# Planificación Integrada de la Electrificación Rural

## Seminario de Acceso Universal a la Energía. La Electrificación Rural Aislada

Santa Cruz de la Sierra – Bolivia
8 al 10 de Junio de 2016

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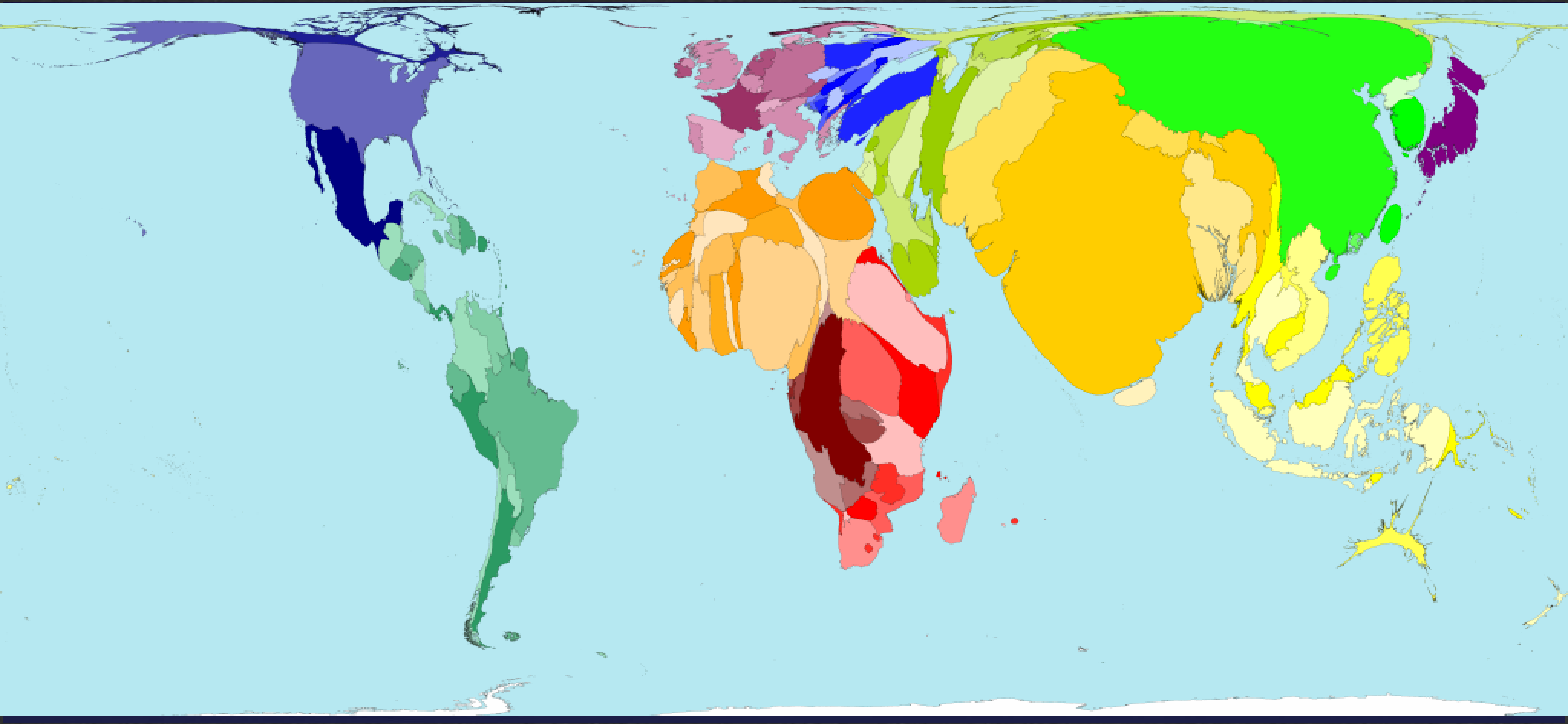
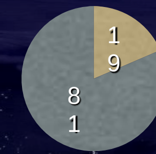
# Access to modern energy services



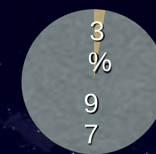
# Access to modern energy services: Facts and figures

- 1.3 billion people lack access in 2011
  - In 2030 this number drops only to 1.2 billion

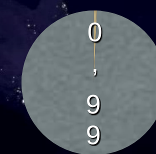



- 2.7 billion people lack access to modern heating in 2011
  - In 2030 this number reaches up to 2.8 billion


- $48 billion per year would provide access for all in 2030
  - $1 trillion is required

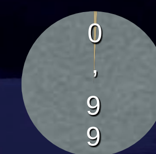



- 0,7% CO2 emissions growth for Universal Access 2030
  - but setting a right path is critical




– Source: WEO 2012

– $37 billion per year spent in 2011
  - on poor-quality energy solutions




– Source: IFC 2012

# Universal Access framework

To this point it is clear that a problem of this magnitude and complexity cannot be seriously approached without a **specific attention by governments**, intervention of **private capital**, the involvement of specialized **companies** and
active participation of the **beneficiary communities.**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# Universal Access framework

Obviously this will only happen if an attractive framework can be defined. This framework must include:

- ❖ The definition of the appropriate **technologies** to be used.
- ❖ The **sources of finance** for this activity.
- ❖ The **sustainable business model(s)** for universal basic services.
- ❖ A universal access **policy** that establishes the goals, resources and mechanisms to be put in motion
- ❖ A **regulation** that clearly defines the rights and obligations of all parties involved and, specifically, the rules of remuneration for the provision of a service.
- ❖ A reference and estable **planning roadmap** for their achievement

# Universal Access activities at IIT-MIT

- Retos del Acceso Universal a la Energía y su impacto en el Cambio Climático. Modelos de ayuda a la decisión. Comillas - UPM (Plan Estatal I+D+i 2015).
- Low-cost energy technologies for Universal Access: business models and enabling environment. Study cases for Kenya and Peru. COMITES* *(ENEL Foundation).*
- Innovative micro-grids for energy access in India. COMITES *(TATA Foundation)*.
- Rural micro-grids for village electrification in Rwanda, with anchor load in the local school. COMITES (*Iberdrola S.A.*)
- Off-grid vs network extension planning in Bihar – India (400 thousand users)
- Off-grid vs. network extension planning for Rwanda (1,5 million users)
- Regulación para la electrificación de Zonas Rurales Aisladas – REGEZRA (por AECID)
- Tecnologías para el desarrollo humano de las comunidades rurales aisladas. Estudio para la Real Academia de Ingeniería *(financiado por la Fundación Endesa)*.
- Members of the Spanish Mesa de Acceso Universal a la Energía**

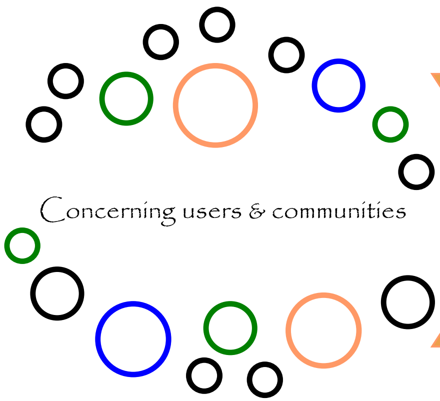
Acceso Universal a la Energía

** COMITES: Comillas – MIT Energy Systems Joint Program*

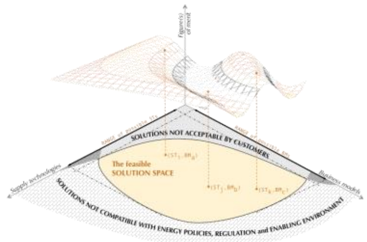
*** Energía Sin Fronteras, Acciona Microenergía, Fundación ICAI para el desarrollo, ONGAWA, Centro de Innovación en Tecnología para el Desarrollo Humano itdUPM*

# A comprehensive view
# Constituent elements for universal access strategies

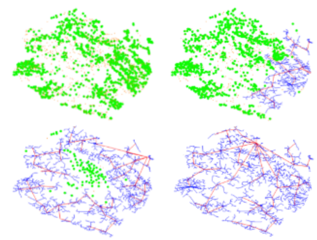
Environmental, Social and Economic context




The challenge
& the solution space



Advanced planning
& tools



Strategic &
comprehensive
decision-making for
Sustainable
Development Goals

Regulatory, Energy Policy and Governance framework



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# What do we mean by “universal access”?

*“access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses [...] needed to improve livelihoods in the poorest countries and drive local economic development”*

Energy for a Sustainable Future (UN AGECC 2010 )

# 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 | >500 | >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 = $\sum(P_T \times T)$

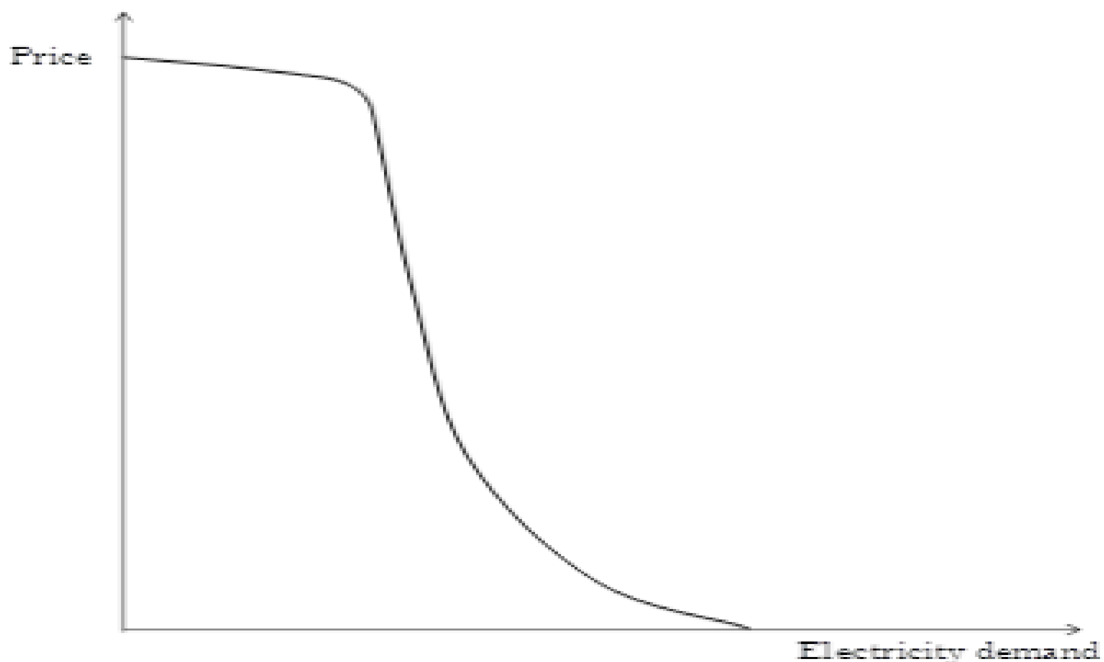
with $P_T$ = Proportion of households at tier T

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

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

# Individual demand-price curve

- Describes the response of demand to price
  - Consumers are willing to pay a high price for the most essential electricity services
  - Then the willingness to pay decreases rapidly



# Energy Access Ladder - Productive uses

| Tier | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Likely energy supply technology resource | Human power | Human power / Animal power | Animal power | Renewable power / Engine | Renewable power / Engine / Electrical power | Electrical power |
| Possible energy technologies for key livelihood activities | | | | | | |
| Water pumping | Bucket | Treadle pump | Hydraulic ram pump | Water-current turbine | Solar PV water pump, motorised pump | High power electric pump |
| Agro-processing | Hand pounding | Animal powered mill | Traditional water mill | Improved water mill | Diesel-powered mill | High power electric mill |
| Small-scale manufacturing | Hand tools | Treadle tools | N/A | Mechanical lathe | Engine-powered circular saw | Electric saw |

Source: Practical Action. Poor People's Energy Outlook - 2013

# Energy Access Ladder - Community: Health

| Tier | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Attributes of energy accessed | Continuous spectrum of improving energy supply attributes including adequacy, availability, reliability | | | | | |
| *Basic energy services*<br>Feasible energy applications (indicative) | Lighting | Limited task lighting + mobile phone + radio | Tier 1 + limited general lighting + air circulation + VHF radio cooking | Tier 2 + multiple lighting + air cooling + refrigeration + computer w/ internet + TV | Tier 3 + air cooling/ heating | All applications are feasible |
| *Medical equipment* | None | None | Vaccine refrigeration<br>Sterilization | Low power medical appliances: microscope, testing equipment etc.<br>Incineration | Tier 3 + high power equipment: x-ray machines, ultrasound scanners etc. | All applications are feasible |
| Likely energy supply technology (indicative) | Kerosene lamps<br>Candles | Third-party charging<br>Improved cookstoves | Small stand-alone solar PV<br>Kerosene/gas refrigerator<br>Solar autoclave<br>Institutional cookstoves | Mini-grid connection (Tiers 3–4)<br>Grid connection: Unreliable<br>Incinerator | Grid connection: Unreliable + backup | Grid connection: Reliable |

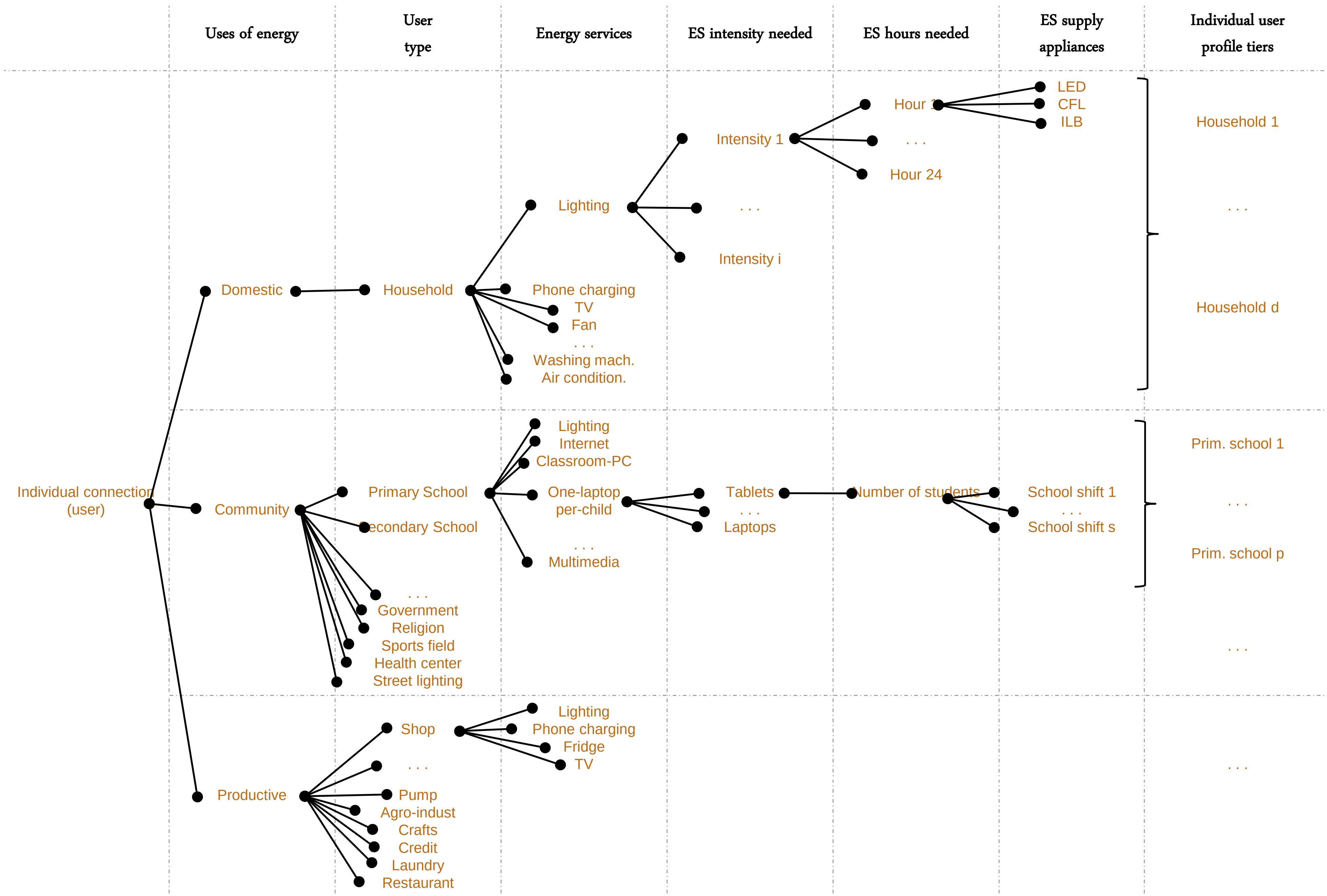
Source: Practical Action. Poor People's Energy Outlook - 2013

