ESMAP
Global Mini Grid Technical Conference
Abuja, Nigeria, December 6, 2017

FRONTIER DEVELOPMENTS IN MINI GRIDS

Geospatial planning

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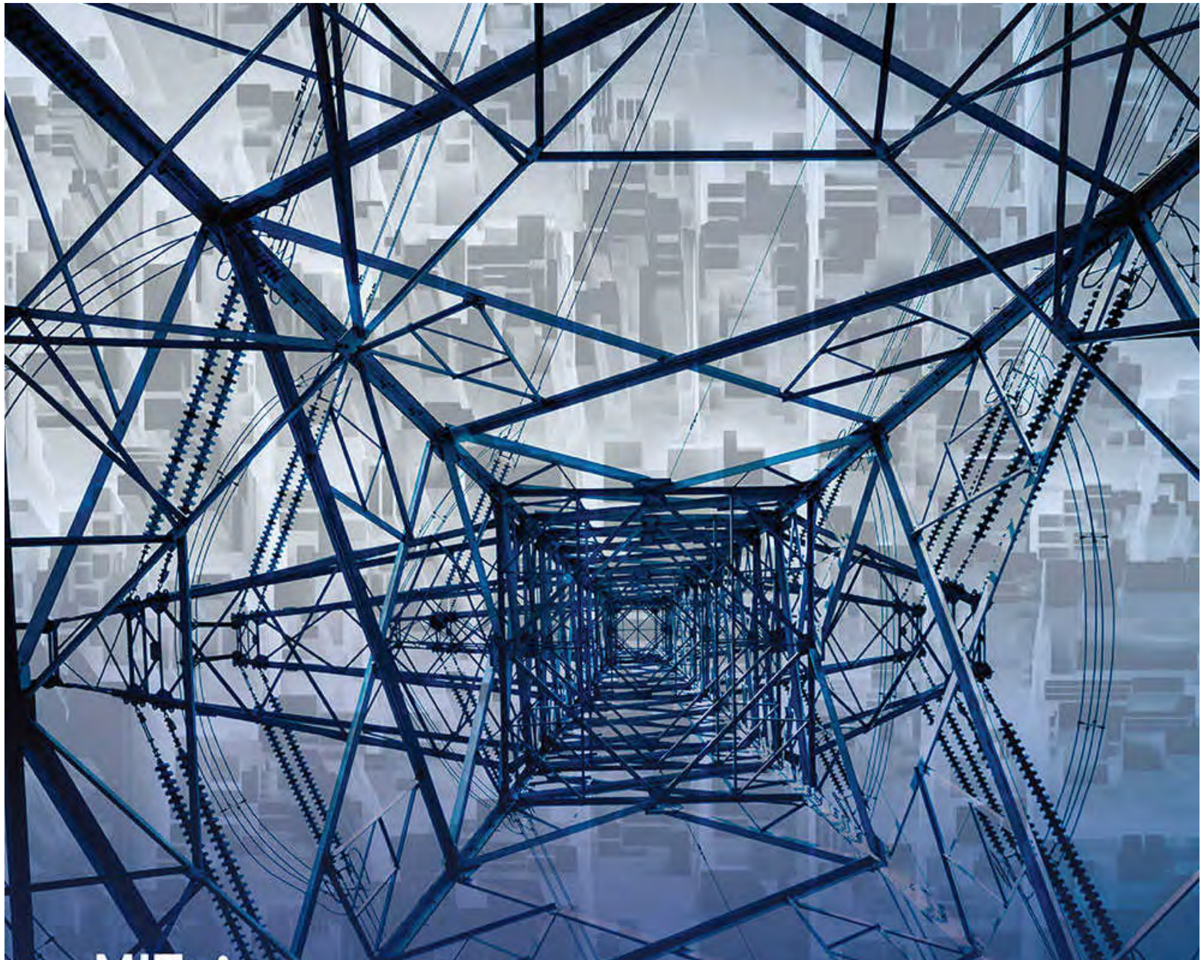

MITei
MIT Energy Initiative

UTILITY OF THE FUTURE

An MIT Energy Initiative response to an industry in transition

In collaboration with IIT-Comillas

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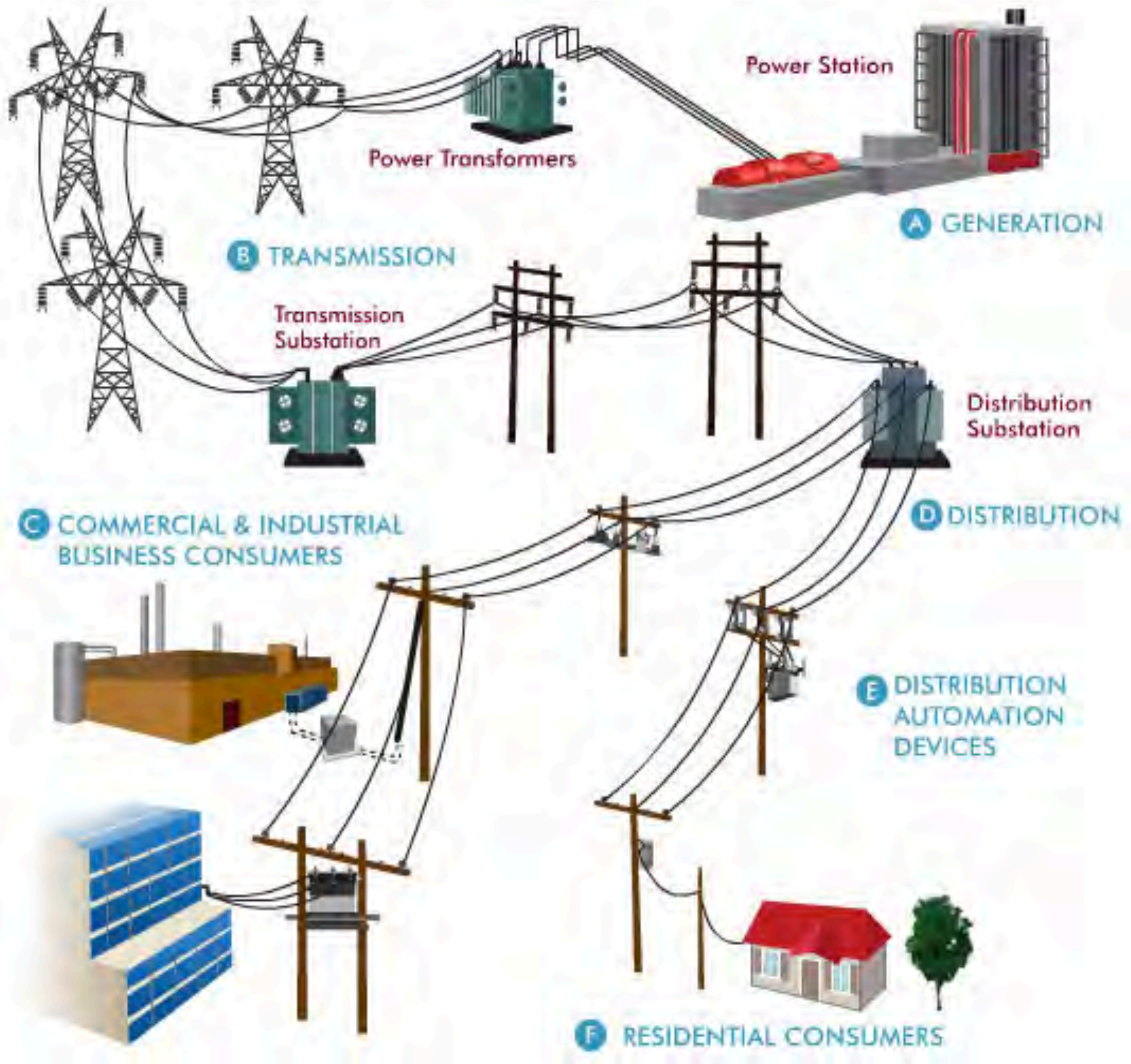
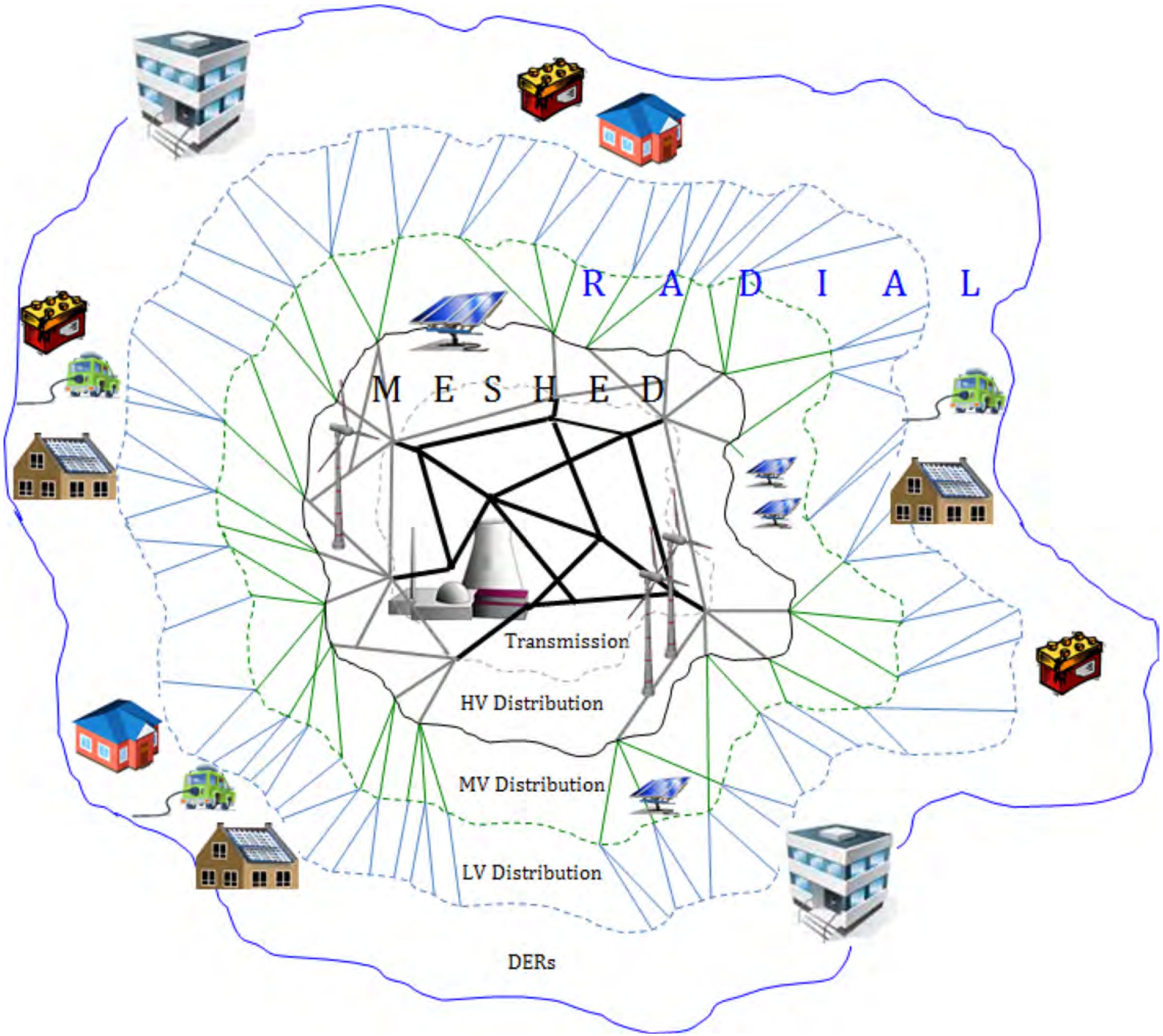
MIT

We have to change the “top-down” perspective…



… by another one with demand & generation all over the place



What could be the true frontier of mini grids in the developing world?

I do believe that mini grids must…

… become integrated as one more component of a comprehensive electrification process…

… led by the incumbent distributor

- **The differentiation between grid extension, mini grids & SHS is becoming blurred**

- **An integrated perspective is becoming increasingly necessary**

How can geospatial planning help in the electrification planning process?

What's an electrification plan?
(the techno-economic answer)

- An electrification plan will consist of some **mix of on- & off-grid** expansions providing electricity access to all consumers at **minimum cost**
  - For some **prescribed demand** for each consumer
  - Meeting **minimum reliability requirements**
  - And **additional constraints** (e.g. limit on the total diesel utilization)

The costs of the plan

- The plan will consist of on- & off-grid expansions
- **Grid extension** costs
  - Investment & operation costs of new grid, reinforcements of existing grid, “upstream” cost of grid-supplied electricity, cost of non served energy
- **Off-grid** development costs
  - **Microgrids**: Investment & operation costs of generation, storage & network, cost of non served energy
  - **Stand-alone systems**: Investment & operation costs of generation & storage, cost of non served energy

The Reference Electrification Model (REM)

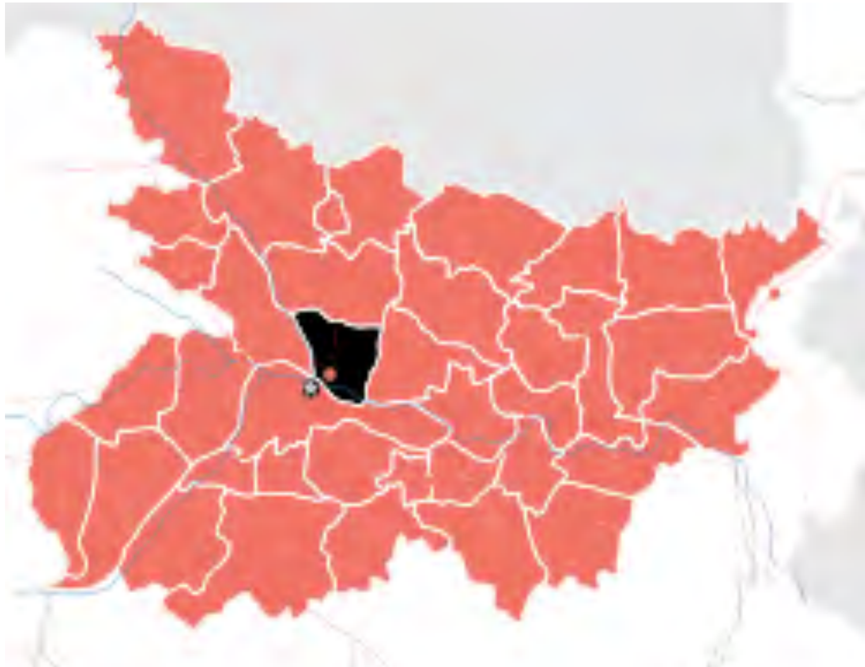
Massachusetts Institute of Technology / Tata Center for Technology and Design
IIT-Comillas University / Institute for Research in Technology

UNIVERSIDAD PONTIFICIA ICAI ICADE COMILLAS MADRID
INSTITUTO DE INVESTIGACIÓN TECNOLÓGICA

Massachusetts Institute of Technology

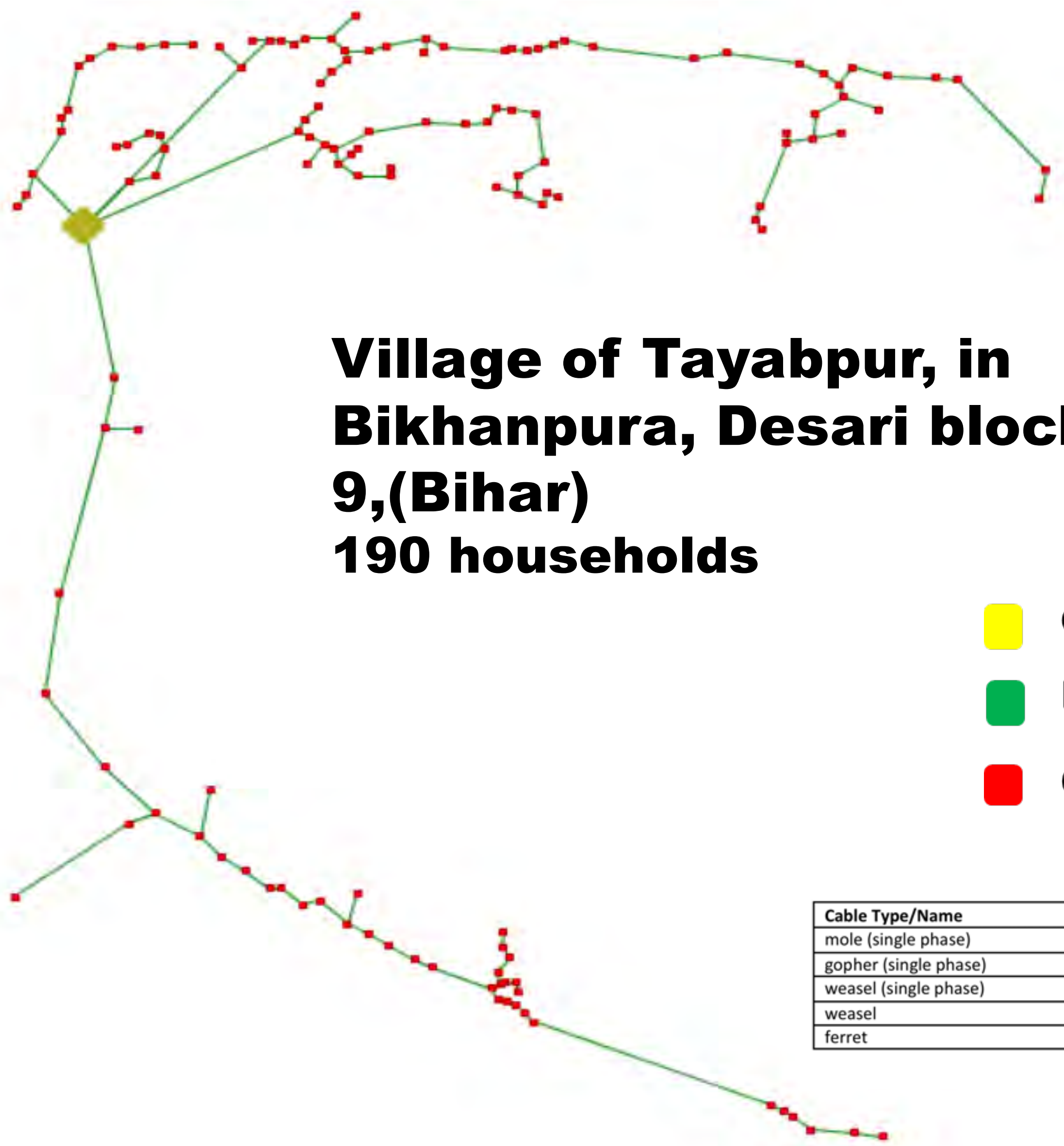
Universal Energy Access Lab
http://universalaccess.mit.edu

