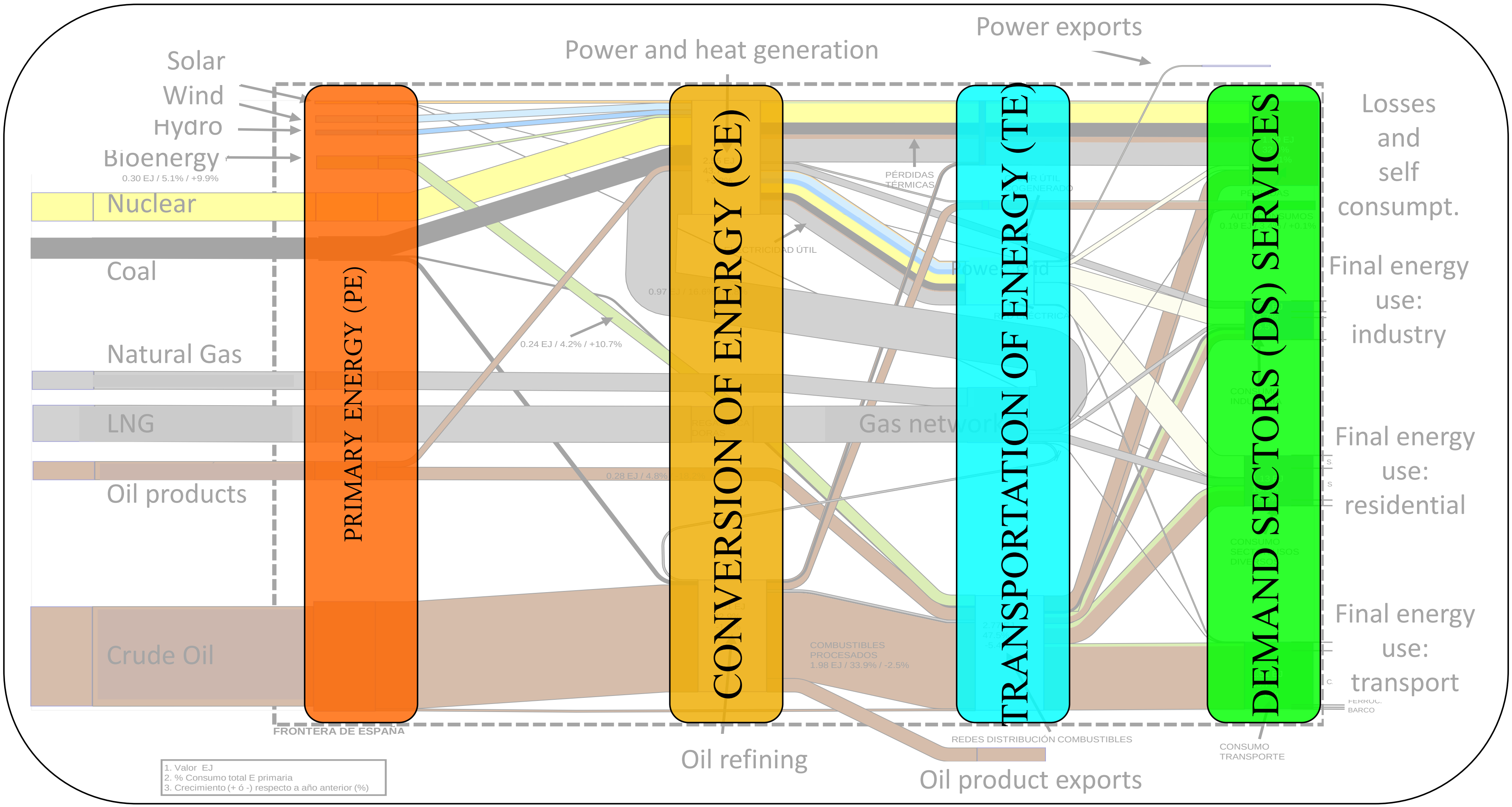
Example of the basic energy flow modeled in MASTER4all



Sankey diagram of the Spanish energy sector in 2011.