# Energy Access Ladder - Community: Education

| Tier | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Attributes of electricity accessed | **Continuous spectrum of improving energy supply attributes** including adequacy, availability, reliability | | | | | |
| *Basic energy services* / Feasible energy applications (indicative) | Lighting | Limited task lighting + mobile phone + radio<br>cooking | Tier 1 + limited general lighting + air circulation + VHF radio<br>cooking<br>space heating | Tier 2 + multiple lighting + air cooling + refrigeration + | Tier 3 + air cooling/ heating | All applications are feasible |
| *Teaching equipment* | None | None | Limited computer use | Projector + Laboratory equipment + Multiple computers w/internet | Tier 3 | All applications are feasible |
| Likely energy supply technology (indicative) | Kerosene lamps<br>Candles | Third-party charging<br>Improved cookstoves | Small stand-alone solar PV<br>Kerosene/gas refrigerator<br>Institutional cookstoves<br>Biomass heater | Mini-grid connection<br>Grid connection: Unreliable<br>Incinerator | Mini-grid connection<br>Grid connection: Unreliable + backup | Grid connection: Reliable |

Source: Practical Action. Poor People's Energy Outlook - 2013

# Individual Customer Energy Service Ladder



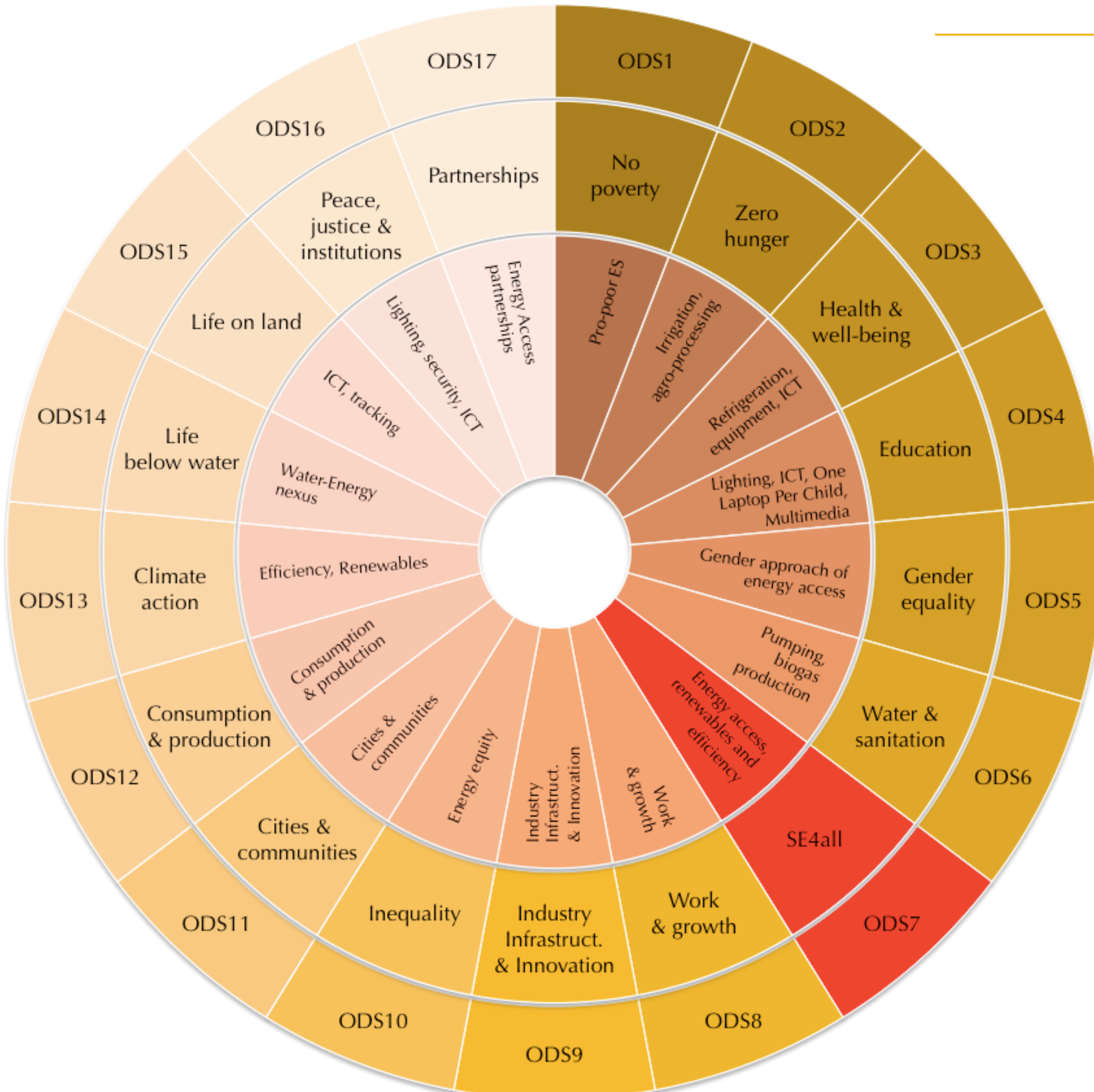
# Nivel adecuado de Acceso a la Energía

- ***Iluminación***: *300 lux durante un mínimo de 4 horas nocturnas.*
- ***Dispositivos electrónicos***: *Comunicación, educación einformación.*
- ***Conservación de alimentos***: *Prolongar la vida de los alimentos perecederos al menos un 50% más de lo que perdurarían en las condiciones ambiente.*
- *Además el suministro de electricidad debe ser:*
  - ***Fiable***: *estabilidad y conocimiento de las horas de servicio está disponible y además coinciden con las que se requieren para su uso.*
  - *De **calidad** y **seguro**: tensión (+/- 10%).*
  - *Conforme a las **necesidades esenciales y capacidades de cada comunidad** de usuarios, definidas **de forma participativa**.*
  - *Con un **coste asumible** por los usuarios, adecuado a su nivel de ingresos y que no impida el disfrute de otros derechos y necesidades, lo que puede requerir la existencia de subsidios para garantizar el nivel adecuado de servicio.*
  - ***Sostenible***, *desde el punto de vista económico, social y medio ambiental,*

# Nivel natural de Acceso a la Energía

- **Replica el nivel de consumo de otras comunidades** de **similares** características en cuanto a necesidades, capacidades e ingresos, y que ya estén electrificadas.
  - Con una **curva de demanda basada en evidencias** (agregada o de forma individual) y una expectativa de **consumo y crecimiento** equiparables.
  - Con datos contrastables de **utilización de servicios energéticos**.
  - Con un **esquema tarifario similar**, ya sea en cuanto a la extensión de red o fuera de red (principio de equidad)
  - Que permita la **sostenibilidad a largo plazo** del modelo de suministro, teniendo en cuenta la disponibilidad de **subsidios adecuados**.

# Energy for Sustainable Development



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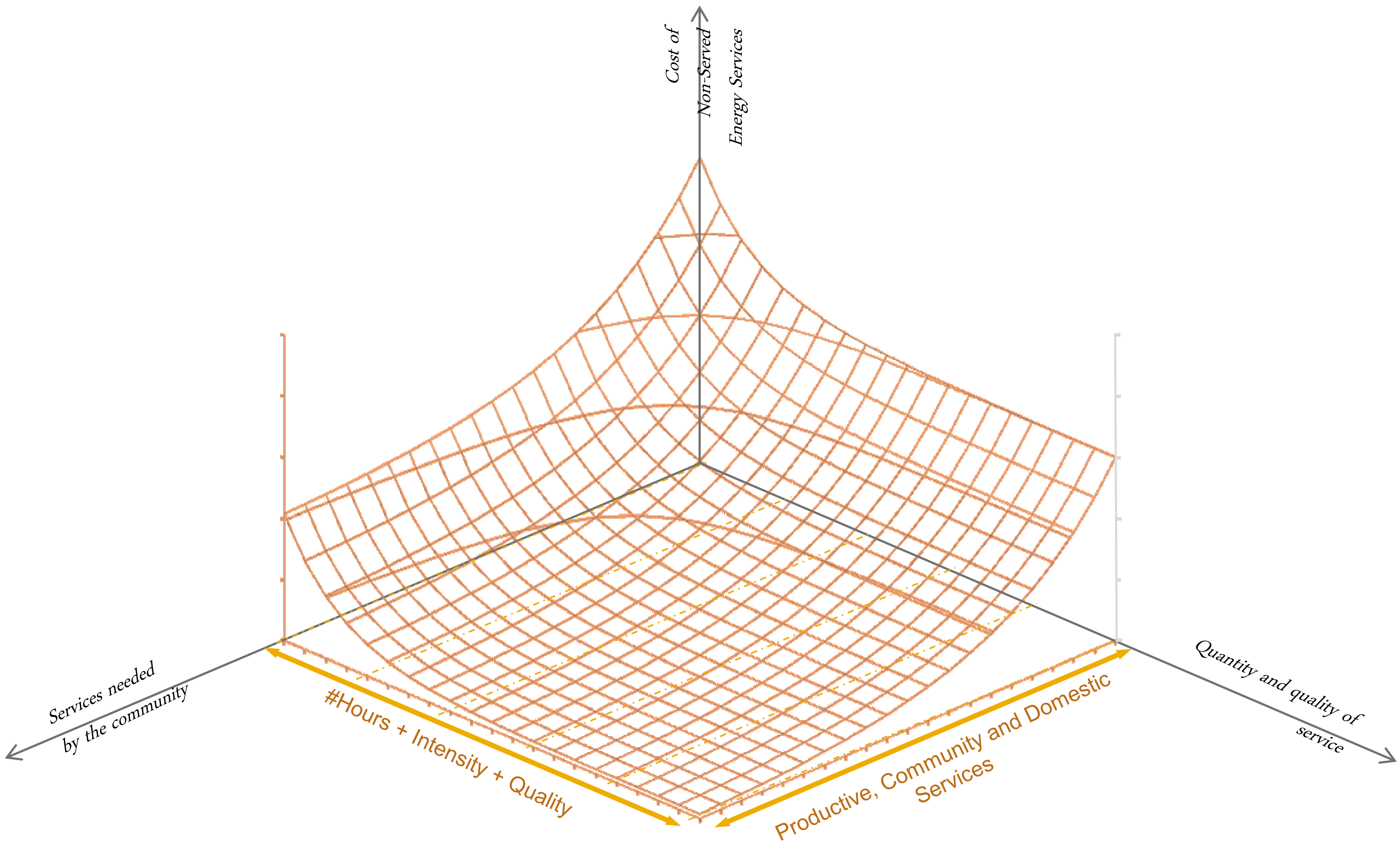
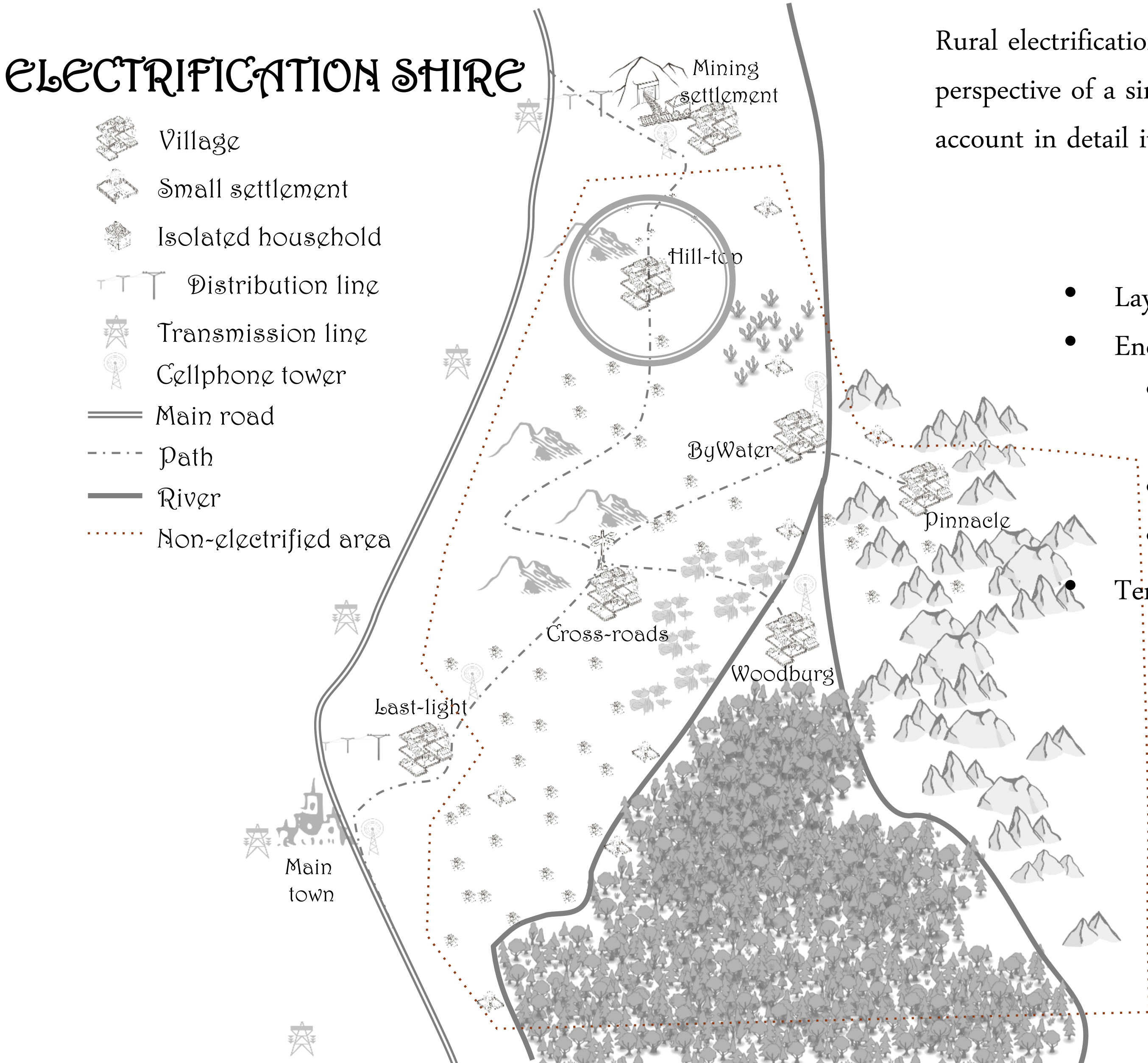
# A communitarian approach to the lack of energy cost