REM supports large-scale electrification planning…



District of Vaishali (Bihar)
About 600,000 households

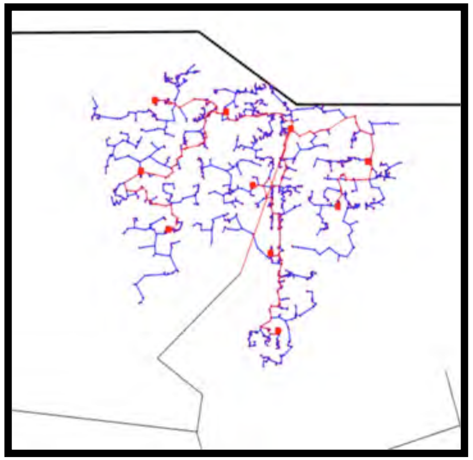
… as well as local electrification projects…

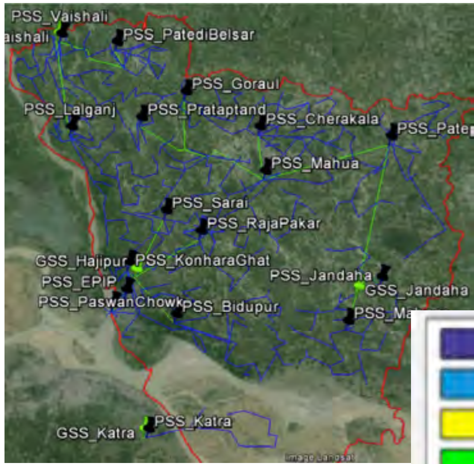


Village of Tayabpur, in Bikhanpura, Desari block, ward 9,(Bihar)
190 households

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

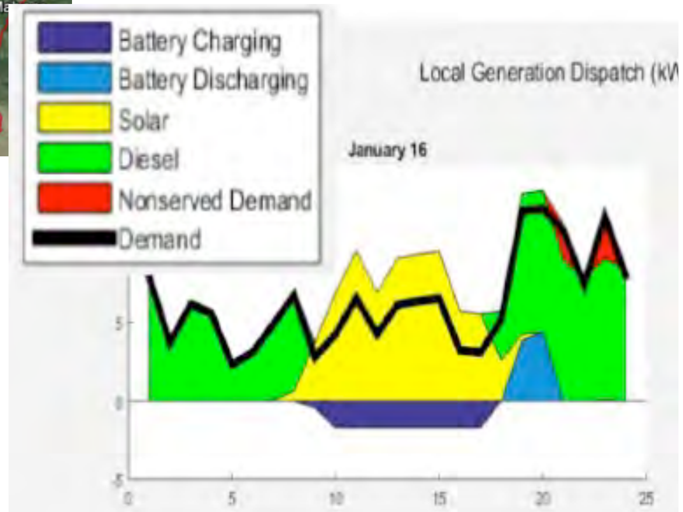
REM output in both cases

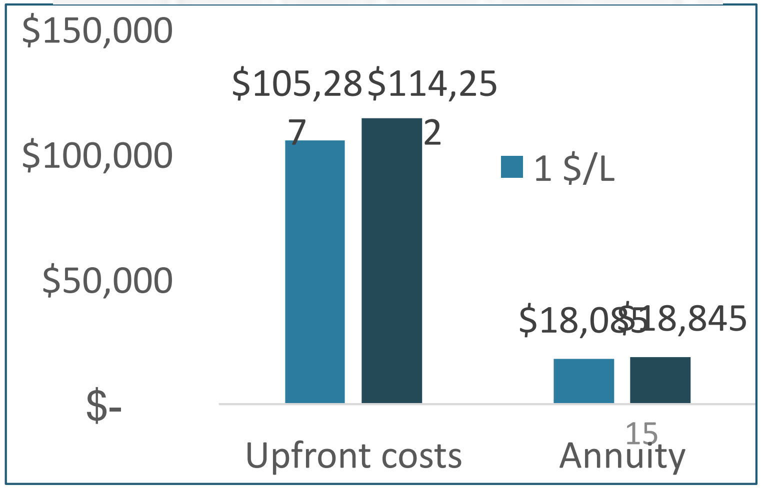




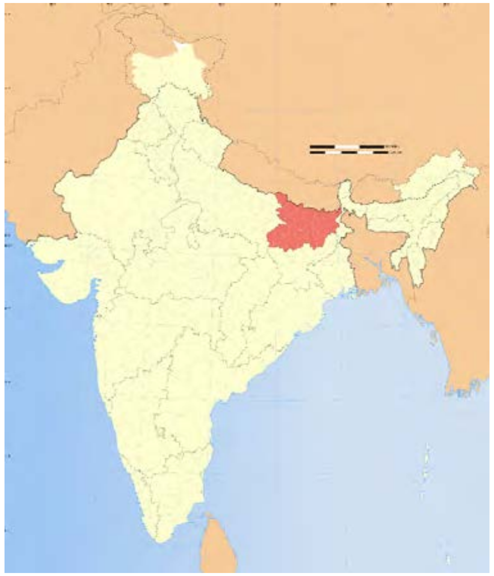
- Network layout
- Generation design (micro-grids), detailed dispatch
- Detailed cost and design figures (tables, charts)
- Geo-referenced solutions (maps)

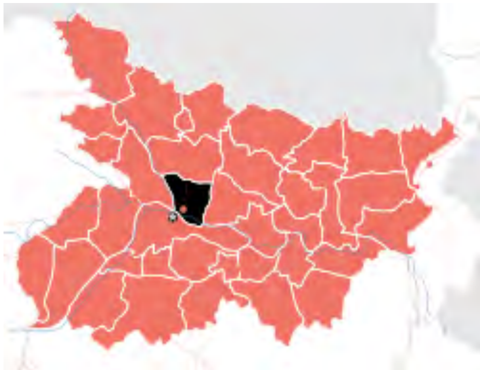
Low Demand Summary Table:	
Total Cost Annuity	$1832
Total Capital Costs	$14057
Annual O&M	$376
LV Correction Costs	$358
LV Prevention Costs	$18
LV Capital Costs	$14057
Annual Losses (MWH)	5.63
Annuity/Load Served ($/kWh)	0.032



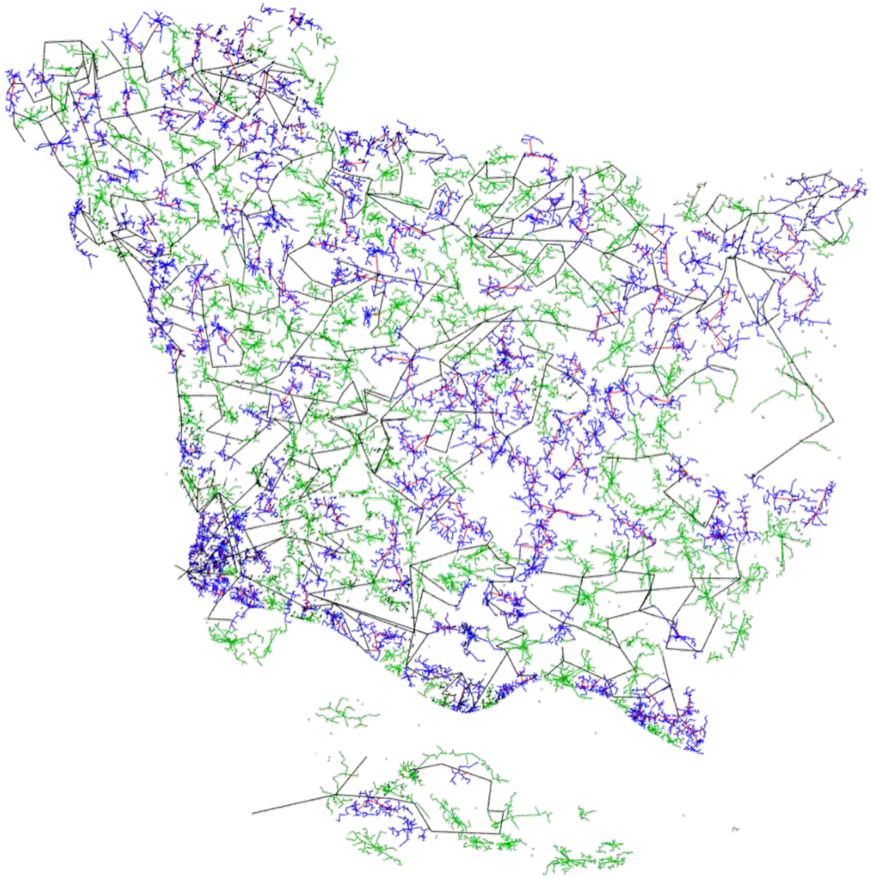


Large-scale REM output



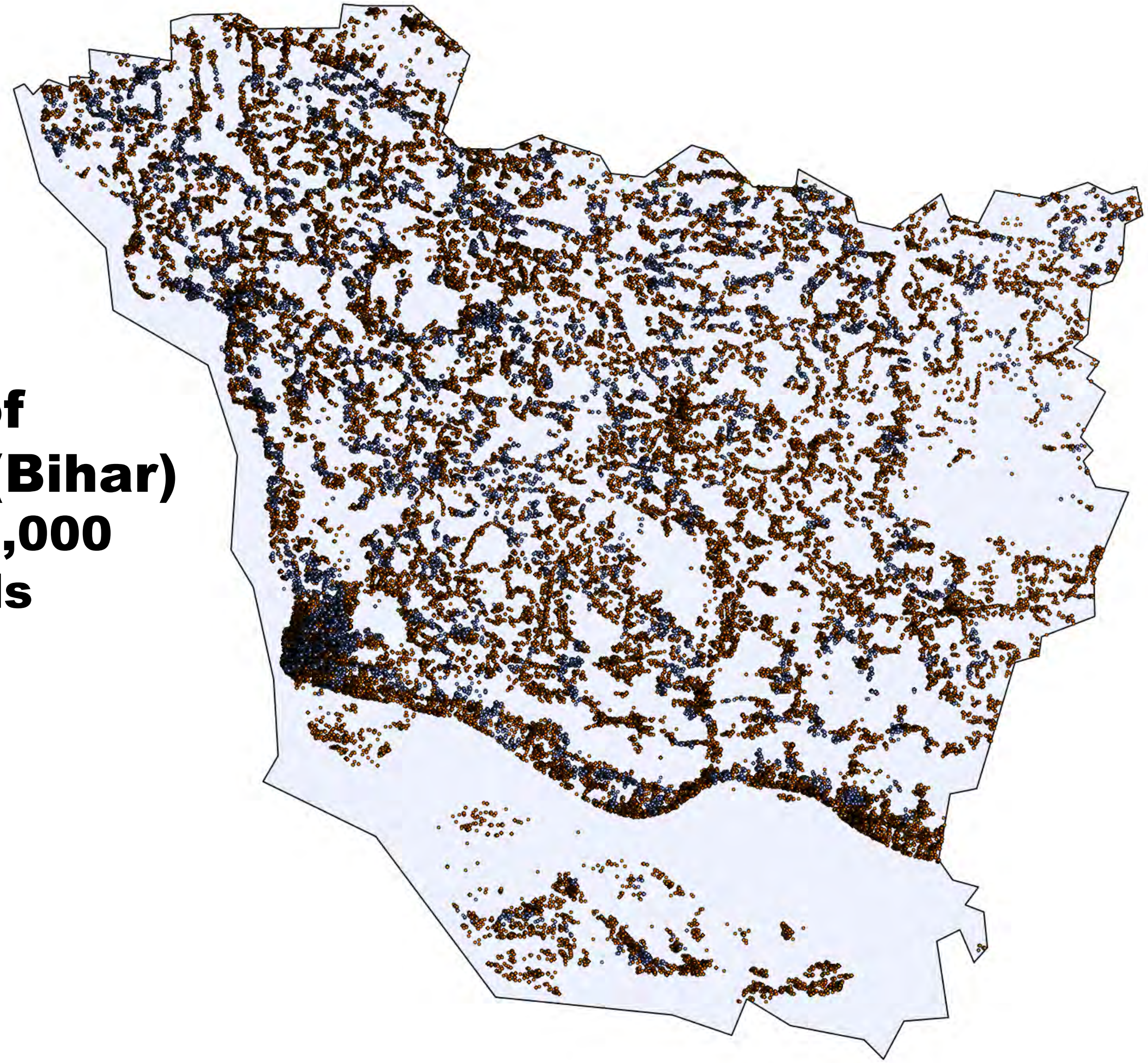


District of Vaishali (Bihar)
About 600,000 households



Existing 11kV | Extension 400V | Extension 11kV | Microgrid 400V | Stand-Alone

We start from the position of every building to be supplied...

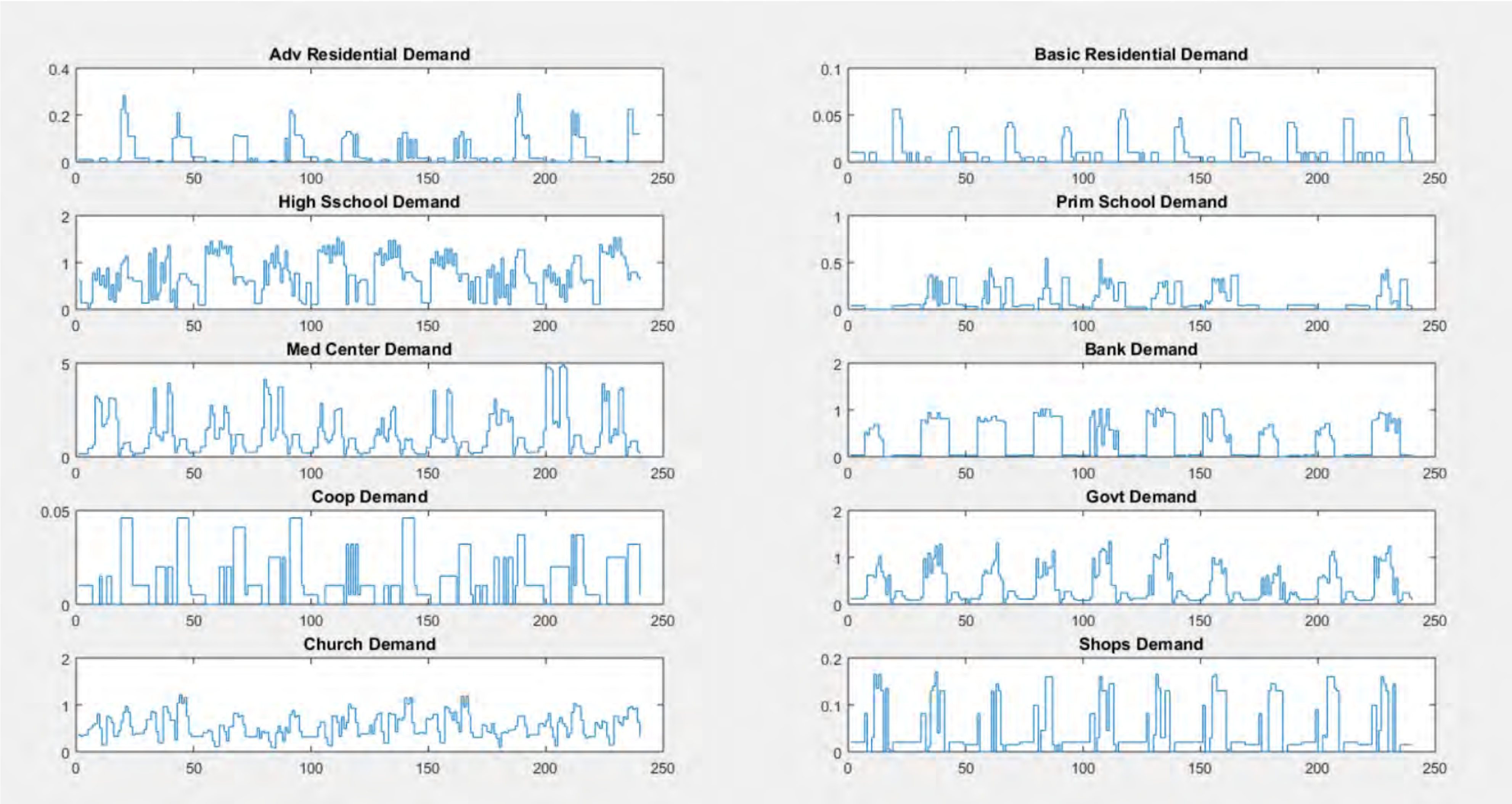


District of Vaishali (Bihar)
About 600,000 households

If geolocation of buildings is not available, starting from satellite imagery...

