Economics for energy

Workshop on Economic challenges for energy

Madrid, January 28 & 29, 2016

Energy security (Access to energy)

Ignacio Pérez Arriaga
IIT-Comillas University & CEEPR-MIT

I am working in a project on security of supply in Iceland...

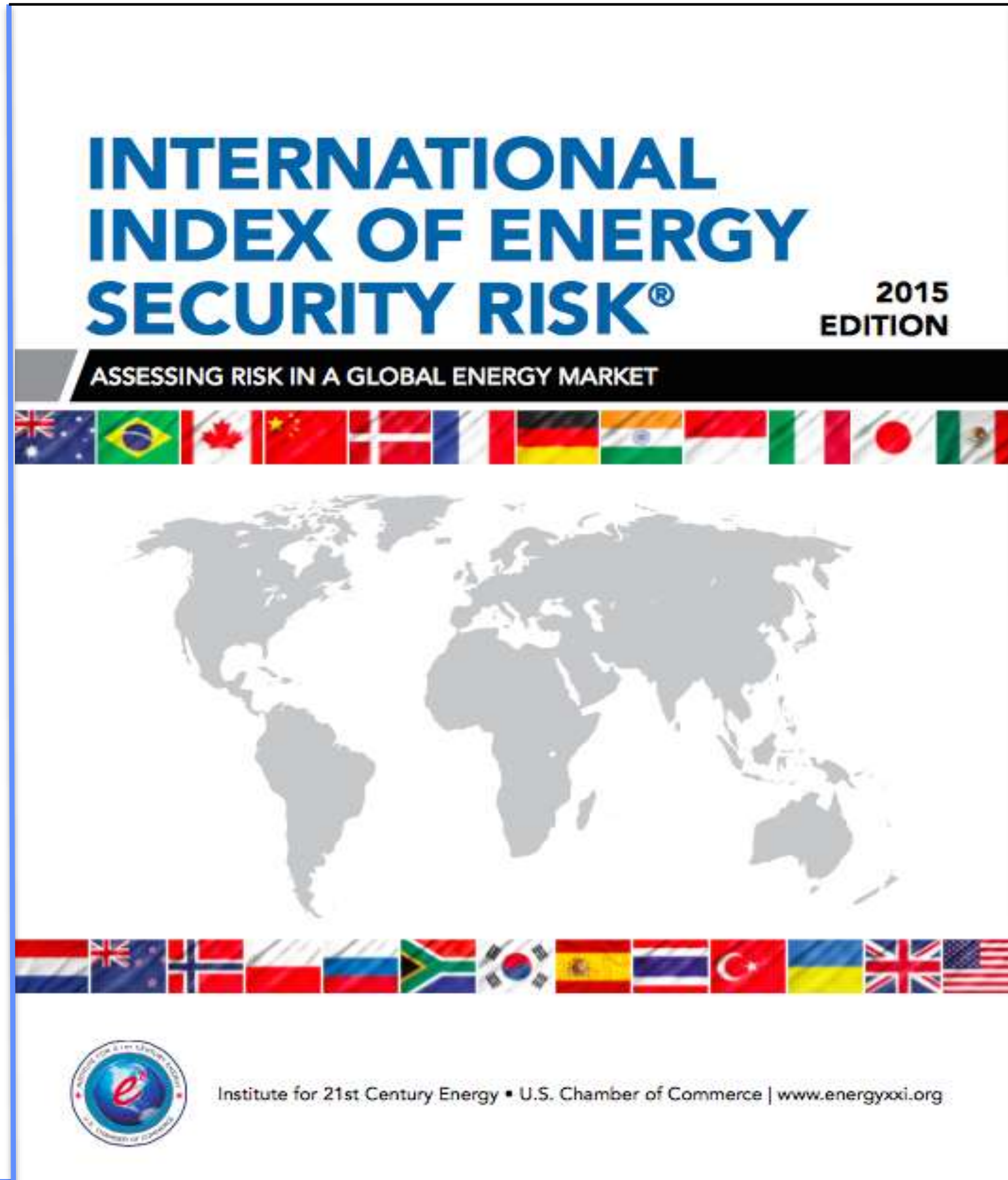
… so I looked for a good definition of energy security …

"A **secure energy system** can be defined as one:

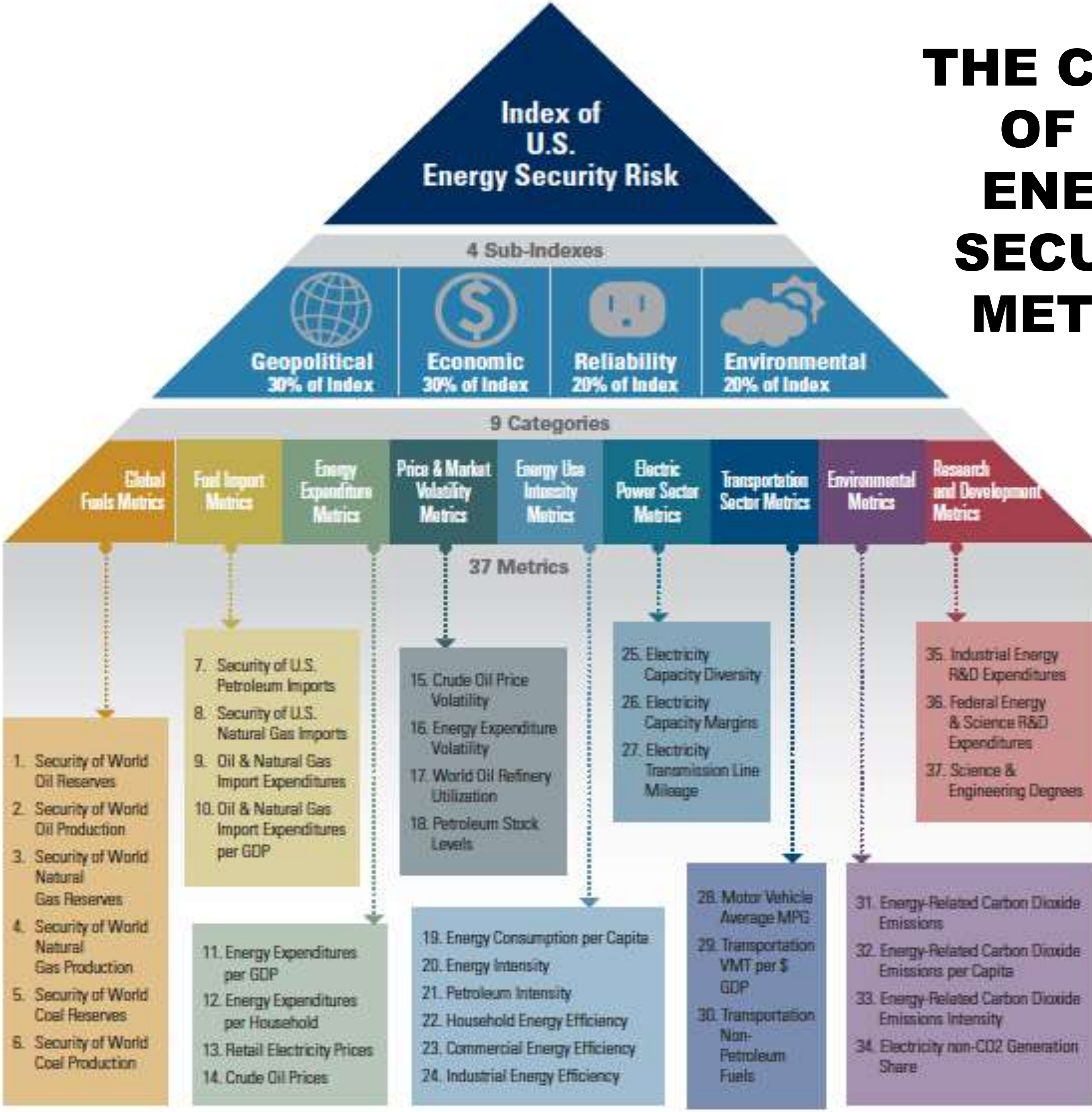
- **evolving** over time
- with an **adequate capacity** to **absorb adverse uncertain events** *(threats)*,
- so that it is able to continue **satisfying the energy service needs** of its intended users
- with **acceptable changes** in their **amount** and **prices**"

Source: EU project MILESECURE 2050, 2013

… as well as for solid references…



THE CHOICE OF (37) ENERGY SECURITY METRICS




... but all that does not apply well here

Village of Behlolpur (Bihar, India)

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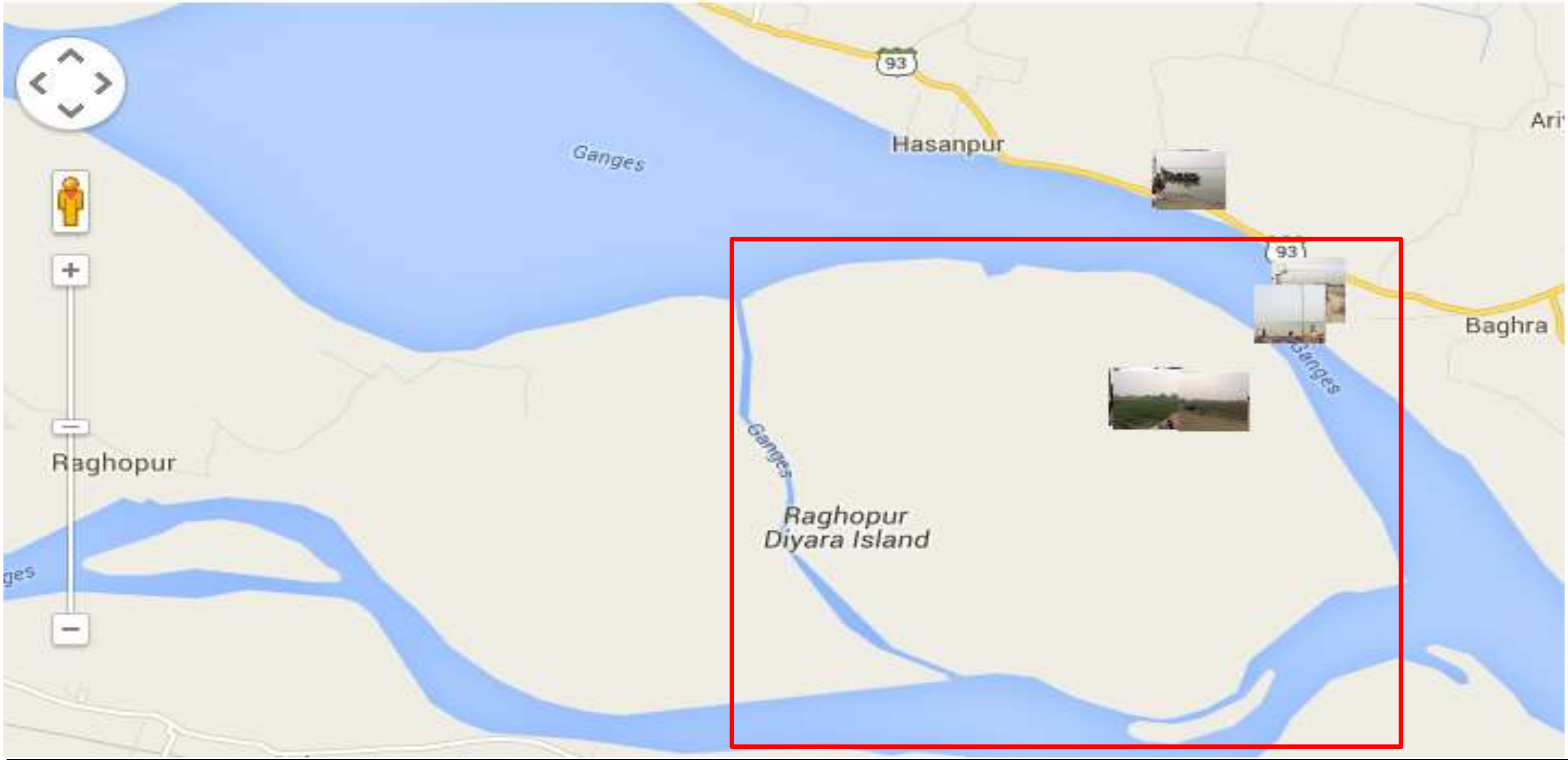
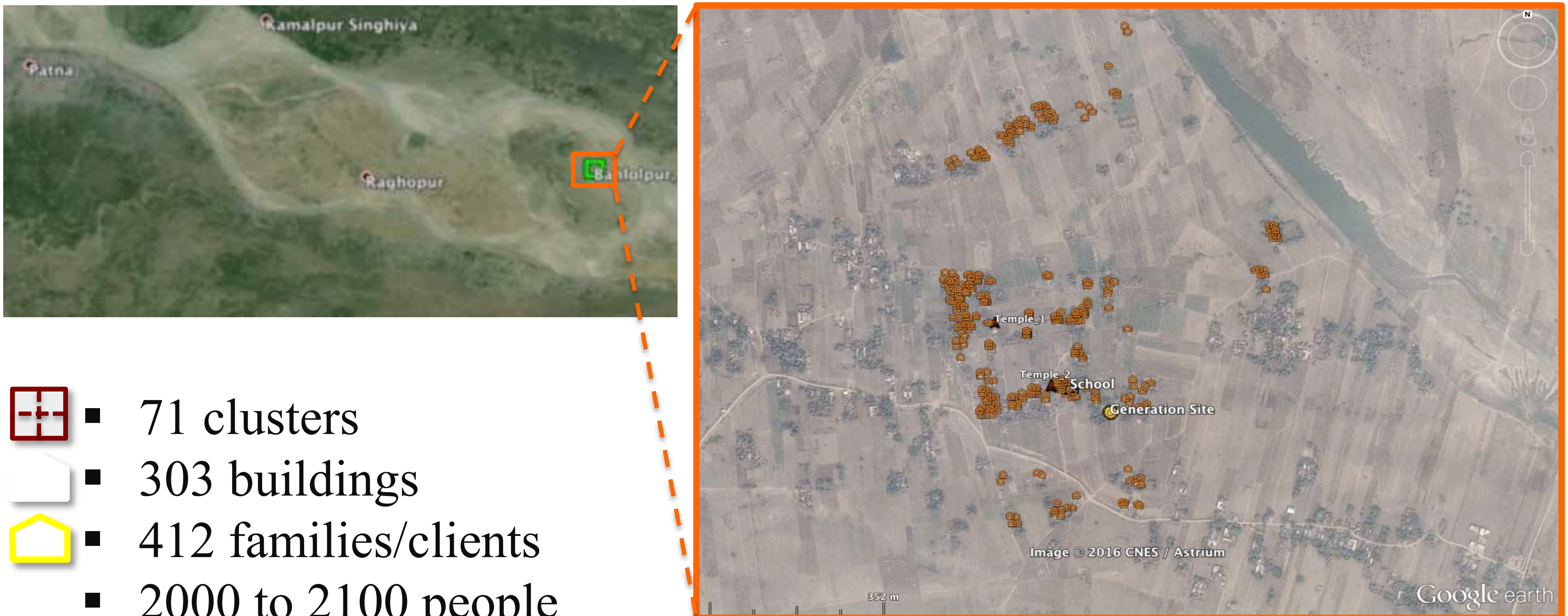
Village of Behlolpur (Bihar, India)



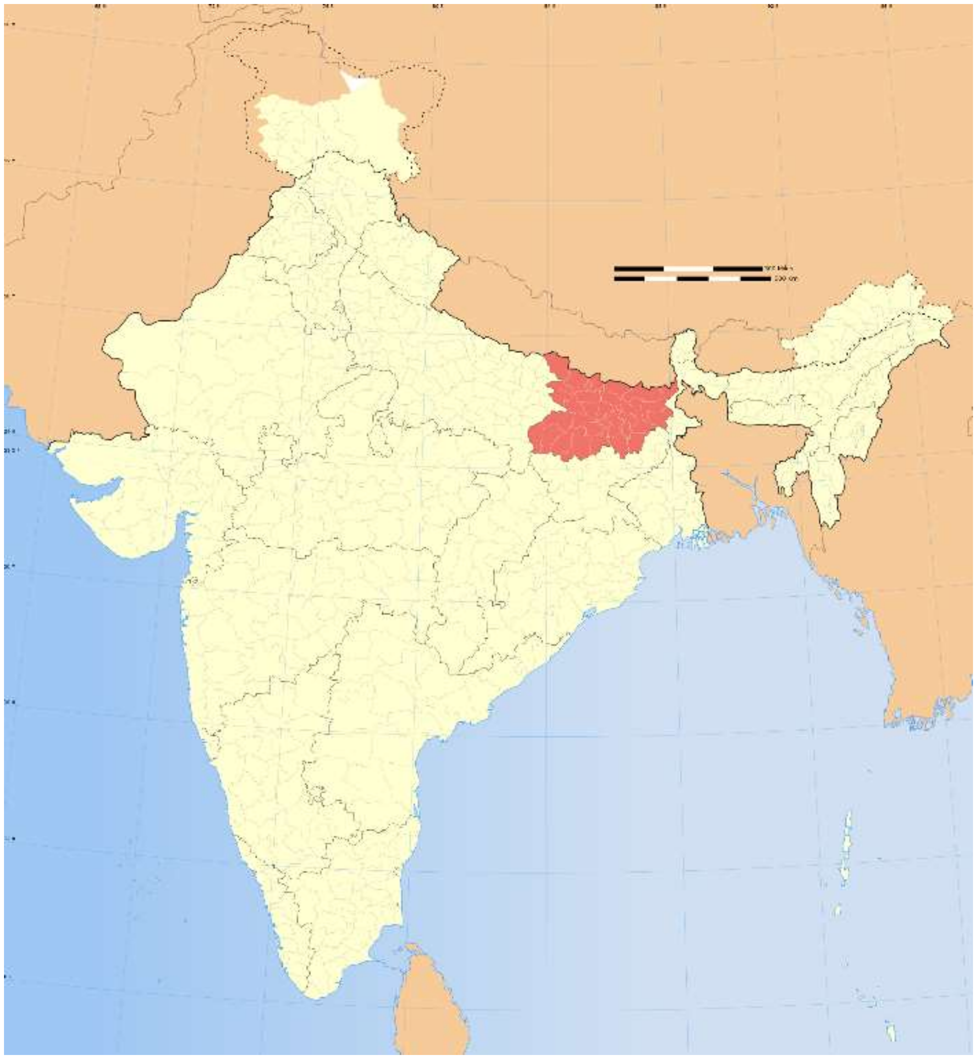
Key features during site visit													
site	Project Site	Name of Block	District	No. Of Houses	Total Population	Shops	Temples	School	Primary Source of Income	Status of Electricity	Distance from transformer (Kms)	Rating of Transformer	Type of Land available for Microgrid
Behlolpur	Behlolpur Dyara (ward-8&9)	Mehnar	Vaishali	225	1200	3	2	1	Agriculture	0%	NA	NA	Private Land

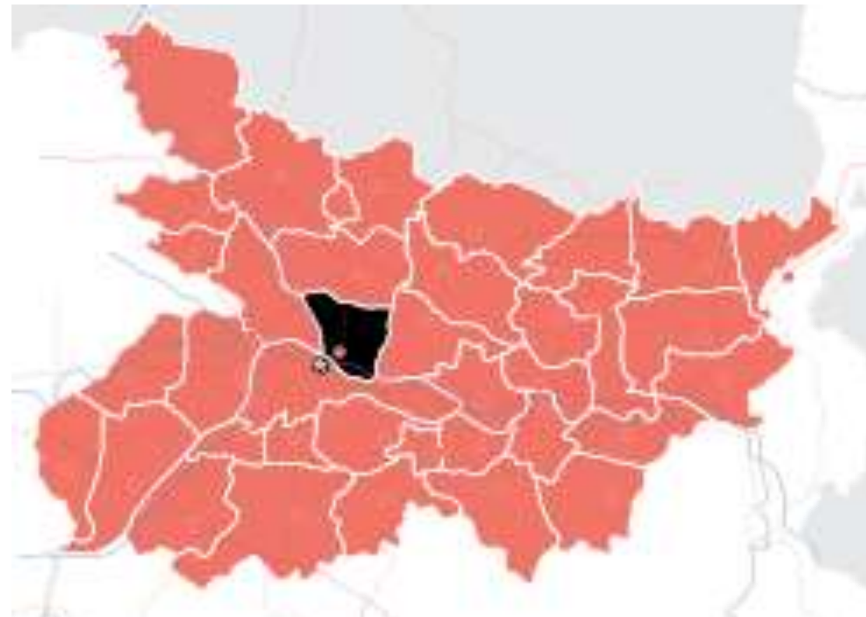
Village of Behlolpur (Bihar, India)



- 71 clusters
- 303 buildings
- 412 families/clients
- 2000 to 2100 people
- 1 Primary school
- 2 small temples
- Generation site
- No anchor shops

State of Bihar (India)
105 million people
Less than 20% have access to electricity





The village of Behlolpur is in the District of Vaishali (5 million people) in an island in the Ganges river

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Energy security

Access to energy

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IIT-Comillas University & CEEPR-MIT

Box 1: Energy poverty in numbers[4]

Worldwide:

• 2.8 billion people rely on inefficient and polluting cooking fuels and technologies.
• 1.2 billion – 1 in 5 – have no electricity access.
• 1 billion have intermittent access.