# Comprehensive perspective for collective planning



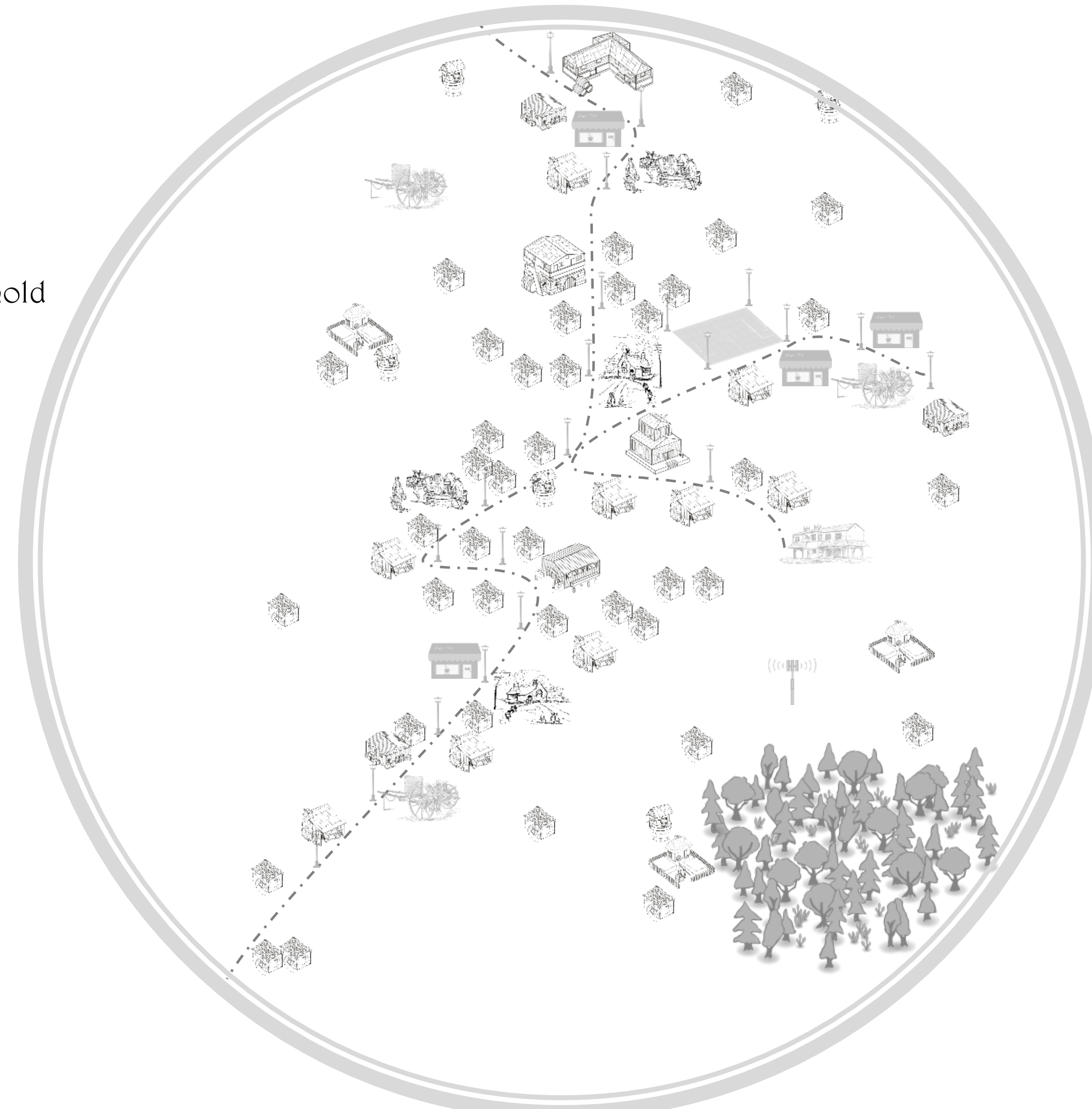

Rural electrification planning requires and holistic perspective of a singular area (Shire), taking into account in detail its characteristics regarding:

- Layout and diversity of customers
- Energy resources
  - Location of existing or planned distribution grid
  - Renewable energy sources
  - Logistics&price of diesel
- Terrain characteristics

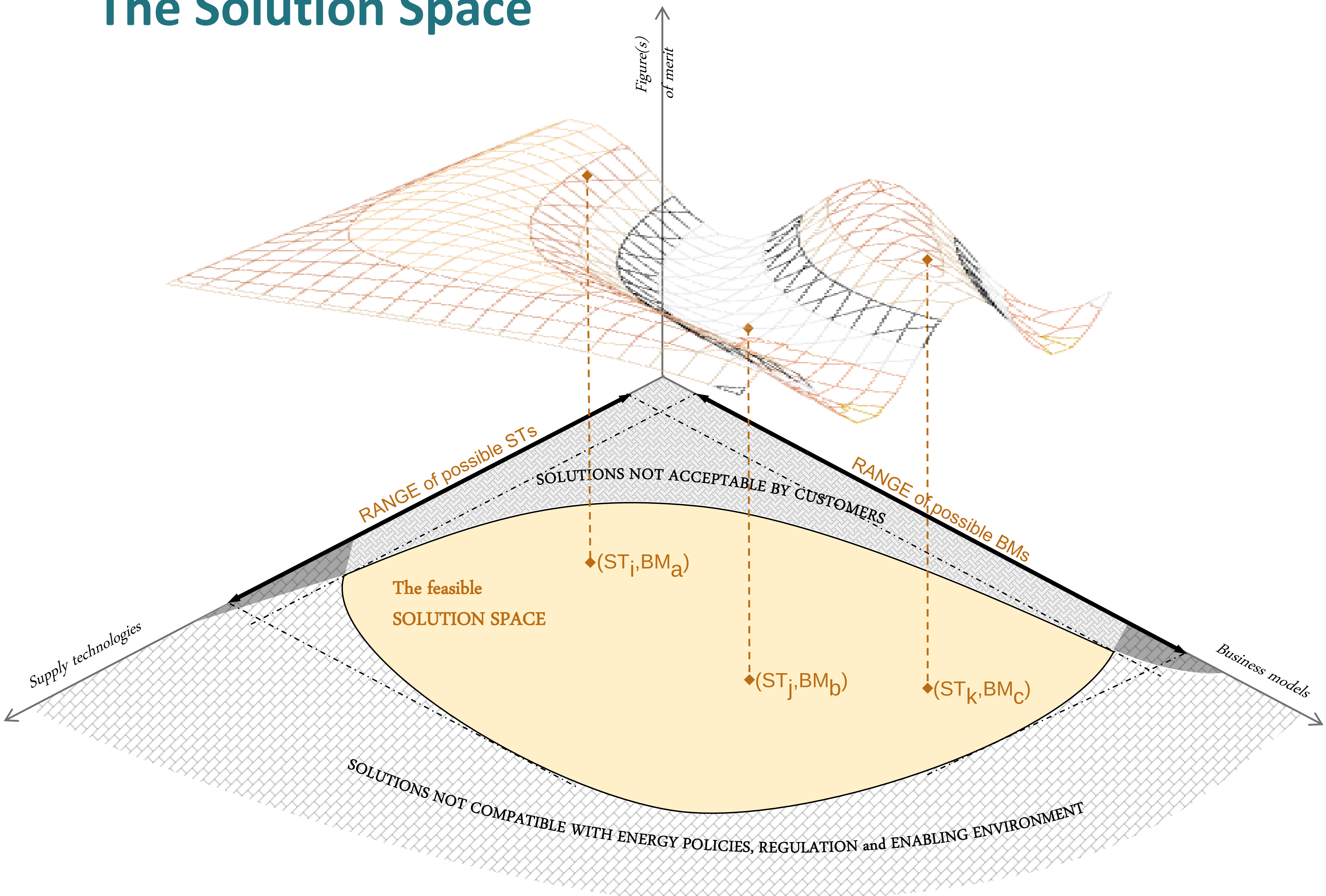
# Detailed design for each customer according to its needs

## Hill-top community

- Low-income household
- Average-income household
- High-income household
- Farm
- Primary school
- Secondary school
- Health center
- Village hall
- Store house
- Shop
- Microcredit cooperative
- Agroindustry
- Productive activity
- Sports field
- Water pump
- Telecom tower
- Street light



# The Solution Space



# Ingredients of a plausible solution
# Grid connection vs off-grid

- **Grid connection** has been the obvious & preferred option since
  - Economies of scale reduce costs
  - Theoretically offers good 24x7 reliability level

However

- Distribution network costs may become **very expensive** in rural isolated areas with low consumption
- Grid connection loses value if it is **unreliable & random** or if it is uncertain when connection will actually happen
- Then, **off-grid technologies** are preferable in these cases, either as a **bridge** to grid connection or as a **permanent** solution

# Ingredients of a plausible solution
# A mix, perhaps? Options

- Let's target the official statement that **all households should be electrified by 2030**
- How to address this problem?
  A. Wait until **DISCOM extends the grid** to every household
  B. Leave **entrepreneurs to engage bilaterally** with villagers to agree on unregulated off-grid solutions
  C. Attract **private investors into building & managing** off-grid *(grid connection seems unlikely)* solutions that are **compatible** with eventual future grid connection

Any /all of them?

# The Iron Law of Rural Electrification Planning

## "Rural electrification needs subsidies"

- This applies to every electrification project, present & past, in developed & developing countries
  - The exception are those projects whose only purpose is to meet the most basic electrification needs with the cheapest available technology

# Computer-aided rural electrification planning

How can **computer models** *(within a comprehensive approach that also considers other relevant factors)* **for rural electrification planning** *(the research work that MIT-IIT do, sponsored by the Tata Trusts, Enel and Iberdrola)* make a positive contribution?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# The approach

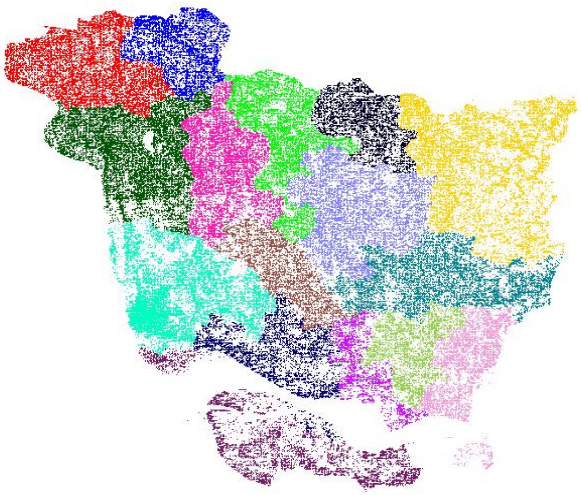
1
- **Data gathering & processing** of raw spatial information to obtain attributes of households & regions in a study area
  *Combine information on location, resources, demand & demographics*

2
- **Reference Electrification Model (REM)** determines an electrification mode for each household. *Optimal choice of electrification mode and design of corresponding generation technologies and network layout*

3
- **MASTER4all model allows large-scale energy system decision making**
  Optimal allocation of resources to provide energy access, subject to budgetary & other constraints, for the whole energy system

4
- **Comprehensive methodology**. Business models, socio-cultural factors, willingness to pay and affordability, governance, regulation and stakeholders ecosystem.

# 1 Identify groups of households to model separately



Satellite images → Identify households → Group by blocks



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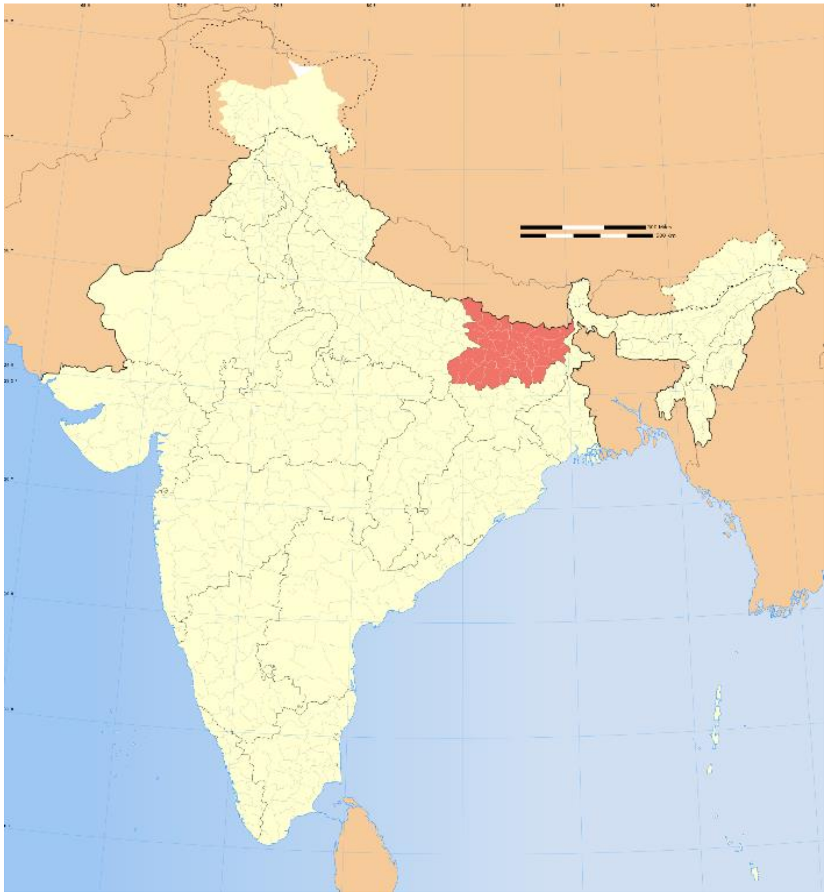
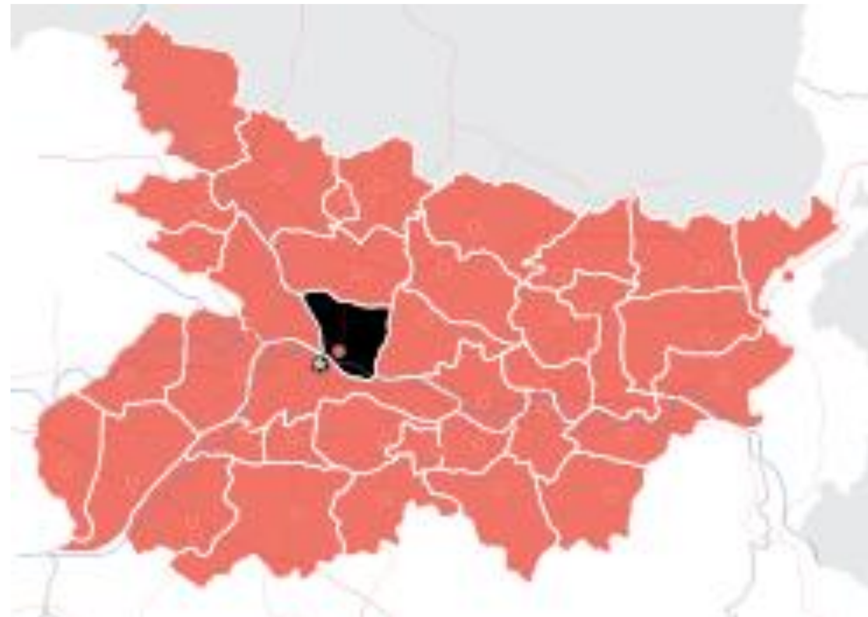
2

# REM
# A first pass of its capabilities

# REM supports large-scale electrification planning…





**District of Vaishali (Bihar)**
**About 400,000 households**



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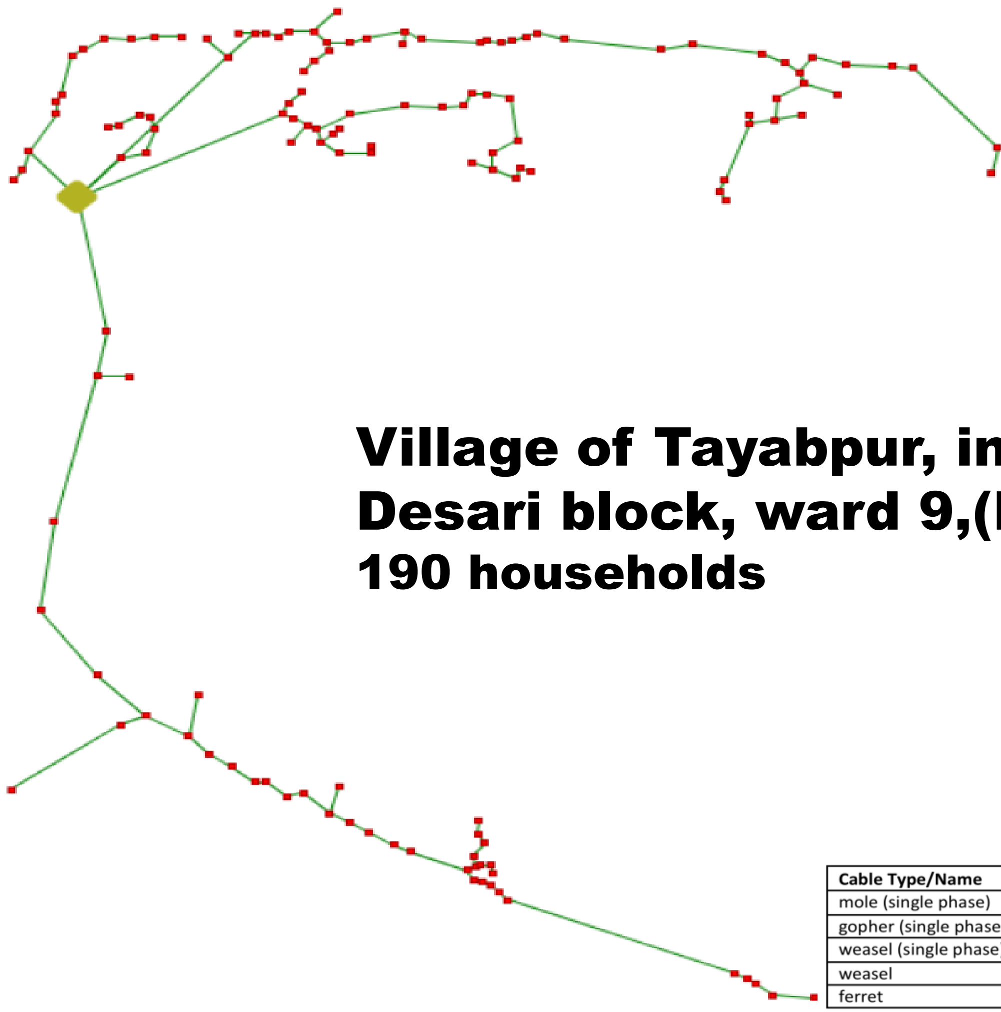
# … as well as local electrification projects…