… our software identifies the location of each building…

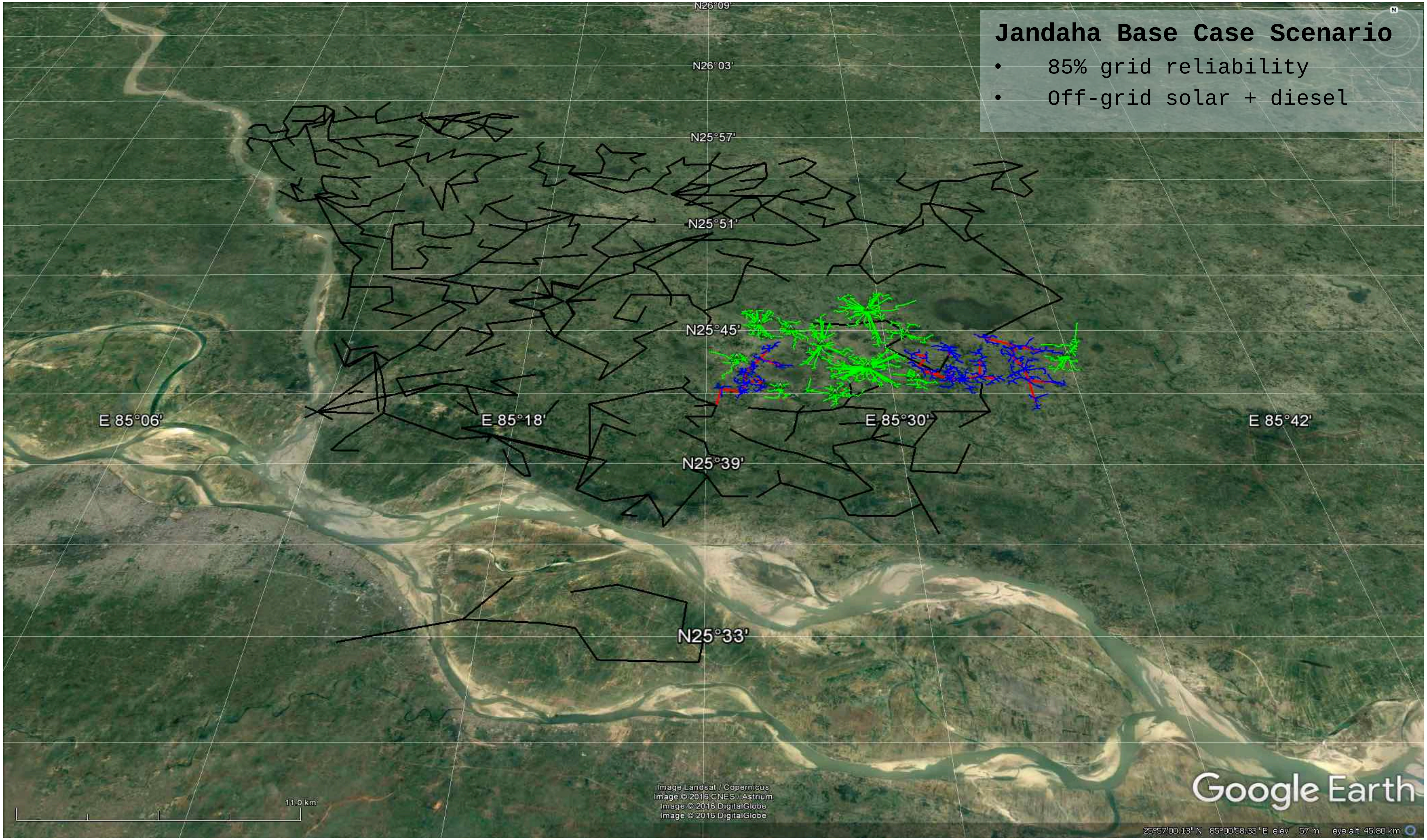
… we also need the estimated demand for each type of building…



… & the location & characteristics of the existing network…

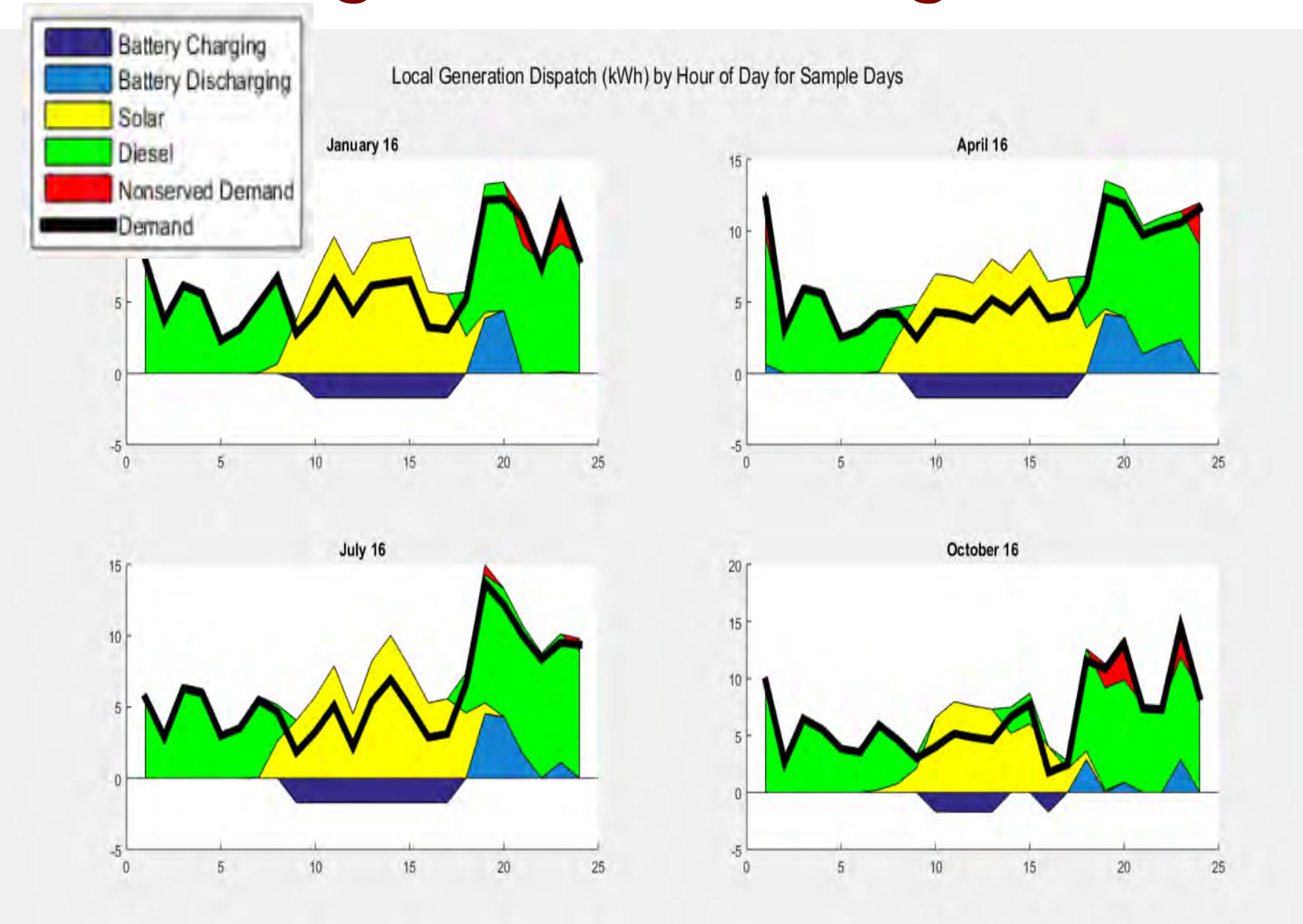
… & then the REM model determines the lowest cost electrification mode for each building & can place it on Google maps

Once REM determines the electrification mode for each building, we can place the solution on Google maps…

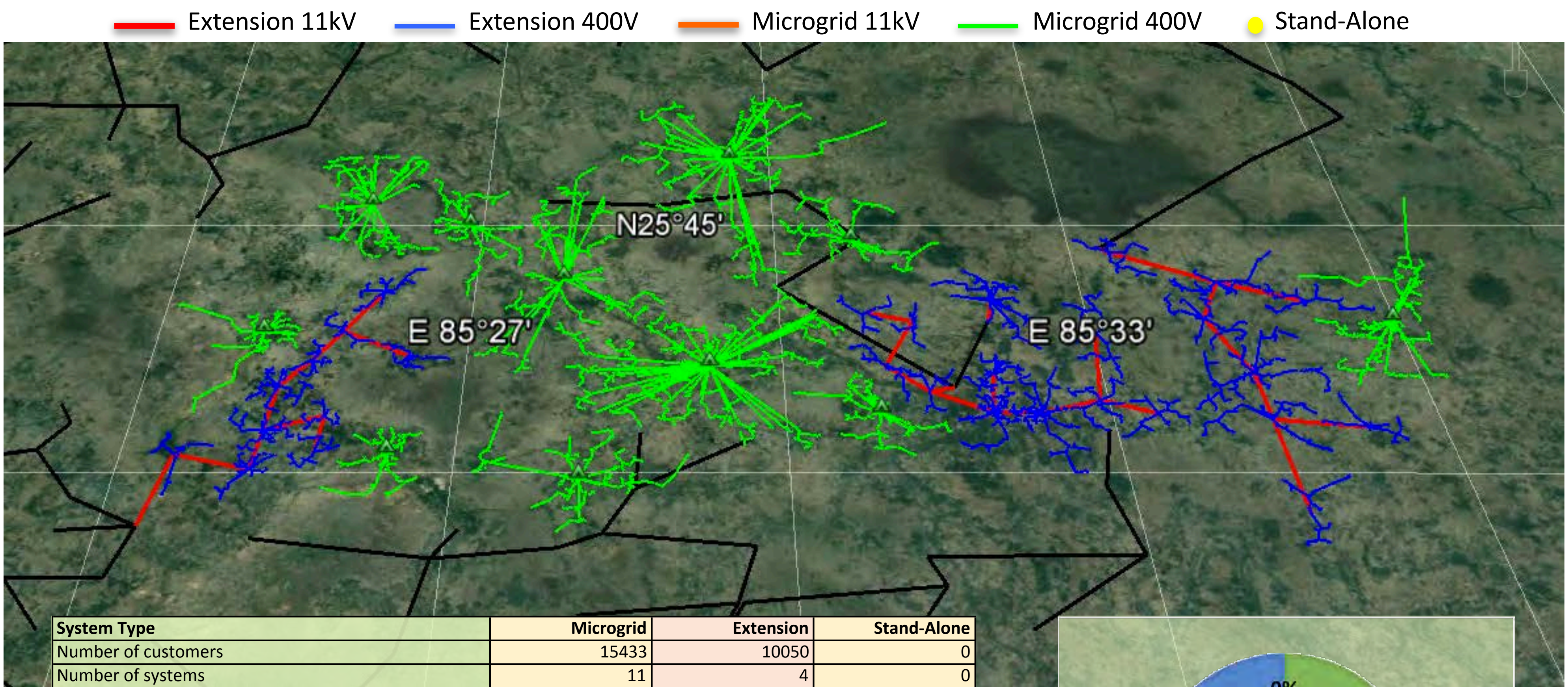


Extension 11kV | Extension 400V | Microgrid 11kV | Microgrid 400V | Stand-Alone

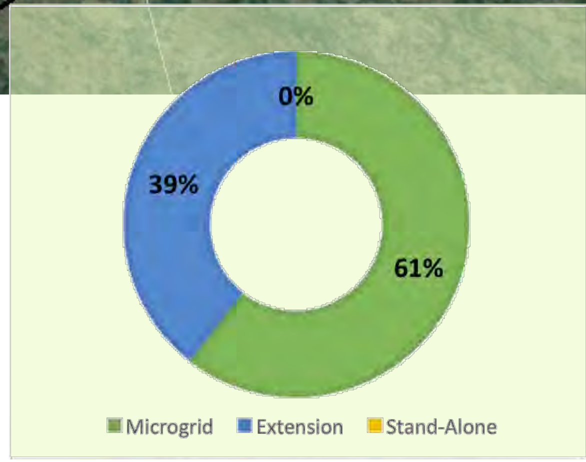
For each microgrid REM optimizes the mix of generation & storage…



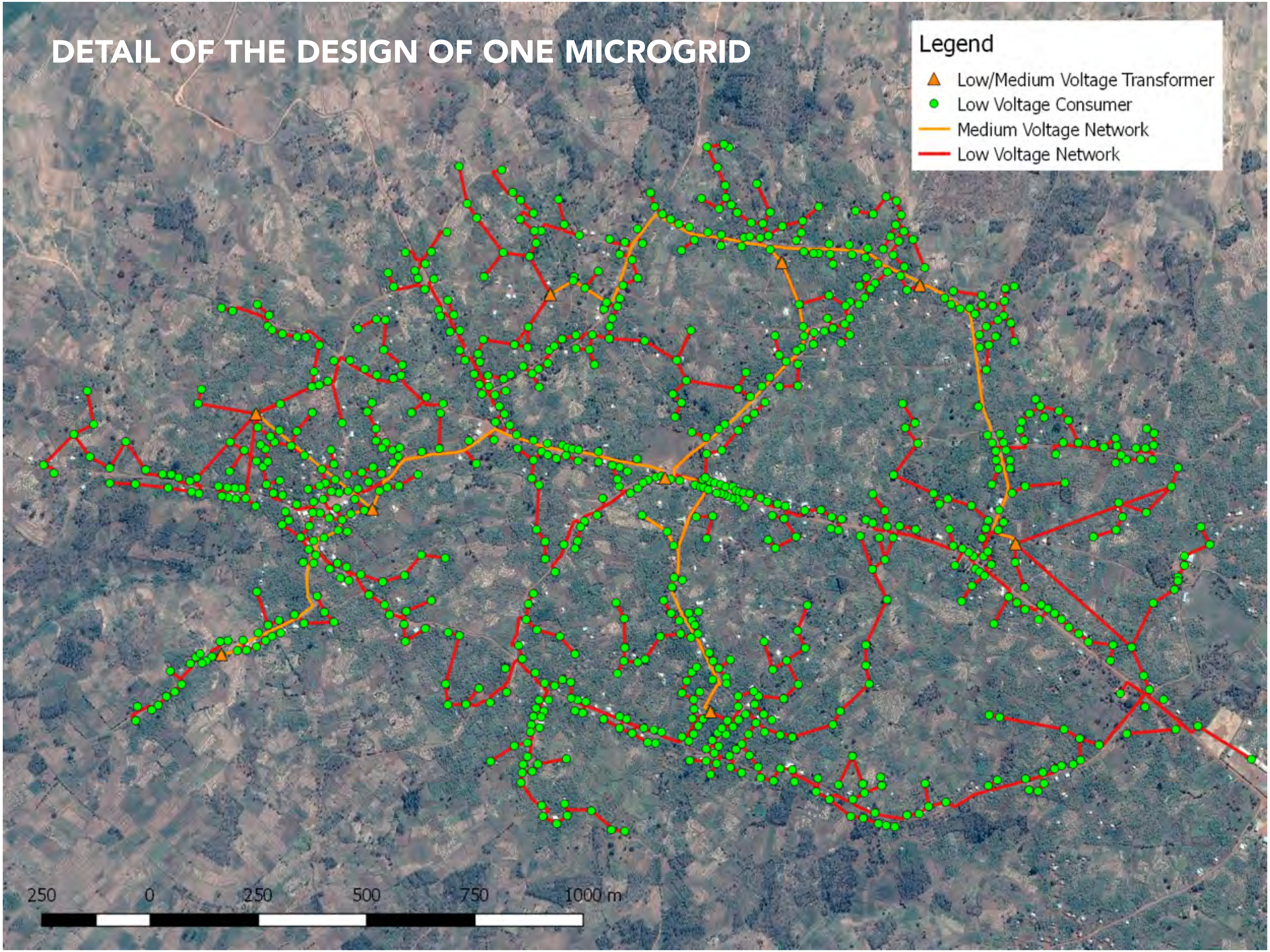
… & provides statistics of cost & performance for each type of supply