In least developed countries:

• 4 out of 5 people have no electricity connection in their home.
• 9 out of 10 people (73% of urban dwellers and 97% of rural dwellers) have no access to modern fuels for cooking.

Is progress stalling on access for the poorest?

• In low-income countries, access to non-solid cooking fuel rose only by 2% — from 7% to 9% — between 1990 and 2010.
• The International Energy Agency estimates that the number of people without access to electricity will fall marginally between now and 2030 — to 1 billion — with sub-Saharan Africa overtaking Asia as the region with the largest deficit. The total number of people without access to non-solid cooking fuels will remain largely unchanged.

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Energy security
Universal electricity access

Ignacio Pérez Arriaga
IIT-Comillas University & CEEPR-MIT

Outline

- The **puzzles** in the provision of electricity access
- **Instruments** that that help in addressing this problem
  - **Regulation**
  - Electrification **planning tools**

The puzzles to solve

Who are these people without electricity access?

And what is “access”?

The people without access to electricity

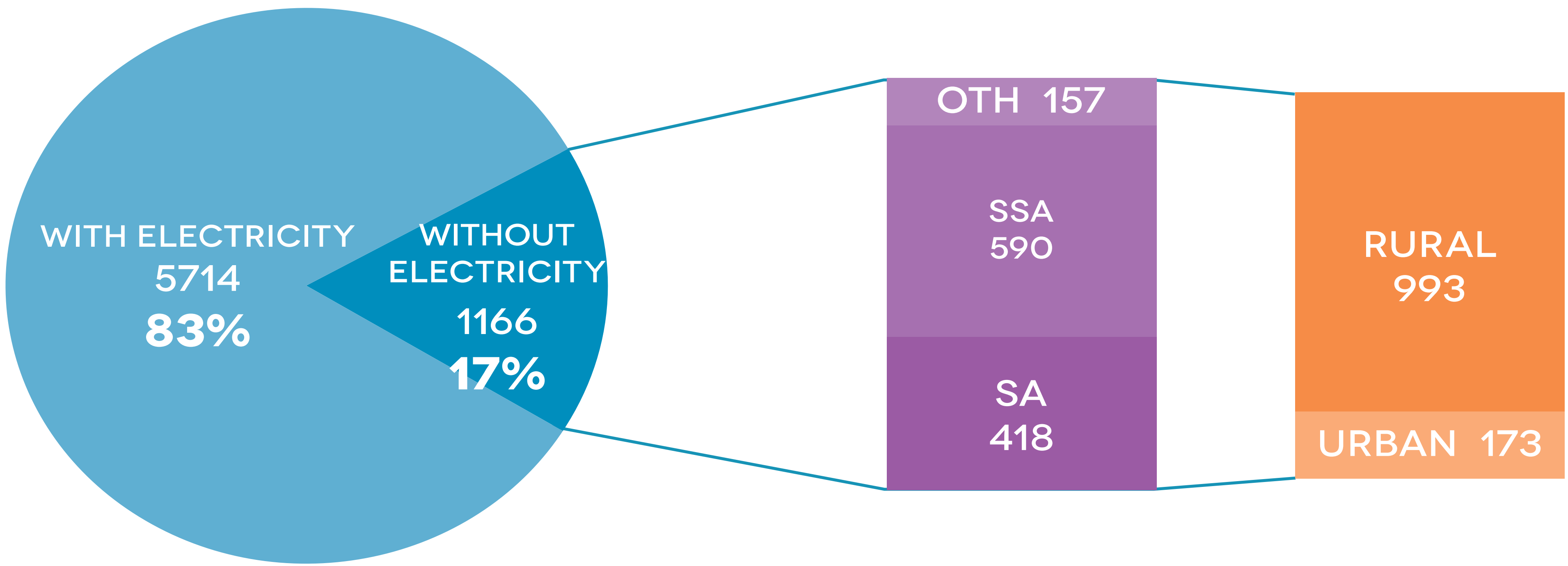


FIGURE O.2A **SOURCE OF ELECTRIFICATION ACCESS DEFICIT, 2010**

SOURCE: WORLD BANK GLOBAL ELECTRIFICATION DATABASE, 2012; WHO GLOBAL HOUSEHOLD ENERGY DATABASE, 2012.
NOTE: ACCESS NUMBERS IN MILLIONS OF PEOPLE. EA = EASTERN ASIA; SEA = SOUTH–EASTERN ASIA; SA = SOUTHERN ASIA; SSA = SUB–SAHARAN AFRICA; OTH = OTHERS.

Lack of access comes in multiple forms

- A large diversity of situations with lack of access
  - Latin America *(reduced number of mostly isolated rural communities)*
  - India *(very large number of non electrified houses in densely populated large areas "under grid" or not far from grid)*
  - Sub Saharan Africa *(very large number of non electrified aggregates of houses with long distances among them and to the grid)*

Isolated rural community in Cajamarca (Peru). Example of dispersed population.
Source: Julio Eisman. Acciona Foundation. Peru Microenergia.

Kya Sand, a peri-urban slum near Johannesburg, South Africa, where formal housing has been electrified but informal dwellings exist outside of electricity supply
Source: IFC, “From gap to opportunity: Business models for scaling up energy access”


Behlolpur (Bihar, India)

What do we mean by "universal access"?

"Access to energy services that are clean, reliable and affordable for cooking, heating, lighting, health, communications and productive uses"

United Nations has set 2030 as the target year to achieve universal access to modern energy services. The universal access goal will be achieved only when every person on the planet has access to modern energy services.

Source: Sustainable energy for all (SE4all)

http://www.se4all.org

Issues

- Diverse official definitions of “access”
- Is unreliable access “access”?
- How much access is “access”?
  - Technology advances in efficiency render definitions based on kW & kWh useless
  - Should access be a minimum level of services provided by electricity?
  - Should the supply of electricity be such that it does not limit the electricity services that a household could afford?
  - Should “access” include community & productive uses?

Reconsider the “official” definition of universal access

- The World Bank’s Sustainable Energy for All Framework’s tiers range from one watt of peak capacity for four hours a day at the bottom, to over 2,000 watts of capacity for over 22 hours per day at the top-most tier.
- The International Energy Agency IEA defines initial electricity access as 250 kWh per year for rural households and 500 kWh for urban households, projecting that this base level increases to 800 kWh per person by 2030.
  - This equates to 50-100 kWh/year per person, about 200 times less of that consumed by the average American or Swede, or about 50 times less than the average Bulgarian.

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Indicative electricity services	-	Task lighting + Phone charging or Radio	General lighting + Air circulation + Television	Tier 2 + Light appliances	Tier 3 + Medium or continuous appliances	Tier 4 + Heavy or continuous appliances
Consumption (kWh) per household per year	<3	3–66	67–321	322–1,318	1,319–2,121	>2,121

Index of access to electricity supply $= \sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

FIGURE 2.17 **MAPPING OF TIERS OF ELECTRICITY CONSUMPTION TO INDICATIVE ELECTRICITY SERVICES**

	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	1	Radio		Radio		Radio		Radio	
			Task lighting	1	Task lighting		Task lighting		Task lighting		Task lighting	
			Phone charging	1	Phone charging		Phone charging		Phone charging		Phone charging	
					General lighting	18	General lighting		General lighting		General lighting	
					Air circulation	15	Air circulation		Air circulation		Air circulation	
					Television	20	Television		Television		Television	
					Computing	70	Computing		Computing		Computing	
					Printing	45	Printing		Printing		Printing	
					Etc.		Air cooling	240	Air Cooling		Air Cooling	
							Food processing	200	Food processing		Food processing	
							Rice cooking	400	Rice cooking		Rice cooking	
							Washing machine	500	Washing machine		Washing machine	
							Etc.		Water pump	500	Water pump	
									Refrigeration	300	Refrigeration	
									Ironing	1,100	Ironing	
									Microwave	1,100	Microwave	
									Water heating	1,500	Water heating	
									Etc.		Air conditioning	1,100
											Space heating	1,500
											Electric cooking	1,100
											Etc.	
Possible electricity supply technologies	Dry cell		—		—		—		—		—	
	Solar lantern		Solar lantern		—		—		—		—	
	Rechargeable batteries		Rechargeable batteries		Rechargeable batteries		—		—		—	
	Home system		Home system		Home system		Home system		Home system		Home system	
	Mini-grid/grid		Mini-grid/grid		Mini-grid/grid		Mini-grid/grid		Mini-grid/grid		Mini-grid/grid	

NOTE: — = NOT APPLICABLE

Energy Access Ladder - Electricity

ACCESS TO ELECTRICITY SUPPLY

ATTRIBUTES	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Peak available capacity (W)	-	>1	>50	>200	>2,000	>2,000
Duration (hours)	-	≥4	≥4	≥8	≥16	≥22
Evening supply (hrs)	-	≥2	≥2	≥2	≥4	≥4
Affordability	-	-	√	√	√	√
Legality	-	-	-	√	√	√
Quality (voltage)	-	-	-	√	√	√

- Five-tier framework.
- Based on six attributes of electricity supply.
- As electricity supply improves, an increasing number of electricity services become possible.

Index of access to electricity supply $= \sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

USE OF ELECTRICITY SERVICES

TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
–	Task lighting AND phone charging (OR radio)	General lighting AND television AND fan (if needed)	Tier 2 AND any low-power appliances	Tier 3 AND any medium-power appliances	Tier 4 AND any high-power appliances

- Five-tier framework.
- Based on of appliances.

Index of access to electricity supply $= \sum(P_T \times T)$

with P_T = Proportion of households at tier T

T = tier number {0,1,2,3,4,5}

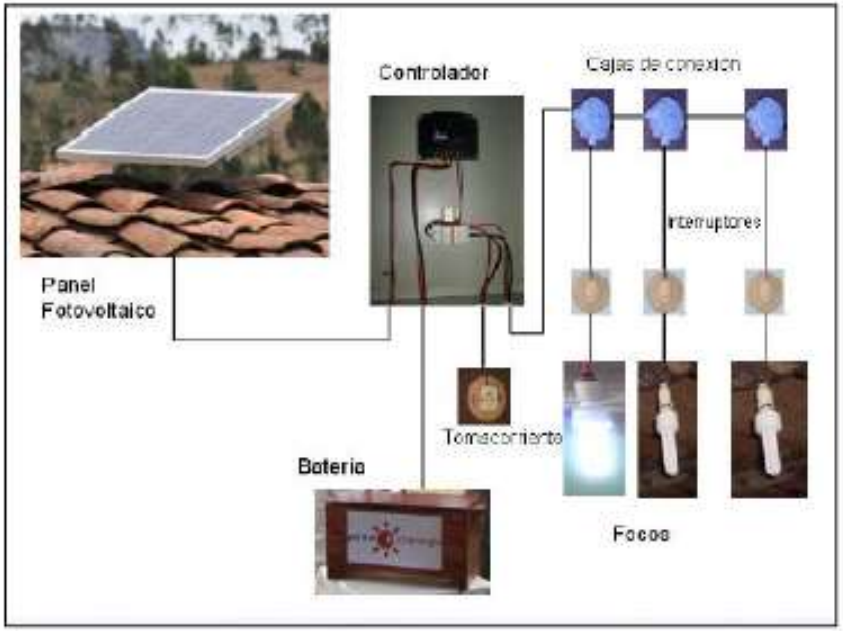
Source: SE4All Global Tracking Framework - ESMAP, WB, IEA 2013

How to factor technological progress in the approaches to provision of access?

The “classic” stand alone solar system

fundaciónacciona microenergía

Sistema Fotovoltaico Domiciliario (SFD)

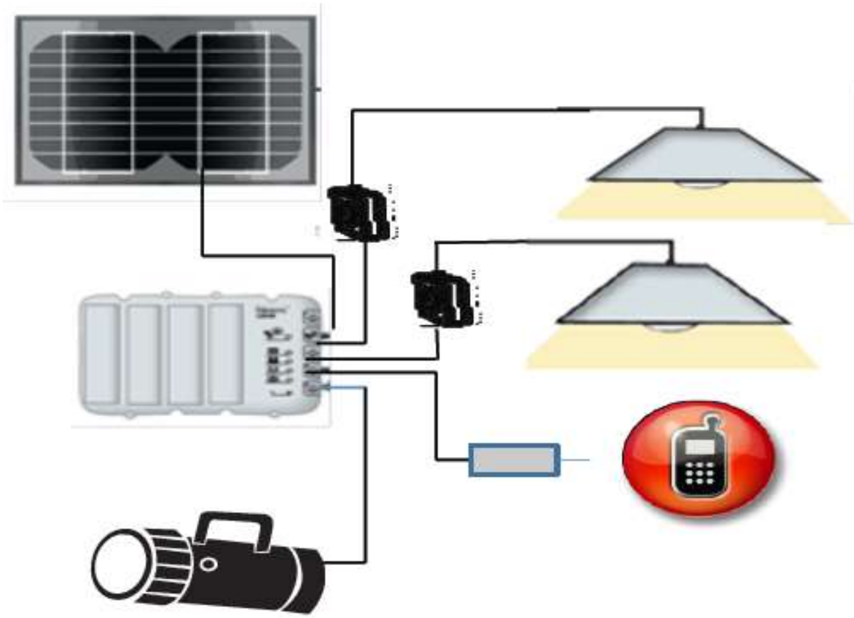


Basic technical characteristics

1. PV solar panel : 60Wp-85Wp (12Vdc).
2. Battery: 100 Ah/ 12Vdc
3. Controller: 10A/10A/12 Vdc
4. Lights: 3x11W / 12Vdc CFL
5. Average available energy 7.24 kWh/month

The “mobile” alternative

Pequeño Sistema Fotovoltaico Domiciliario (PSFD)



Basic technical characteristics

1.PV solar panel : 10Wp-50Wp (12Vdc).

2.Battery: Ion-Li/ 12Vdc

- 2.000 cycles (80% PDD)
- 1 day autonomy

3.Lights: Led tecnology with high power & efficiency

- 30.000 hours lifetime
- Min. 400 lumen & 4 hours/day
- Two fixed lights & a portable one

4.Outlet for cell phone, radio or high efficiency TV

5.Easy to install, less than 10Kg weight

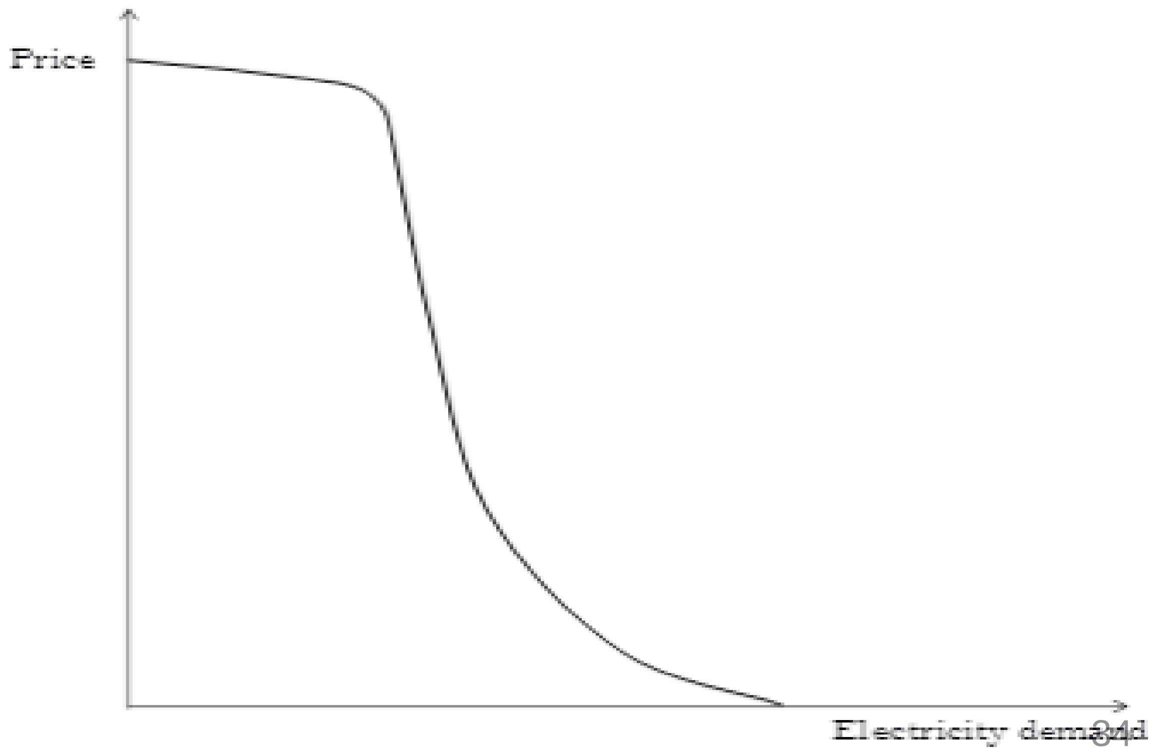
Peru Microenergía
A new *(technology-driven)* business model

- More compact, lighter *(7 Kg total instead of more than 35)* & efficient equipment makes possible to create new business models
  - A utility-based model with house maintenance service only makes sense now if there are 3000 households within 3 km from a customer attention center
- The “portable” technology makes possible another business model
  - Customer owns the equipment & brings it to the customer attention center *(conveniently sited)* for repairs

The iron law of rural electrification
The "viability gap"

Can rural electrification be economically viable?

- The **demand-price curve** describes the response of demand to price
  - Consumers are willing to pay a high price for the most essential electricity services, but not beyond



Can rural electrification be economically viable?

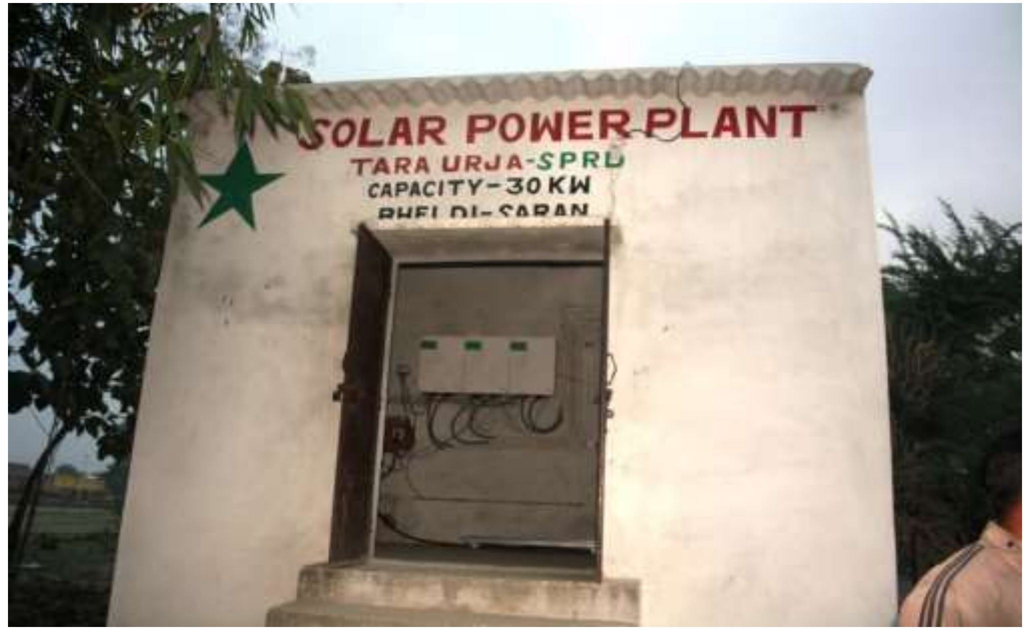
- **Yes**, with very basic electricity supply
  - E.g. two LED lights & one socket to charge the phone or connect a radio
  - Rudimentary electricity installation
- **No**, with enhanced service or improved installations & bearing full costs
  - Favorable microfinancing can help to narrow the gap (Grameen Shakti in Bangladesh)
- Rural electrification (as opposed to urban electrification) is **systematically subsidized in all countries** when the same tariff is applied to all low voltage consumers

A single PV panel & battery for the entire village...