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

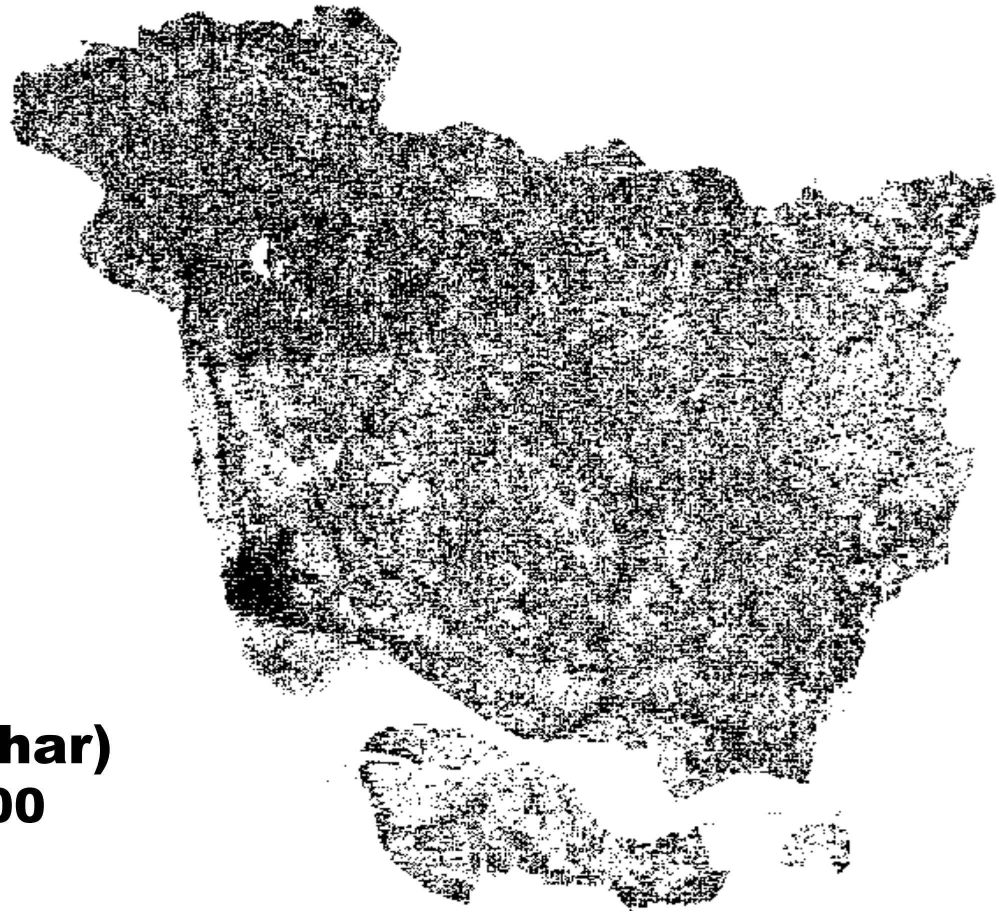
Generation Site

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 400,000 households**



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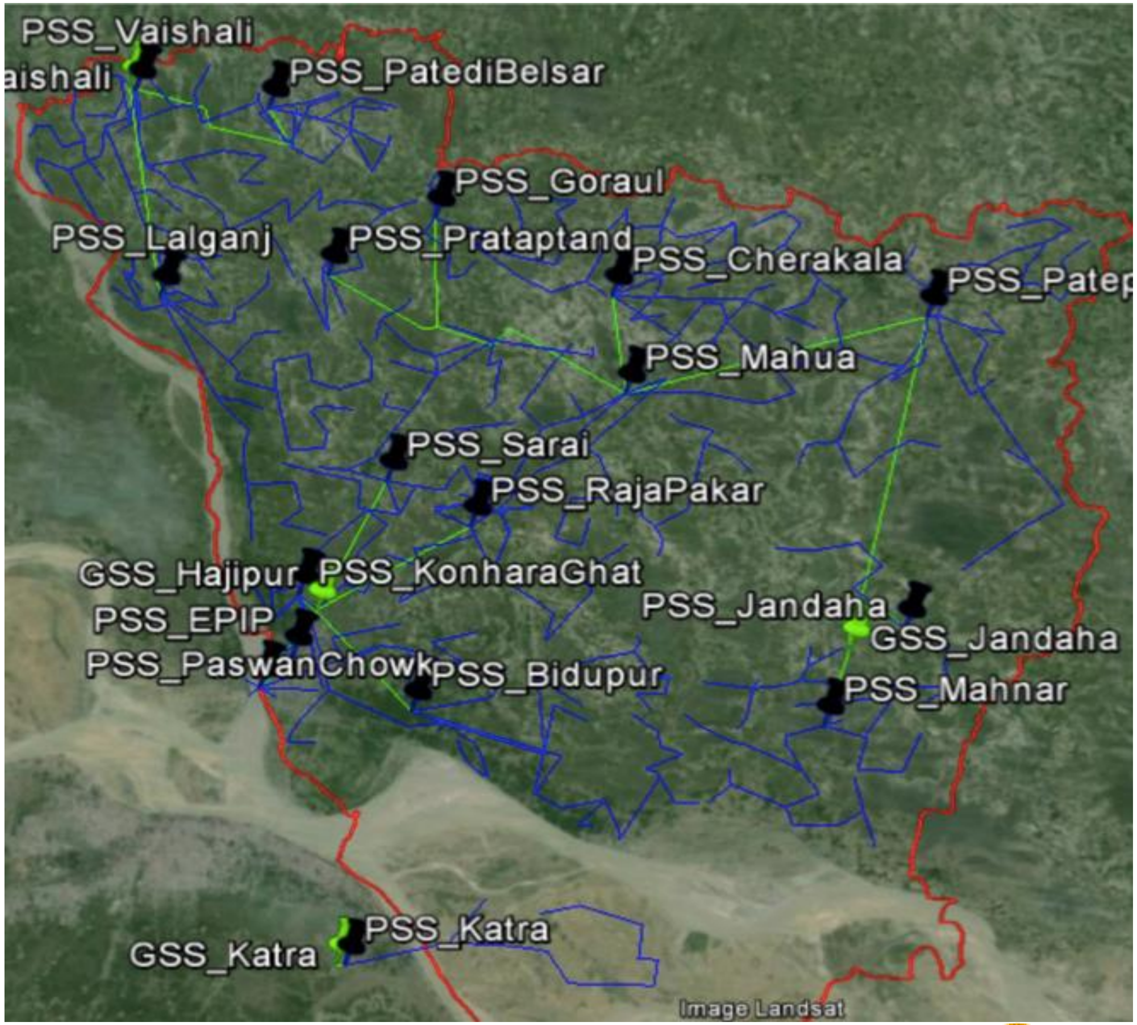
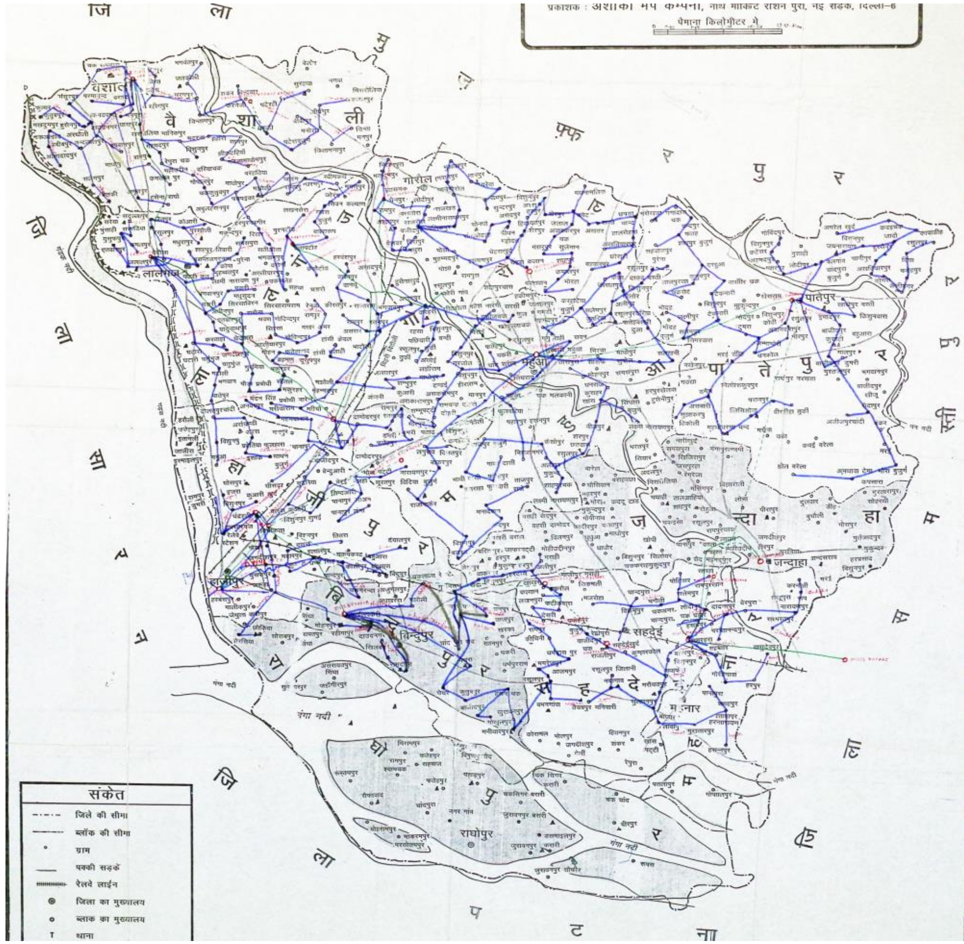
# … & the location & characteristics of the existing network…



# … & the location & characteristics of the existing network…



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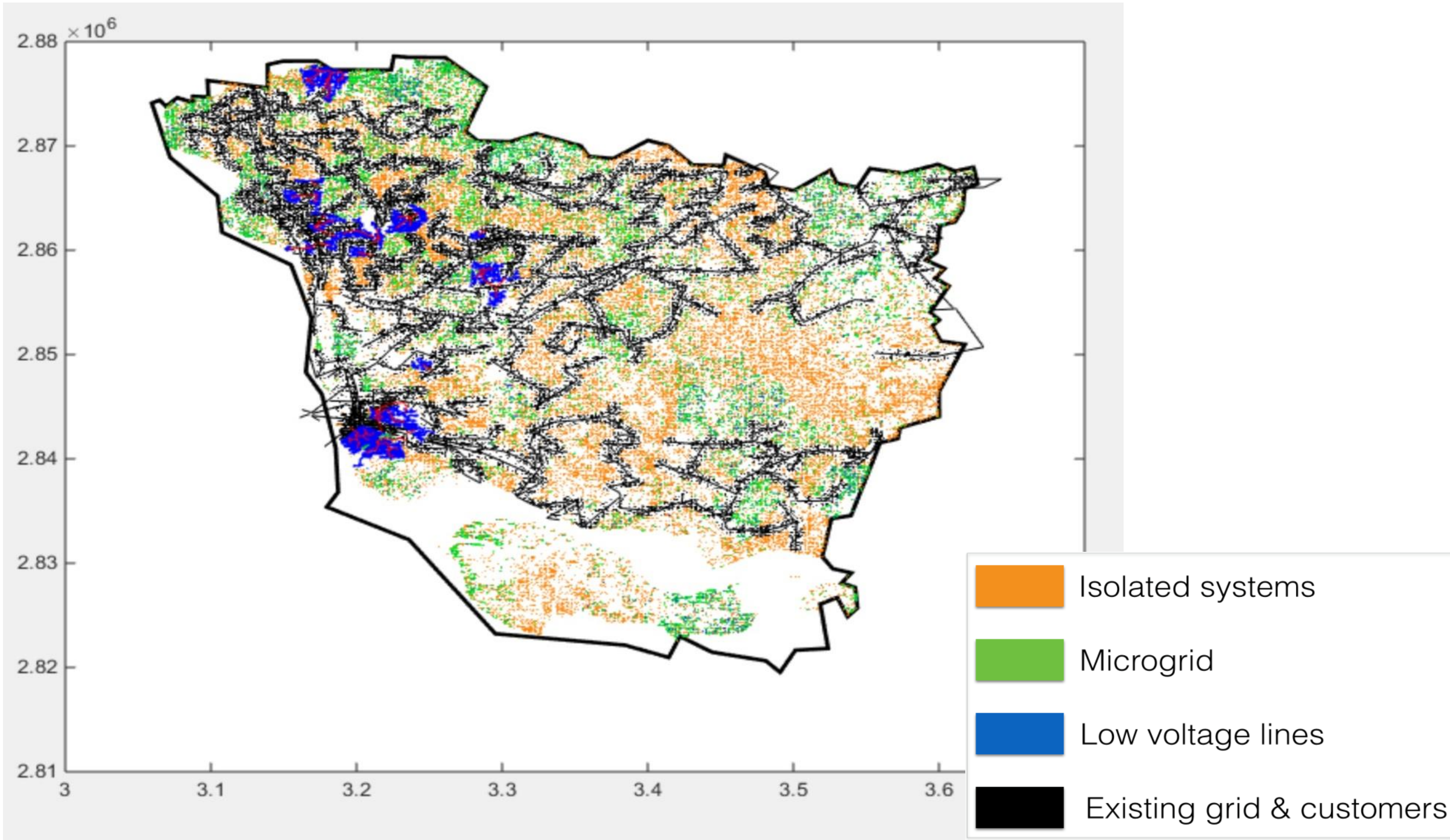
# … & selects the best electrification mode *(grid connection, microgrid or stand alone)* for each customer…