System Type	Microgrid	Extension	Stand-Alone
Number of customers	15433	10050	0
Number of systems	11	4	0
Avg. customers per system	1403.00	2512.50	0
Avg. PV array size (kW)	462.99	0	0.16
Avg. battery bank size (kWh)	0	0	0.853
Avg. generator size (kW)	1218.88	0	0
Total system investment & running cost ($/yr)	1 299 642.00	432 371.00	-
Cost per kWh demand served ($/kWh)	0.5199	0.3102	0.0000
Avg. fraction of demand served (%)	99.0%	85.0%	0.0%
Annual Non-served Energy Cost (kWh/yr)	3 021.57	140 830.42	-
Administrative costs ($/yr)	39 089.40	72 462.44	-
Energy Served (kWh/yr)	2 500 003.11	1 393 644.74	-
Energy per customer (kWh/yr)	161.99	138.67	0.00
Annuity per customer ($/yr)	84.21	43.02	0.00

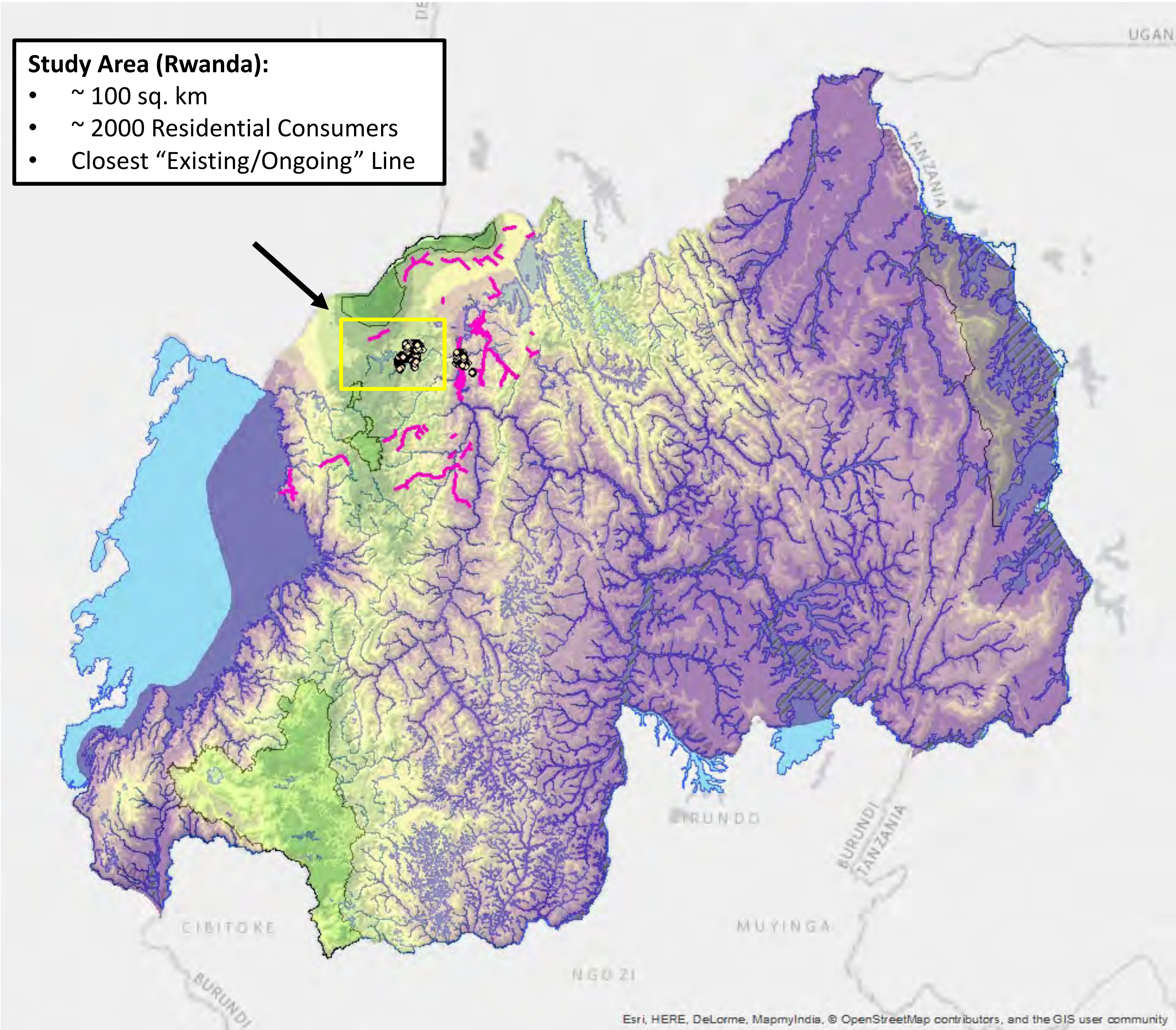


… & it can adapt the network layout to the pattern of roads and paths in the village

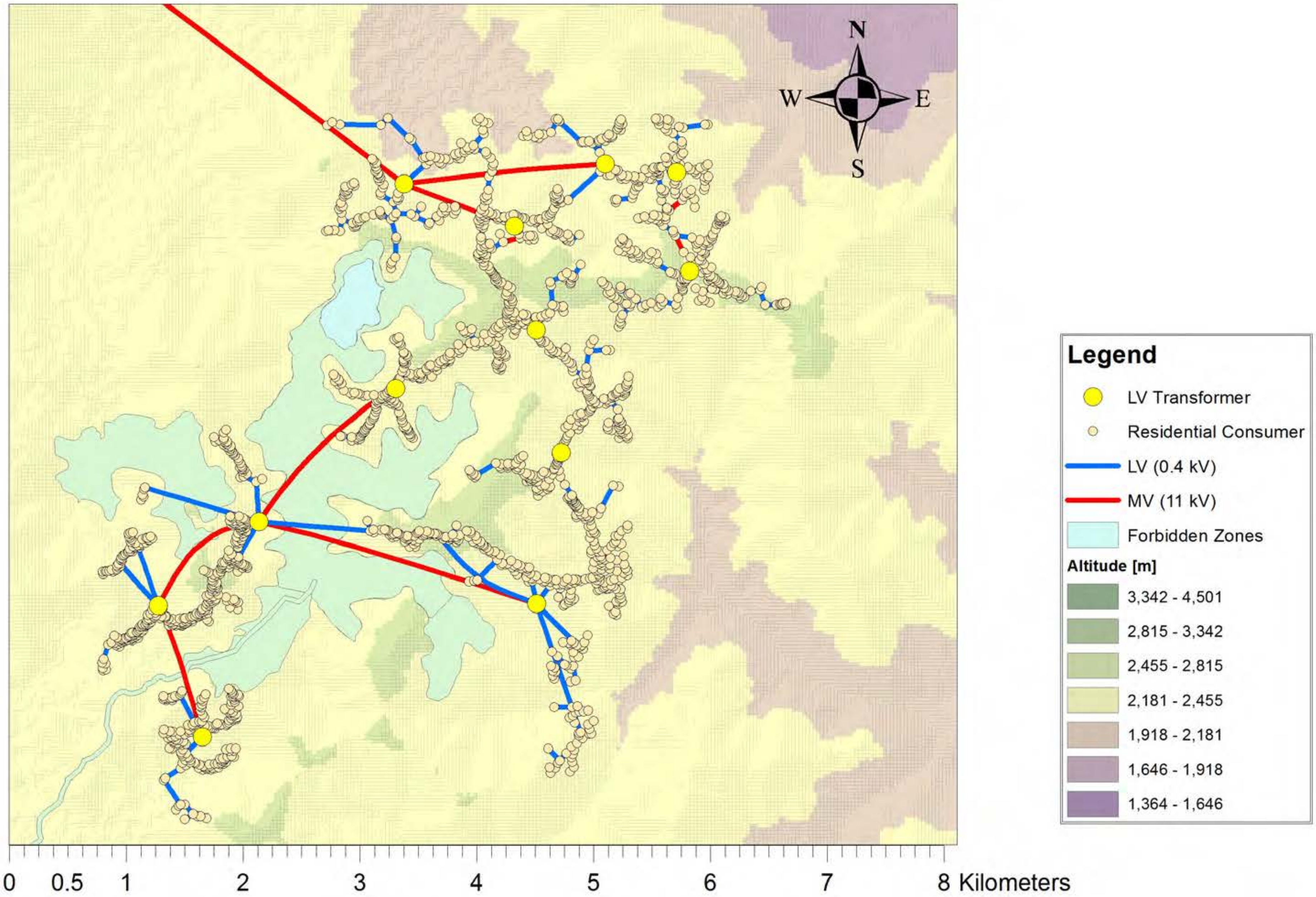

DETAIL OF THE DESIGN OF ONE MICROGRID
Legend
Low/Medium Voltage Transformer
Low Voltage Consumer
Medium Voltage Network
Low Voltage Network
250
0
250
500
750
1000 m

Topography…

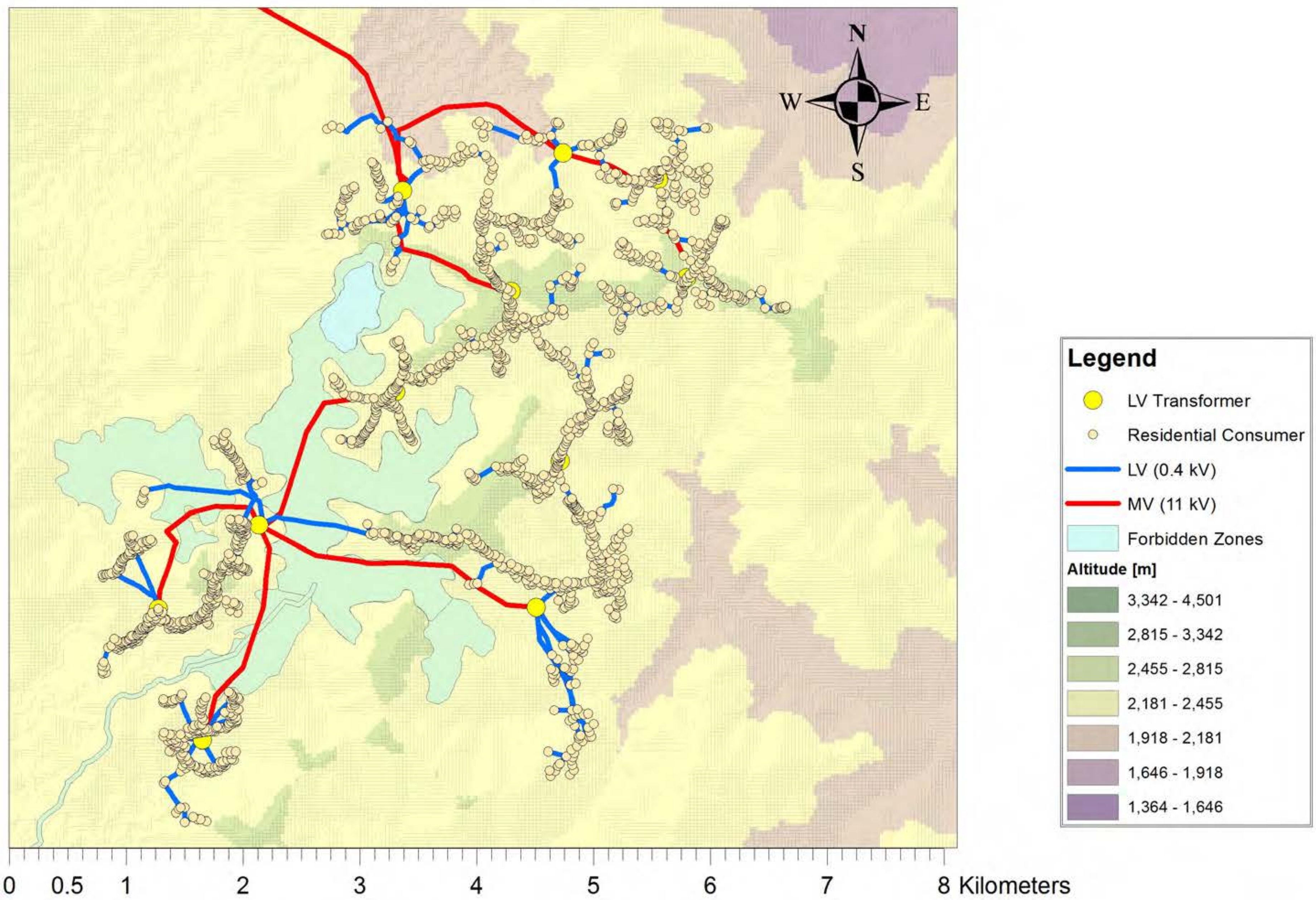
(ongoing implementation)


Study Area (Rwanda):
~ 100 sq. km
~ 2000 Residential Consumers
Closest "Existing/Ongoing" Line
UGAN
TANZANIA
KIRUNDO
BURUNDI
TANZANIA
CIBITOKE
MUYINGA
NGOZI
BURUNDI
Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

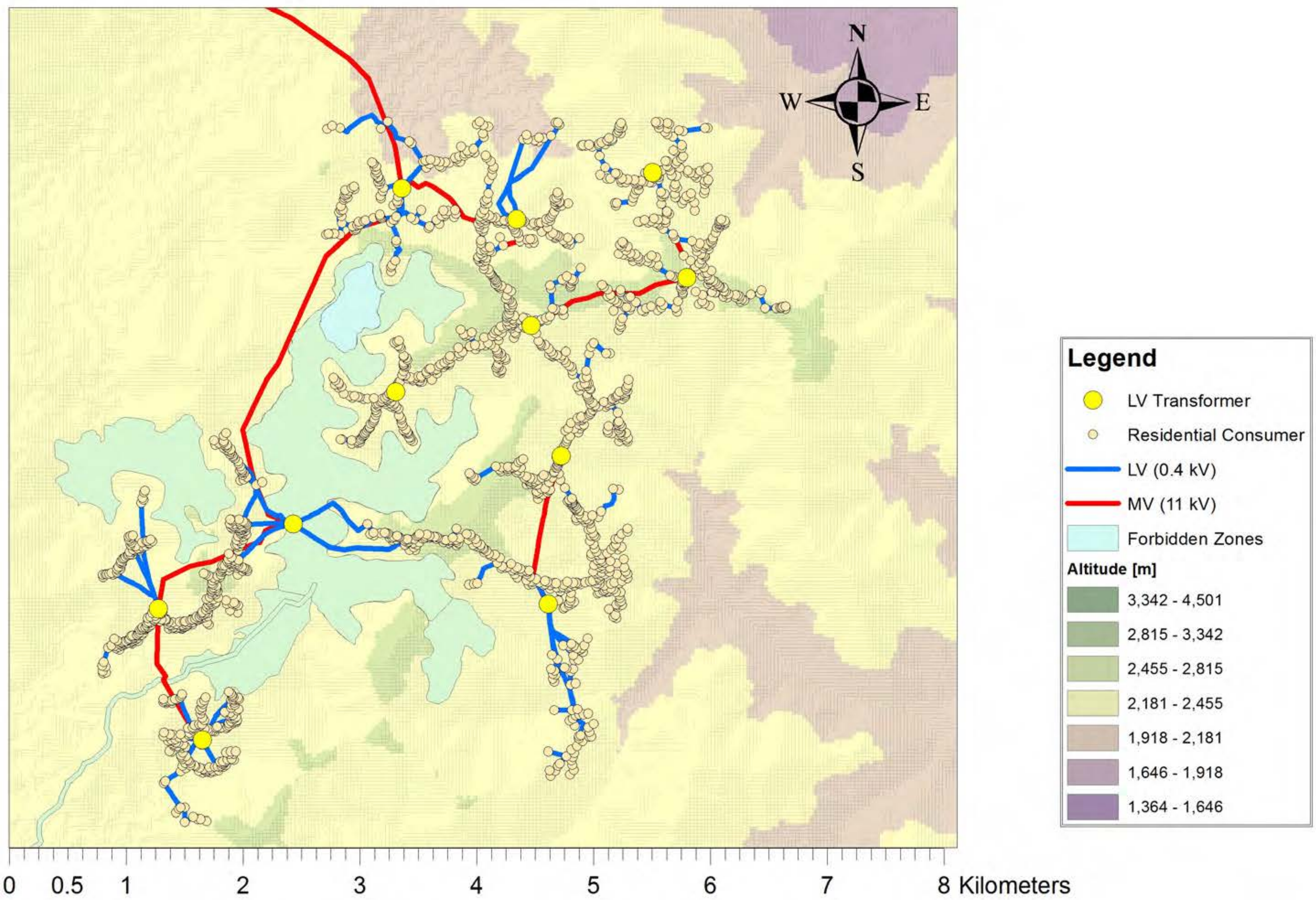
Topography: NO
Forbidden Zones: NO
Forbidden Zone Cost Multipliers: N/A