MERA GAO, Uttar Pradesh, India, July 2014


... using the trees as support for the cables...

Grid compatible microgrid facilities
(Source: TARA Urja, India)



Grid compatible microgrid facilities

(Source: TARA Urja, India)

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Grid compatible microgrid facilities
(Source: TARA Urja, India)

Individual load limiters per household

Is there room for private investors in rural electrification?

The "opportunity gap"

From Gap to Opportunity:
Business Models for Scaling Up Energy Access

In partnership with Austria

International Finance Corporation
World Bank Group

The opportunity gap

"Despite intensified efforts at the national and international levels, there remains a significant **shortfall in the volume of investment needed to achieve universal energy access**. While it will cost $48 billion per year to reach this goal, according to the International Energy Agency, only about $14 billion is available annually. Given the size of this difference, it is clear that **the public sector cannot meet the need alone**. **Leveraging the private sector—both in terms of capital and innovation—will be critical** to closing the energy access financing gap. There is another way to look at the challenge: **energy access as an opportunity for business**."

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

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

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

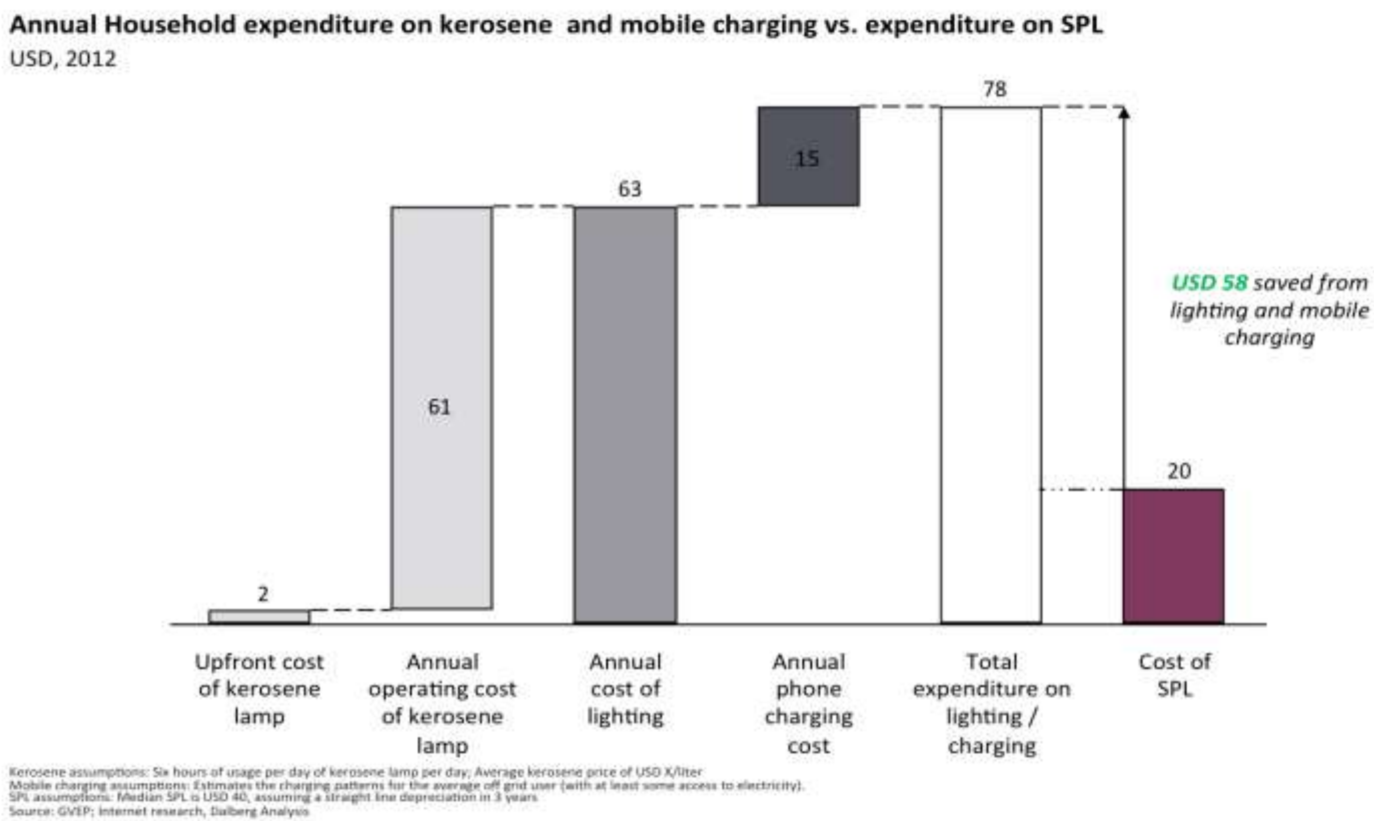
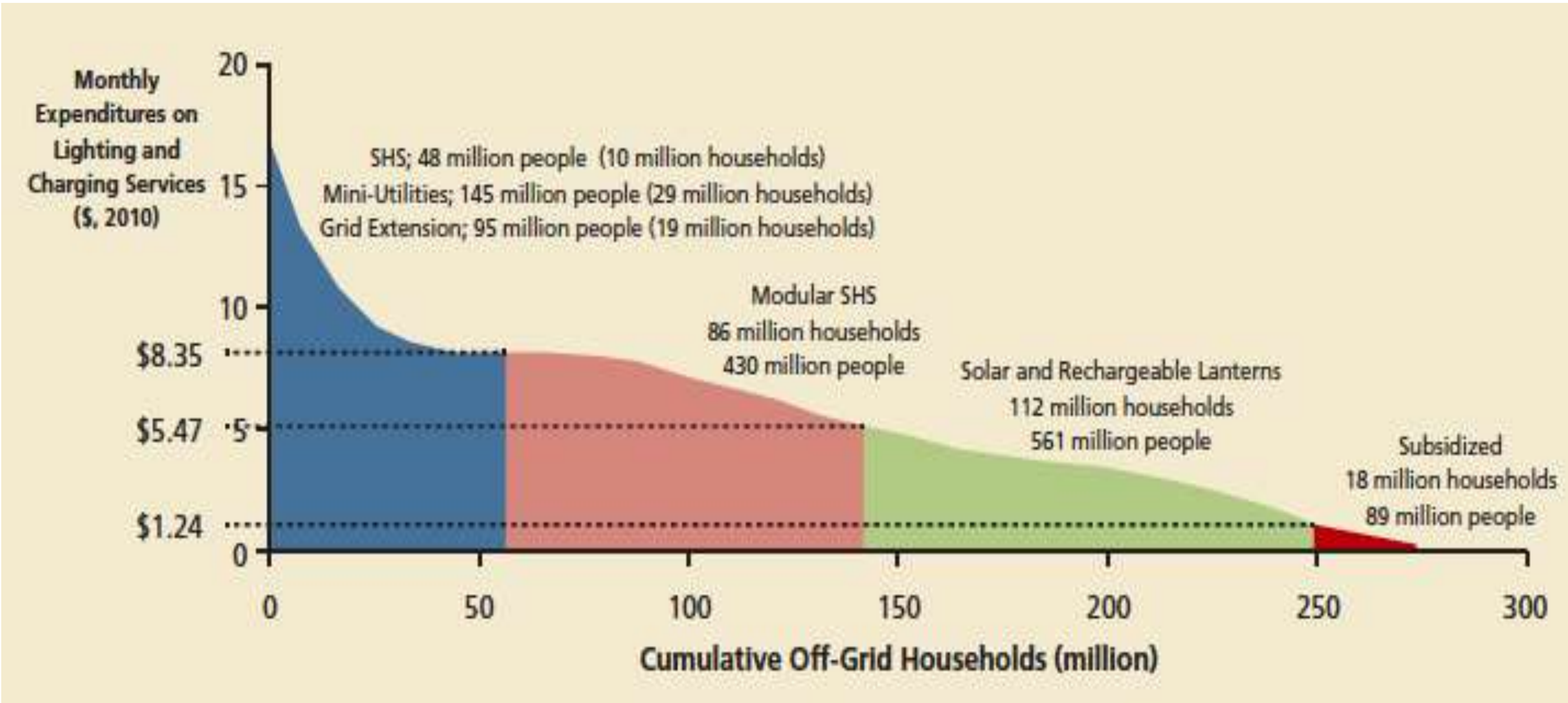


Figure 1. Comparison of the annual cost of kerosene lighting with the cost of a simple solar lantern with integrated phone charging functionality (World Bank 2012).

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

OK, fine, but…

What to do with the viability gap?

and…

What do people understand by "financing"?

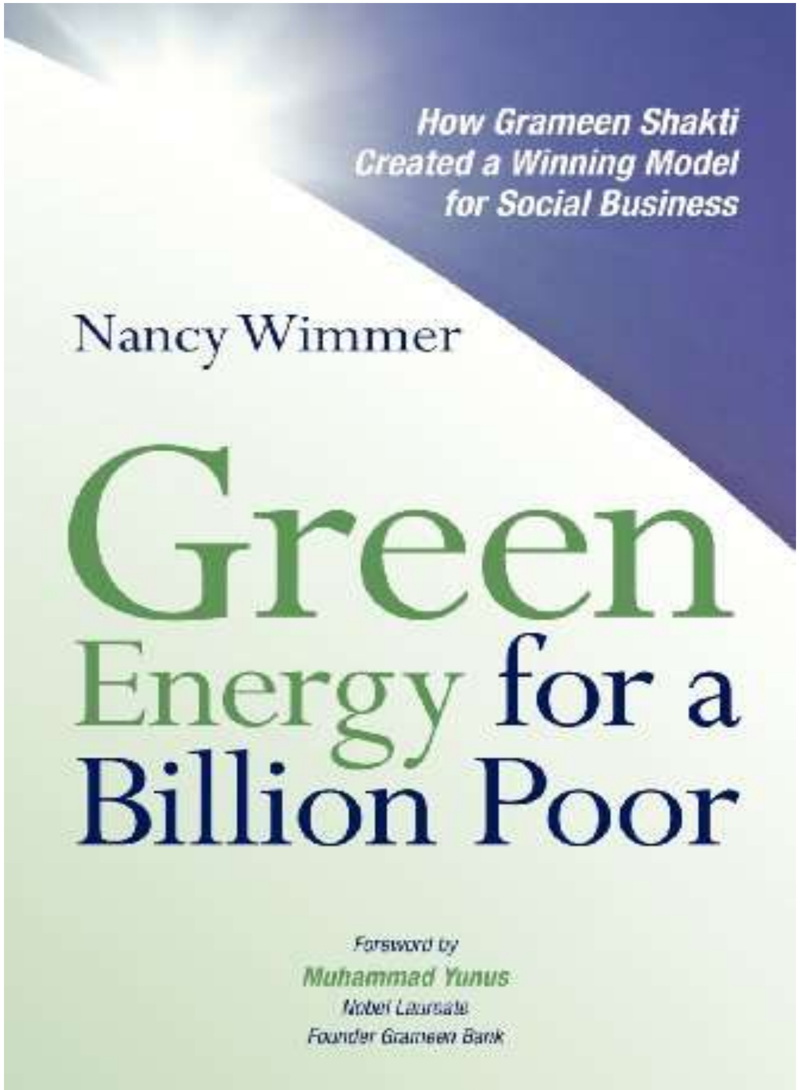
What business models are viable in the different situations?

Case example 1

Grameen Shakti in Bangladesh

Social firm providing PV stand alone systems

Socially oriented company



- Bangladesh
- Non-profit social company: Grameen Shakti, sister company of the Nobel Prize winning Grameen Bank
- Stand-alone solar PV systems, also Small & Pico Lighting systems
- Local equipment assembly & manufacturing
- Close relationship between staff and customers. Each branch provides an integral service including sales, financing, installation operation & maintenance, repairs and training for users and technicians

Case example #2

In the mountains of Cajamarca in Peru…

Peru Microenergia

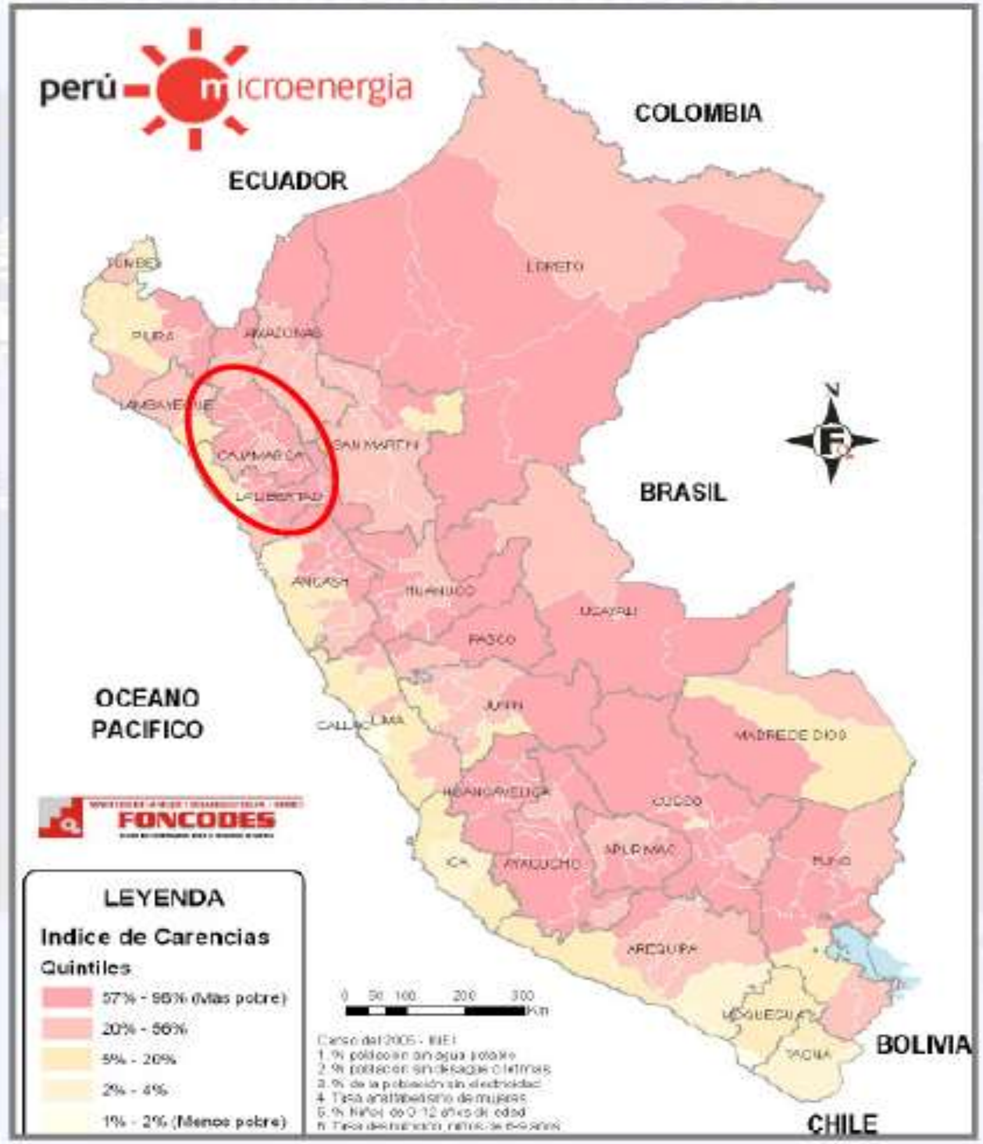
(A utility-like approach to rural electrification of isolated rural communities)

Systems based on a self-financing model (I)

Peru has the second-lowest electricity coverage in South America

Cajamarca is Peru's province with the lowest level of electrification.

About 70% of households in rural areas of Cajamarca have no electricity supply.



Source: Julio Eisman. Acciona Foundation. Peru Microenergia.

Isolated rural community in Cajamarca (Peru). Example of dispersed population.
Electrified by Peru Microenergia. Acciona Foundation.

Isolated rural community in Cajamarca (Peru). Example of dispersed population.
Electrified by Peru Microenergia. Acciona Foundation.

A smartly designed business model

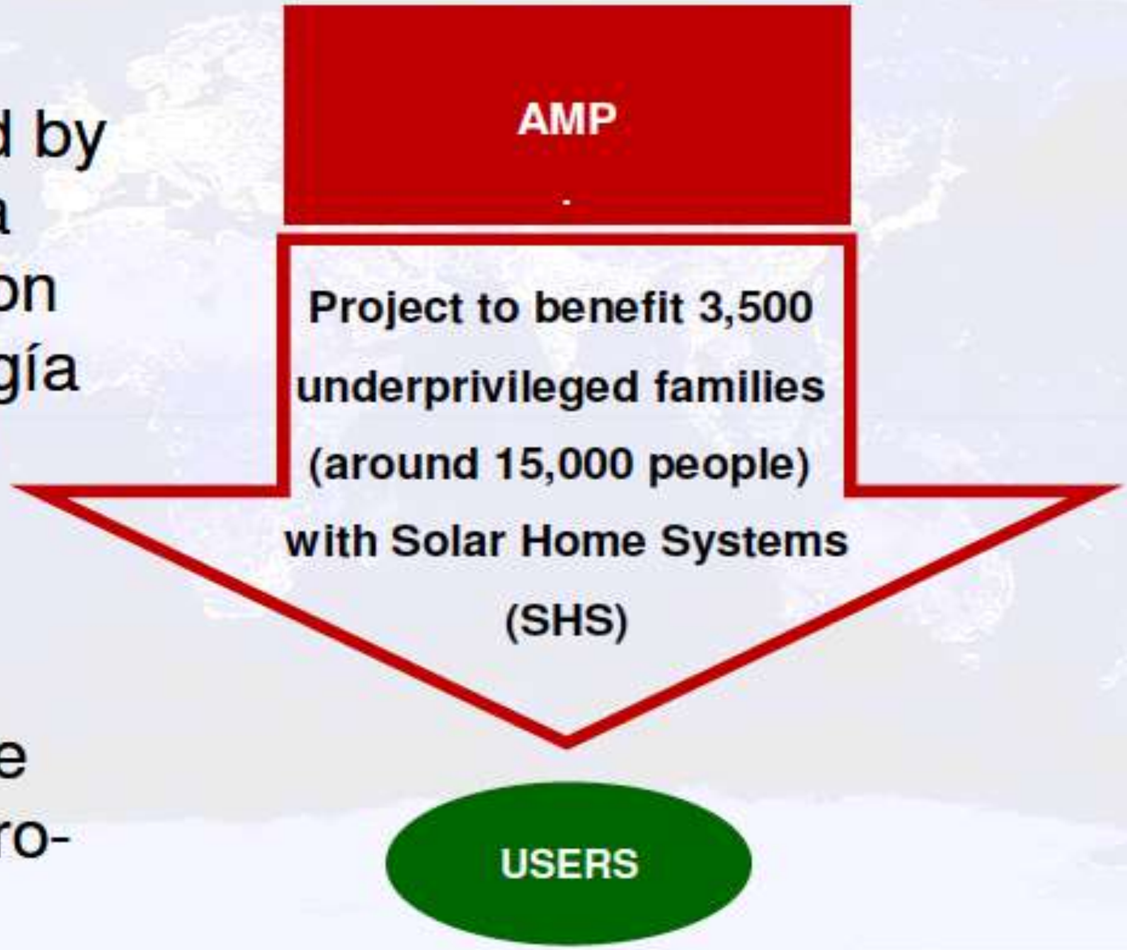
- Consumers pay an **affordable & officially regulated periodic charge** (tariff) in exchange for basic service
- **Regulated cross-subsidy from tariffs of grid connected consumers** covers the viability gap
- PV systems are owned by the utility (Peru Microenergía) to **guarantee quality & continuity**
- **Local community members** in charge of immediate maintenance tasks *(as employees of Peru Microenergia)*

LUZ EN CASA

"Luz en Casa"

(Light at Home) the programme was developed by ACCIONA Microenergía Foundation in collaboration with ACCIONA Microenergía Perú (AMP) -non-profit Peruvian association.

Aims to be a sustainable energy service social micro-enterprise.



Source: Julio Eisman. Acciona Foundation. Peru Microenergia.