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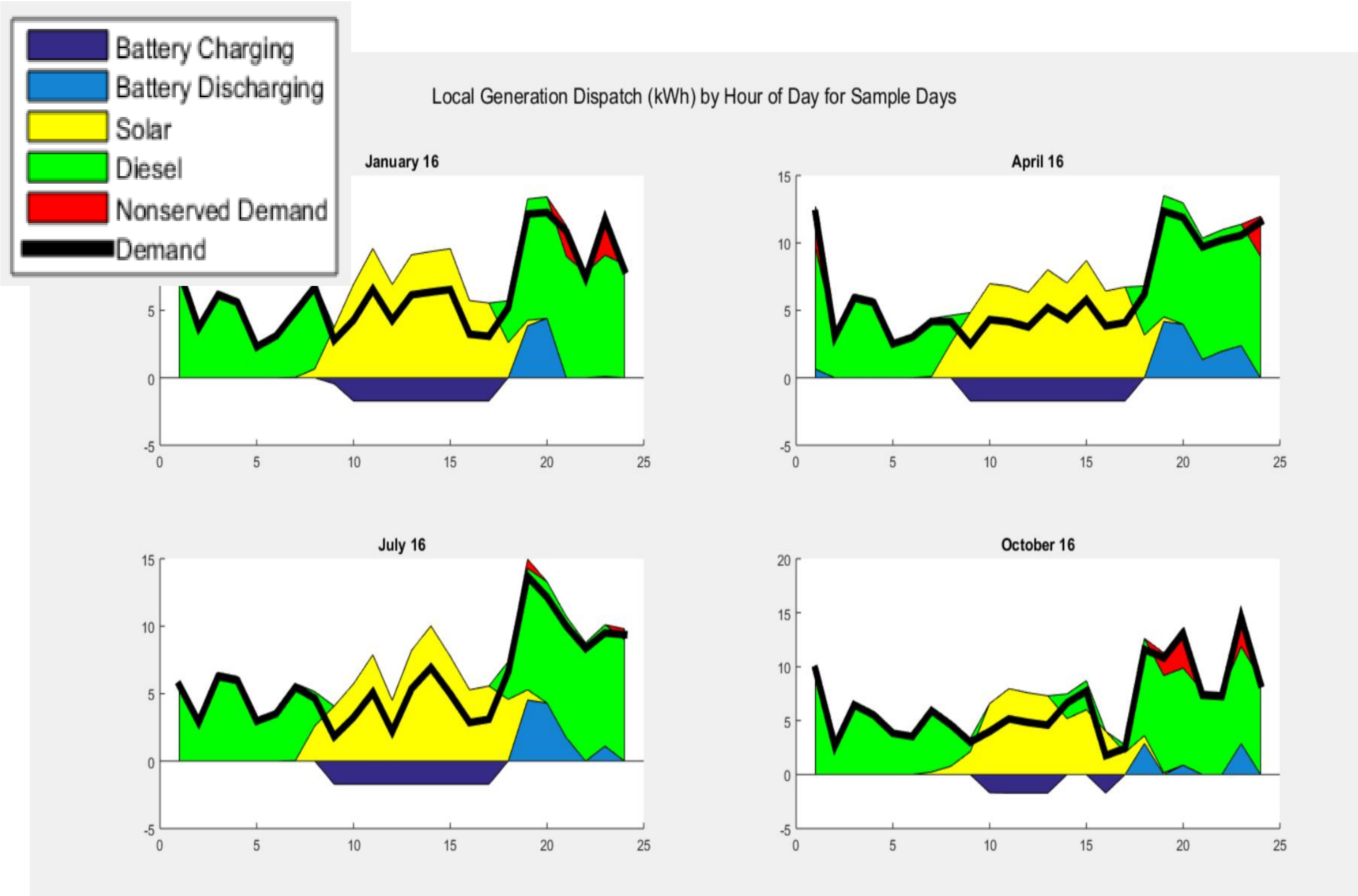
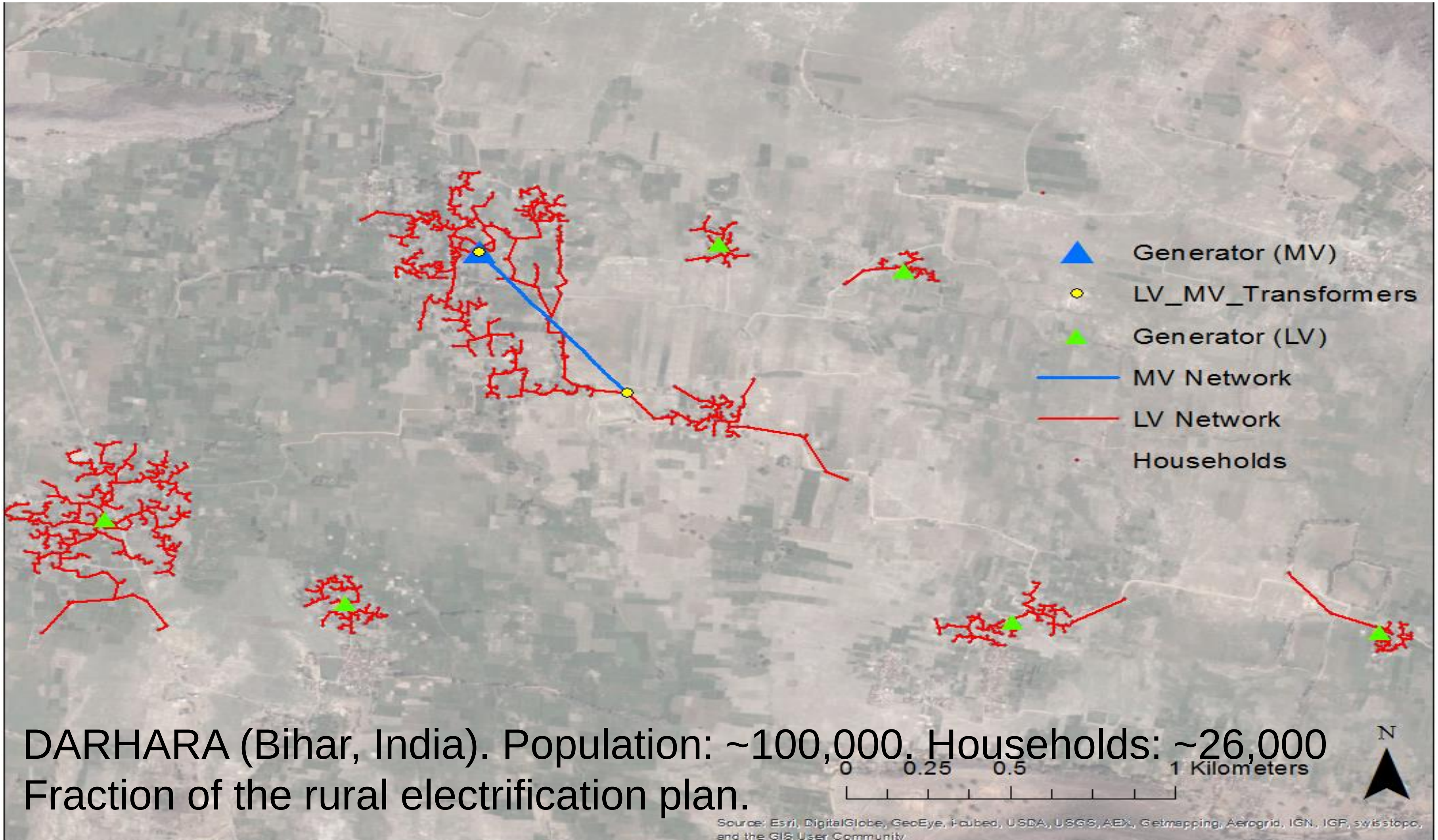
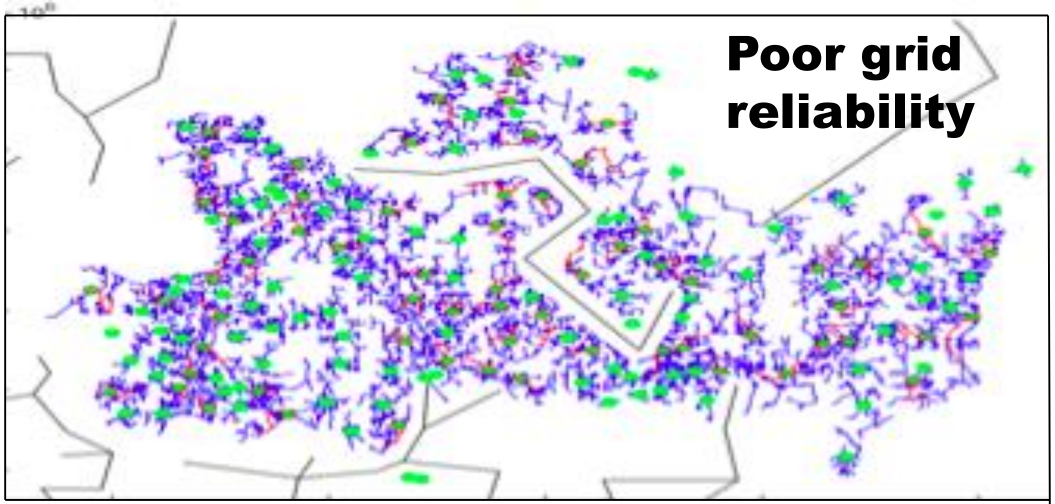
# …optimizing the mix of generation & storage…

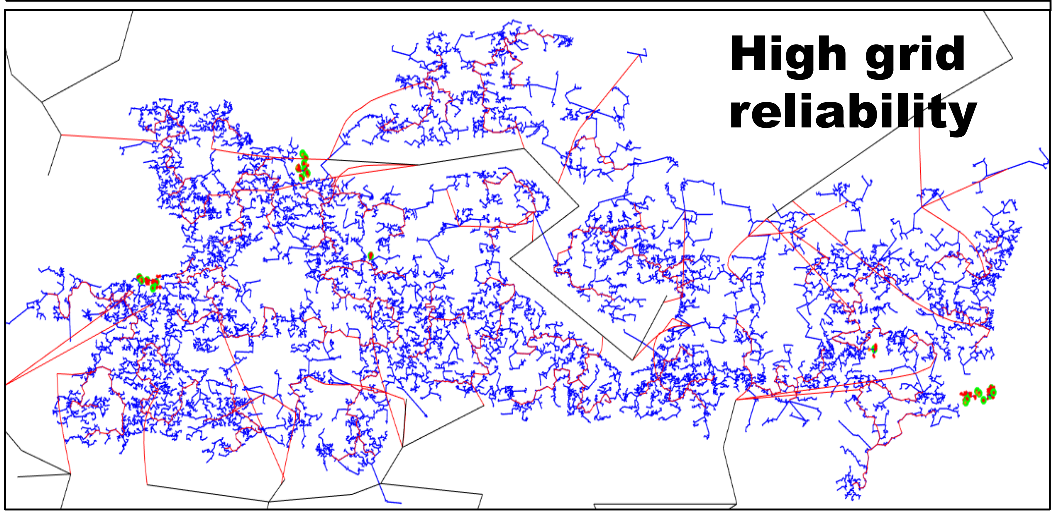


# … & the network layout



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




REM results for the region of Jandaha, in the district of Vaishali (Bihar, India)

Isolated system
Microgrid Customer
Microgrid generation
Low voltage lines
Medium voltage lines
Existing grid lines



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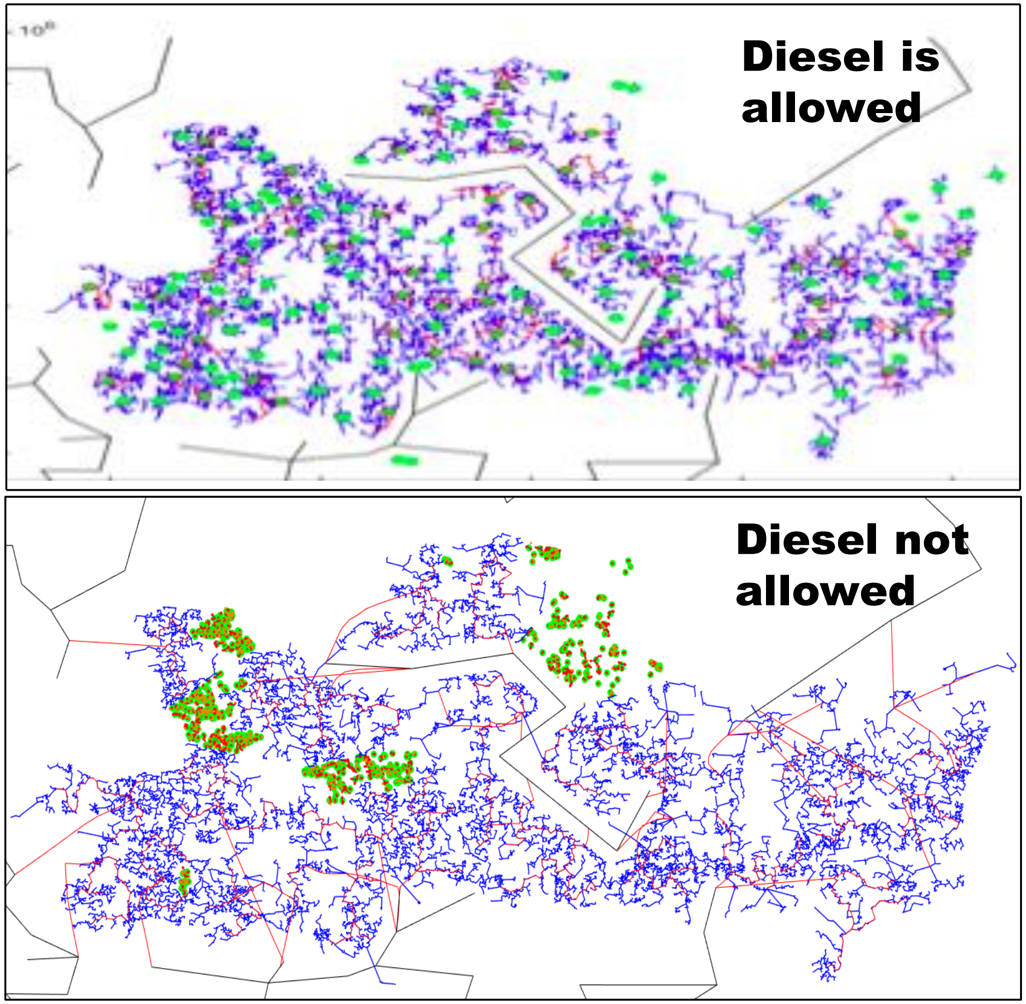
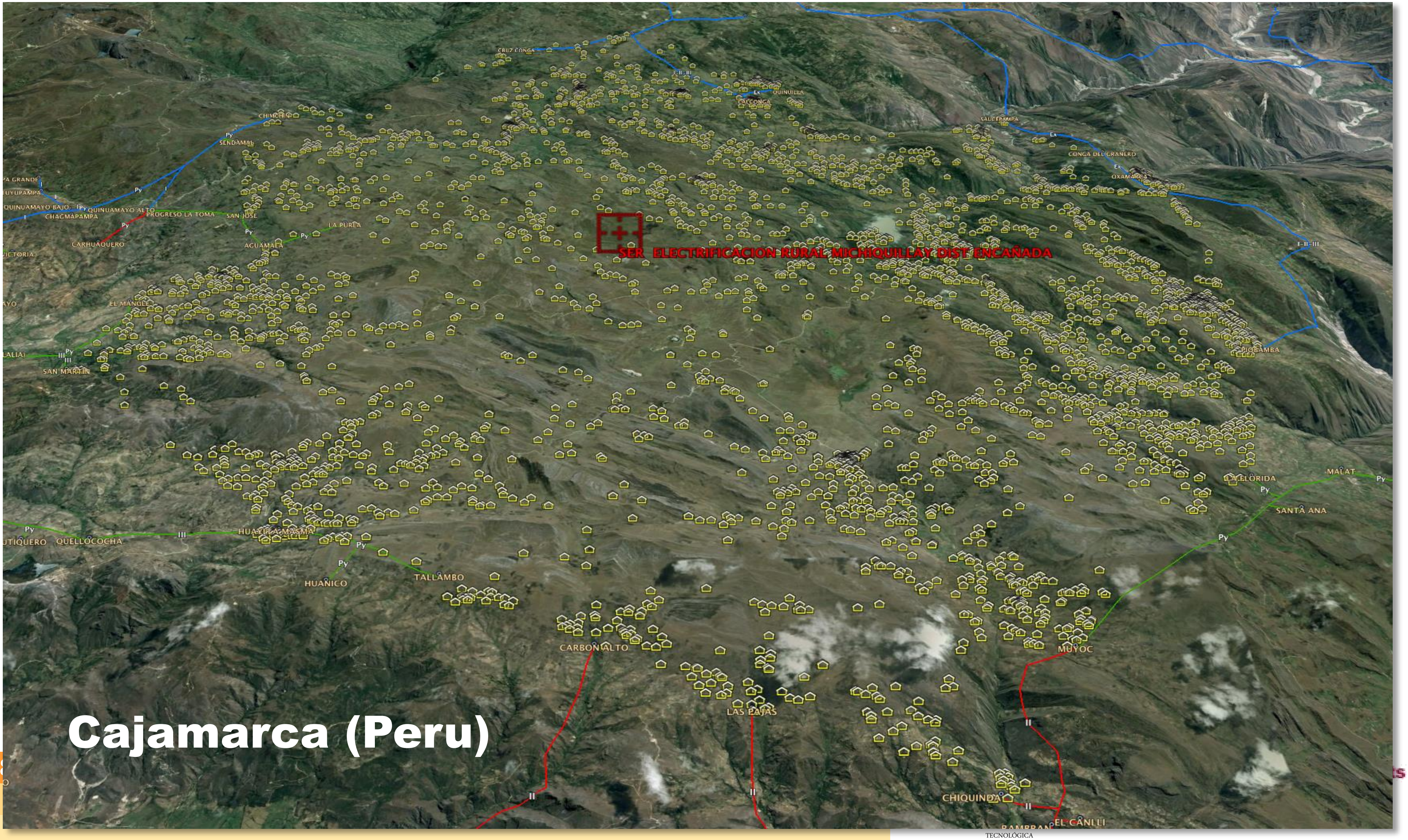
# … as well as to the available generation options *(diesel allowed or not)* …