Source: Alvaro López-Peña

MASTER: Abstraction process of the energy chain



MASTER4all: Abstraction process of the energy chain: Details

- Primary Energy Sources (PE).
  - Geographical classification of costs of distributed energy generation *(RES potential, fuel cost, investment and O&M costs)*
- Conversion of Energy (CE)
  - Both for central and distributed generation.
- Transport of Energy (TE)
  - On & off-gas electrification & heating modes.
- Demand Sector (DS)
  - Supply technologies (ST) grouped by SE4All Tiers compatible with each access mode.
  - Energy Services (ES) growing supply ladder.

	TIER 0		TIER 1		TIER 2		TIER 3		TIER 4		TIER 5	
				Watts		Watts		Watts		Watts		Watts
Likely feasible applications (May not be actually used) (Wattage is indicative)			Radio Task lighting Phone charging	1 1 1	Radio Task lighting Phone charging **General lighting** **Air circulation** **Television** **Computing** **Printing** Etc.	 18 15 20 70 45	Radio Task lighting Phone charging General lighting Air circulation Television Computing Printing **Air cooling** **Food processing** **Rice cooking** **Washing machine** Etc.	 240 200 400 500	Radio Task lighting Phone charging General lighting Air circulation Television Computing Printing Air Cooling Food processing Rice cooking Washing machine **Water pump** **Refrigeration** **Ironing** **Microwave** **Water heating** **Etc.**	 500 300 1,100 1,100 1,500	Radio Task lighting Phone charging General lighting Air circulation Television Computing Printing Air Cooling Food processing Rice cooking Washing machine Water pump Refrigeration Ironing Microwave Water heating **Air conditioning** **Space heating** **Electric cooking** **Etc.**	 1,100 1,500 1,100
Possible electricity supply technologies	Dry cell Solar lantern Rechargeable batteries Home system Mini-grid/grid		— Solar lantern Rechargeable batteries Home system Mini-grid/grid		— — Rechargeable batteries Home system Mini-grid/grid		— — — Home system Mini-grid/grid		— — — Home system Mini-grid/grid		— — — Home system Mini-grid/grid	

NOTE: — = NOT APPLICABLE

Choices in the supply of residential electricity services

PRIMARY ENERGY (PE)

- Sun
- Wind
- Hydro
- Biomass
- Biodiesel
- Imported Oil
- National Oil

GENERATION / CONVERSION

- PV
- Diesel
- Hybrid PV-Diesel
- Wind
- Hydro
- Biomass

TRANSPORT / DISTRIBUTION

Grid extension
- Triphasic
- Monophasic
- SWER

Micro-grid
- AC Isolated
- AC Connected
- DC Isolated

Single House
- AC Isolated
- AC Connected
- DC Isolated

Portable Kit
Portable Lamp

DEMAND SECTORS (DS)