Community meetings for information






Signature of agreements with Municipalities





Pilot installations





Training courses and PV Electrification Committees




Instalation





Operation





The basic electric service provided

Basic electrical service provided is lighting (three low-energy bulbs) and communication and entertainment (mobile phone charger and radio and TV) for at least four hours a day. This implies an average energy available of 86 kWh. year, which is achieved with a 60 Wp solar panel and a battery of 100Ah. Source: Julio Eisman. Acciona Foundation. Peru Microenergia

Perú Microenergía

Case example #3

In the villages of the densely populated state of Uttar Pradesh in India…


A single PV panel & battery for the entire village...
Uttar Pradesh, India, July 2014


... using the trees as support for the cables...


... and not far away from the existing power grid

How come the village is poorly electrified by an independent entrepreneur company & not just connected to the nearby grid?

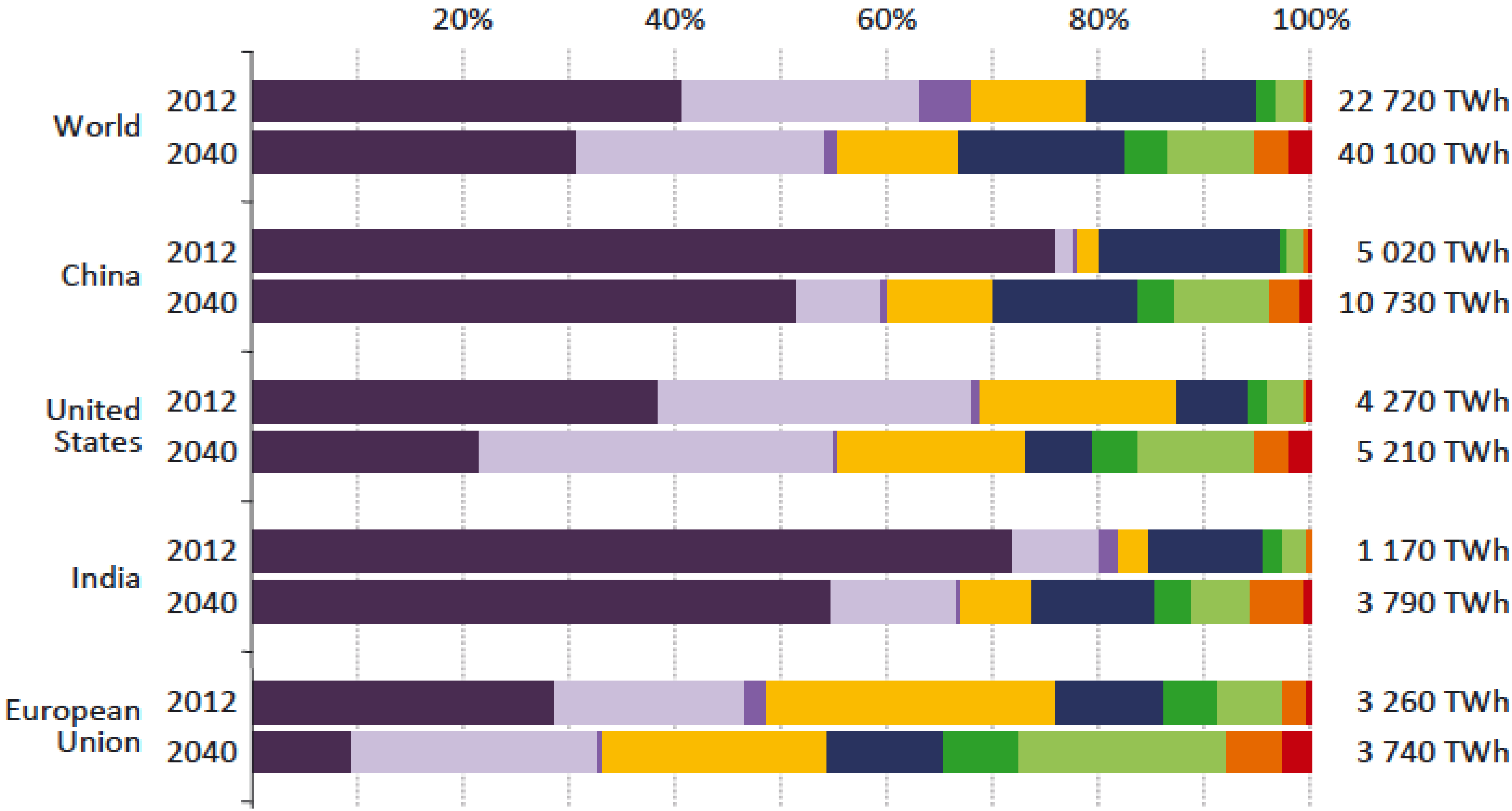
The context (1 of 2)

- Electricity tariffs are heavily subsidized, even free for irrigation, with separate feeders
  - Distribution companies are not interested in connecting more customers since that would increase their losses
  - Distribution companies refuse buying wholesale power at peak times, as the cost is not recovered via tariffs
- Quality of service is very poor; in rural areas typically 8 hours of electricity per day are provided, but not at the most convenient times
- Some microgrids have been deployed by private investors
  - Either supported by donors who bear the viability gap
  - Or providing very basic service with poor performance

The context (2 of 2)

- The official strategy is grid extension, multiple programs have been launched, but the progress has been too slow
- Recent measures in India try to address the root problems *(similar situations, microgrids below the regulatory radar & helpless distribution companies exist in other countries)*:
  – Reconfiguration of the financial situation of the distribution companies by **reducing their debt**
  – Impulse to the States to **increase the tariffs** getting closer to the actual costs
  – Facilitating the investment in microgrids by **reducing the associated risks**

Share of electricity generation by source & selected regions *(New policies scenario)*



Source: IEA WEO 2014

Strategy issues for discussion

- Should unregulated microgrids be allowed?
  – People at least get some electricity
  – But grids are not compatible, will eventually be discarded & the present solar generation will become the national mix (dominated by coal)
- Why to encourage grid compatible microgrids?
  – Grid compatible microgrids provide better reliability, do not waste investment & solar can remain
  – They can mitigate the social & financial pressure on the distribution company by providing a transitory solution
  – But the viability gap will exist & has to be covered
  – Subsidized kerosene for lighting erodes the viability of microgrids

How could regulation help?

- **Think big**

"Expected results can only be achieved if the **private sector operates in a business environment** which allows to step out of the traditional practice of pilot projects and move into successful deployment of off-grid technologies which will allow for upscaling and replication"

- Rely on **service supply firms** subject to regulation

Source: "Risk mitigation in mini-grids", ARE, 2014. Executive summary.

How could regulation help?

- Regulation should
  – establish access to electricity as a fundamental right
  – not impede or delay approaches to electrification
  – promote electrification approaches that
    - allow future demand growth to developed country levels
    - are compatible with grid extension
    - reduce the risk to investors in off-grid solutions to acceptable levels

A tentative regulatory template *(1 of 2)*

- **Electrification franchises** should be allowed & promoted to provide **off-grid access** *(individual systems or microgrids)* within the territories of licensed incumbent distribution companies who do not provide electricity service, presently or in the near future
  - The franchisee will have to follow some generic or *(better)* specific **minimum technical requirements**
- Consumers of the franchise would pay the same **regulated social** *(if this exists)* **tariff** as those who are already connected to the grid
  - The difference with respect of the actual cost of supply will be covered by a **subsidy**, which could be obtained from a levy in all the remaining tariffs or with public funds

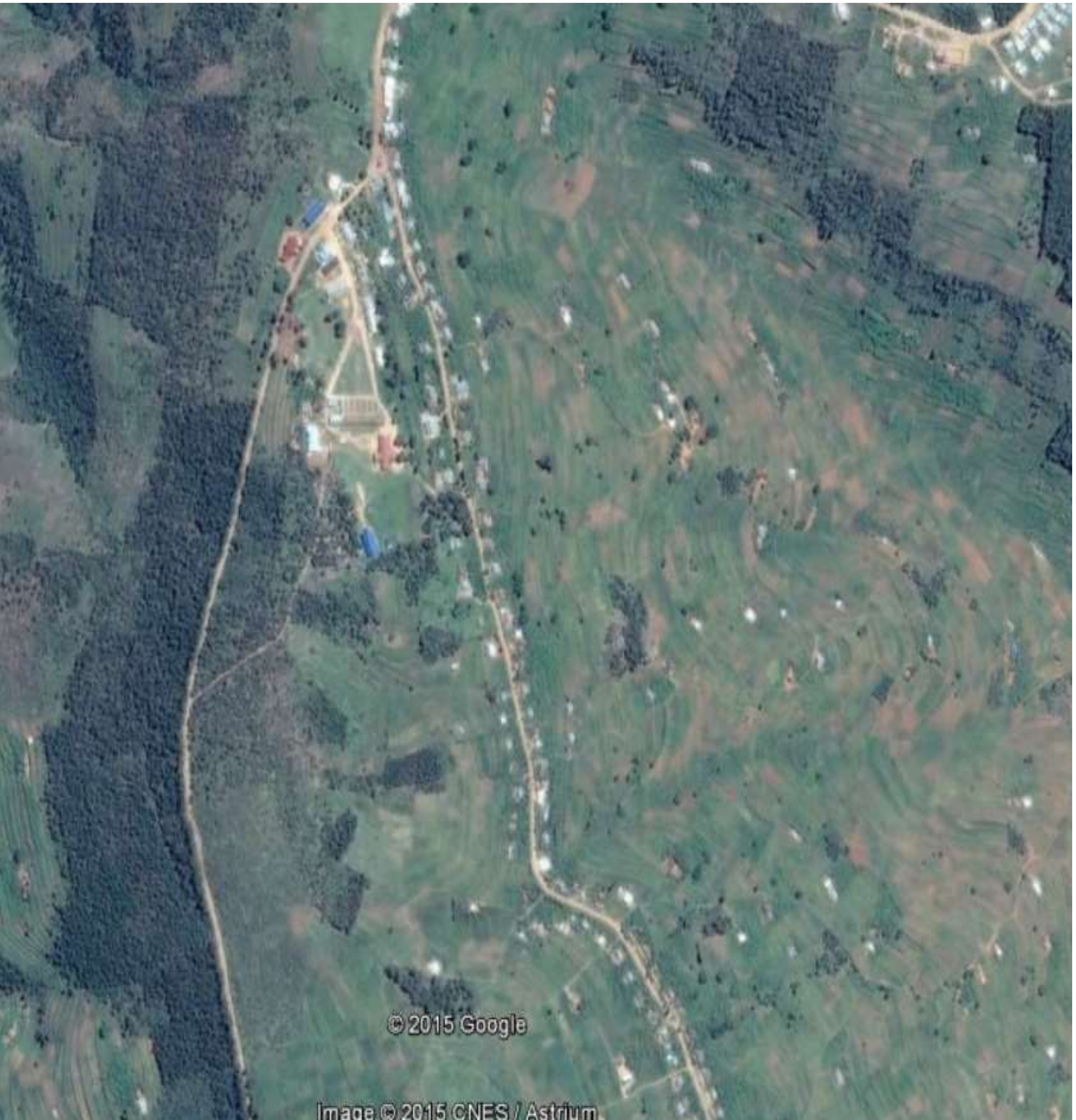
A tentative regulatory template *(2 of 2)*

- In case the consumers of the franchise are offered grid connection
  - The franchisee will be remunerated for the book value of its grid
  - The production of electricity by the existing distributed generation facilities will become an independent power producer and will be remunerated by some sort of feed-in-tariff or the market price
- This should **reduce the risk of potential investors** to a reasonable value
  - and makes possible to **maintain and to expand the current off-grid generation** *(typically mostly renewable)*

Case example #4

In the village of Karambi, district of Mutete, in Rwanda…

Karambi (Mutete district, Rwanda)



Village of Karambi (Rwanda)

Many consumer Types:

- 176 residential homes
  - 1 high school
  - 1 primary school
  - 1 health center
  - 1 bank
  - 1 government building
  - 1 coop
  - 9 shops

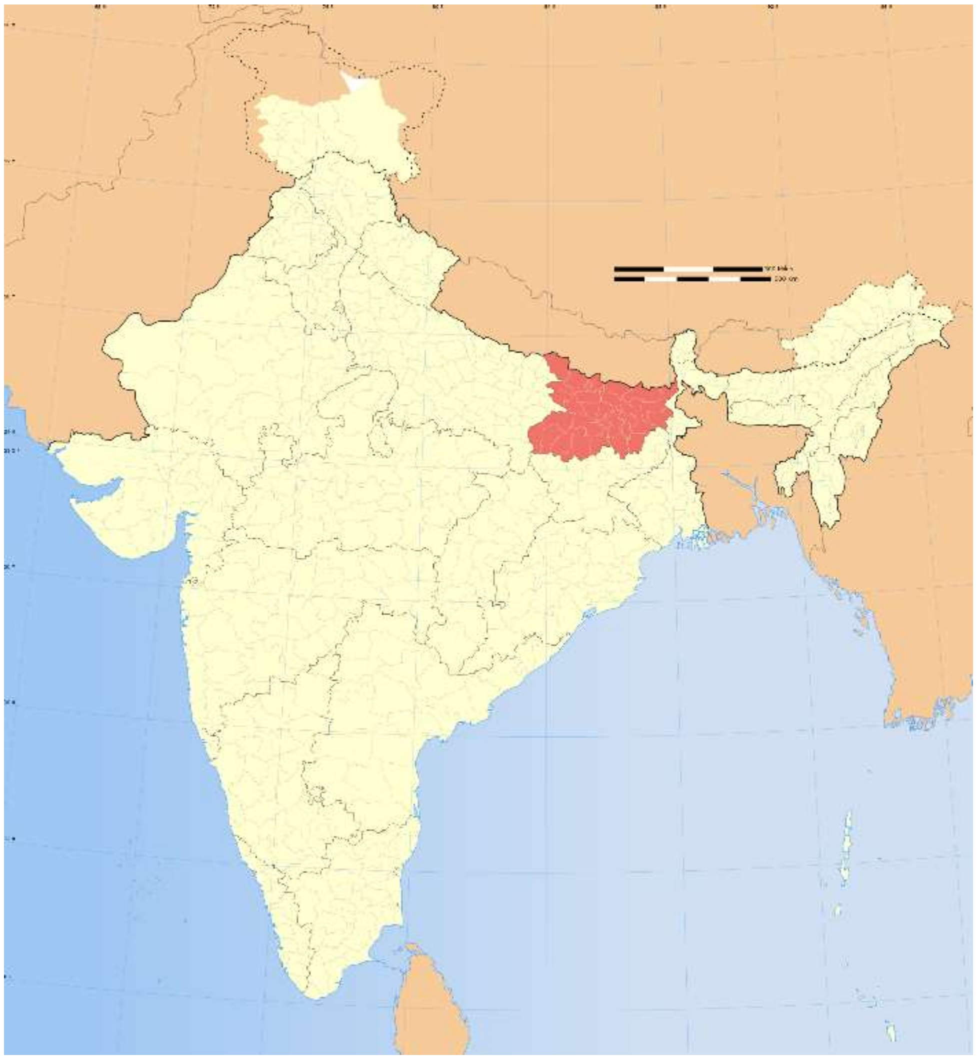
How to make the case that the electrification of the school &/or the health center & the surrounding area is an attractive business model for potential investors?

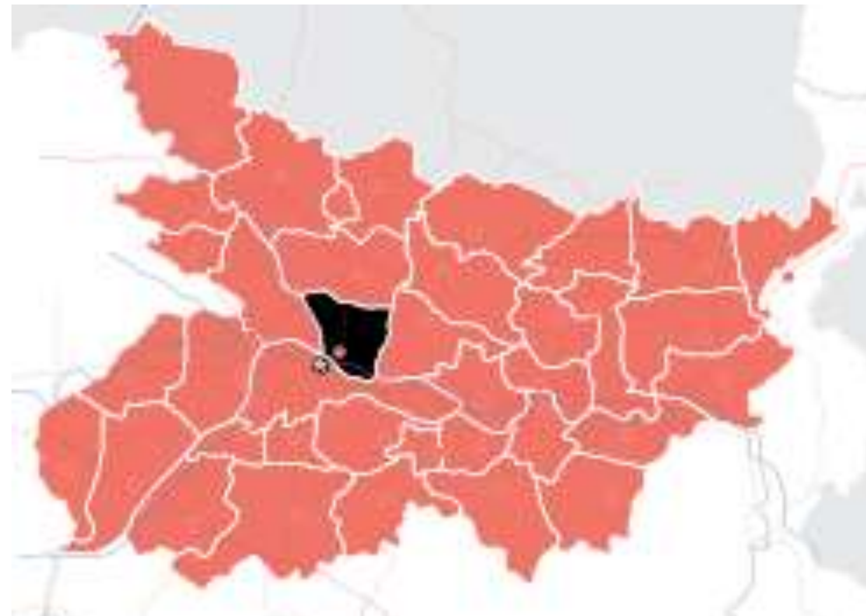
Can computer-based electrification planning models be of any practical use?

Reference electrification model (REM)

A high level description of its capabilities

REM supports large-scale electrification planning…

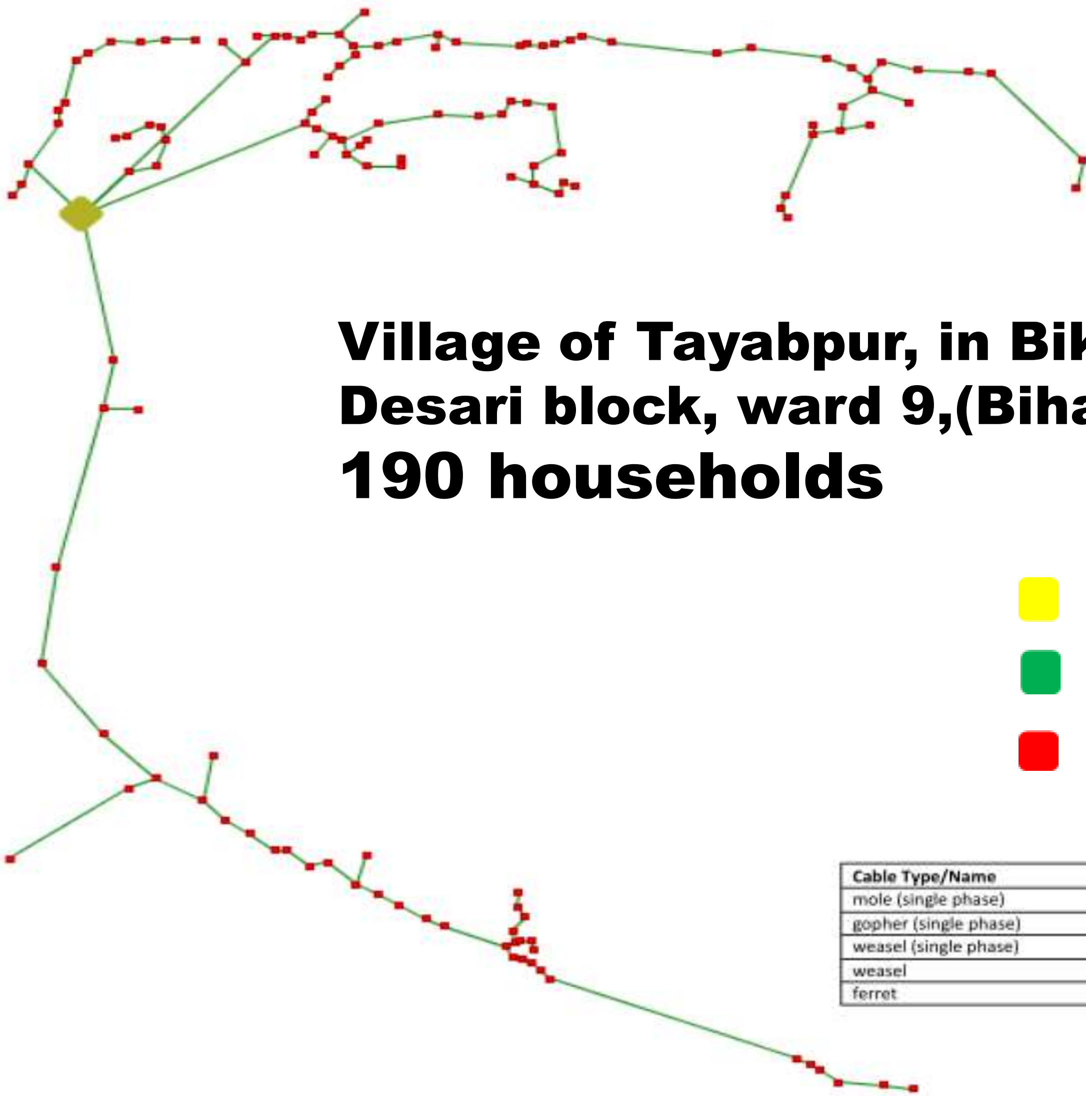




District of Vaishali (Bihar)

