The AI Revolution and the Future of Electrification

Planning with Models, Satellites, and Machine Learning Tools

February 25, 2019, Asian Development Bank Innovation Speakers' Series

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Fellow, Energy for Growth Hub
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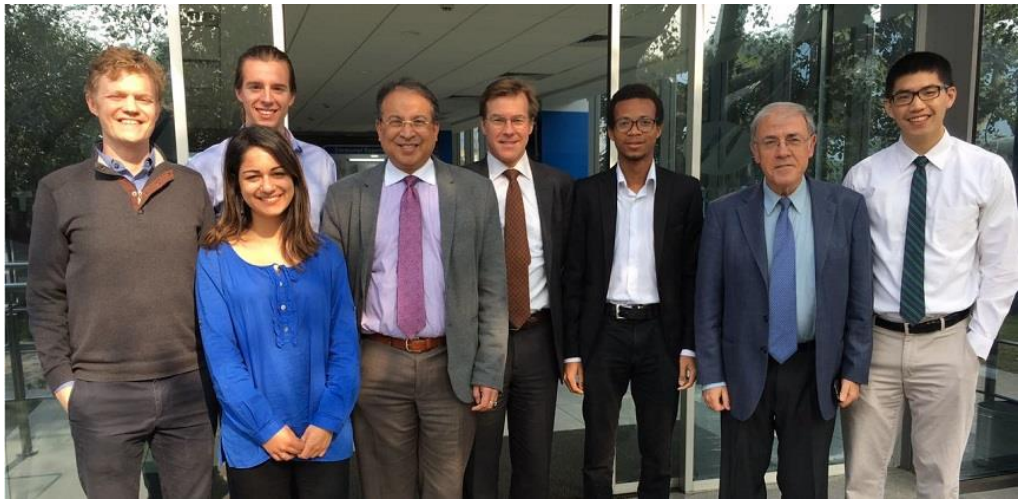
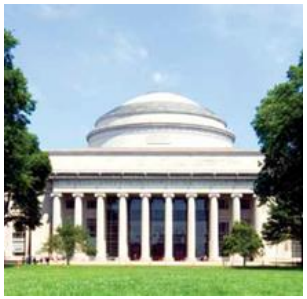
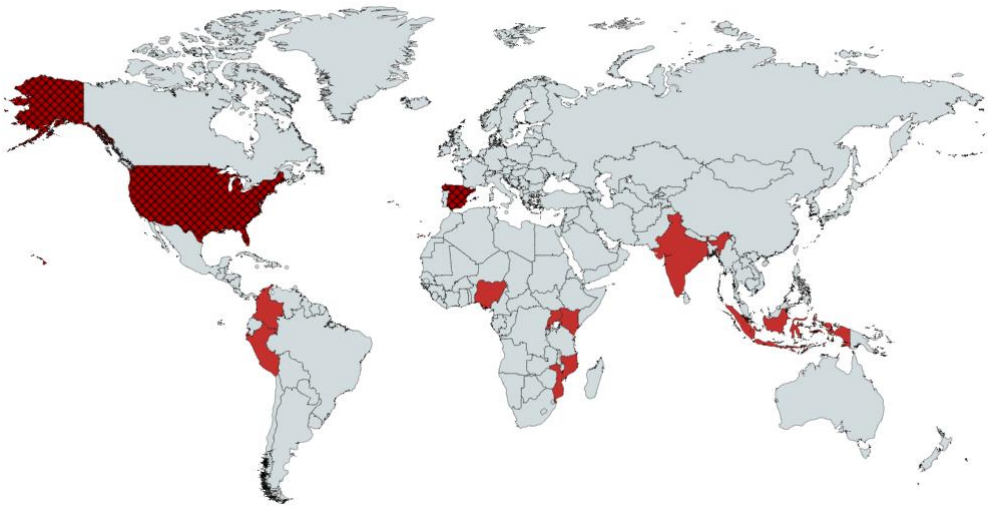
MIT-Comillas Universal Energy Access Lab
Cambridge MA, USA and Madrid, Spain







Universal Access | Team | Inference Tools | REM | Our Projects | Regulation & Business Models | Teaching, Papers, Media | Contact & About