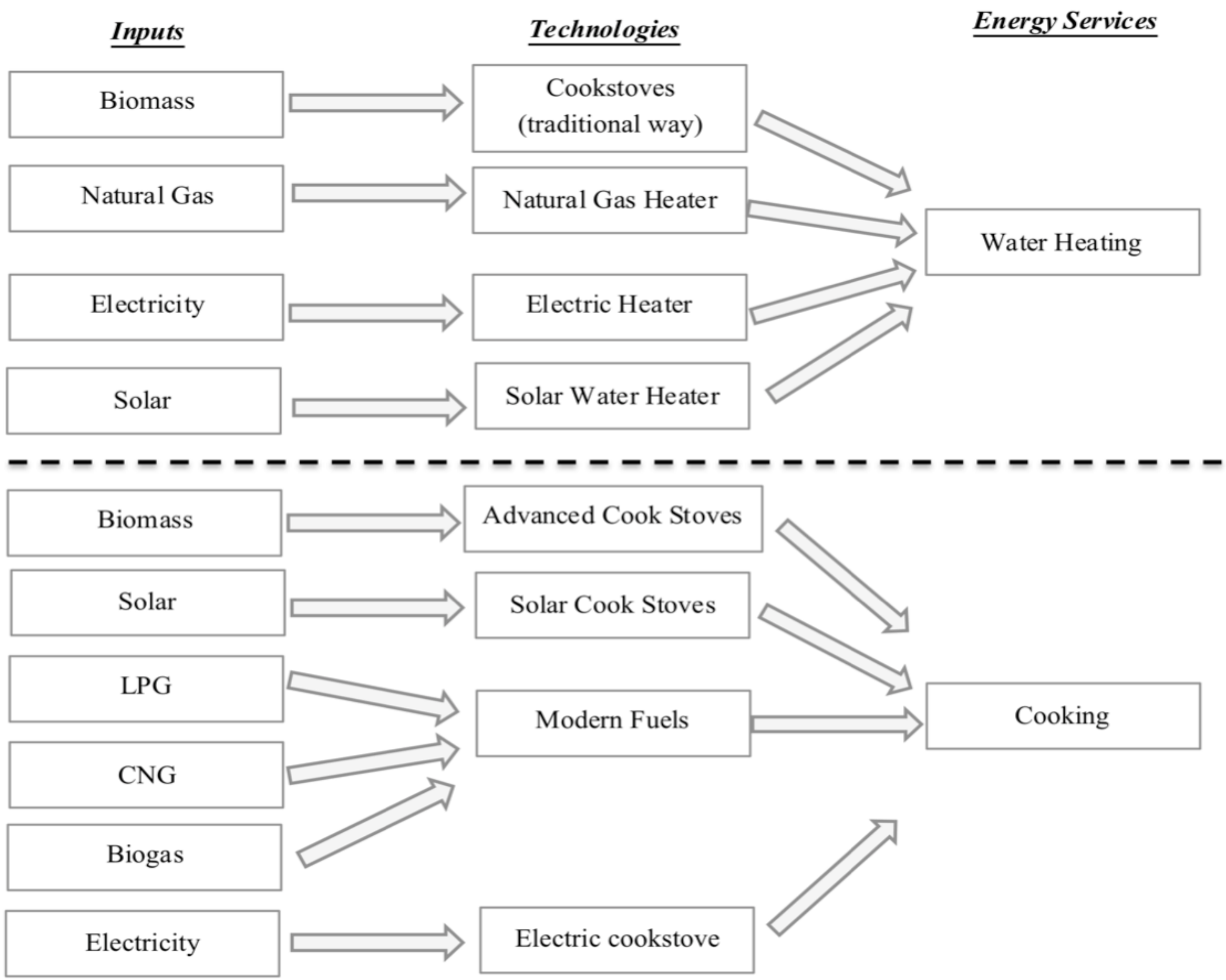
Bundle of Supply Technologies

E.g. Tier 3 profile 1
- Home lighting
- Phone charger
- Radio