About 600,000 households

… as well as local electrification projects…



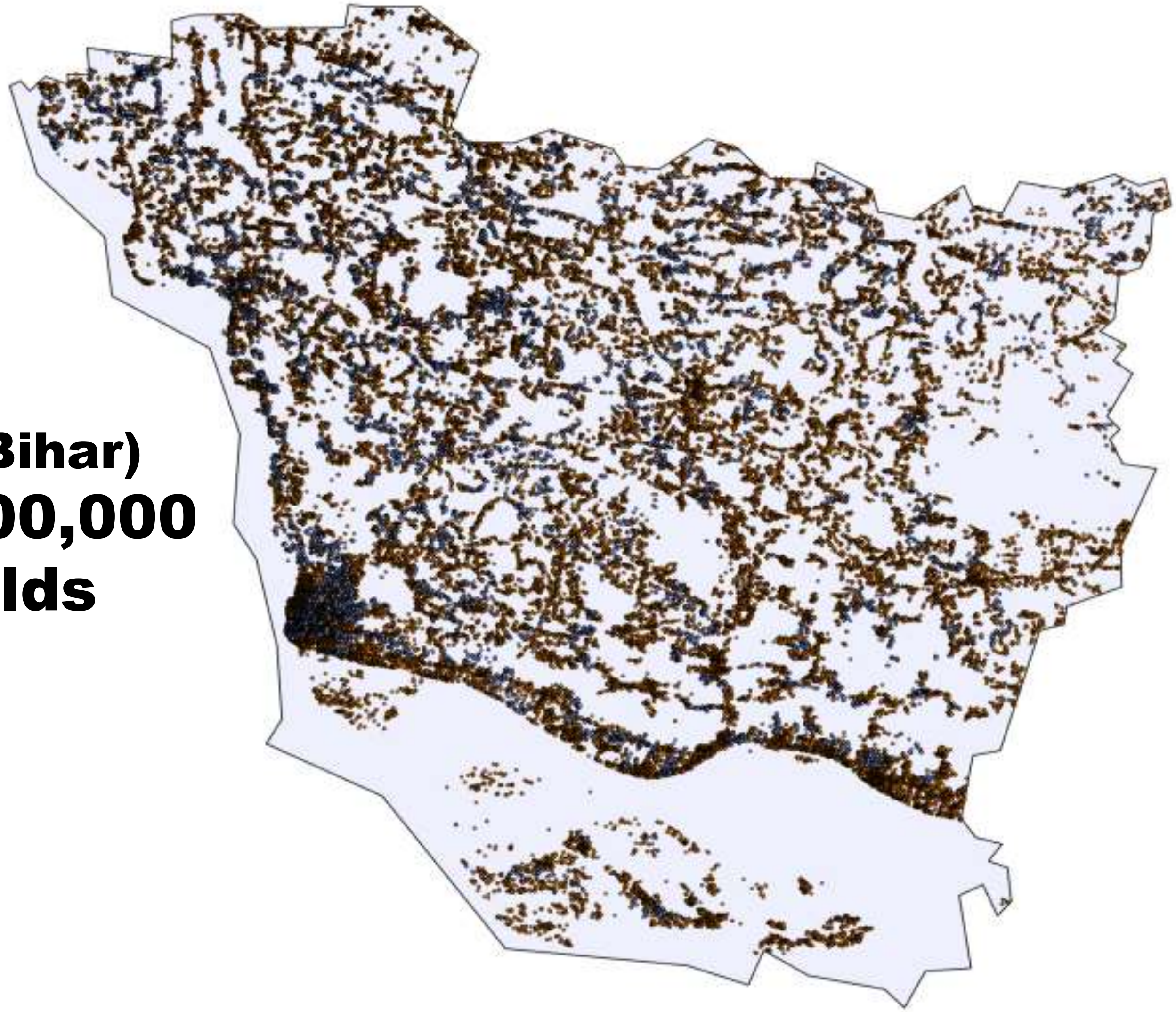
Village of Tayabpur, in Bikhanpura, Desari block, ward 9,(Bihar)

190 households

- Generation Site
- Low Voltage Network
- Consumers

Cable Type/Name	kVA	Length (km)	Costs (euros)
mole (single phase)	15	1.14	1130.82
gopher (single phase)	27	0.26	495.74
weasel (single phase)	30	0.04	87.21
weasel	89	1.05	3505.63
ferret	107	0.35	1532.83

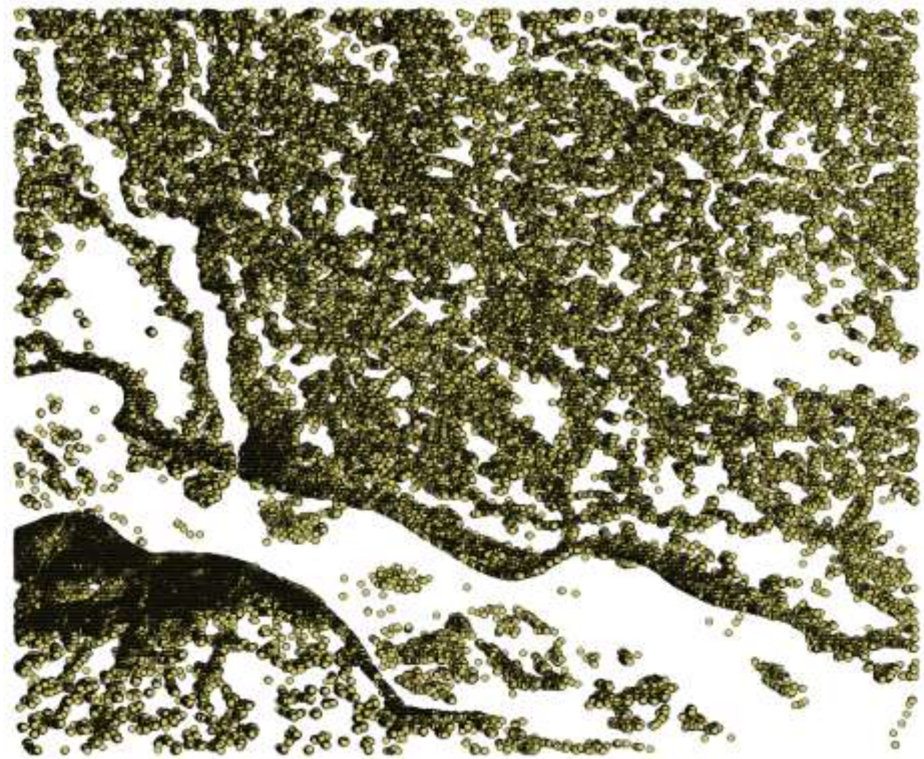
… starting from the position & estimated demand of every building to be supplied…



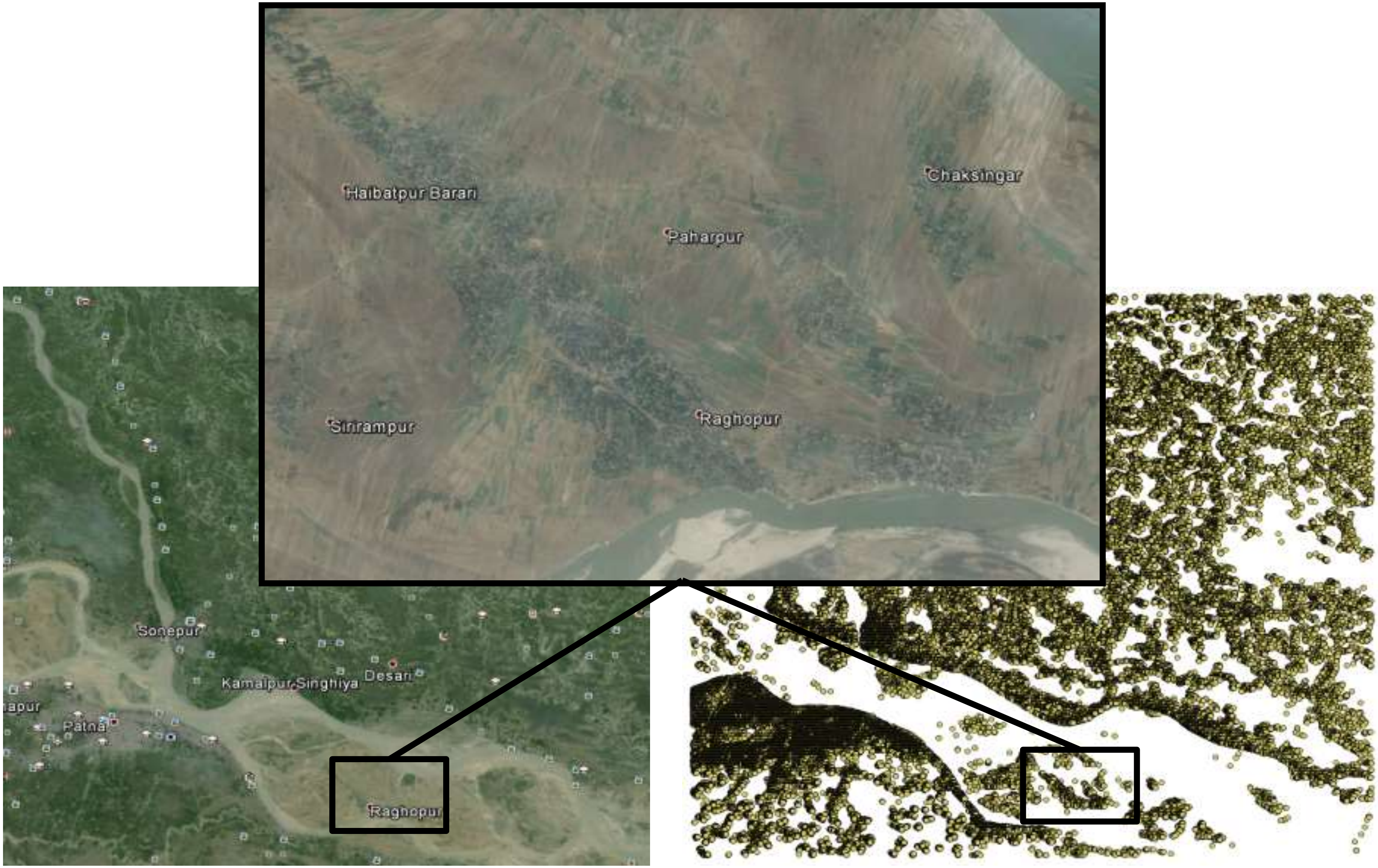
District of Vaishali (Bihar)

About 600,000 households

The fully convolutional network (FCN) was applied to free Google Maps images in Vaishali /Bihar, India). Augmented by the discretization algorithm, 599,743 buildings were identified in image areas downloaded



Houses were even identified in the area of Raghopur, situated between two streams of the Ganges river. The areas identified qualitatively reflect areas that appear to be visibly more developed in satellite imagery



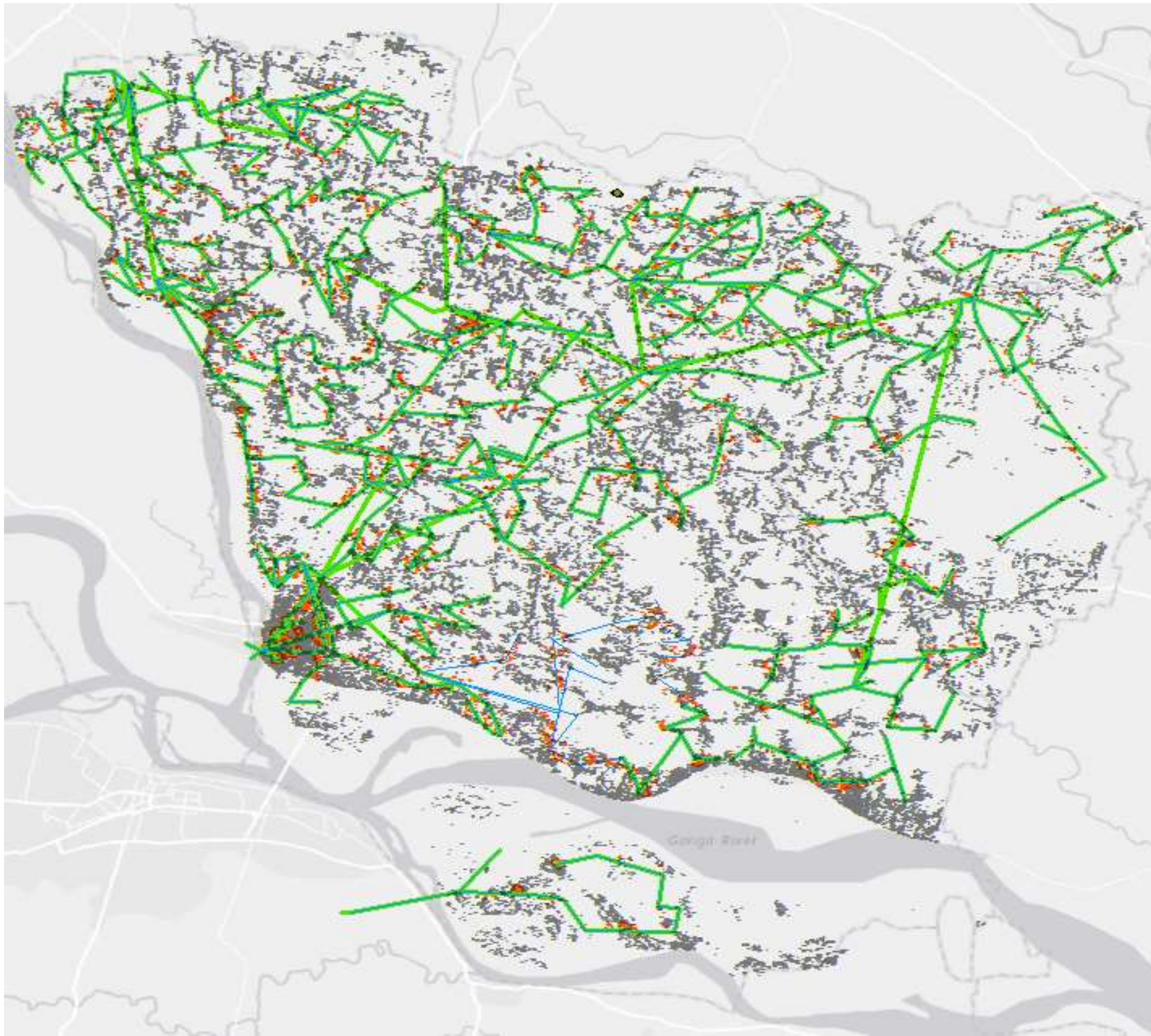
Satellite Base Image

Buildings Detected

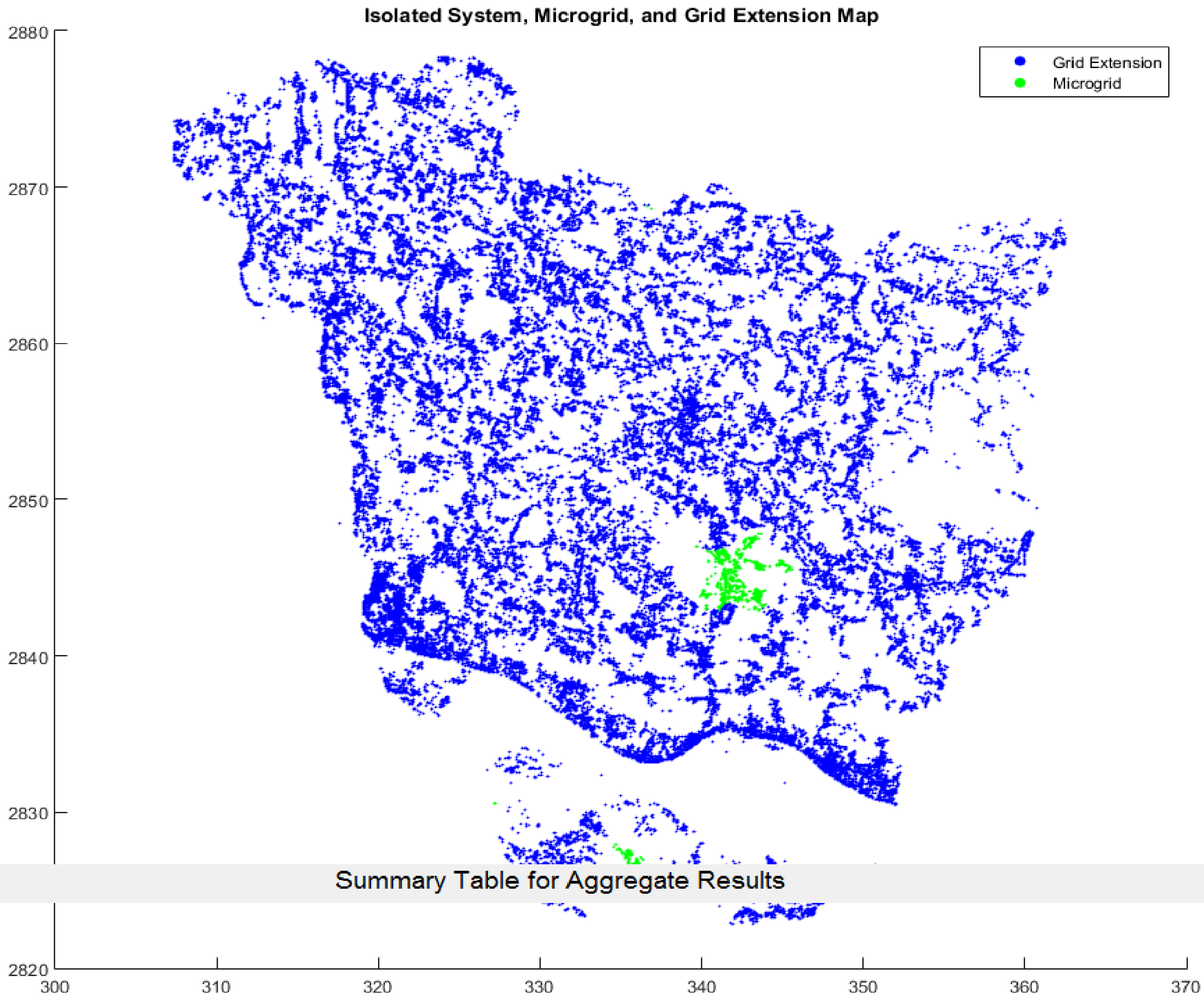
Electrified

Not Electrified

& the location & characteristics of the existing network…



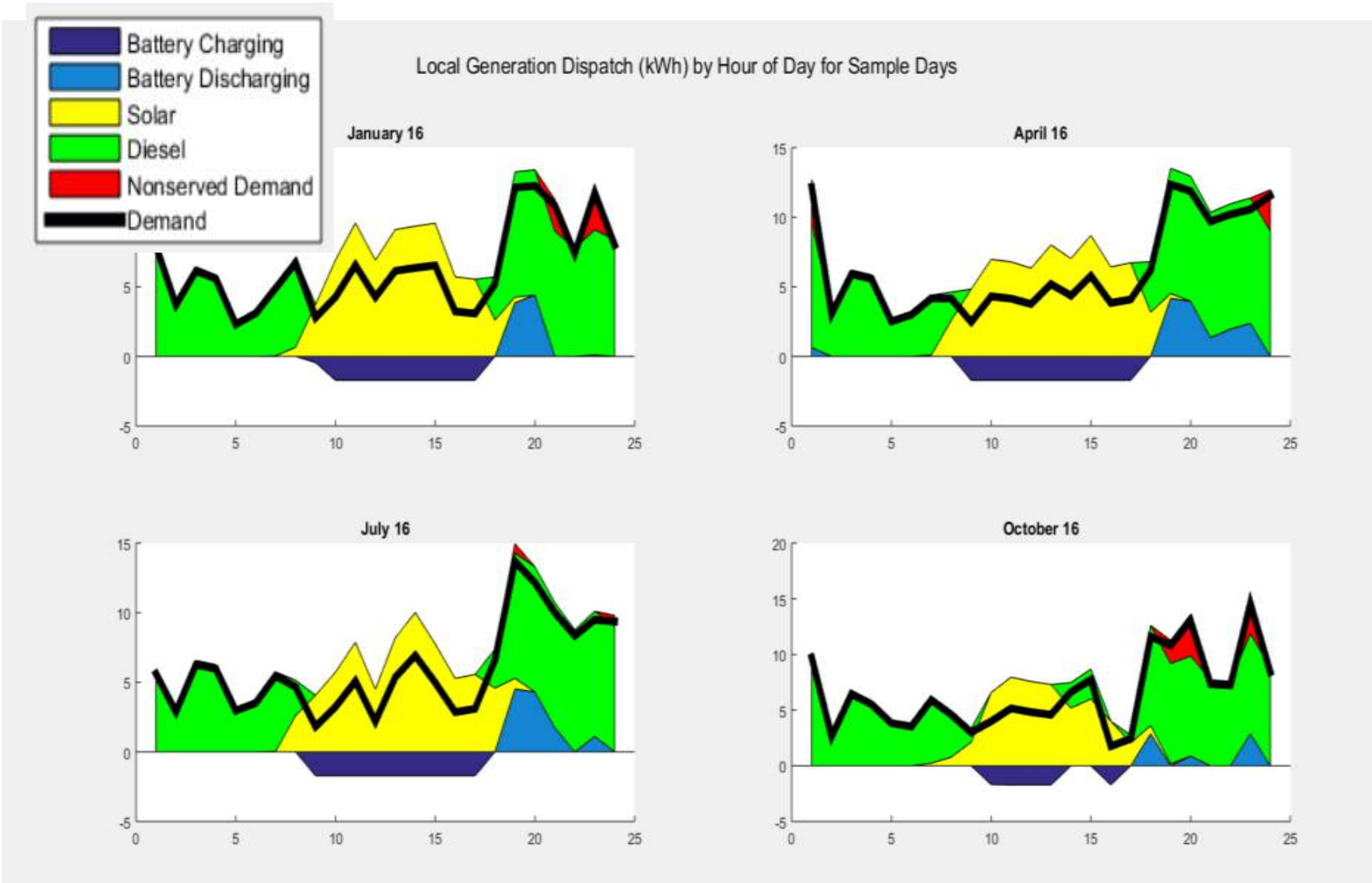
& selects the best electrification mode *(grid connection, microgrid or stand alone)* for each customer...