Teaching

- Fall 2018: MIT Graduate subject, "Engineering, economics and regulation of universal energy access in developing countries"
- Spring 2018: Florence School of Regulation online course "Regulation for universal access to energy." Course website
- Spring 2017: MIT graduate subject, "Planning, Policy, and Technology for Energy Access in Developing Countries" for Spring 2017. Course flyer and website

Publications

[18] **Optimal Electrification Planning Incorporating On- and Off-Grid Technologies: The Reference Electrification Model (REM)** (P. Ciller, D. Ellman, C. Vergara, A. González, S. Lee, C. Drouin, M. Brusnahan, Y. Borofsky, C. Mateo, R. Amatya, R. Stoner, F. de Cuadra, I. Pérez-Arriaga), *Proceedings of the IEEE, Submitted* (2018)

[17] **Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM).** (MIT-Comillas Universal Energy Access Laboratory), *IIT WP 188 112-A* (2018) [link]

[16] **Electrification planning with a focus on human factors** (R. Rahnama, I. Perez-Arriaga), *Oxford Energy Forum – Electrifying Africa, Issue 115* (2018) [pdf]

[15] **One size does not fit all: New business models for universal electricity access** (I. Perez-Arriaga, G. Jacquot), *Open Africa, Accepted* (2018)

[14] **Stochastic sizing of isolated rural mini-grids, including effects of fuel procurement and operational strategies** (D. Fioriti, R. Giglioli, D. Poli, G. Lutzemberger, A. Micangeli, R. Del Citto, I. Perez-Arriaga, P. Duenas-Martinez), *Electric Power Systems Research* (2018) [link]

In the Media

- Empowered Planning with Models, Satellites, and Machine Learning (Energy for Growth Hub, November 2018)
- Tata Power Delhi Distribution launches microgrid project in Bihar village (ETEnergyWorld, January 2017)
- Modeling Solutions to Energy Access Problems (Development Seed Blog, May 2016)
- Going off grid: Tata researchers tackle rural electrification (MIT News, January 2016)
- India's Energy Crisis (MIT Technology Review, October 2015)
- Rural Electrification in Rwanda: Technical and Policy Challenges (The Energy Collective, October 2015)

Website: universalaccess.mit.edu

The Energy for Growth Hub, Washington D.C.

Global research network dedicated to the idea that all countries need a high-energy future to become prosperous and economically competitive.

Website: energyforgrowth.org

AI: Hype or Help?

"Just as electricity transformed almost everything 100 years ago, today I actually have a hard time thinking of an industry that I don't think AI will transform in the next several years."

– Prof. Andrew Ng, Stanford, Co-founder of Coursera

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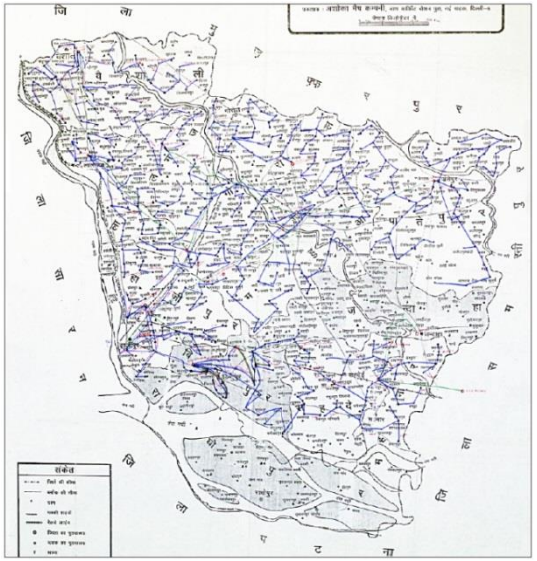
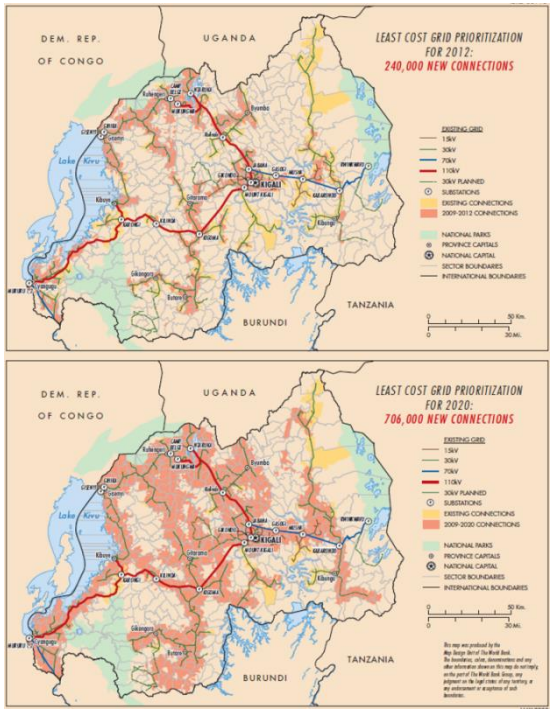
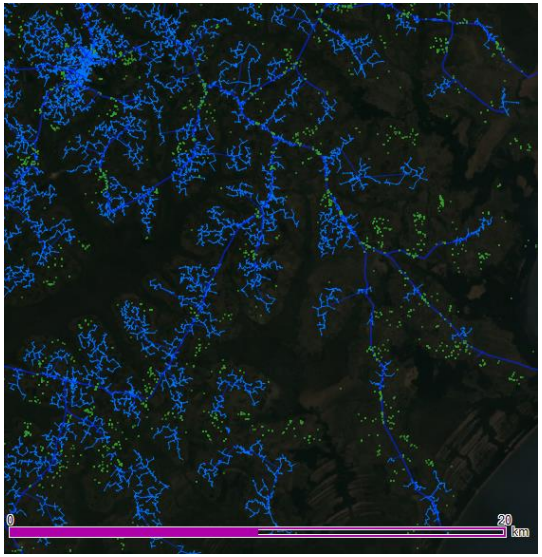
Optimization-based methods represent a new paradigm in master electrification planning