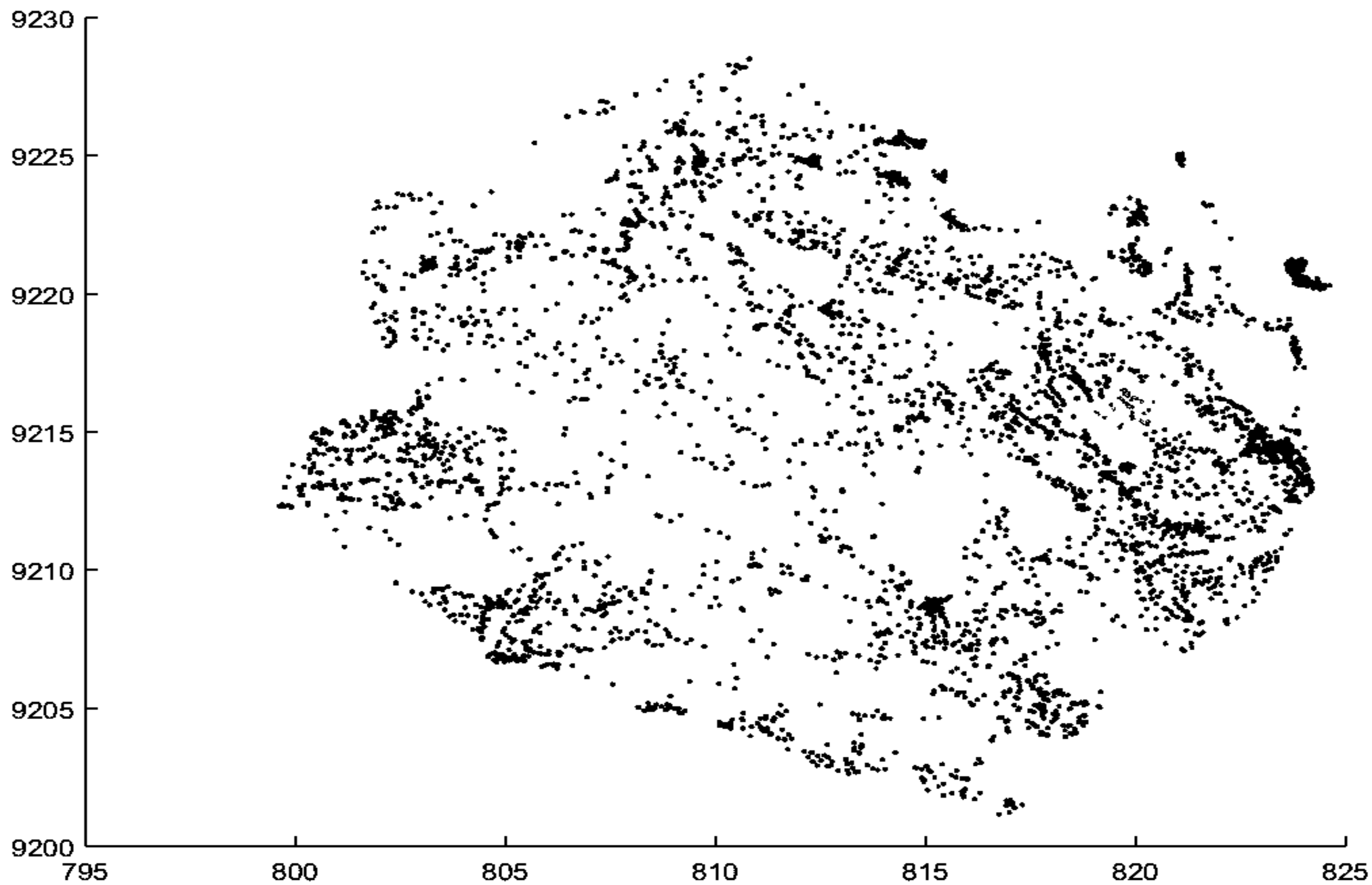

- Microgrids need some diesel to have sufficient reliability
- Without diesel, grid connection dominates except:
  - Far from the existing grid
  - Where consumers are highly dispersed

Isolated system
Microgrid Customer
Microgrid generation
Low voltage lines
Medium voltage lines
Existing grid lines

# … & to the demand level …



# Cajamarca *(Peru)*
# Location of buildings



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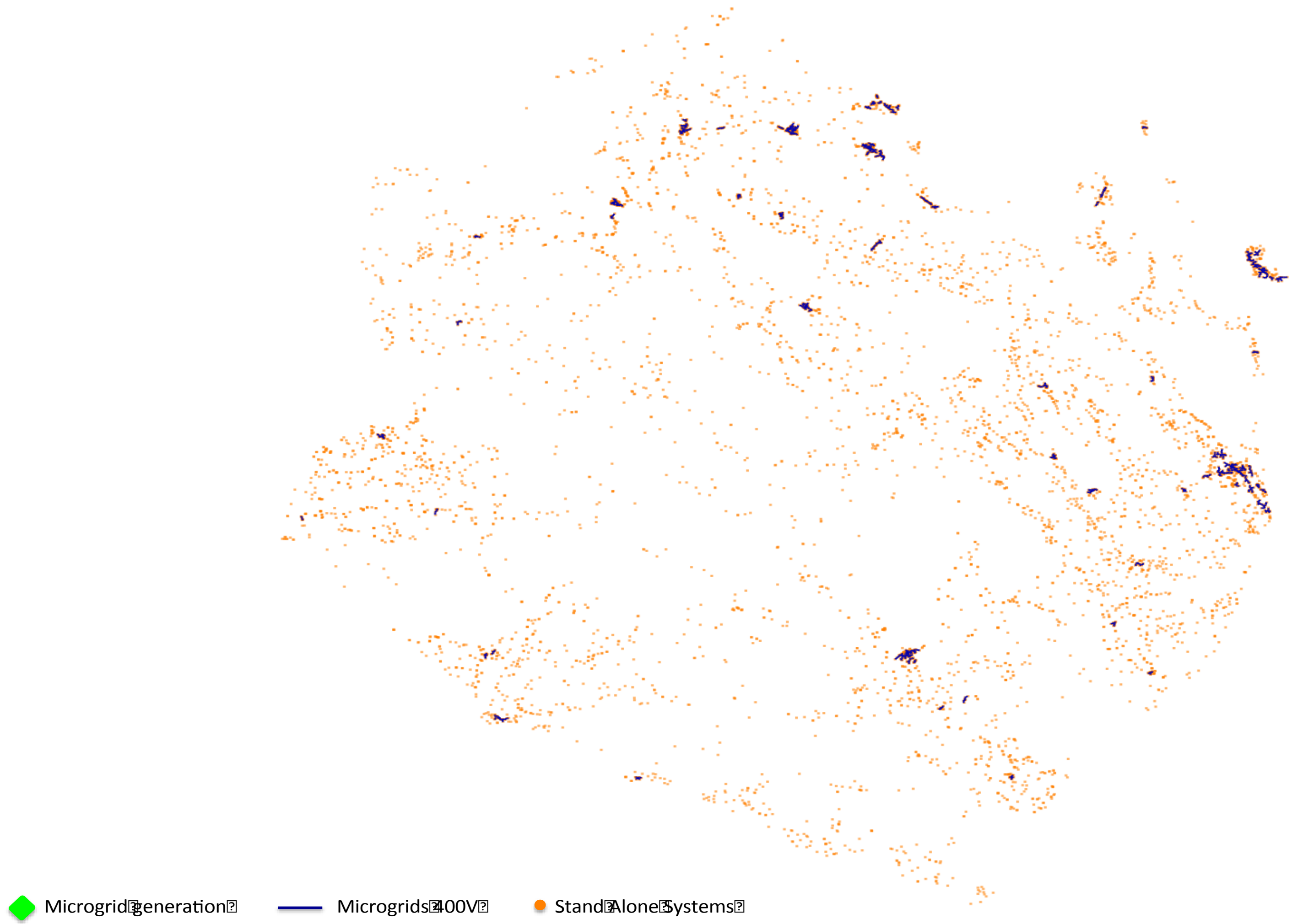
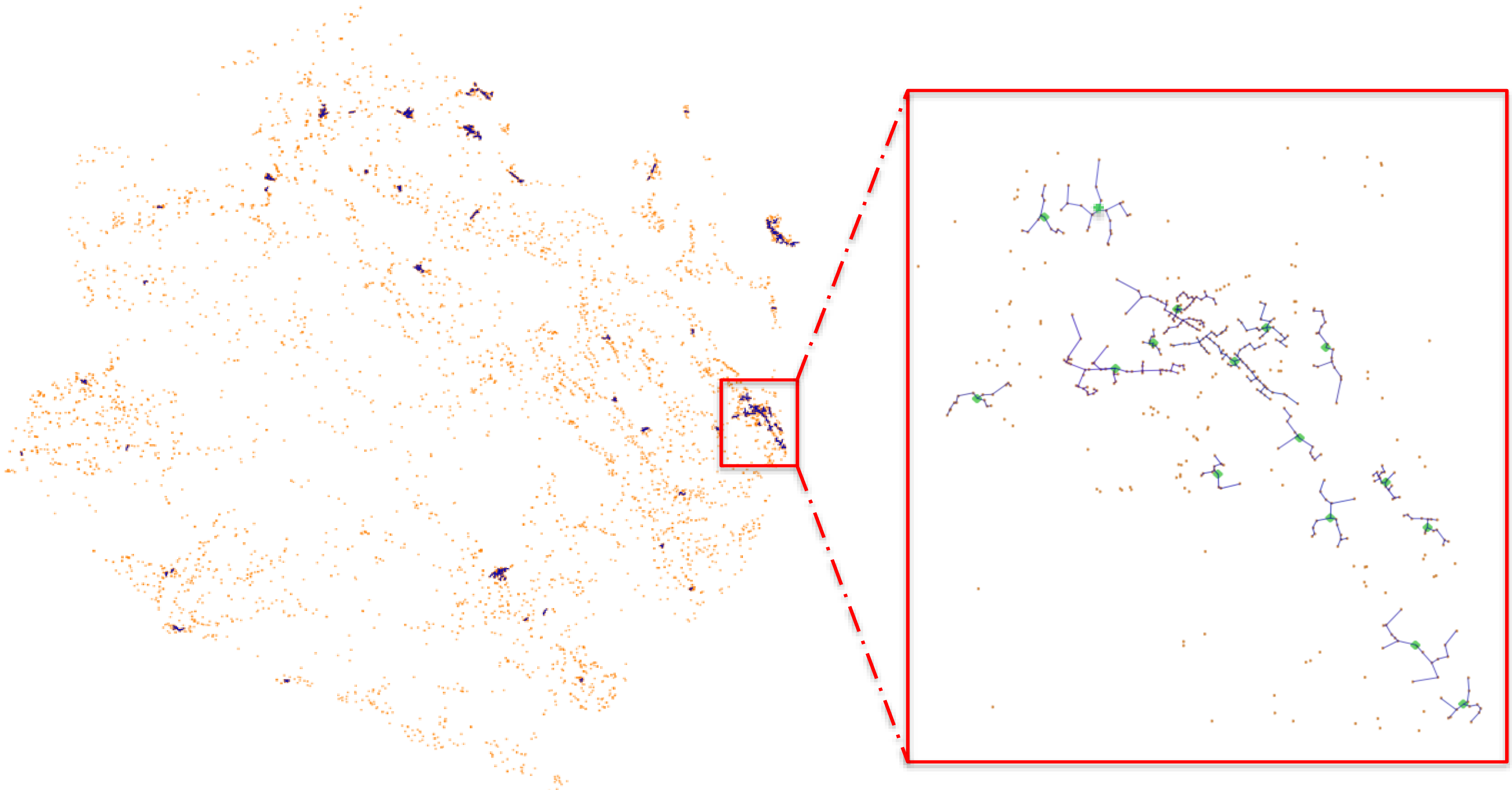
# Cajamarca *(Peru)*