Summary Table for Aggregate Results

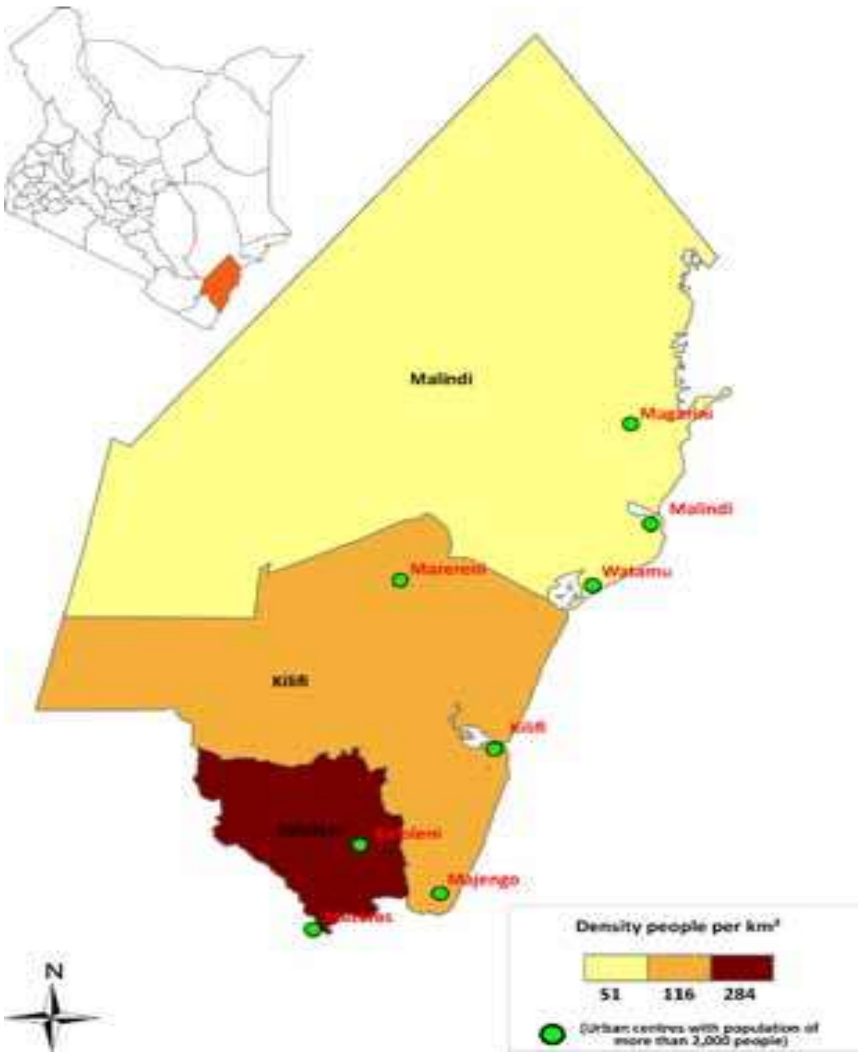
… designing the layout of the network ...

… & optimizing the mix of generation & storage…



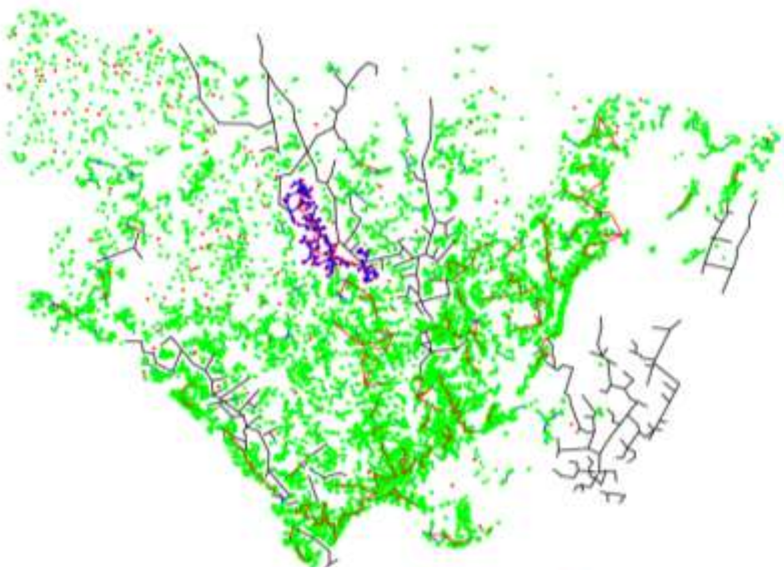
The results are very sensitive to the level of reliability of the existing grid…

Kaloleni district *(Kilifi, Kenya)*

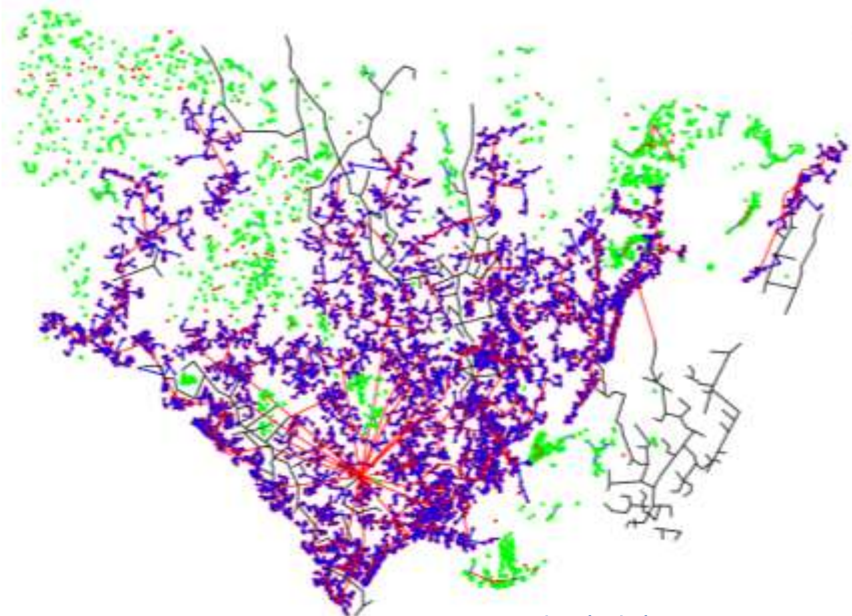


42,755 unelectrified households in Kaloleni

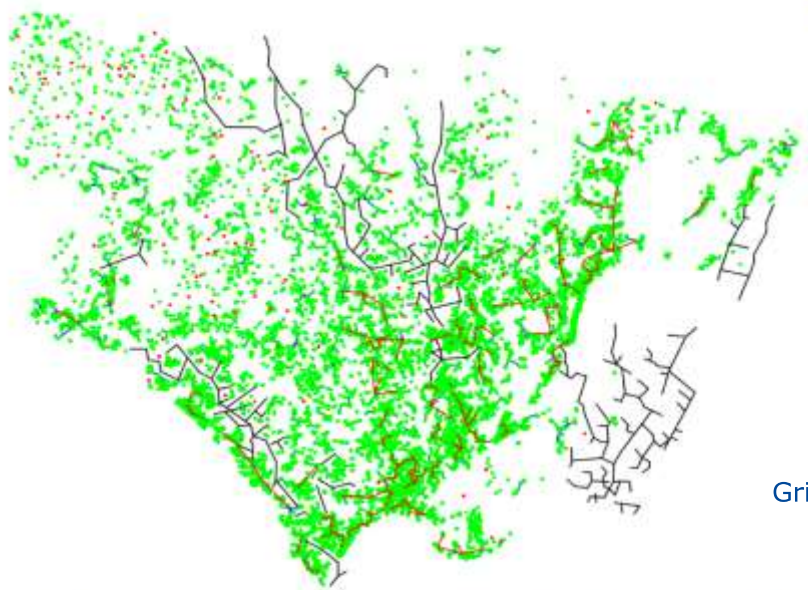
Sensitivity with respect to grid reliability



Grid reliability = 93.75%



Grid reliability = 100%



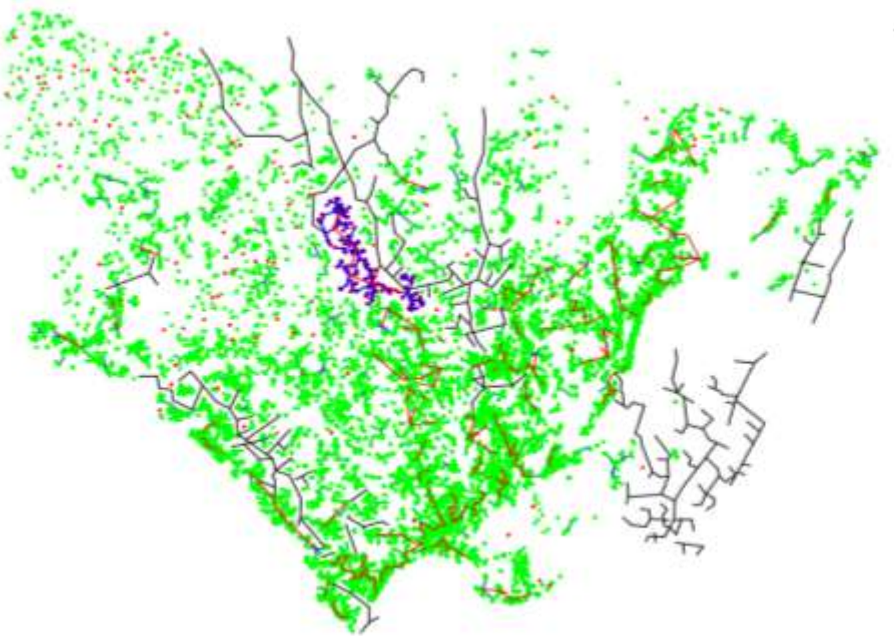
Grid reliability = 50%

SAS Microgrid Grid extension Existing 11kV New 11kV New 415V

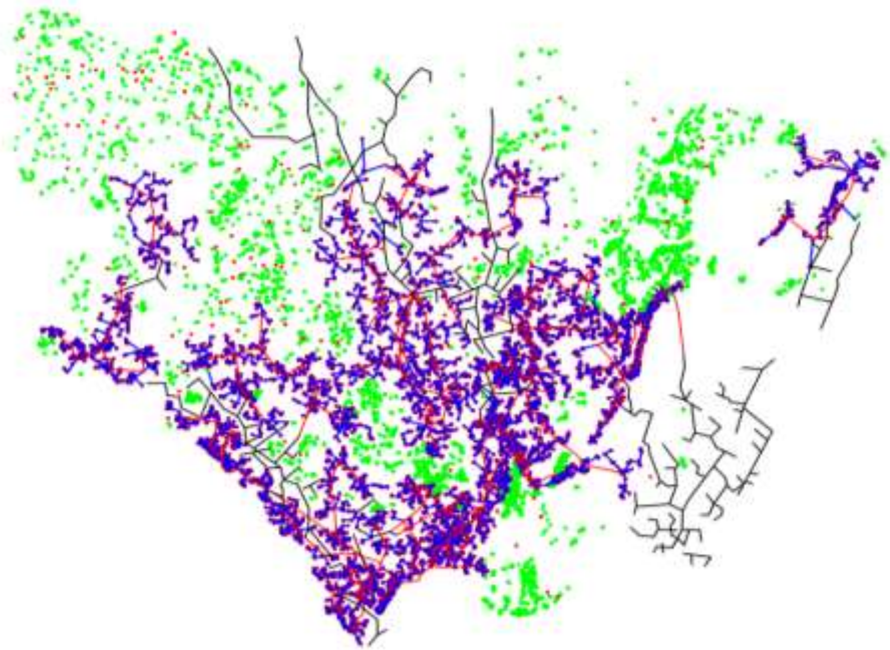
… as well as to the available generation options & their cost

*(example: **diesel** allowed or not, price of diesel)* …

Sensitivity with respect to diesel price



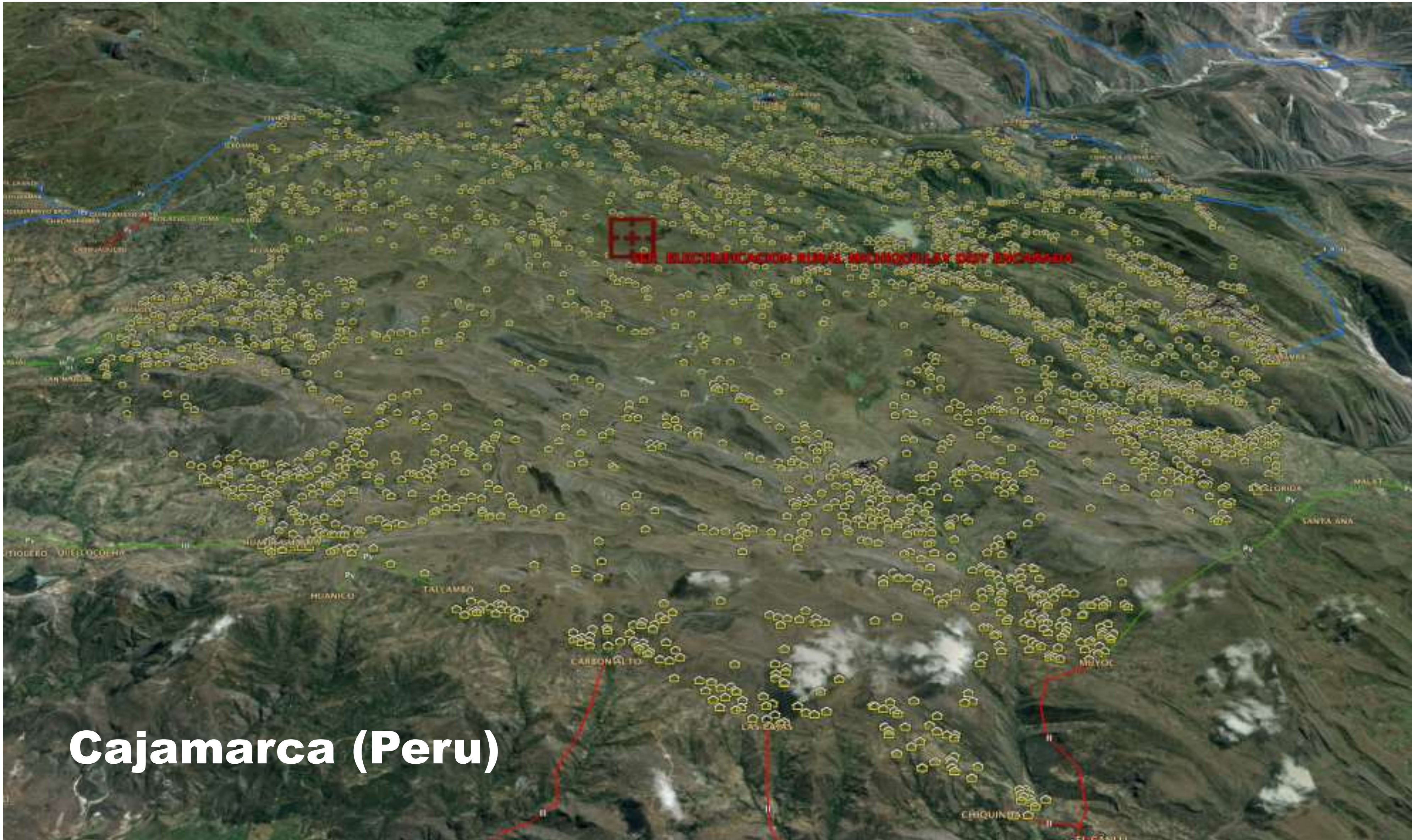
Diesel price = $1/liter



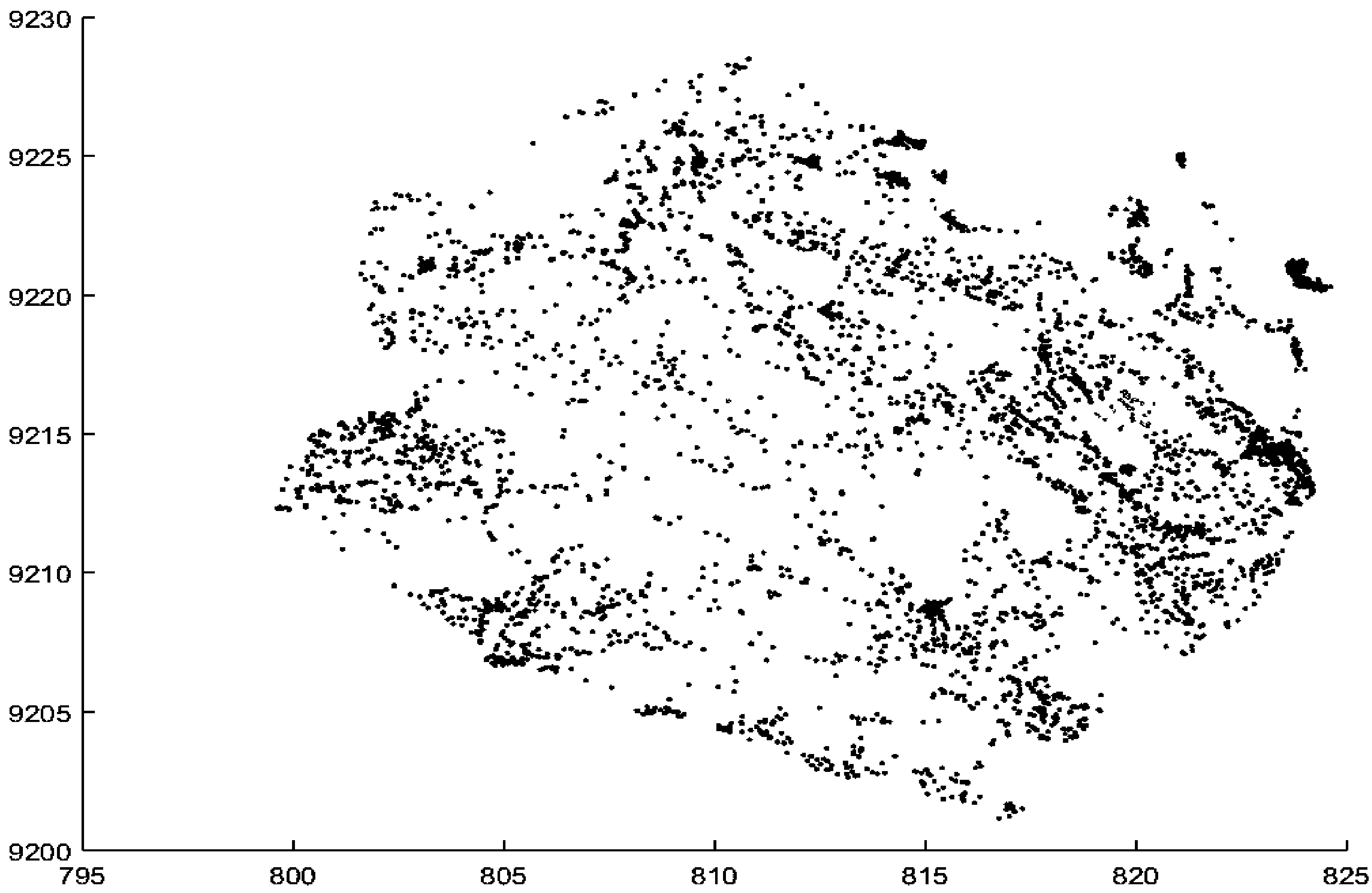
Diesel price = $2/liter

… & to the demand level

Analysis of demand level in Cajamarca (Peru)