- TV
- Iron

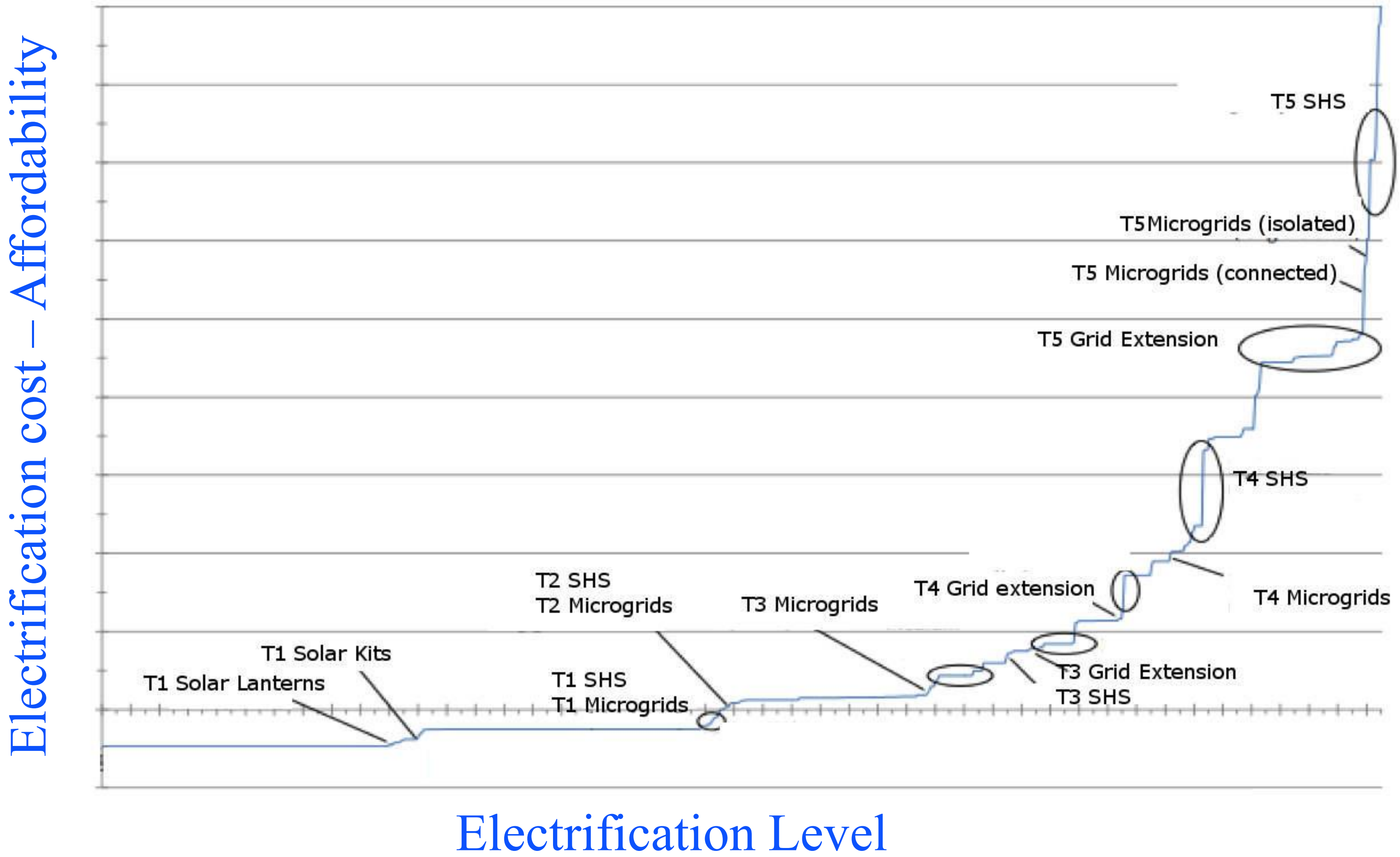
E.g. Tier 3 profile 2
- Home + street lighting
- Phone charger
- Radio
- TV
- Fan