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



# Cajamarca *(Peru)*
# Base case *(detail of network layout)*

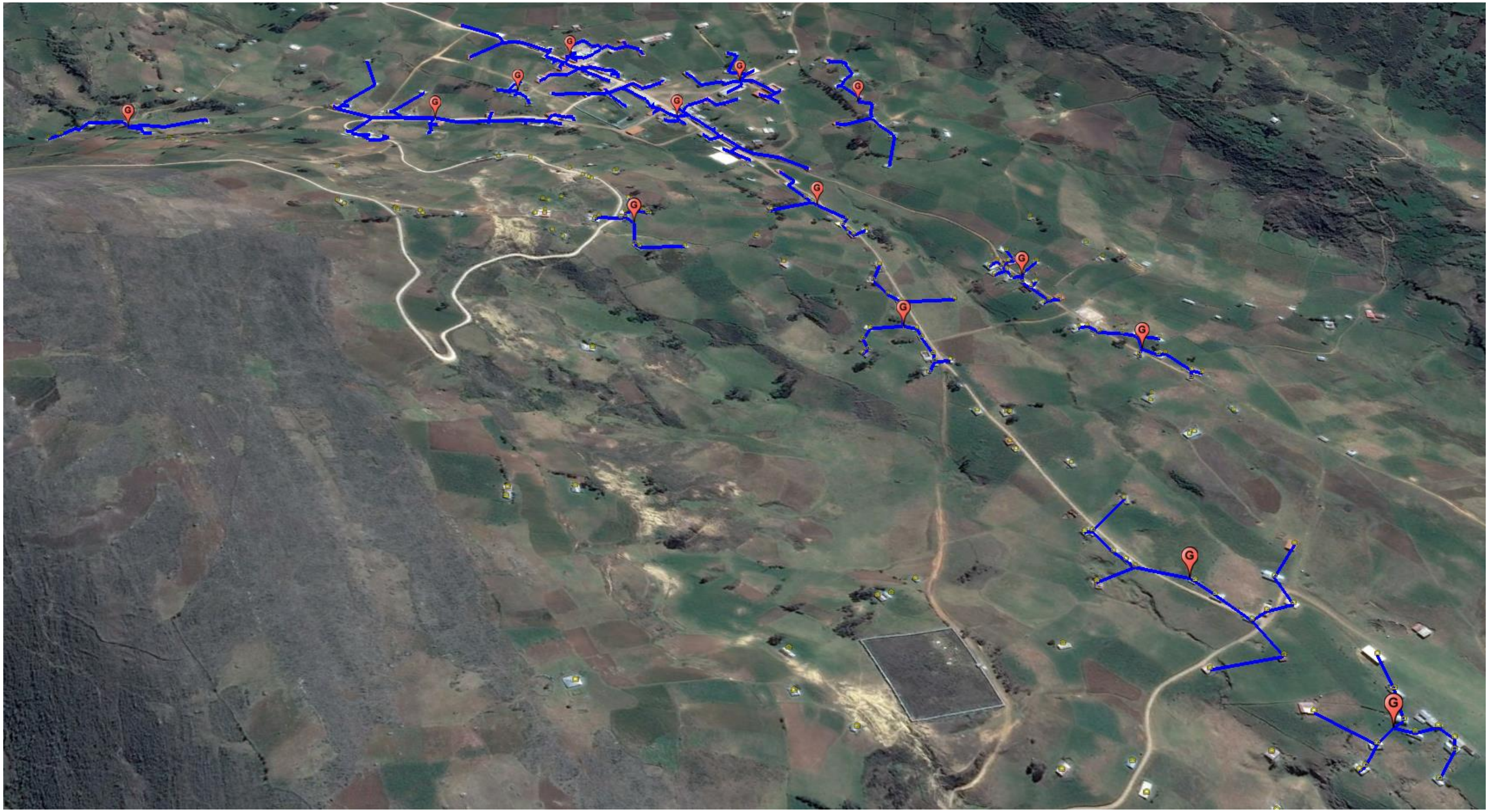




Microgrid generation — Microgrids 400V — Stand Alone Systems

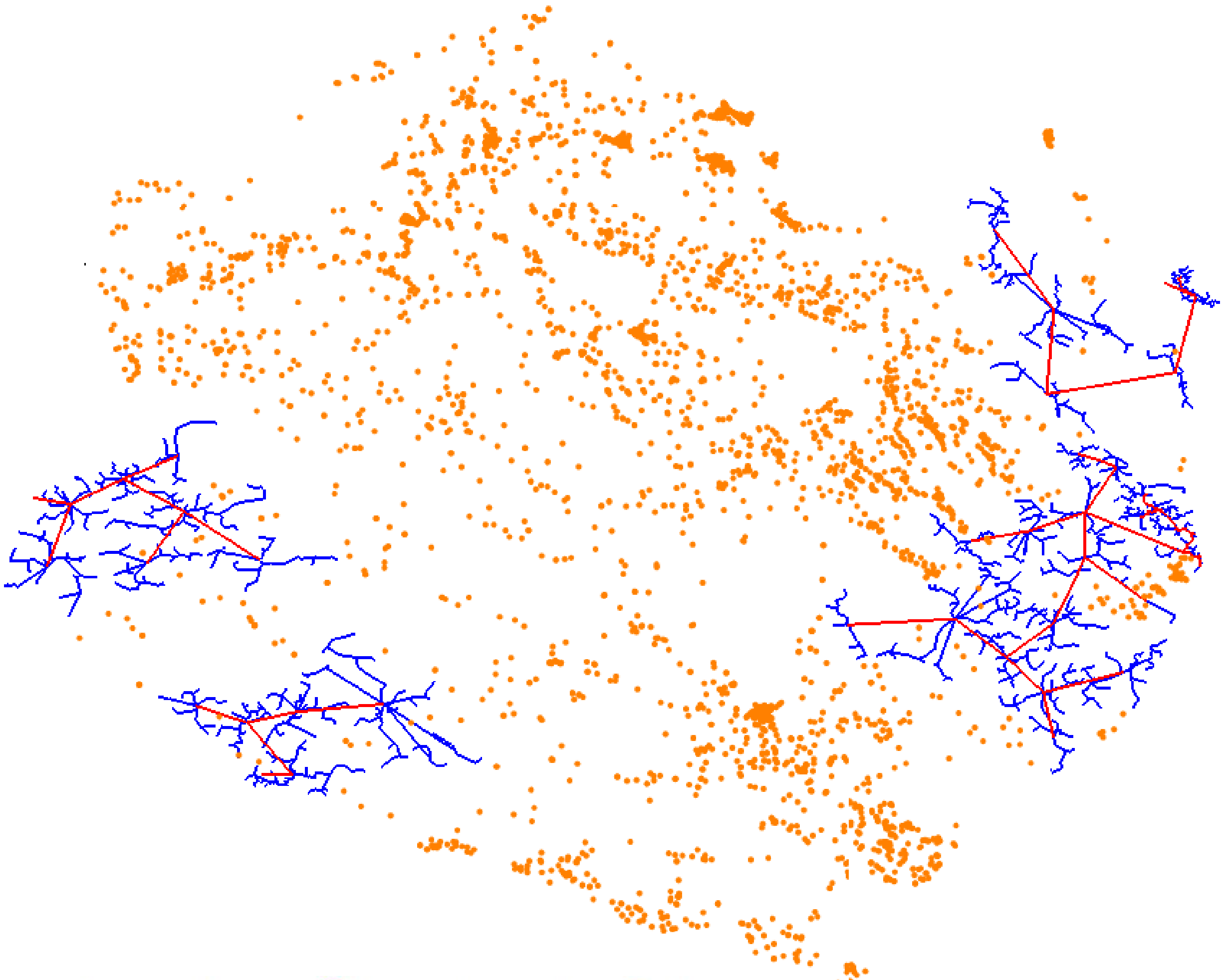
# Cajamarca *(Peru)*

# Base case *(detail of network layout)*

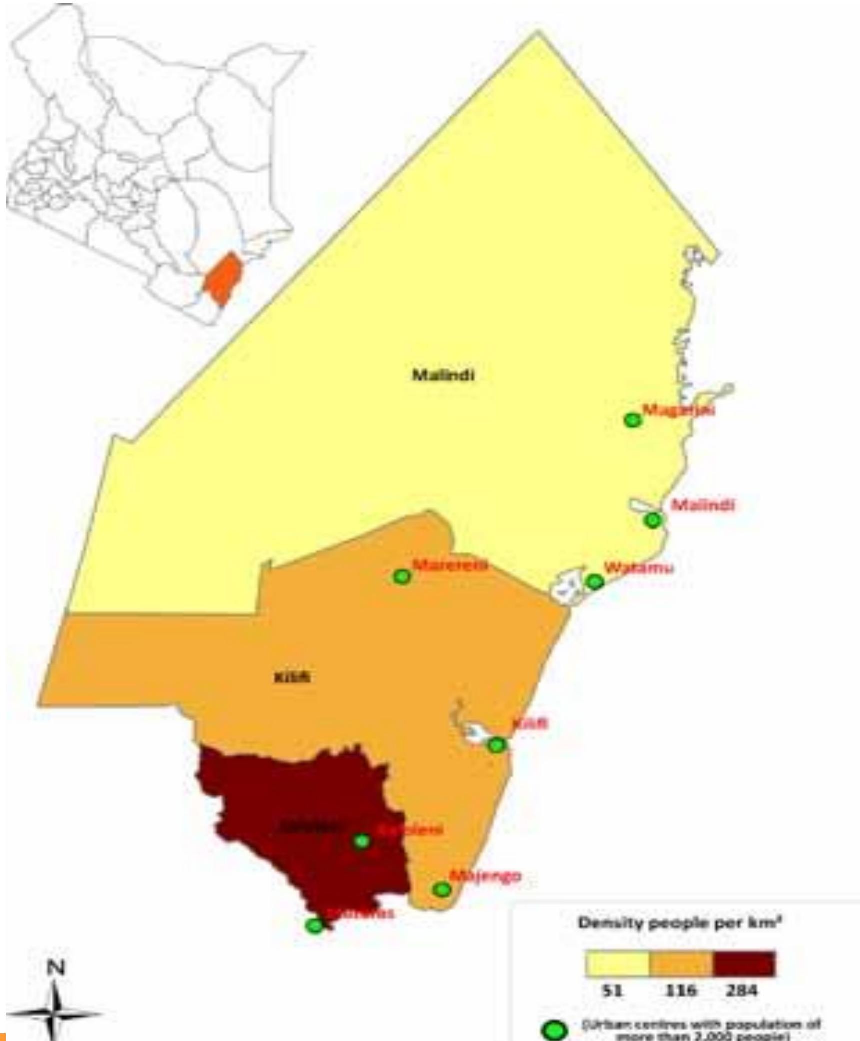


# Cajamarca *(Peru)*

# Demand growth *(500 kWh/year & household)*

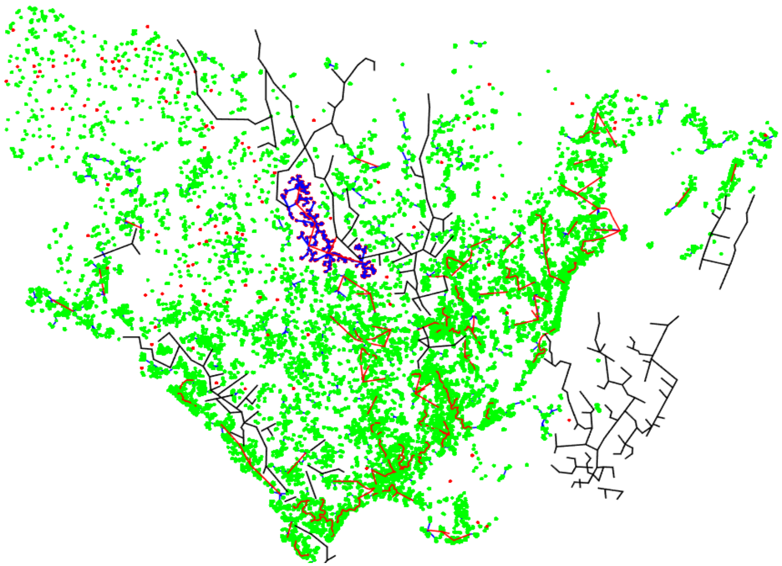


# Kaloleni district *(Kilifi, Kenya)*

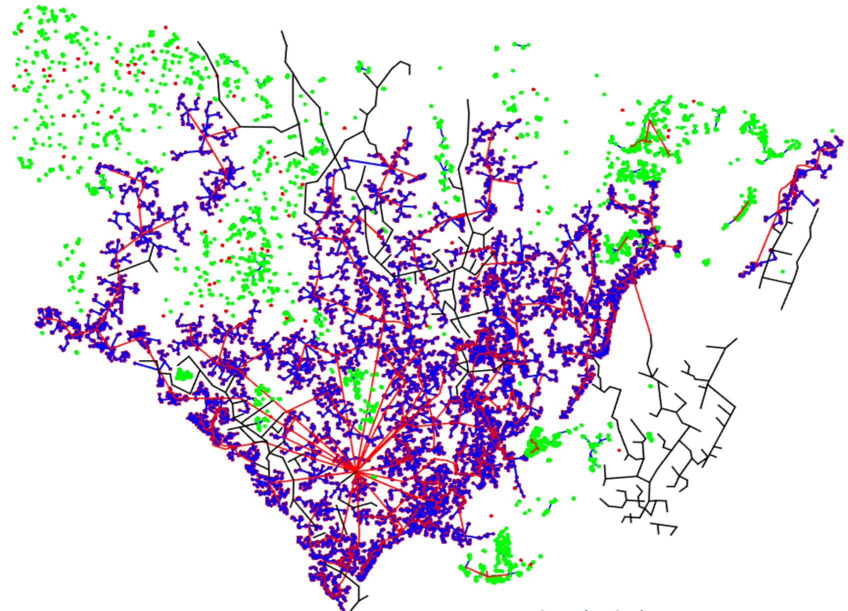



42,755 unelectrified households in Kaloleni

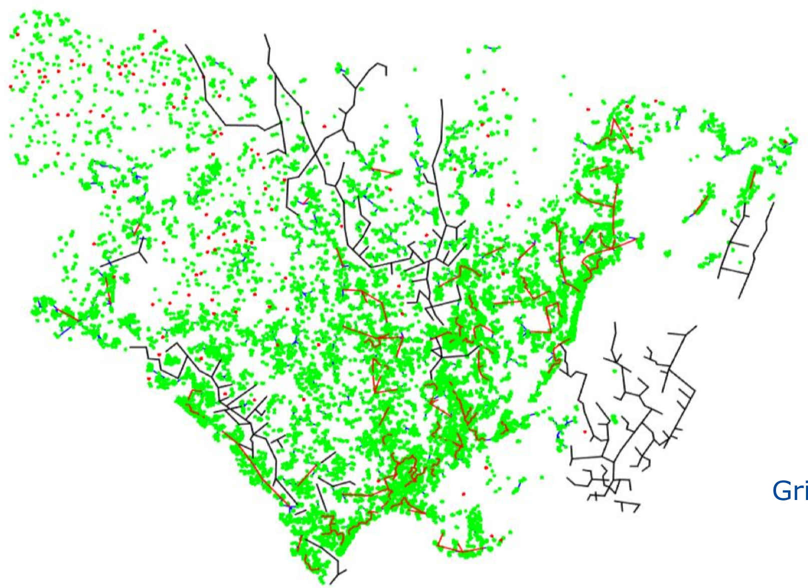
# Sensitivity with respect to grid reliability



Grid reliability = 93.75%



Grid reliability = 100%



Grid reliability = 50%

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

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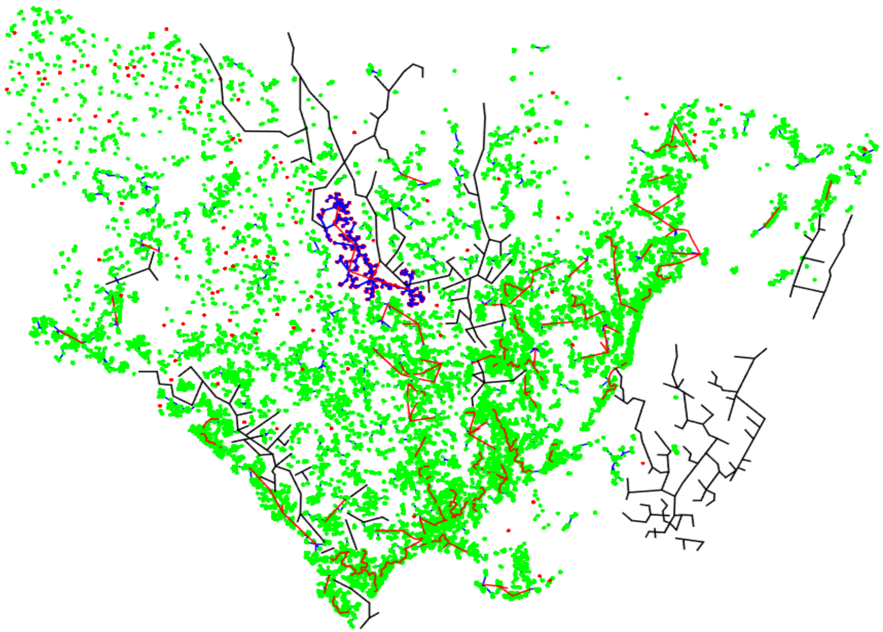
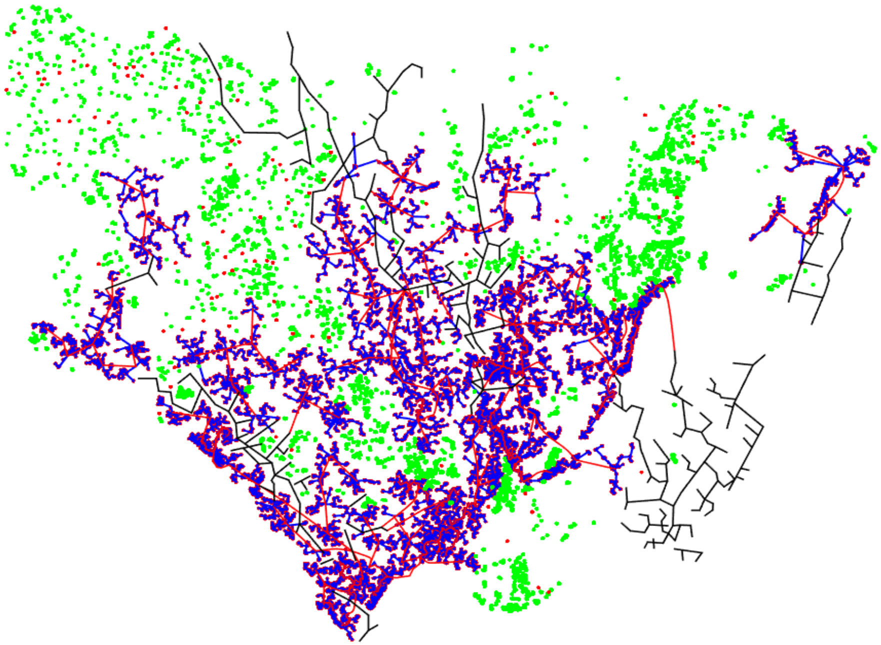
# Sensitivity with respect to diesel price



Diesel price = $1/liter



Diesel price = $2/liter



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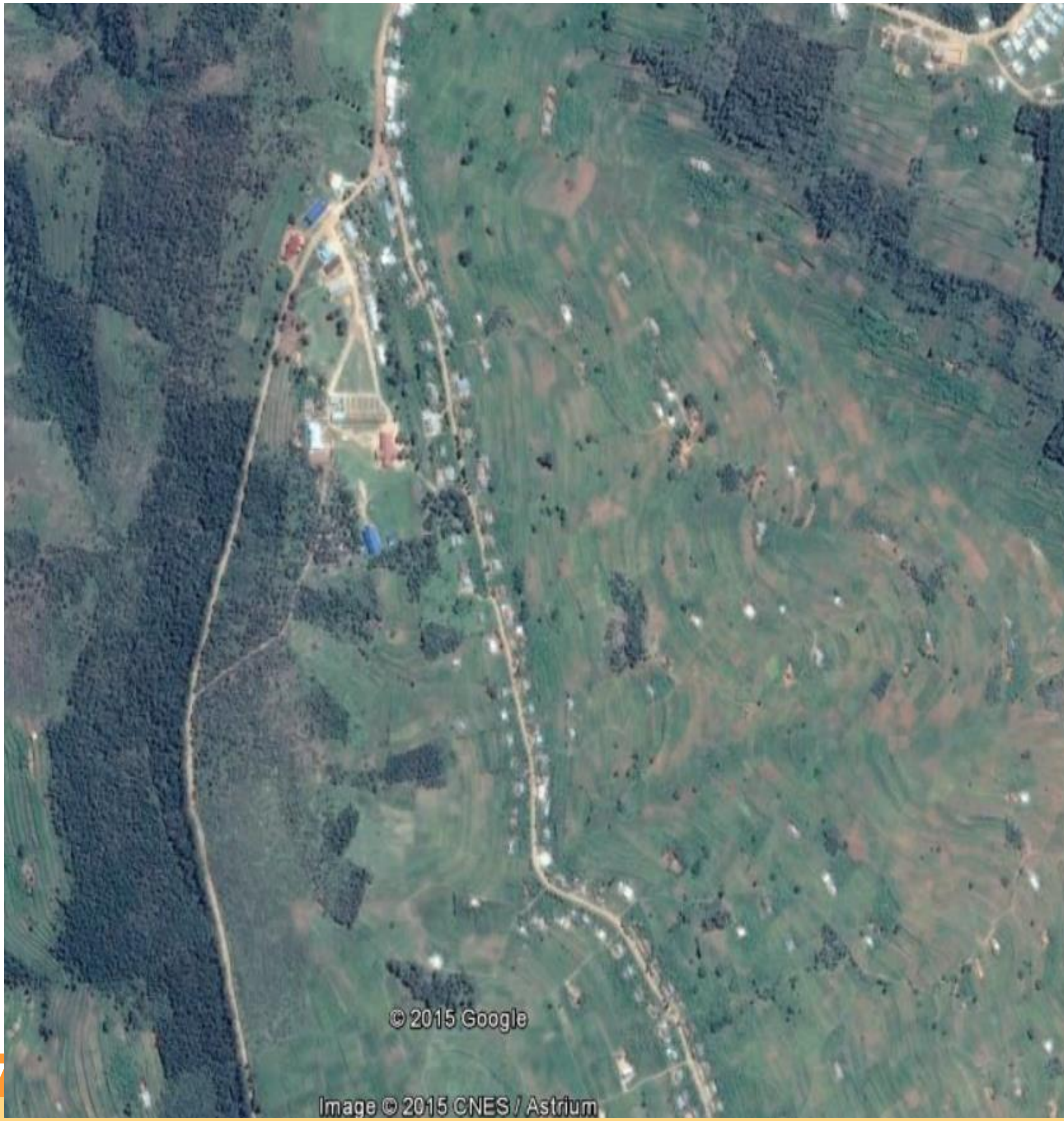
# Sensitivity to demand at village level