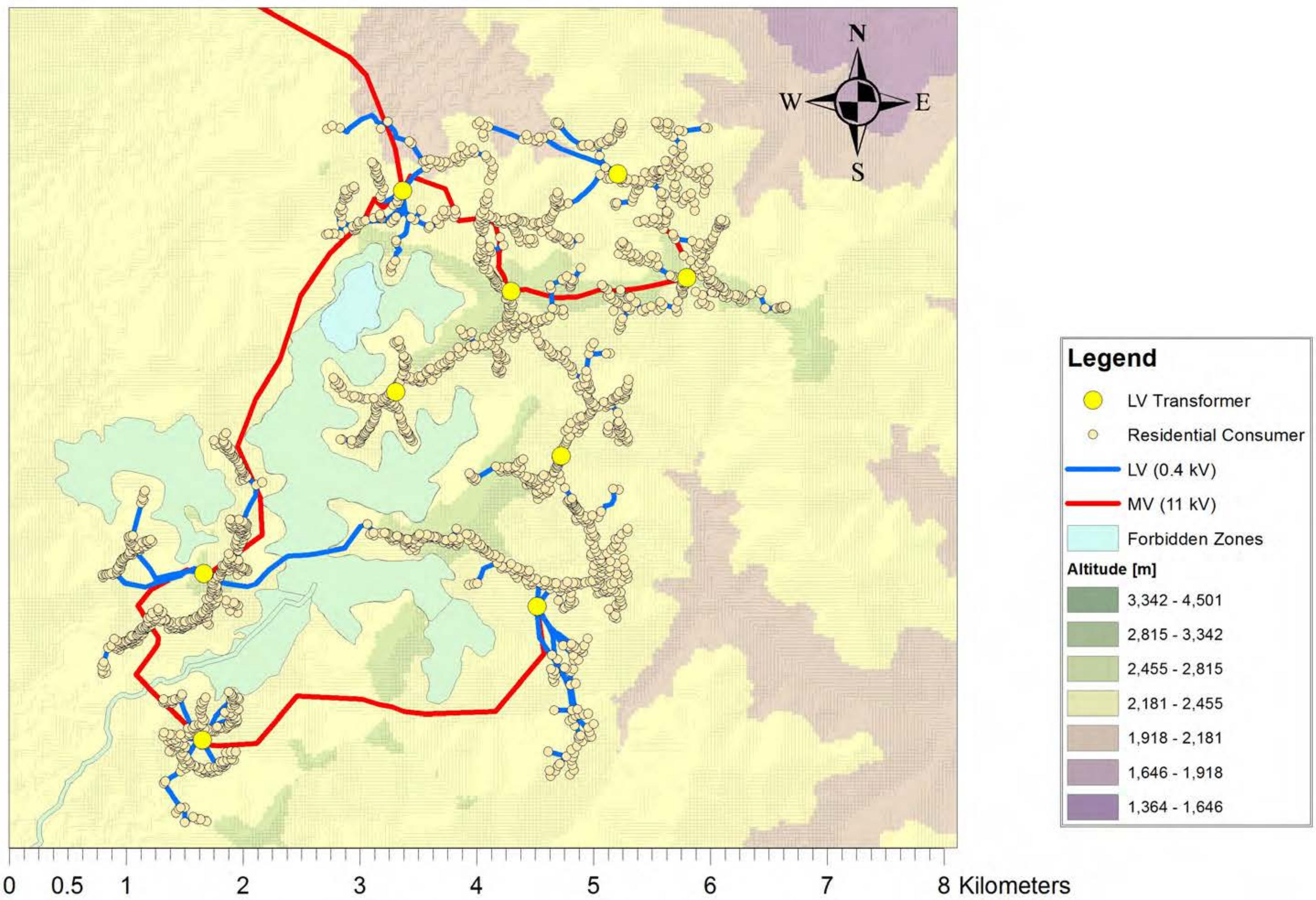
Topography: YES
Forbidden Zones: NO
Forbidden Zone Cost Multipliers: N/A



Topography: YES
Forbidden Zones: YES
Forbidden Zone Cost Multipliers: 10



Topography: YES
Forbidden Zones: YES
Forbidden Zone Cost Multipliers: 100



Sensitivity analysis
For both large scale & village levels

The model can be used to answer “**what if questions**” by comparison of various scenarios

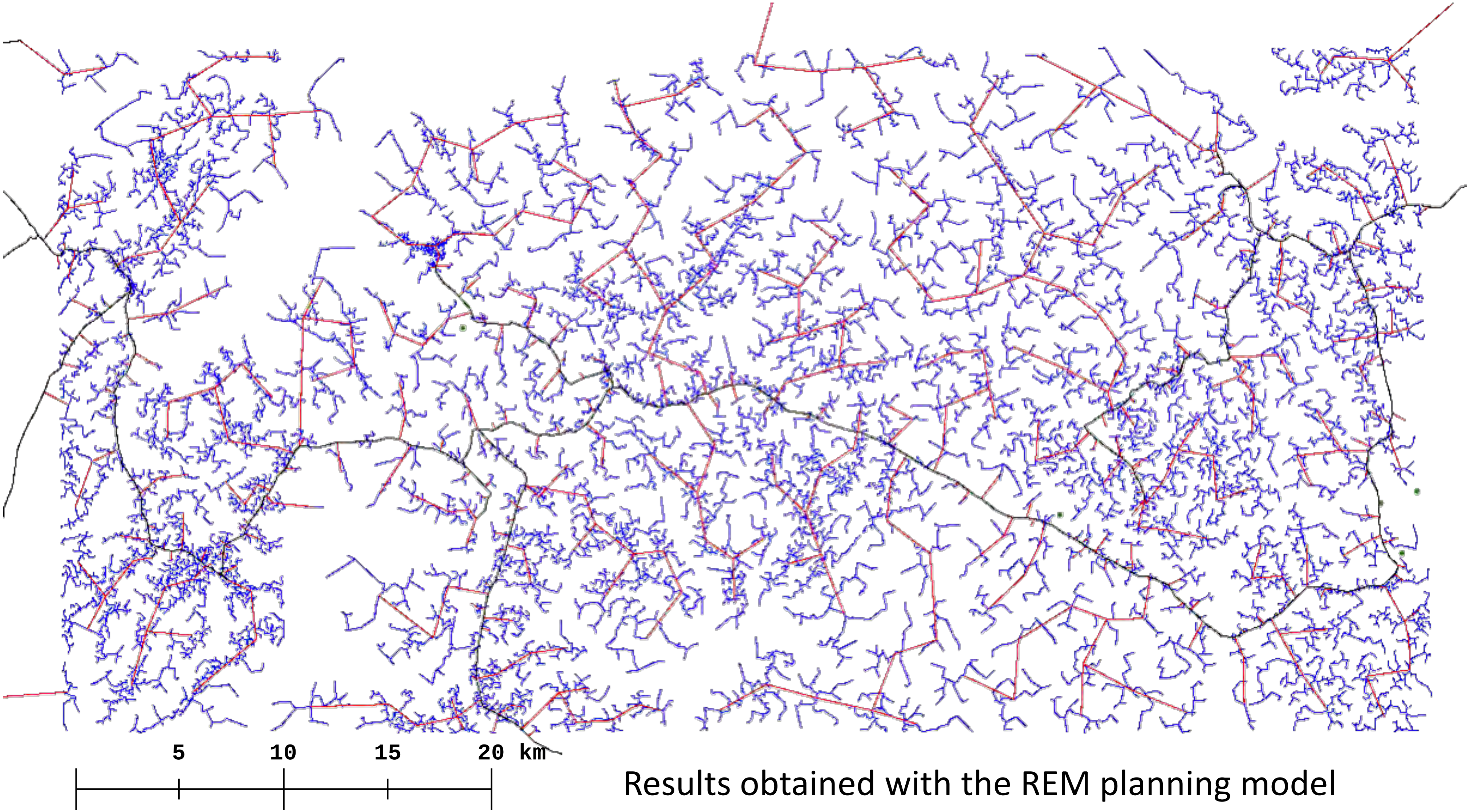
For example, how would the optimal electrification mode change if…

- … grid **reliability** improves?
- … electricity **demand grows** significantly?
- … microgrids are required to be built to **grid code**?
- … some **technology** (e.g. diesel, DC) is excluded?

Uganda

(Southern Territories)

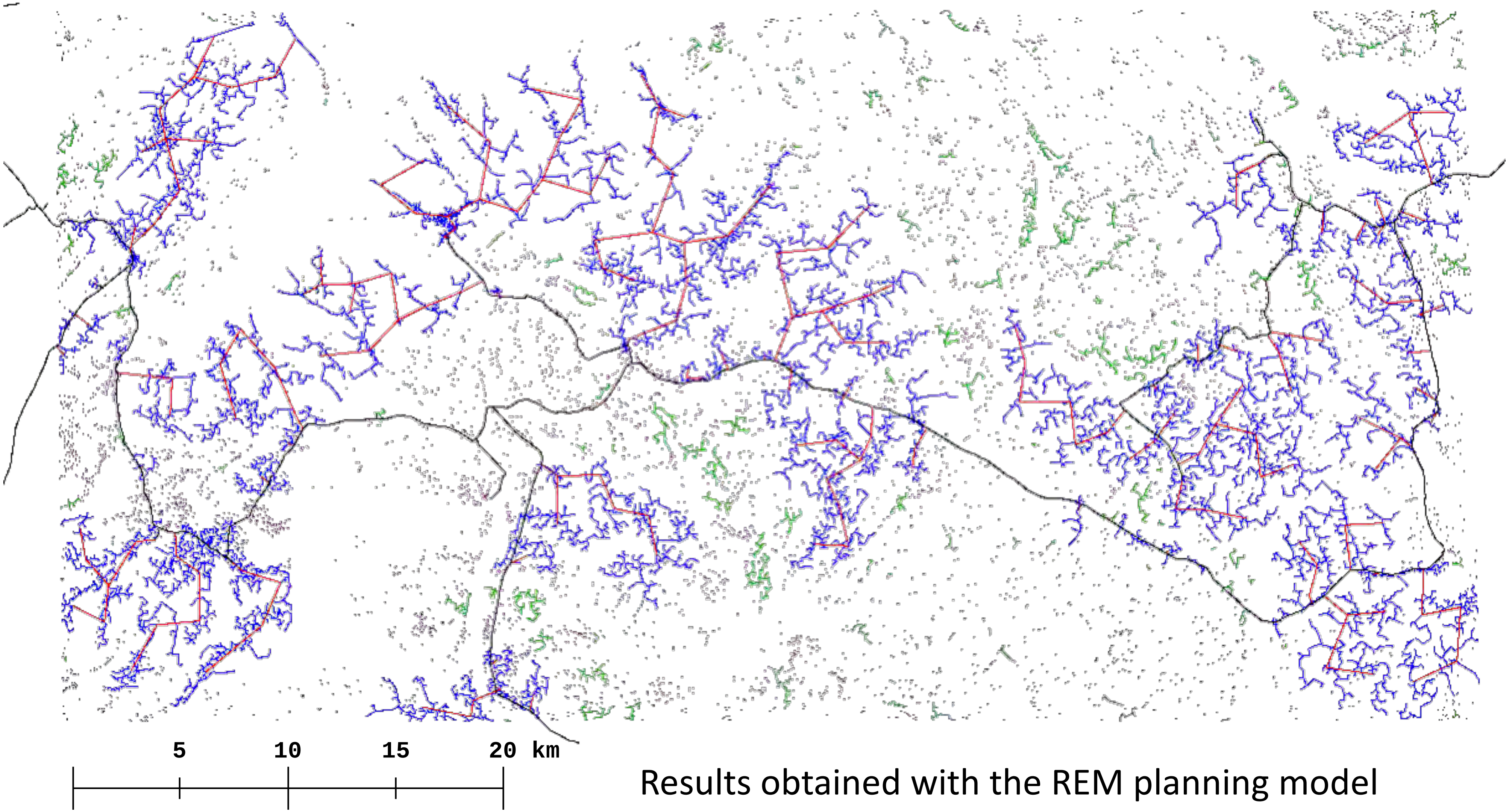
Uganda – Southern territories
Forced 100% Grid Extension



Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main

Extension 11kV | Extension 400V | Microgrid 11kV | Microgrid 400V | Stand-Alone

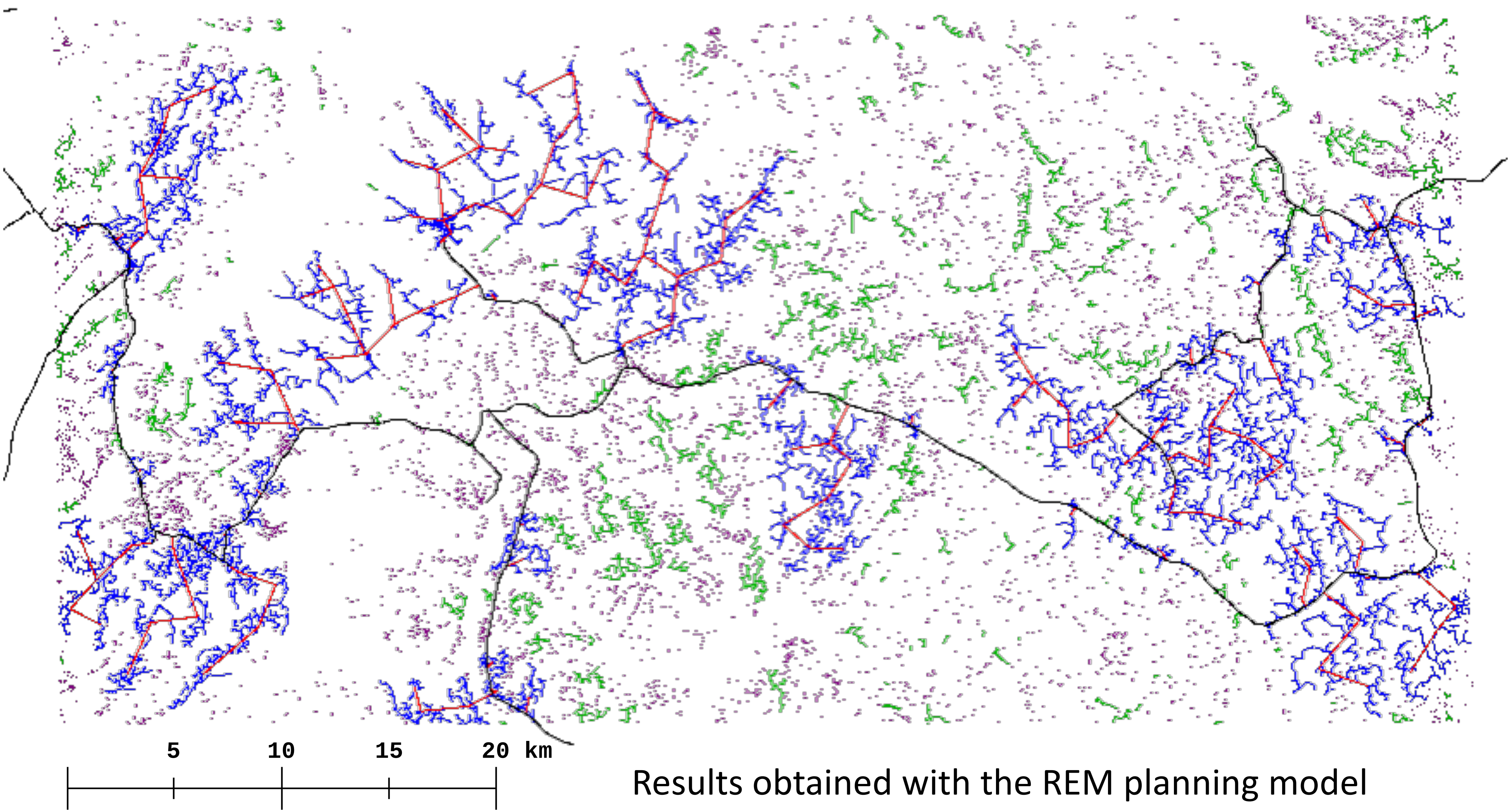
Uganda – Southern territories
100% Grid Reliability



Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main

Extension 11kV | Extension 400V | Microgrid 11kV | Microgrid 400V | Stand-Alone

Uganda – Southern territories
85% Grid Reliability



Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main

Extension 11kV | Extension 400V | Microgrid 11kV | Microgrid 400V | Stand-Alone

Cajamarca

(Peru)

The Cajamarca region

- The region of Cajamarca is located in the north of Peru and close to Ecuador.
- The case study focus on the Michiquillay district.
- It has an area of approximately 400 km^2 and around 6,700 buildings.