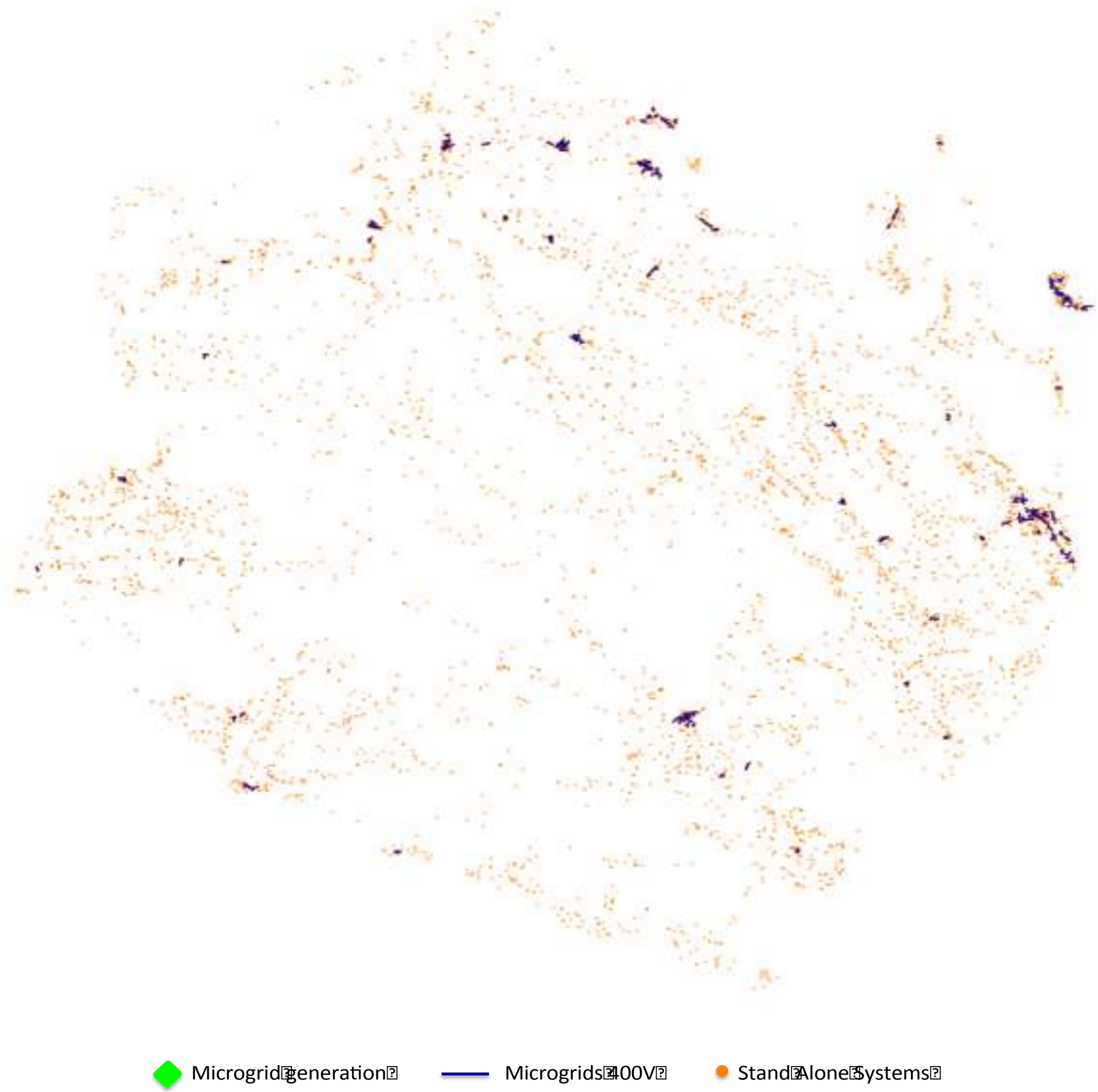


Cajamarca *(Peru)*
Location of buildings

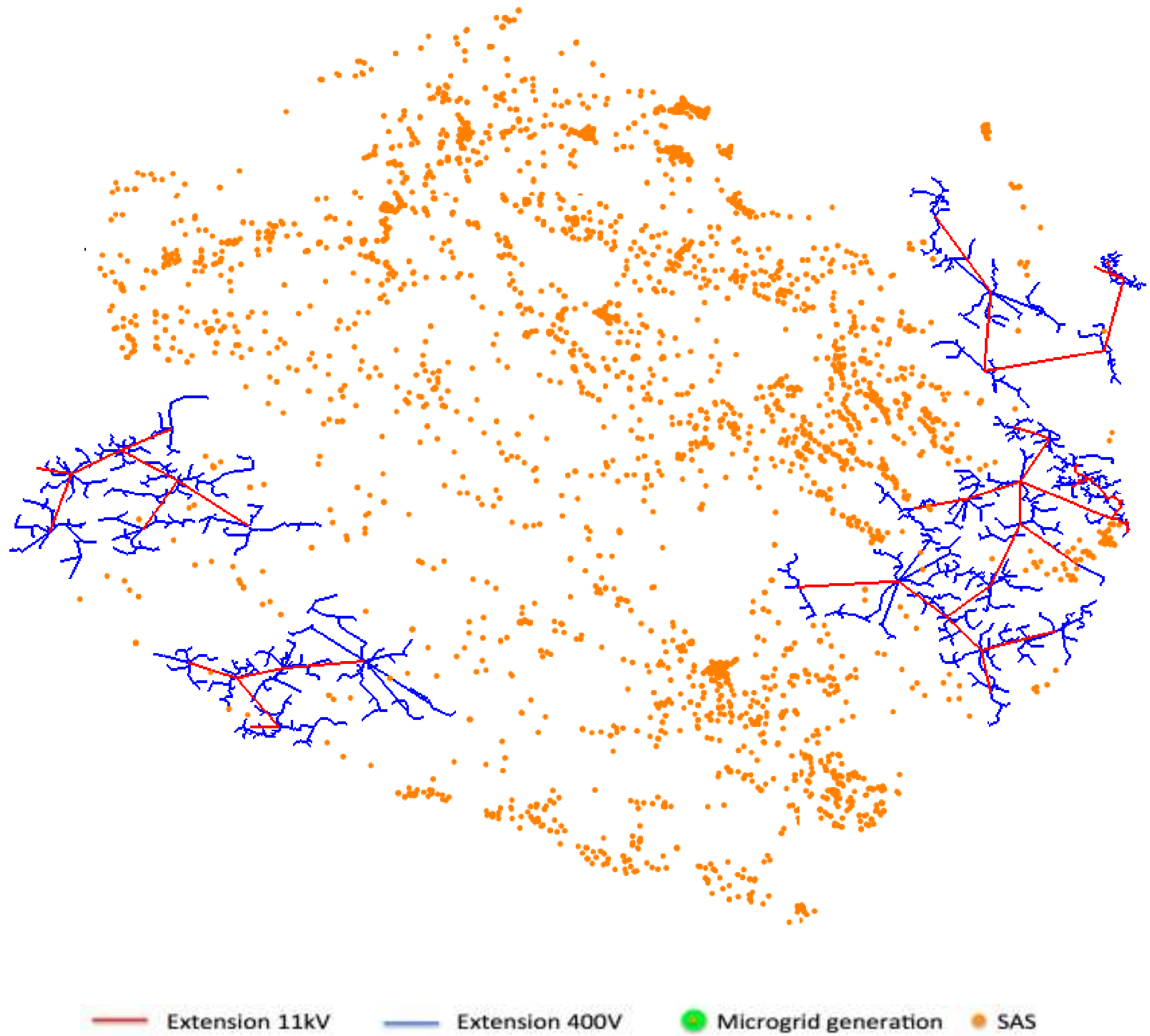


Cajamarca *(Peru)*

Base case *(estimated household demand: 185.5 kWh/year)*



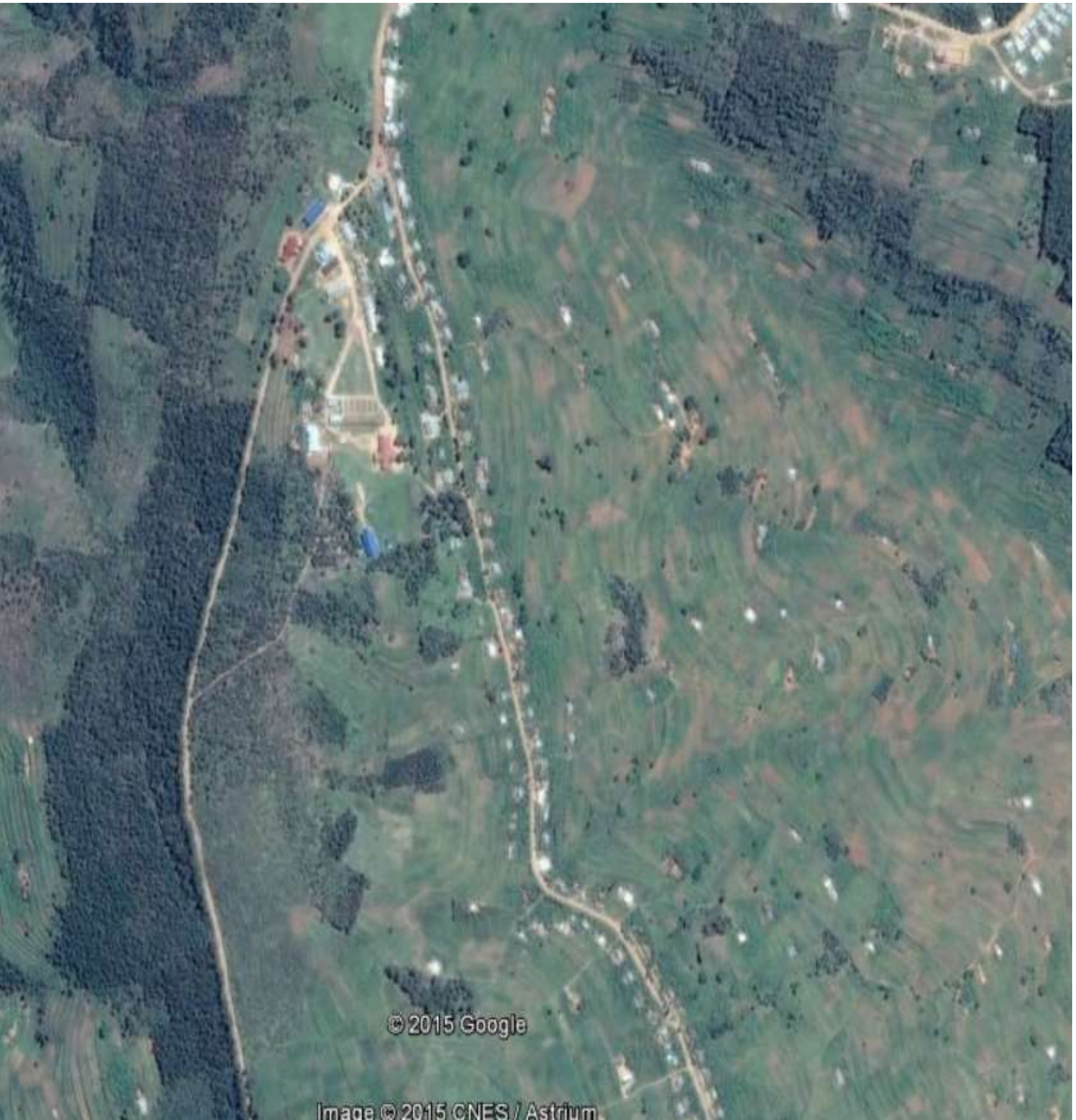
Cajamarca *(Peru)*
Demand growth *(500 kWh/year & household)*



Cajamarca *(Peru)*

Base case *(detail of network layout)*

Sensitivity to demand at village level

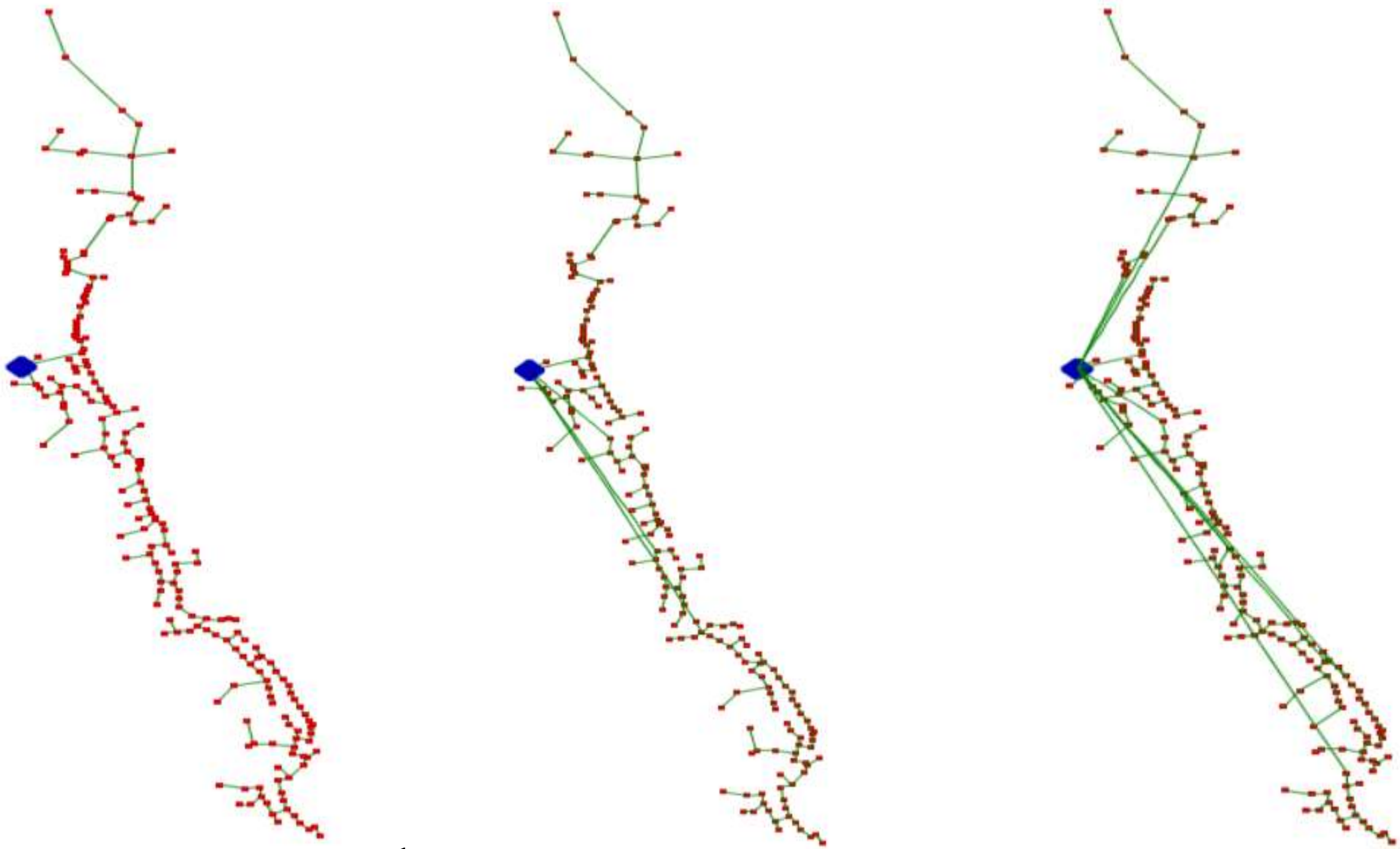


Village of Karambi (Rwanda)

Many consumer Types:

- 176 residential homes
  - 1 high school
  - 1 primary school
  - 1 health center
  - 1 bank
  - 1 government building
  - 1 coop
  - 9 shops

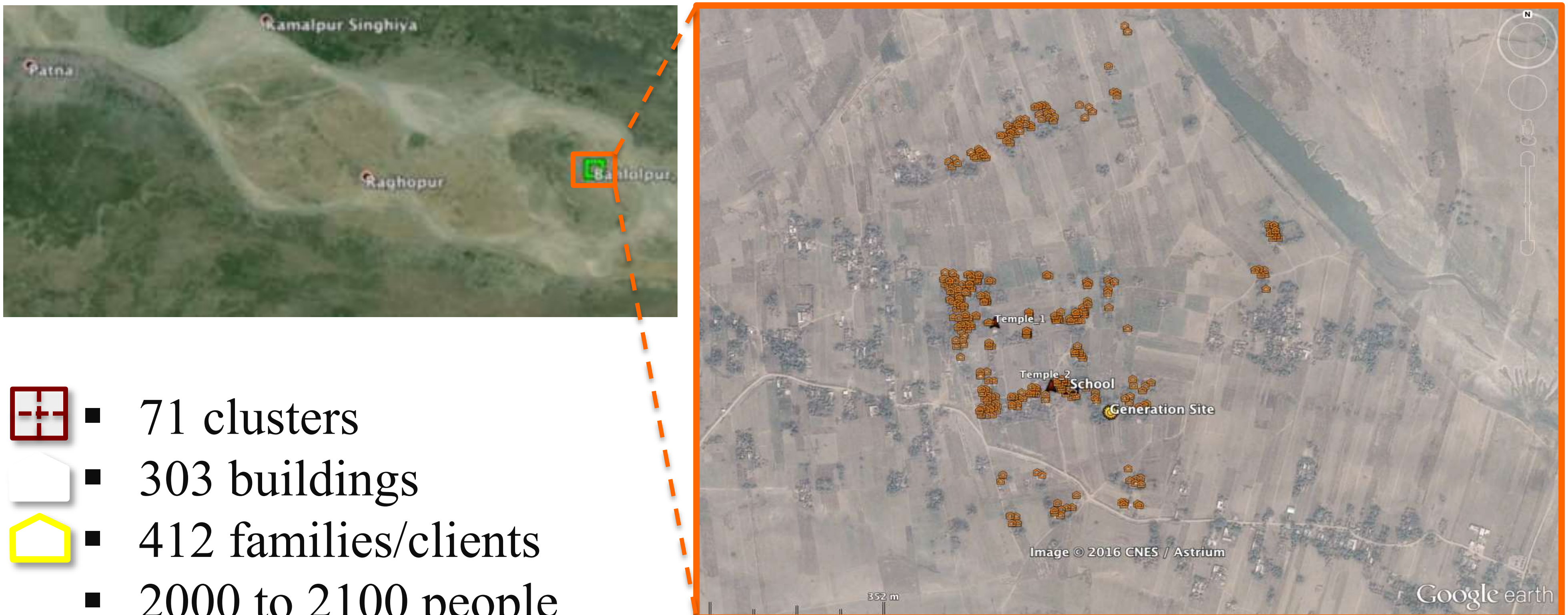
Sensitivity of the network layout to the demand level