## 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



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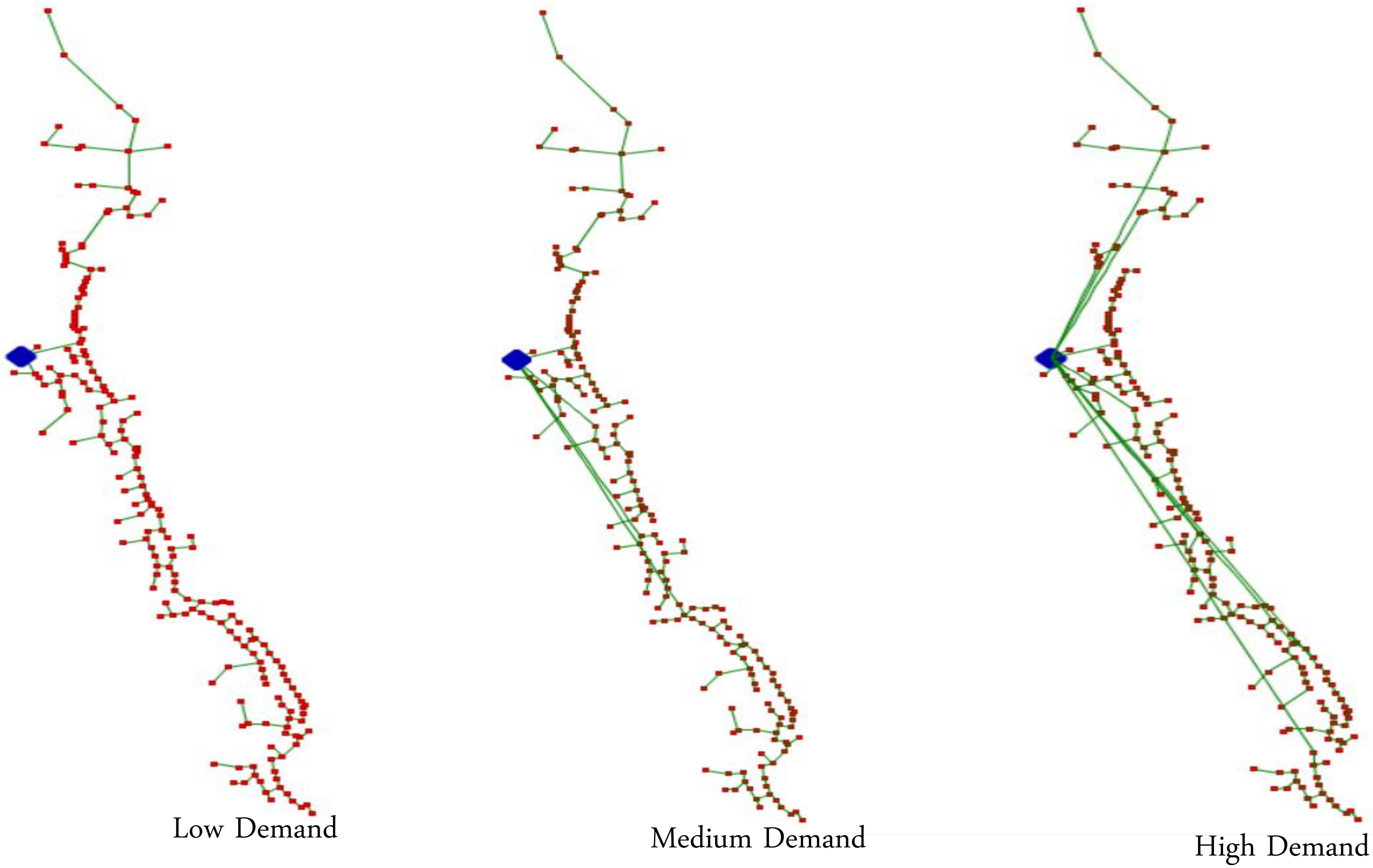
Generation Site
Low Voltage Network
Consumers

# Sensitivity of the network layout to the demand level



# 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**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# 2 Sample set of scenarios

- **Scenarios** (output of different runs of the REM model):
  - Demand: Average Tier 1 to Tier 5 demand, plus any additional target of choice (e.g. demand in other already electrified regions)
  - Electrification mode:
    1. ***Optimal share*** of network extension/microgrids/stand alone systems) & ***optimal generation mix*** (minimum cost)
    2. Variations (examples):
       1. ***Maximum network extension***
       2. ***100% off-grid***
       3. ***100% solar***
- Electrification mode input:
  - For each electrification shire and scenario, REM analysis at household level of the electrification mode solution (network extension, micro-grids, stand alone systems)


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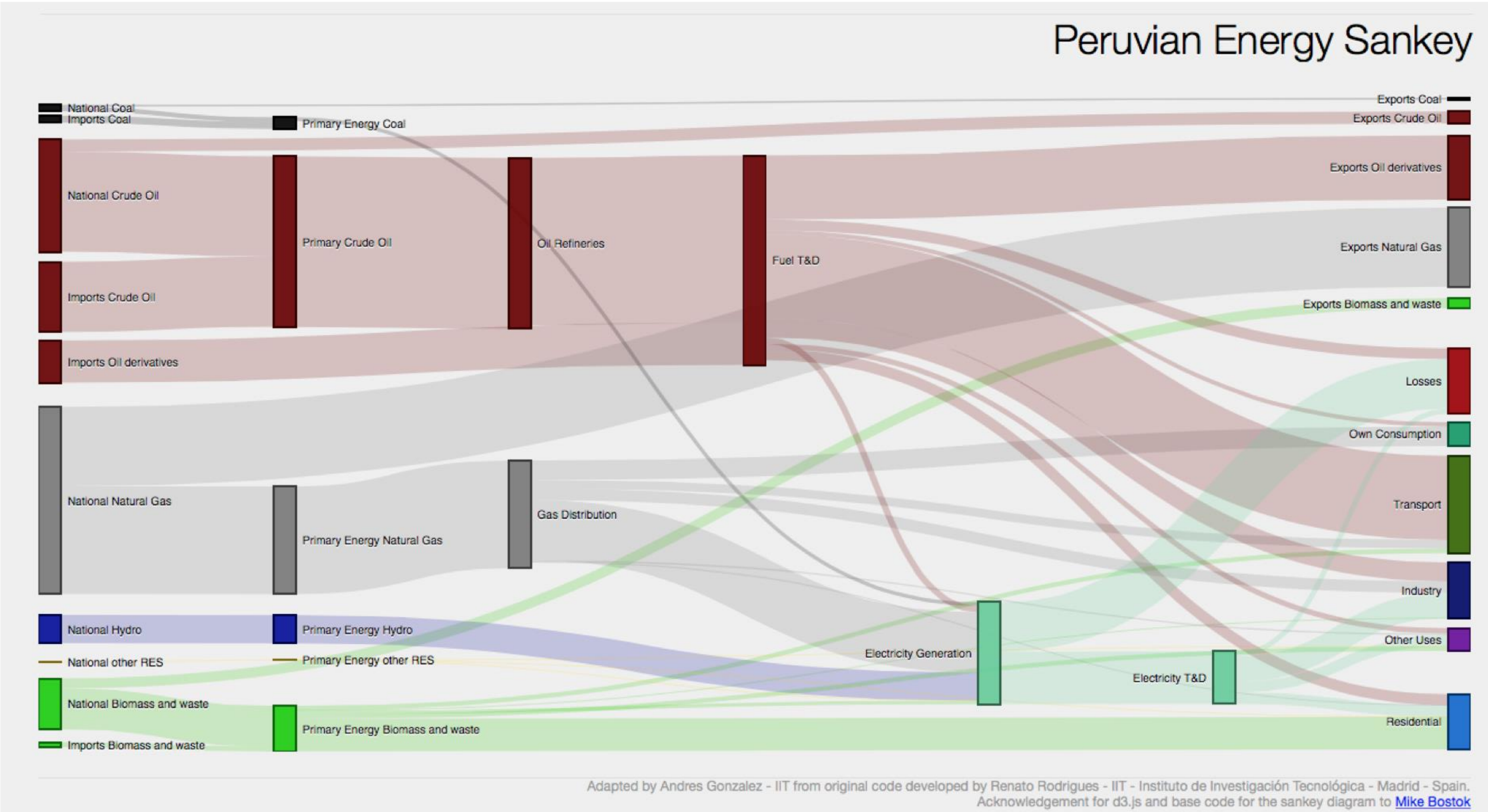
# MASTER4all
# Integrated planning and policy-making

# MASTER4all model:
# Impact of Energy Access in Energy Policy decisions



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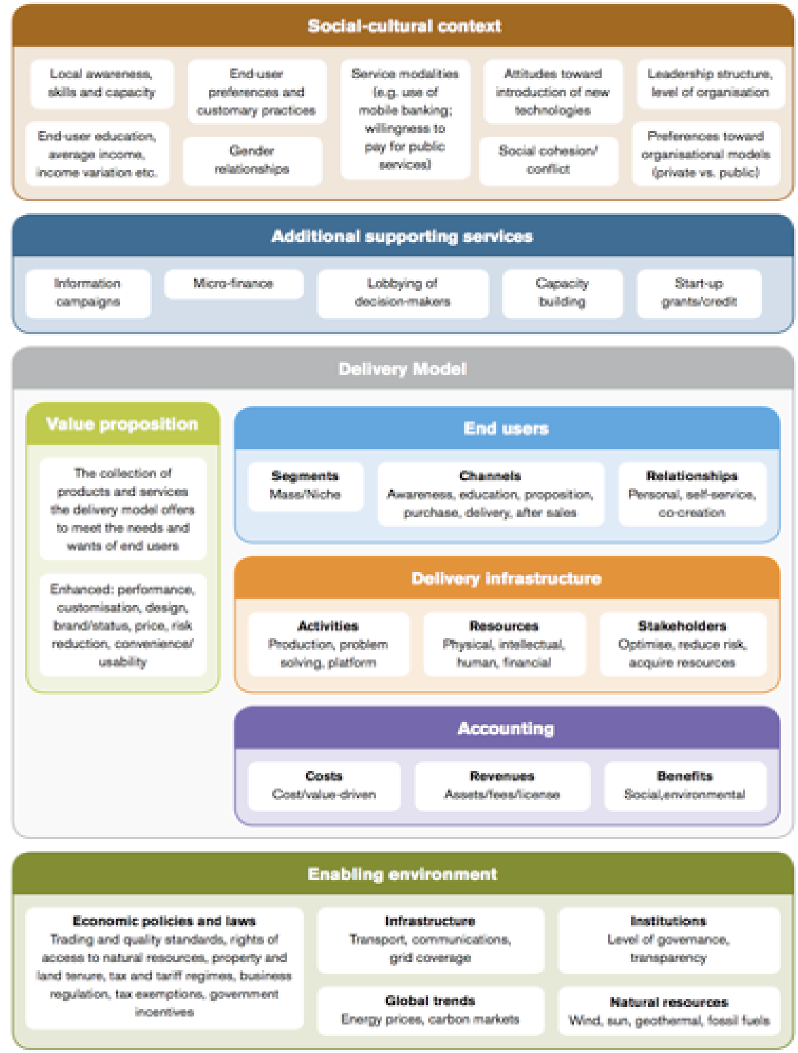
# Master4all model*

- Optimizes the supply of electricity and modern heat services jointly with the rest of the delivery of energy services
- Satisfies different level of demand of electricity and heat (Tiers 0 to 5) for different population groups with different characteristics (needs, affordability, preferences)
- Optimizes over a diversity of on-grid, under-grid and off-grid electrification options provided by the REM model (brute force or training samples)
- Considers also a diversity of modern heating and cooking options provided by RCM.
- Respects budget constraints, electrification targets & planner priorities
- Estimates impacts on the broader energy system
- Comprehensive consideration of the three SE4all targets:
  - Universal access
  - Renewables
  - Energy efficiency

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

# 4 Business model analysis

- User centric approach
- Value proposition: Services and product fo development targets
  - Residential
  - Commercial
  - Productive
  - Community
- Socio economic and cultural context
- Market niche and segmentation
- Delivery model & revenue estructure
- Key issues
  - Sustainability
  - Scalability
  - Replicability




Source: Bellanca and Garside 2013

# Technologies vs. business models classification

| | | Grid Extension | Isolated Mini grid | Single User System | 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), Fenosa-Gas Natural (Guatemala), Condensa (Colombia), Schneider (Global) | NPDCAPL (India), Dresser-Rand (Brazil) Schneider-Electric (Global) | 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<br>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 | |

Alternative Techs & Business Models



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# Ingredients of a plausible solution
# A mix, perhaps? Discussion *(1 of 5)*

- What level of demand to target?
  - Acceptable access (MAUNE)?
  - Natural access?
  - Affordable access? (including devices)
  - SE4all Tiers?
  - According to development priorities?
- How to balance between energy services?
  - Domestic
  - Community
  - Productive

# Ingredients of a plausible solution
# A mix, perhaps? Discussion *(2 of 5)*

- Truly **isolated shires** *(to be identified & acknowledged as such)* need ad hoc off-grid solutions
- Effective "bridge" solutions in **"electrified" shires** have to be made available soon, to prevent postponement of provision of basic electricity service to every household
- Permanently **isolated households** also need an appropriate solution

# Ingredients of a plausible solution
# A mix, perhaps? Discussion *(3 of 5)*

- **Unregulated off-grid solutions** meet immediate needs, but
  - They **cannot be scaled up** to allow necessary demand growth
  - They are **not compatible with grid extension**
    - This increases the risk (& cost) for entrepreneurs
    - The physical assets may become useless or underutilized
    - Solar (mostly) generation will be replaced by (mostly) coal, defeating clean energy & GHG emissions targets
    - Entrepreneurs can always try to exercise their monopolistic power and abuse consumers

# Ingredients of a plausible solution
# A mix, perhaps? Discussion *(4 of 5)*

- **Grid-compatible off-grid solutions** for "electrified" villages seem to have most **advantages**
  - They can be used to meet immediate needs & can be scaled up to allow necessary demand growth
  - They can become grid-connected whenever the grid is ready technically & financially
  - Solar generation infrastructure will remain
- But **private investment will not happen unless**
  - Conditions **after-grid-connection** are clear & guaranteed
  - Risk of financing the **income deficit** is acceptable

# Ingredients of a plausible solution
# A mix, perhaps? Discussion *(5 of 5)*

- **Off-grid solutions** are the only option for isolated rural villages and households with low consumption
  - **Permanent** solutions should allow for demand growth beyond a few electricity units for very basic services
    - Typically similar to grid-compatible microgrids or maybe solar home systems (SHS)
  - **Transitory** solutions may be based on power packs of the 3rd solar PV generation technology
    - With a completely different business model
- Private investment for full electrification will not happen unless the **income deficit** can be financed with an acceptable risk

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# ¡Gracias!

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