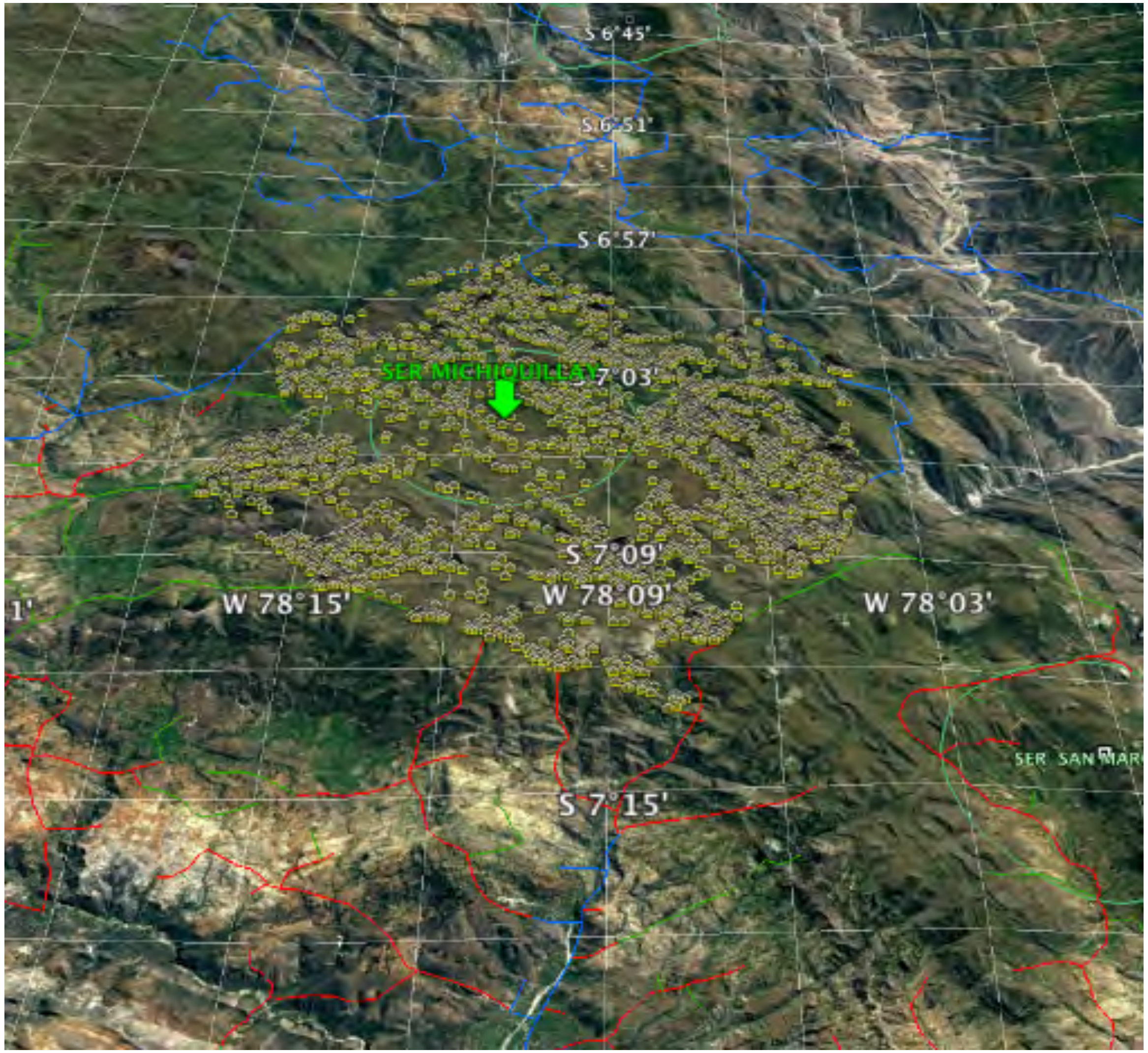
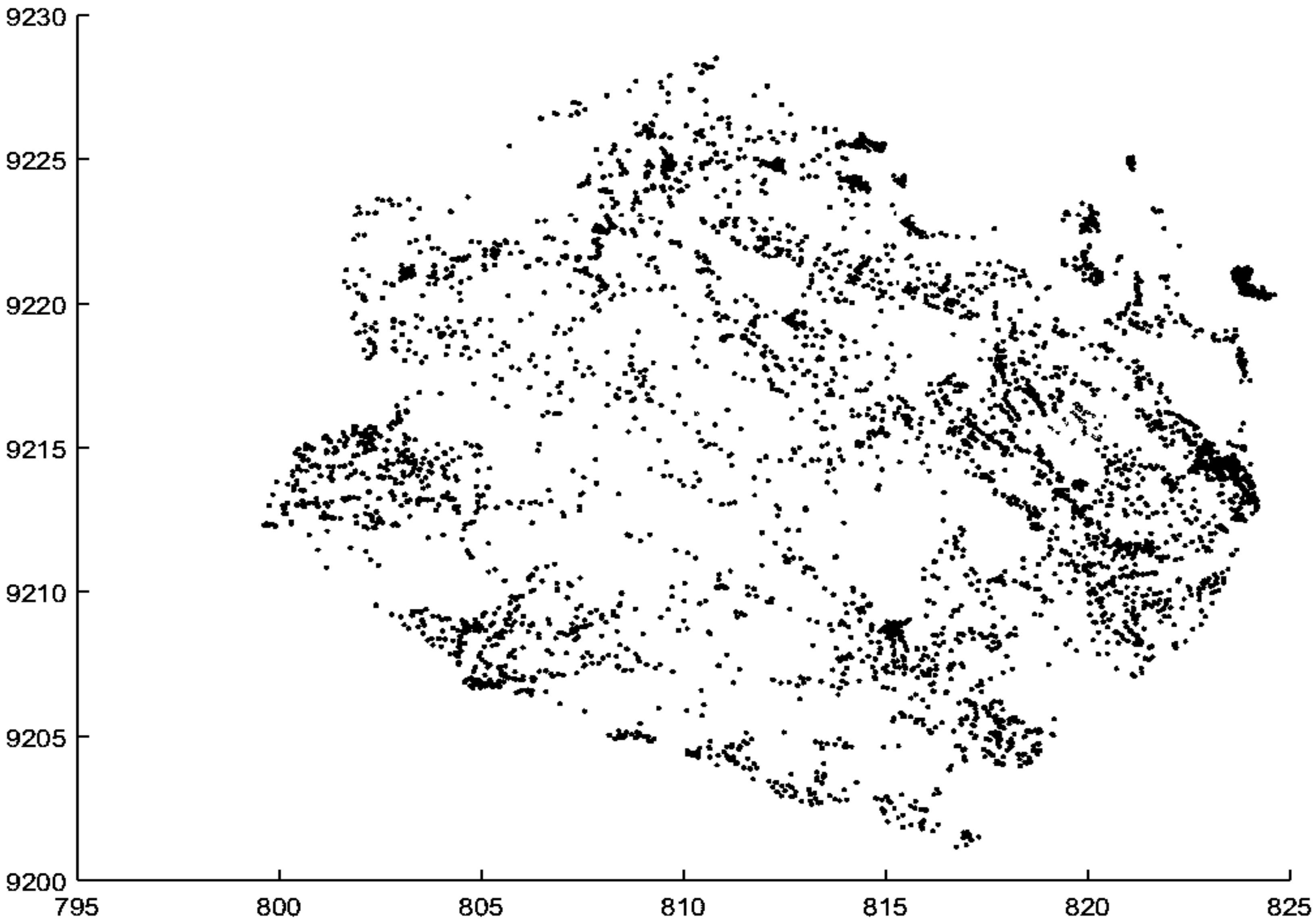


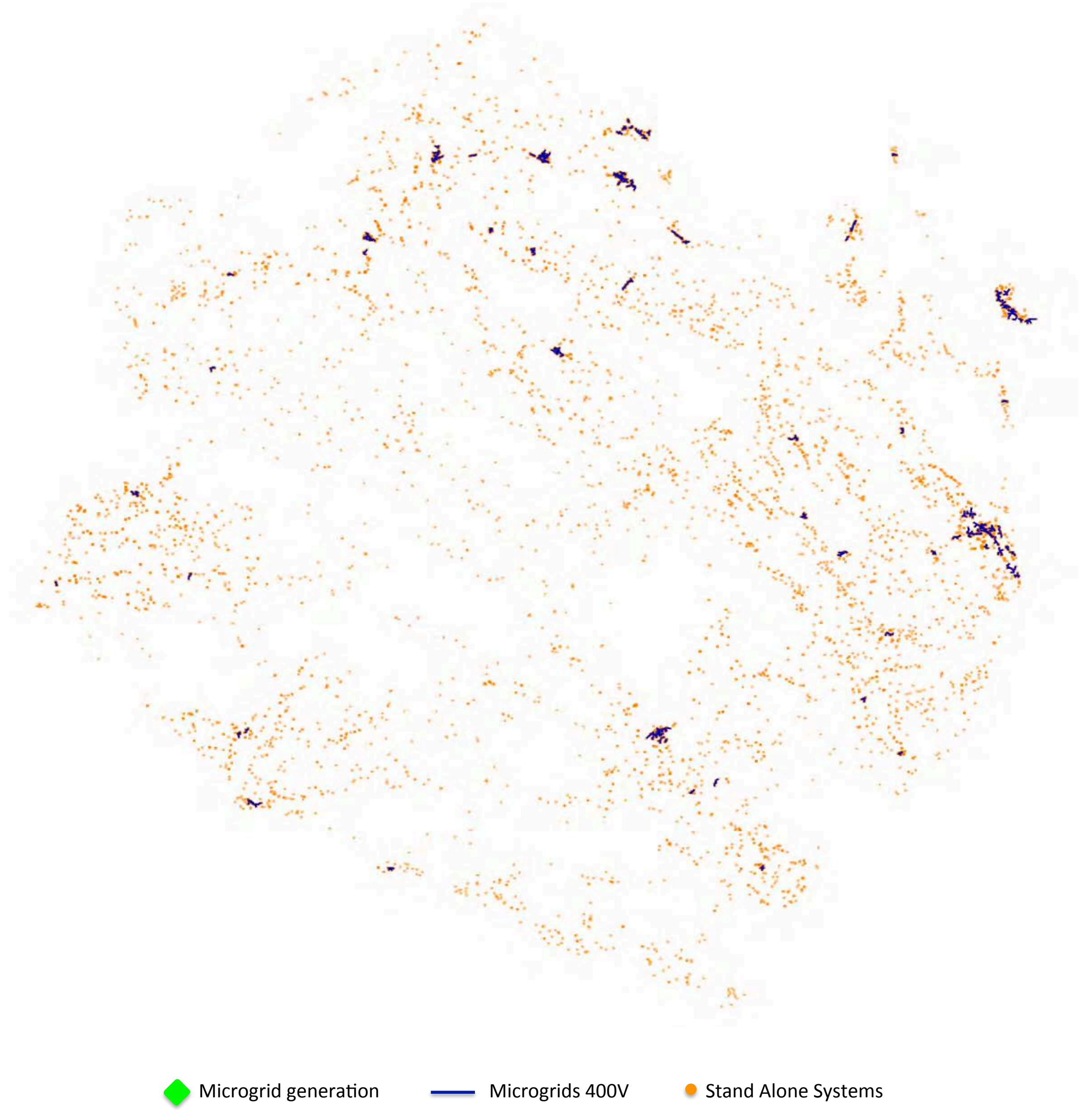
Image source: Andres Gonzalez-Garcia, Reja Amatya, Robert Stoner, and Ignacio Perez-Arriaga, 'Evaluation of universal access to modern energy services in Peru. Case study of scenarios for Electricity Access in Cajamarca.' Enel Foundation, 2015.

Cajamarca *(Peru)*
Location of buildings

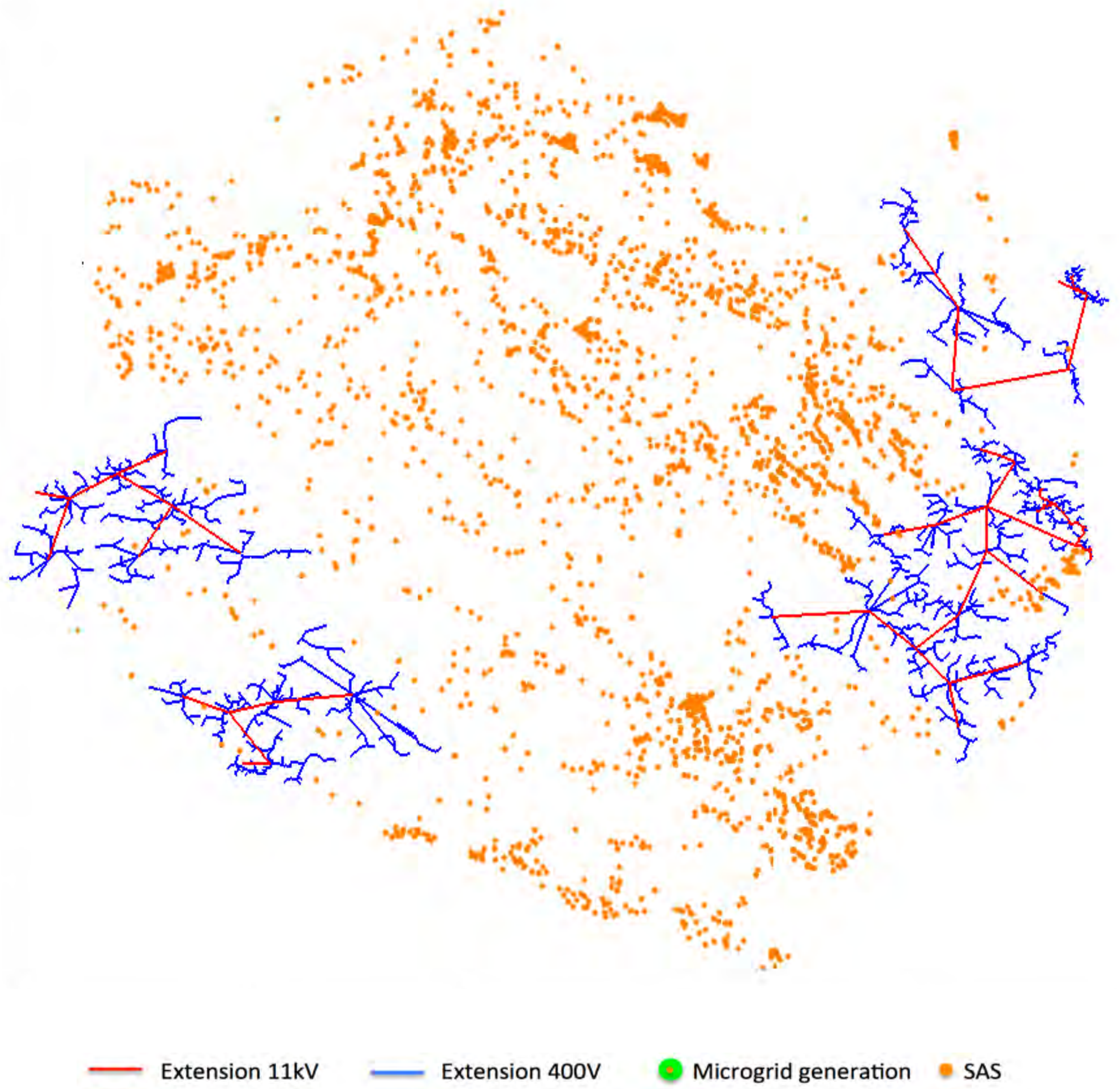


Cajamarca *(Peru)*

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



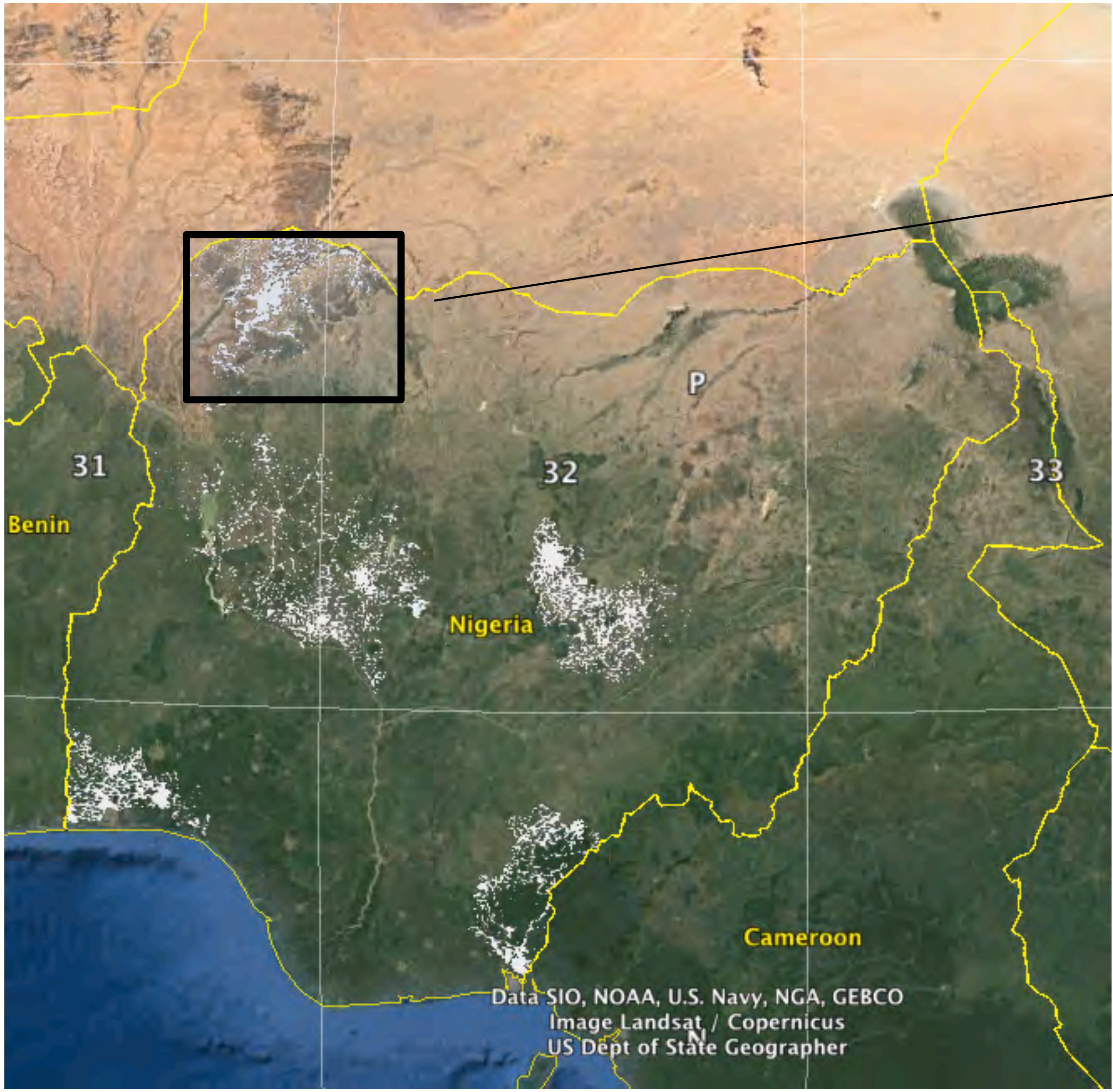
Cajamarca *(Peru)*
Demand growth *(500 kWh/year & household)*