Low Demand | Medium Demand | High Demand

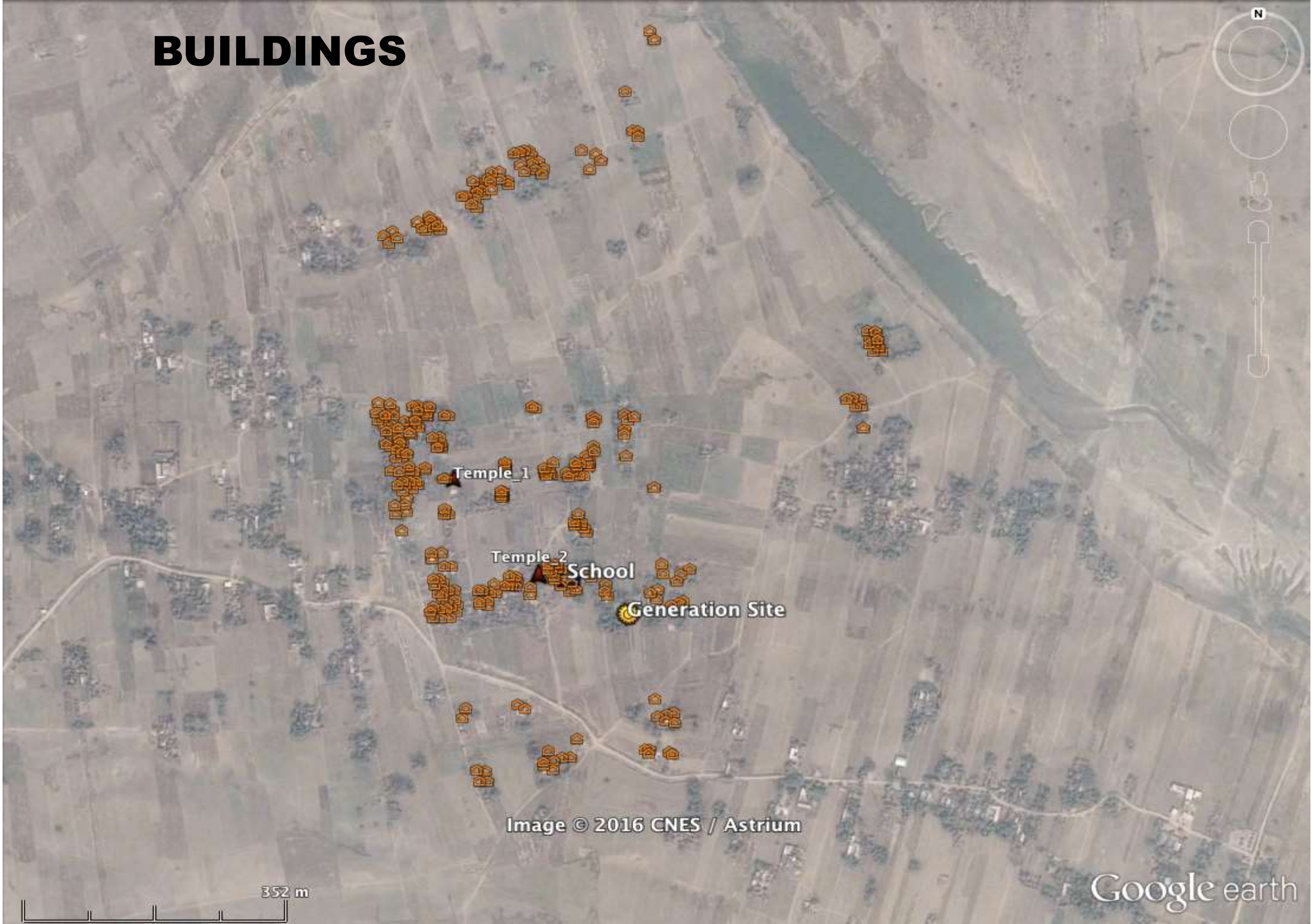
Detailed design at village level

Village: Bahlolpur *(Bihar, India)*



- 71 clusters
- 303 buildings
- 412 families/clients
- 2000 to 2100 people
- 1 Primary school
- 2 small temples
- Generation site
- No anchor shops

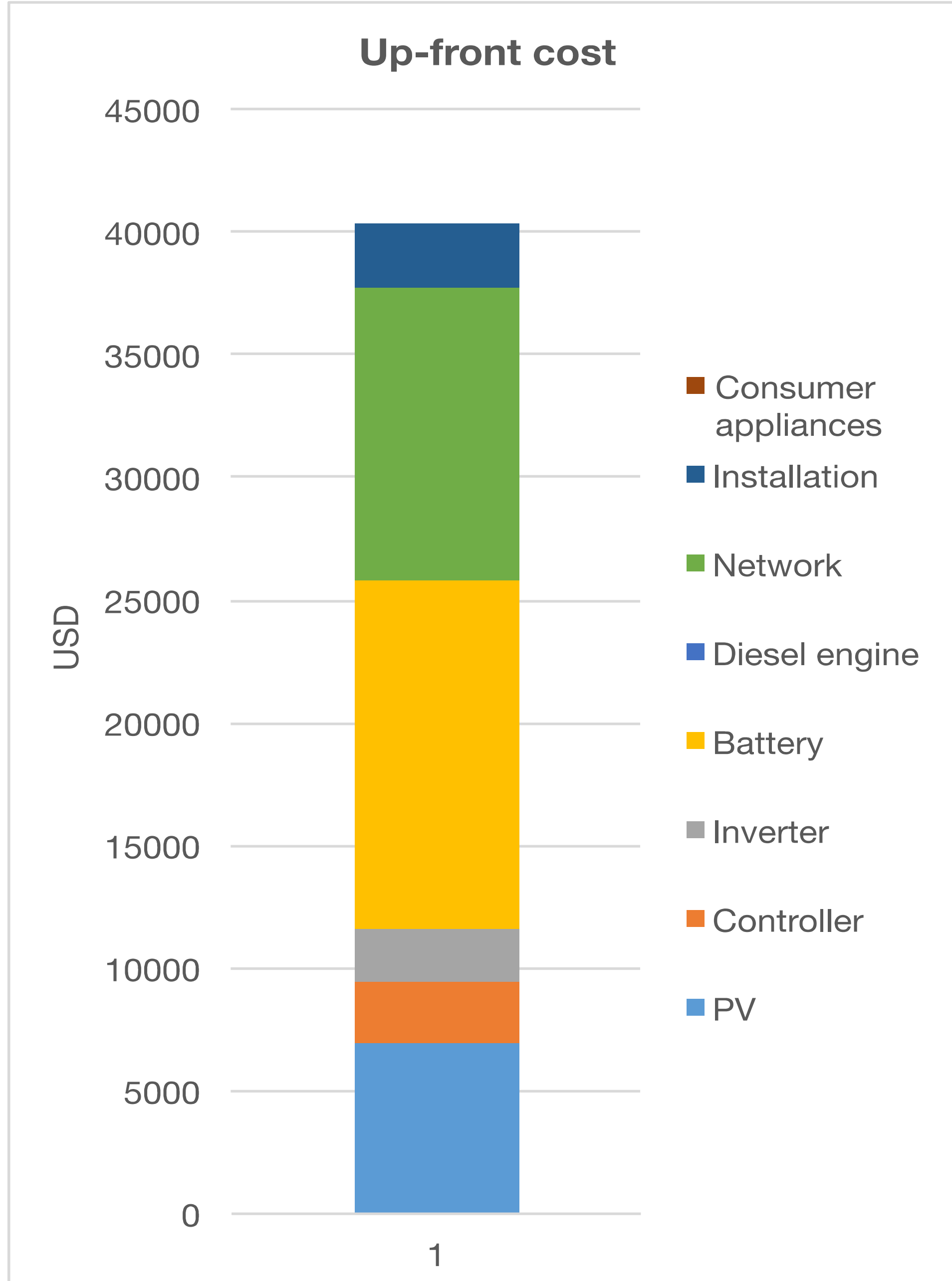
BUILDINGS



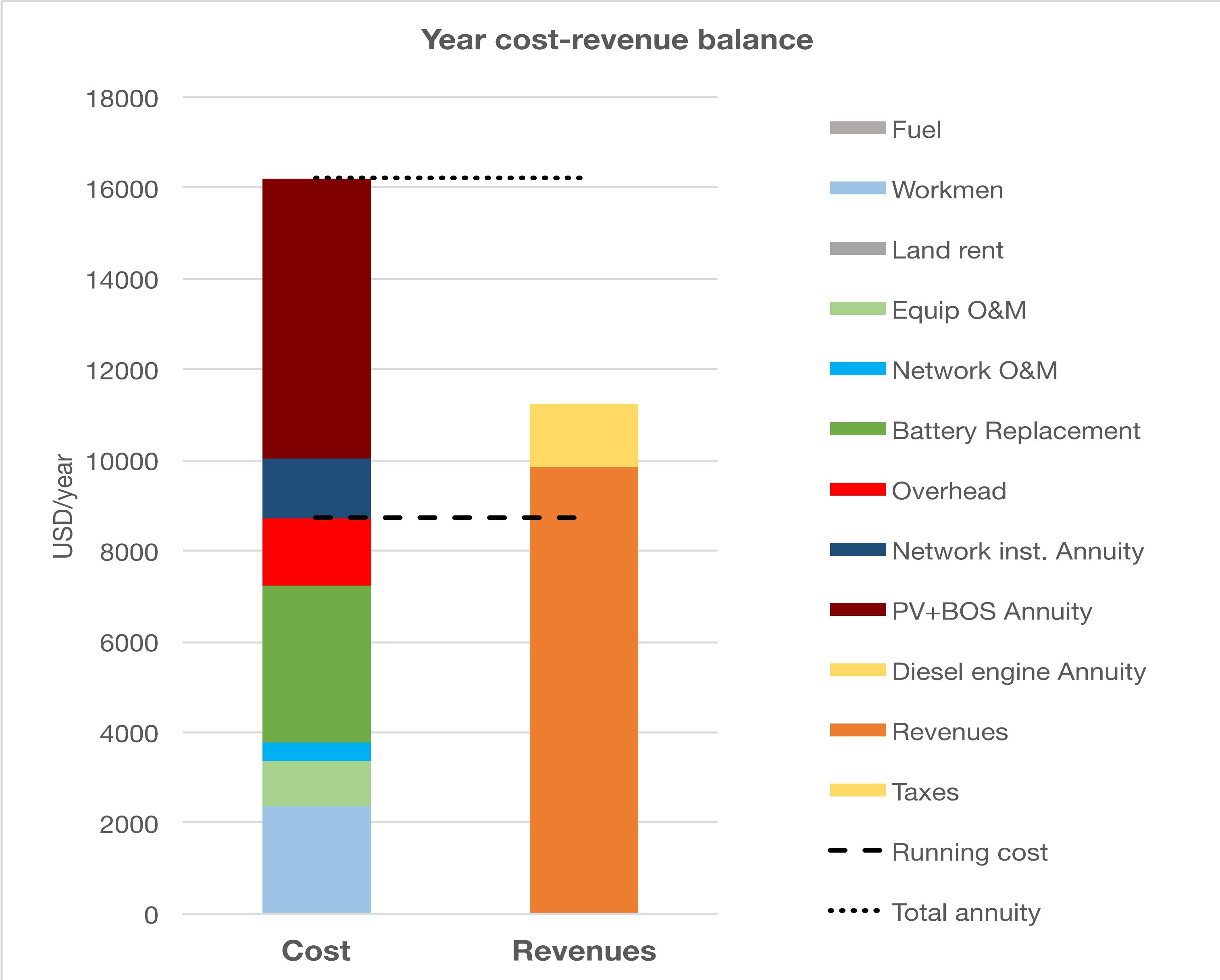
N
Temple_1
Temple_2
School
Generation Site
Image © 2016 CNES / Astrium
352 m
Google earth

Bahlolpur
Up-front costs

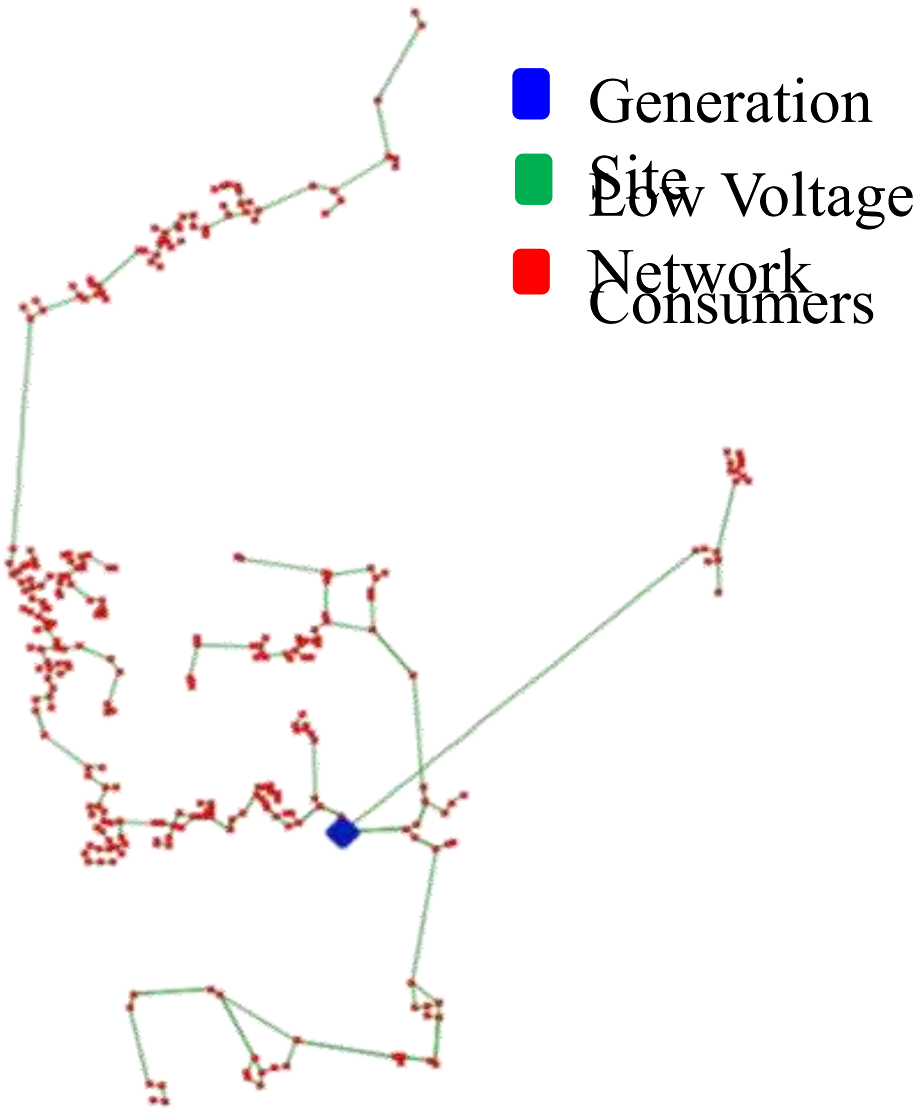
Solar capacity: 10.5 kW
Genset capacity: 0
Storage capacity: 54 kWh
Energy cost: 0.59 $/kWh
Demand: 11 1167 kWh/year



Bahlolpur: cost-revenue balance



Bahlolpur Network (only)
Designed for high demand (long term)



Network Summary Table:	
Total Cost Annuity	$1365
Total Capital Costs	$6861
Annual O&M	$353
LV Correction Costs	$337
LV Prevention Costs	$16.6

Correction Costs = Annual costs to fix problems due to failure

Preventative Costs = Annual maintenance costs to prevent failure in the network

REM output
Minimum cost electrification plan

- REM determines the **minimum cost solution** for the combined deployment of on- and off-grid systems, while accounting for:
  - Distances, demand level, cost of components, generation & storage design, reliability preferences of consumers, etc.
- **REM output**
  - Electrification mode for each building
  - Complete network layout & microgrids generation
  - Cost of the electrification plan, including off-grid systems, grid extension & any required reinforcements *(not in current version)*

What is different about REM?

- REM makes electrification decisions at **individual building** level
- REM can be applied at **large scale** & also at individual **microgrid** level
- REM **optimizes** the **generation** mix of microgrids & the **network** layout of microgrids & grid connections
- REM is a **live product**, supported by the MIT-Comillas team, which can incorporate new features as the need arises
- REM will be made available **free of charge** & will use **license-free** software

In summary

REM supports **large-scale electrification planning** & **local electrification projects** by producing optimal system designs

- Selects the **best electrification mode for each individual customer** (grid, microgrid, isolated)
- Selects technologies and sizes components for electricity **generation** and the distribution **network**
- Produces **detailed** network & generation **designs**
- Produces system **cost** and **performance** estimates
- Allows a diversity of **sensitivity analysis**

There is more than REM in electrification planning

- There may be good reasons to **deviate from the minimum cost electrification plan**
  - Beyond the techno-economic analysis, other factors will have a major impact on the electrification mode to be finally adopted:
    - **Social**, including biases for on/off grid solutions, affordability & access to finance
    - **Political**, including willingness to address access, subsidies to electricity &/or kerosene
    - **Regulatory**, that may make create viable business models for private investors, e.g. net metering
    - **Environmental**, e.g. favoring renewable technologies

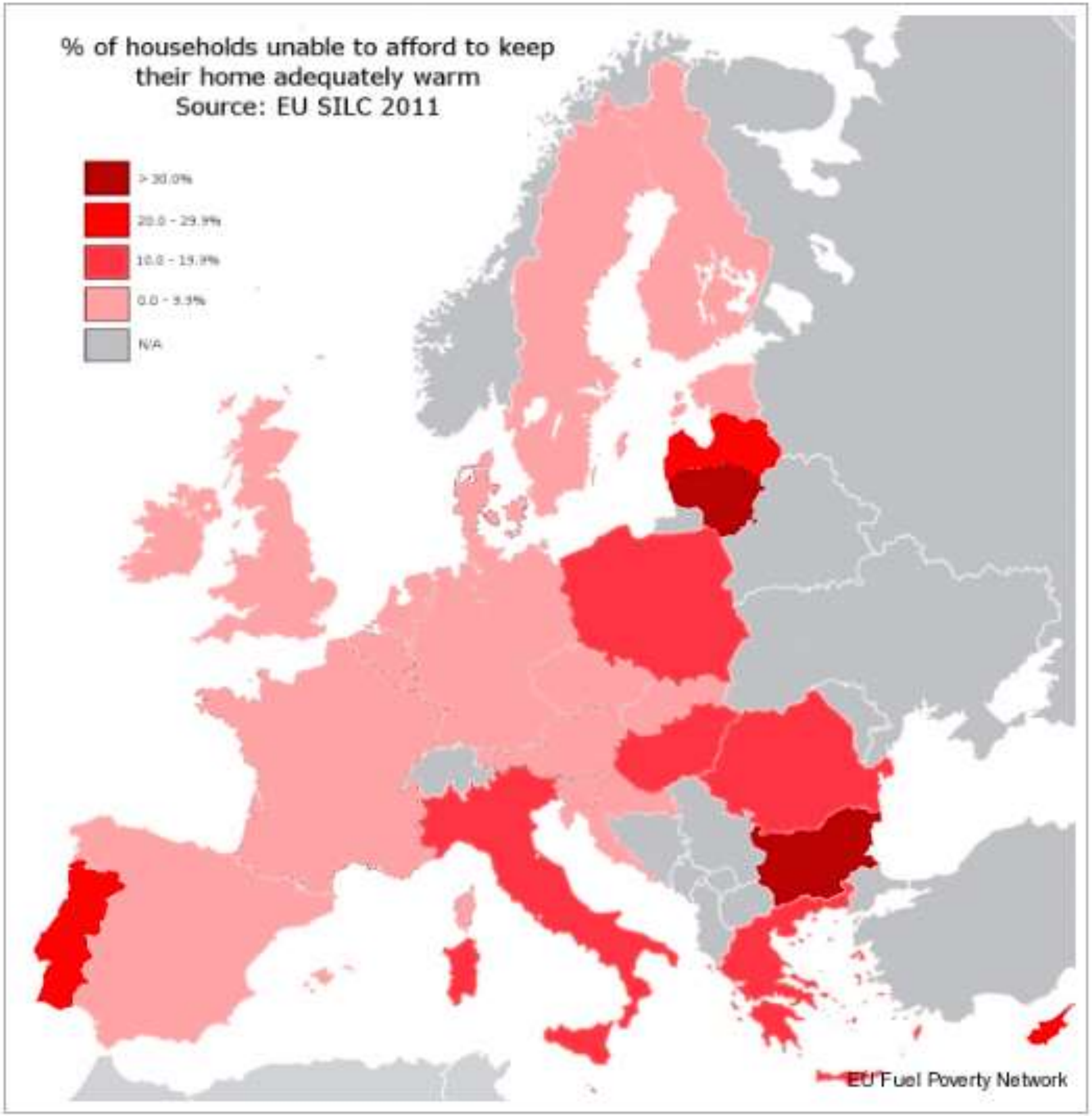
Gracias

Energy poverty

Fuel poverty: A European reality

- Fuel poverty, or energy poverty which is commonly used in EU, can be defined as **the inability of a household to meet their basic energy needs**, such as to maintain the dwelling in adequate thermal conditions for health.
- It is a reality that affects all Member States of the European Union (EU). In 2012 **54 million European citizens** (over 10% of the total population) lived in households that declared to be unable to maintain an adequate temperature at home in the winter.

% of households unable to afford to keep their home adequately warm



Wand, C.R. (2013). Available: http://fuelpoverty.eu.