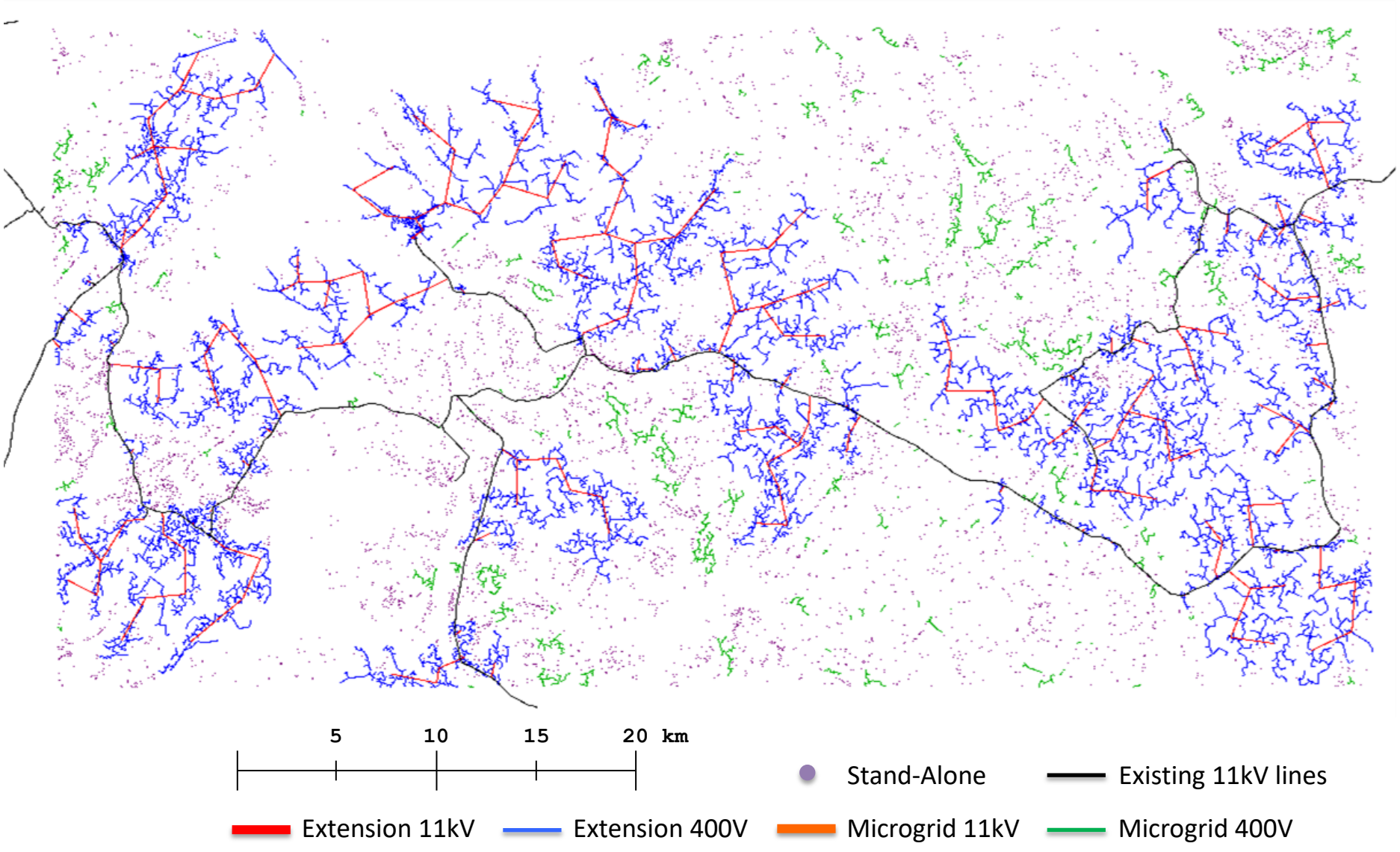
Traditional master plans
- Can take 2 to 3 yrs
- Cost >$2 MM[1]