Nigeria

(Identification of best mini grid sites in Sokoto)

Google Earth With UTM regions



- Sokoto region:
  - 2 UTM zones (31/32)
- Village-level boundary data and additional information such as population, number of schools & health centers available

Sokoto State data

- Total population: 4.37 million
- 1,503 clusters (clusters identified using global population dataset, NMIS school data, and polling units)
- Largest cluster 904,798 population – identified as an electrified cluster
- Largest cluster 29,865 population (~ 6000 hh) – identified as unelectrified cluster
- Total number of electrified clusters: 167 (12.5%)
- Total population electrified: 2.33 million (53%)

Assumptions:

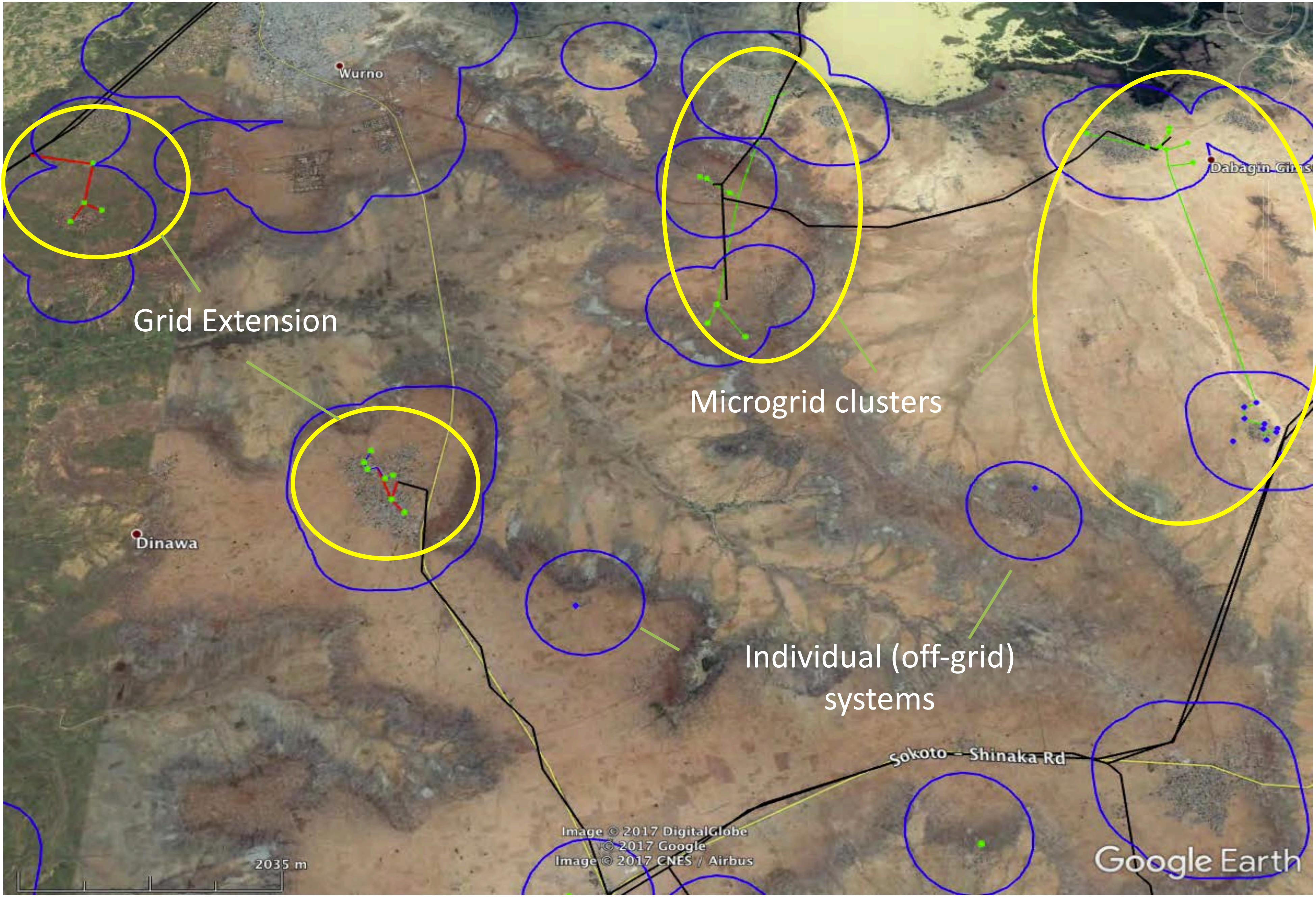
- Household population = 5 people (* given population is not a round number – probably came from some statistical measurement)
- Electrified village cluster data provided by the WB (based on nightlight data, and information about electrified schools)

Run 1 (Base case; grid reliability: 85%)

- Grid reliability = 85% (assumption)
- Result: 15% of the demand nodes created should be grid connected as it is the least cost option, rest should be off-grid systems
- At this level of granularity, there is no distinction between a microgrid and an isolated system, as a single isolated system in a green dot would be a microgrid for 100 household customer.

Column1	Microgrids	Isolated Systems	Grid Extensions	All
Number of Customers (#households)	2156	1792	688	4636
Fraction of Customers	0.47	0.39	0.15	1
NPV per Customer ($)	61756	24422	31340	42811
System Cost Per Customer ($/yr)	6315.11	3677.07	2628.21	4748.25
Administrative Cost Per Customer ($/yr)	49.3	60	9.02	47.46
Non-served Energy Cost Per Customer ($/yr)	8	20.67	3453.2	524.18
Final Cost Per Customer ($/yr)	6372.41	3757.74	6090.43	5319.89
Total System NPV ($)	133145465	43764702	21562187	198472353
Total System Cost ($/yr)	13615377	6589305	1808208	22012890
Total Administrative Cost ($/yr)	106290	107520	6206	220016
Total Non-served Energy Cost ($/yr)	17254	37038	2375802	2430095
Final Cost ($/yr)	13738921	6733863	4190217	24663001
Fraction of Demand Served (p.u.)	1	1	0.85	0.98
Cost Per kWh of Demand Served ($/kWh)	0.22	0.22	0.13	0.21
Cost Per kWh of Total Demand ($/kWh)	0.22	0.22	0.11	0.2

Resulting electrification modes

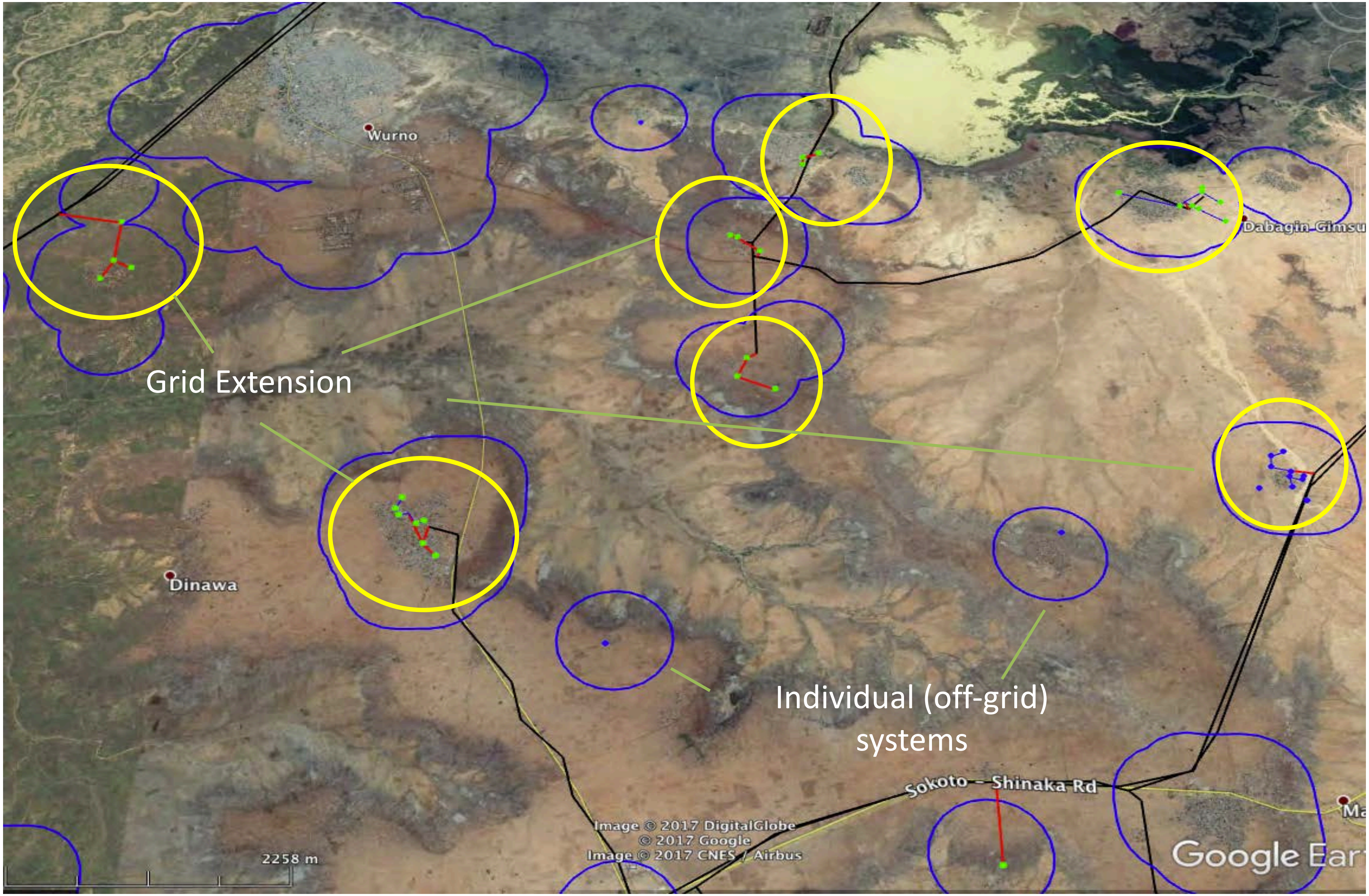


Run 2 (increasing grid reliability to 90%)

- Grid reliability = 90% (assumption)
- Result: 64% of the demand nodes created should be grid connected as it is the least cost option, rest should be off-grid systems

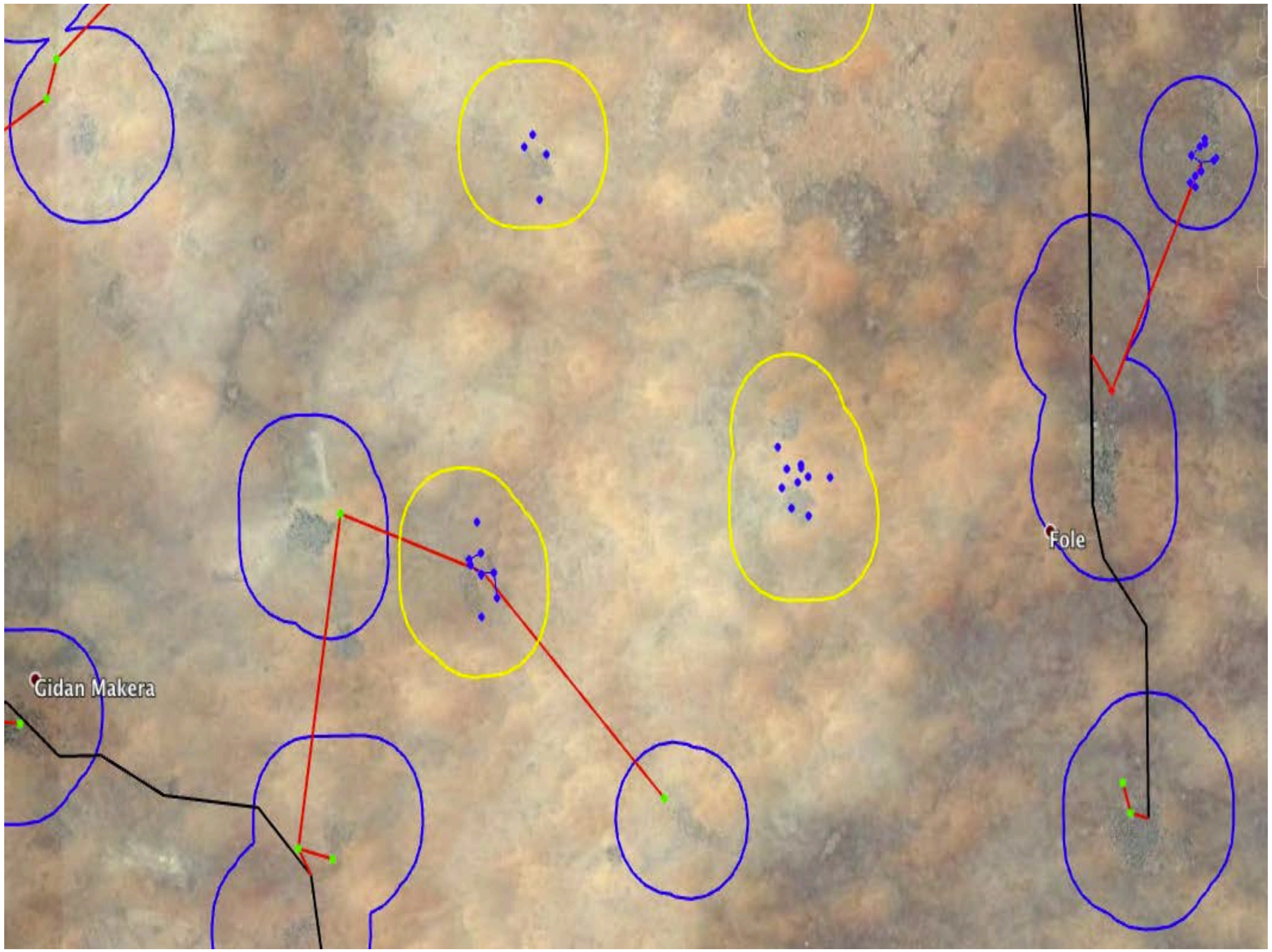
Column1	Microgrids	Isolated System	Grid Extensions	All
Number of Customers	335	1329	2972	4636
Fraction of Customers	0.07	0.29	0.64	1
NPV per Customer ($)	20956	7358	40843	29807
System Cost Per Customer ($/yr)	2142.92	1107.77	3425.11	2668.15
Administrative Cost Per Customer ($/yr)	54.88	60	9.02	26.95
Non-served Energy Cost Per Customer ($/yr)	10.65	20.37	3272.41	2104.45
Final Cost Per Customer ($/yr)	2208.44	1188.14	6706.54	4799.55
Total System NPV ($)	7020161	9778228	121385860	138184249
Total System Cost ($/yr)	717878	1472230	10179438	12369546
Total Administrative Cost ($/yr)	18384	79740	26810	124935
Total Non-served Energy Cost ($/yr)	3566	27074	9725593	9756233
Final Cost ($/yr)	739828	1579044	19931841	22250714
Fraction of Demand Served (p.u.)	1	0.99	0.9	0.91
Cost Per kWh of Demand Served ($/kWh)	0.26	0.29	0.11	0.12
Cost Per kWh of Total Demand ($/kWh)	0.26	0.29	0.1	0.11