Residential Electrification Level
- Tier 1
- Tier 2
- Tier 3
- Tier 4
- Tier 5

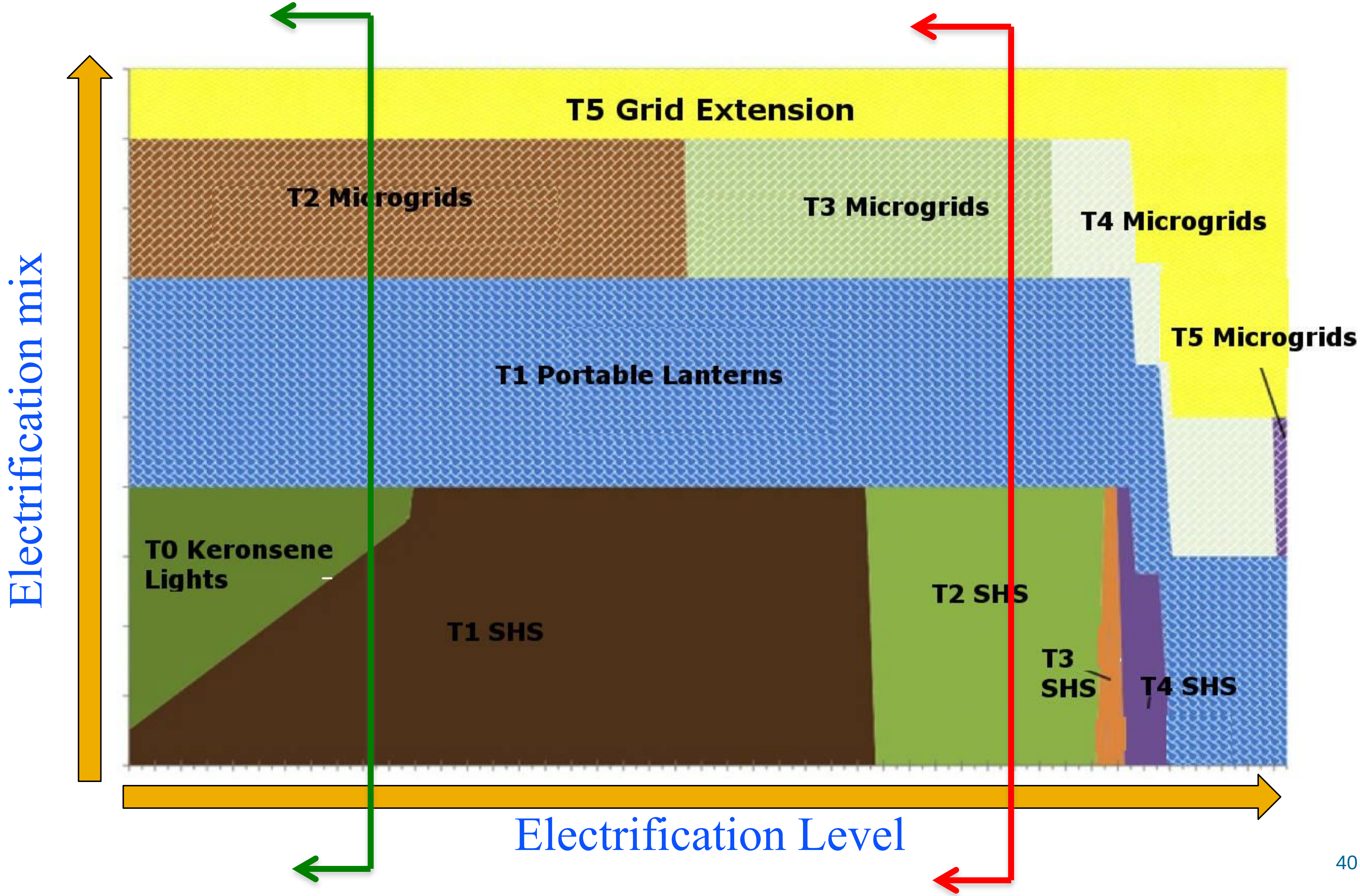
Choices in the supply of residential heating & cooking services



The energy ladder



Possible outcomes from MASTER4all



Suite of computer tools
Electrification planning: MASTER4all

Outputs

- Energy supply: *by desired level of granularity in location, technology, access tier*
- Supply cost & subsidies: *also at several granularity levels*
- Capacities used in the conversion processes *(existing, new, utilization factors)*
- Energy flows
- CO_2 emissions, indoor pollution & other energy-derived externalities
- Electricity generation for every defined demand level in the considered year