Resulting electrification modes



440 village clusters are always electrified via off-grid systems

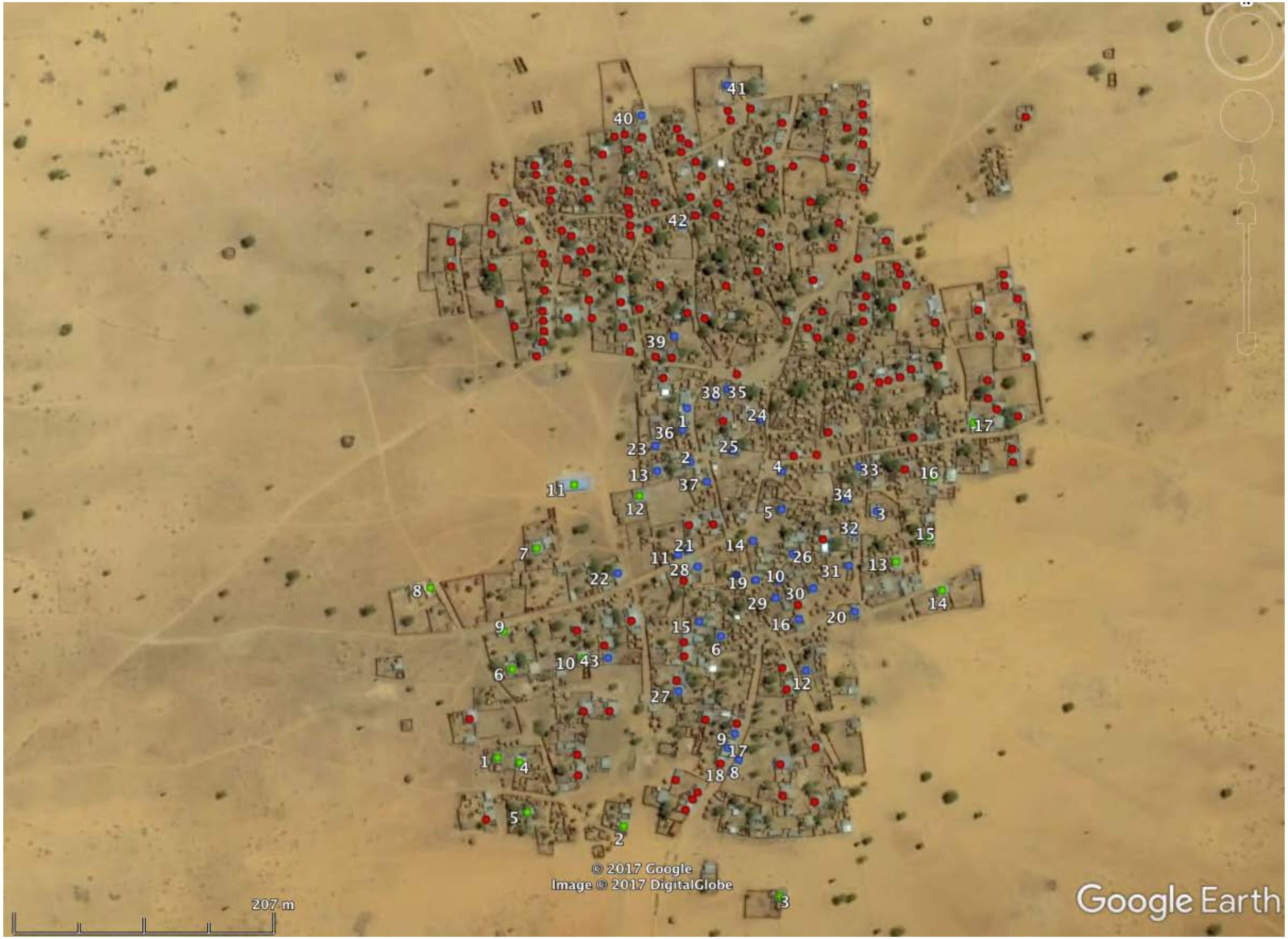
(even with high reliable grid scenario)



- Clusters in blue boundaries – grid connected
- Clusters in yellow/green – some or all off-grid nodes
- Current granularity level does not allow for distinction between isolation home systems and microgrids – all compiled as off-grid systems
- High priority off-grid project – probably the ones where all demand nodes are served by off-grid systems (440 village clusters)

Now for a single mini grid

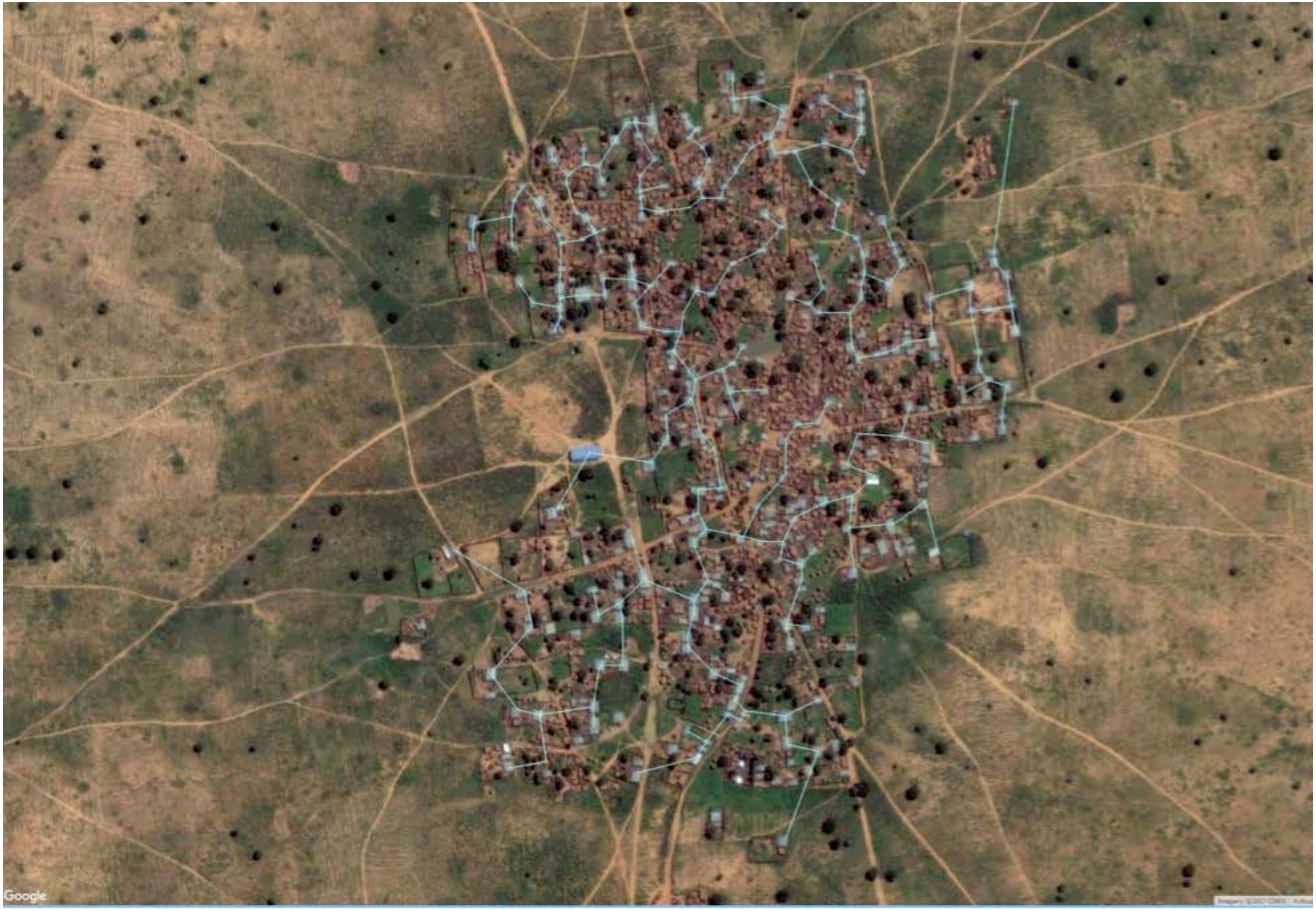
(manually identified households from Google Earth)



Chosen cluster

- Cluster NESP_ID 7379
- Population: 833
- Total number of customers *(assumption)*:
  - Residential: 170 (Daily energy usage ~ 0.75kWh)
  - Commercial: 43 (Daily energy usage ~ 3.5 kWh)
  - Productive: 17 (Daily energy usage ~ 8.5 kWh)

REM result (with network layout)

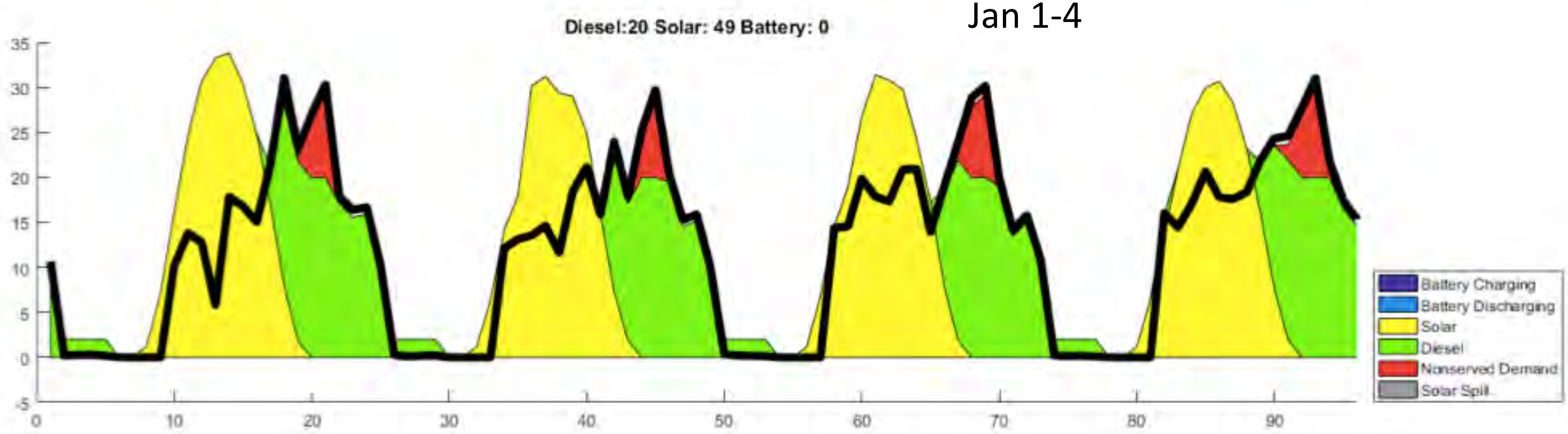


REM results (no diesel constraint)

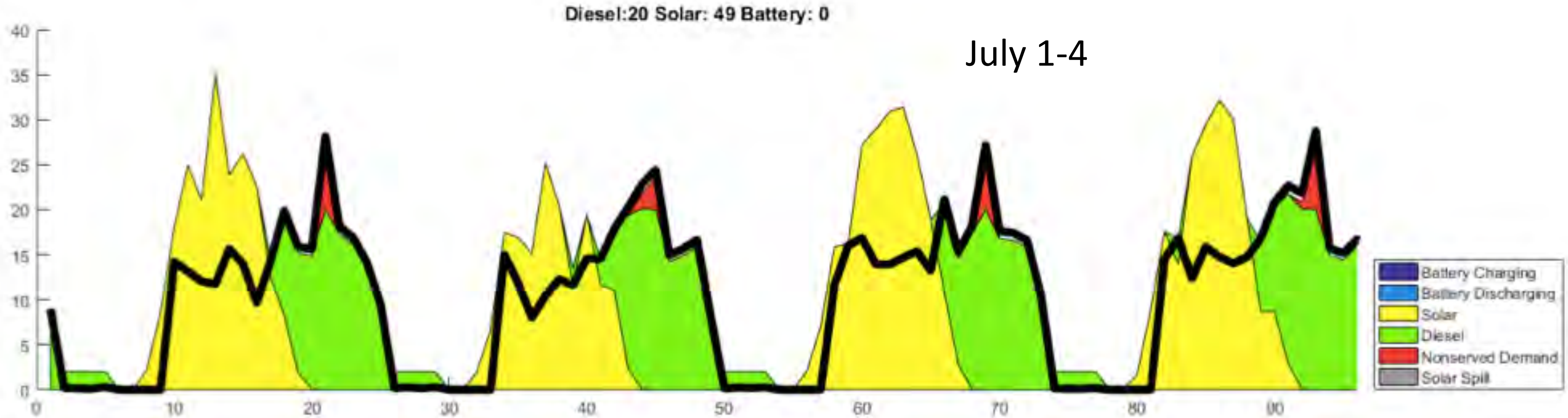
Capital cost:		
	Size	Capital (USD $)
Solar PV + installation	49 kW	34,300
Battery + installation	-	-
Diesel Generator	20 kW	12,127
Inverter	40 kW	8,192
MPPT Charge controller	-	-
Network + distribution transformers (incl. poles cost)	4.89 km	65,956
Total		120,575
Network (component breakdown)		
Name	Length (km)	Capital (USD $)
Weasel	4.14	49,638
Ferret	0.30	3,916
Rabbit	0.39	5,513
Dog	0.02	346
Panther	0.04	977

Microgrid (generation/load profile)

Jan 1-4



July 1-4



Diesel constrained scenario

Limiting the total demand met by diesel generator

	20% constraint		No constraint	
Capital cost:				
	Size	Capital (USD $)	Size	Capital (USD $)
Solar PV + installation	92.75 kW	64,925	49 kW	34,300
Battery + installation	488 kWh	105,900	-	-
Diesel Generator	5 kW	5,760	20 kW	12,127
Inverter	36 kW	7,532	40 kW	8,192
MPPT Charge controller		9,811		
Network + distribution transformers	4.89 km	65,862	4.89 km	65,956
Total		259,790		120,575
Net Present Value (incl. replacement, O&M, fuel costs: project lifetime = 20 years) **		370,000		183,350

** Does not include network (capital, O&M)

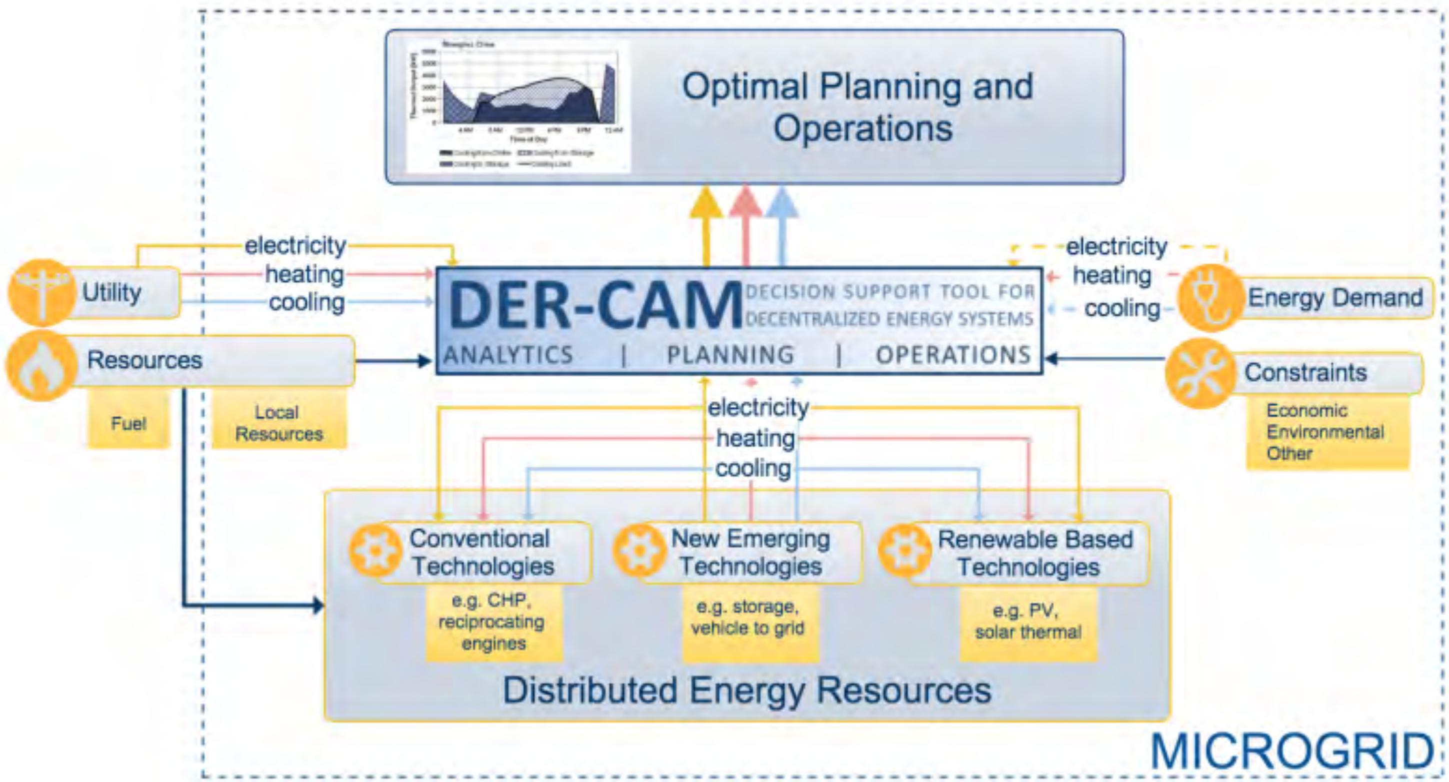
Some other practical constraints of having a diesel generator – such as uncertainty in fuel supply, theft of fuel etc. has not been captured in the cost of running a diesel generator

Any similar models to LittleREM?

Models similar to LittleREM

HOMER ENERGY

RETScreen® International



Any similar models to BigREM?

Models similar to BigREM

- **NP** (Network Planner, from Columbia University)
  – Uses LandScan data & or clusters at village level to describe where population (& therefore demand) are located
    - Therefore less granularity then REM, but still good
  – Only considers one type of medium voltage line
  – Professional interface

Models similar to BigREM

- **LAPER** (Logiciel d’ Aide à la Planification de l’Électrification Rurale)
  - Also aggregates consumers into villages and does not design the interior of the village.
    - Therefore less granularity then REM
  - It can consider non-economic criteria
- **NPAM** (Network Performance Assessment Model, from KTH) does clustering to identify locations suitable for microgrids.

Thank you

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FRONTEER DEVELOPMENTSIN MINI GRIDS

Geospatial planning

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