Business models

“Non-conventional” premises

- Utilities that do not want to connect more consumers, even at a short distance
  - Why? Tariffs that do not cover costs
  - Why? Poor financial situation to incur in new investments
- Very low initial consumption levels
  - A 5 kW peak PV panel feeding 200 households with very few & very efficient appliances
- Grid connection may not bring a reliable supply
  - Connected consumers may ask for alternative solutions
- Absence of regulatory control for off-grid solutions

Electricity supply modes & business models

		Grid Extension	Isolated Mini-grid	Stand-Alone-Systems	Pico Solar Systems
For profit	Small, decentralized	Sunlabob (Laos)	OMC Power (Africa, India), Scatec Solar (India), Sunlabob (Laos), Asantys (Africa, Asia)	Barefoot Power (Africa), Sunlabob (Laos), Soluz (LatAm), Asantys (Africa, Asia)	Barefoot Power (Africa), Sunlabob (Laos), Soluz (LatAm), Teri (India), Asantys (Africa, Asia)
	Large, centralized	NDPL (India), ENEL (Brazil), Fenosa-Gas Natural (Guatemala), Condensa (Colombia), Schneider (Global)	NPDCAPL (India), ENEL (Chile, Peru), Dresser-Rand (Brazil) Schneider-Electric (Global),	ENEL&Barefoot Colllege (Latin America), Schneider-Electric (Global)	Schneider (Global), Philips (Africa, India), Tata Power Solar (India)
Non-profit	Cooperatives	Coopesantos et al. (Costa Rica), REB (Bangladesh), NEA (Philippines)	ESD (Sri Lanka), Coopesantos et al. (Costa Rica)	Costa Rica Energía Sin Fronteras (Guatemala)	
	Social enterprises		Mera Gao Power (India)	Grameen Shakti (Bangladesh), AccionaME (México), D.Light (Asia, Africa)	Grameen Shakti (Bangladesh), AccionaME (México), D.Light (Asia, Africa), ToughStuff (Africa)
	NGOs		Teri (India)	Practical Action (LatAm, Africa)	Solar Aid – SunnyMoney (Africa)
Public	Small, decentralized		RVEVESP (India)	Municipalities (Sunlabob) EnDev (Africa, Asia, LatAm)	EnDev (Africa, Asia, LatAm)
	Large, centralized	ONE-PPP (Morocco), Eskom (South Africa), WAPP (West Africa)		Government owned utilities in Peru	

Source: MIT-IIT (Comillas) report for the Enel Foundation, 2014

Considerations for the selection of business models *(from the bottom up)*

- Demand for energy services
  - Local activities & skills, impact on development
- Business model planning context
  - Resources, technology choices, support services
- Macro enabling environment
  - Policy & regulatory environment, infrastructures
- Actors & governance
  - Key players, stakeholders & key relationships
- Value proposition
  - Cost structure & revenues. Value for consumers. Delivery channels, resources & infrastructures.
- Advance
  - Sustainability, replicability, scalability, demand growth

Final remarks *(1 of 3)*

- Adequate institutional, technical, financial & capacity building approaches are needed to dramatically **scale up access** to modern energy services and close the **equity gap**
  - **Private investment** must play an essential role, contributing technology, finances and capacity. Governments and the donor community can leverage this to develop **scalable & replicable models** to solve energy poverty

Final remarks *(2 of 3)*

- Rural electrification plans should satisfy the urgent energy access needs, but should **also look ahead into the future** to avoid locking in solutions that cannot grow with demand
  - Given the great variety of situations of electrification, **regulation has to be flexible**, as light-handed as reasonably possible, & adapted to the circumstances
  - **Deregulated electrification**? Strike a balance between comprehensive regulation & free initiative, remembering that the immediate priority is access

Final remarks *(3 of 3)*

- There are **business opportunities** if adequate business models are adopted, including whatever **subsidies** might be needed

Thank you for your attention