GIS-based plans
- Can take ~1 yr[2]
- Cost ~$1 MM[1]

Optimization-based plans
- Weeks, days, or hours[3]
- A fraction of this cost[4]

[1]Independent Evaluation Group, "Reliable and Affordable Off-Grid Electricity Services for the Poor: Lessons from the World Bank Group Experience." Technical report, World Bank (2016).
[2]Plans for Rwanda and Kenya
[3]Provided requisite network input data
[4]Static plans can be produced by trained local personnel for no cost; consulting costs vary

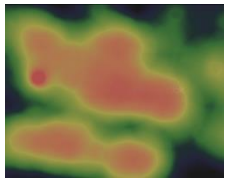
Example large scale REM output in Uganda



Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

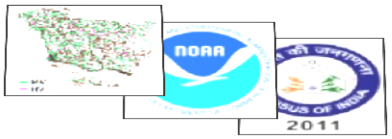
Demand Characterization

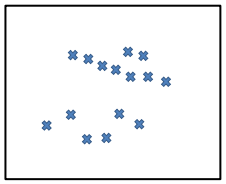
Supply Characterization



Building Extraction

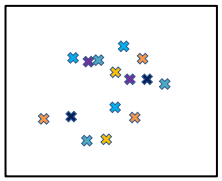
Load Localization

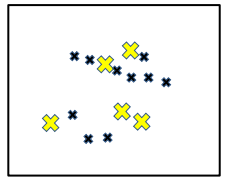


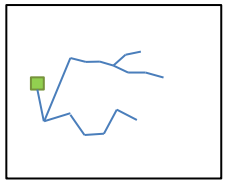


Demand Classification

Electrification Status Estimation





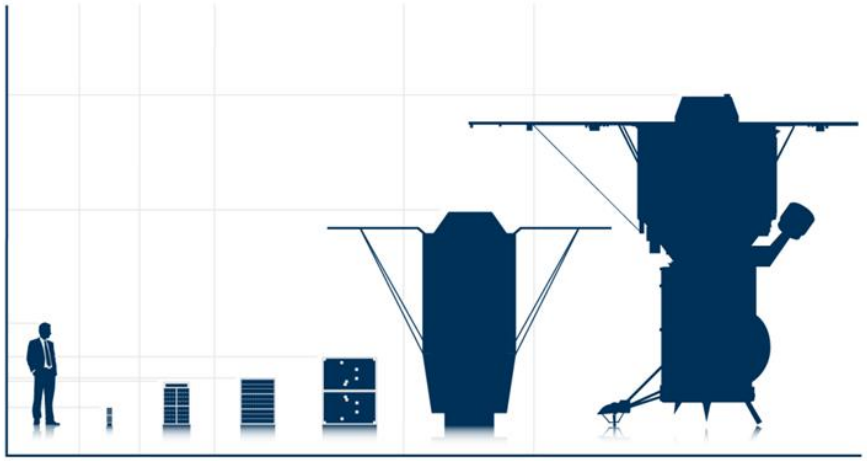


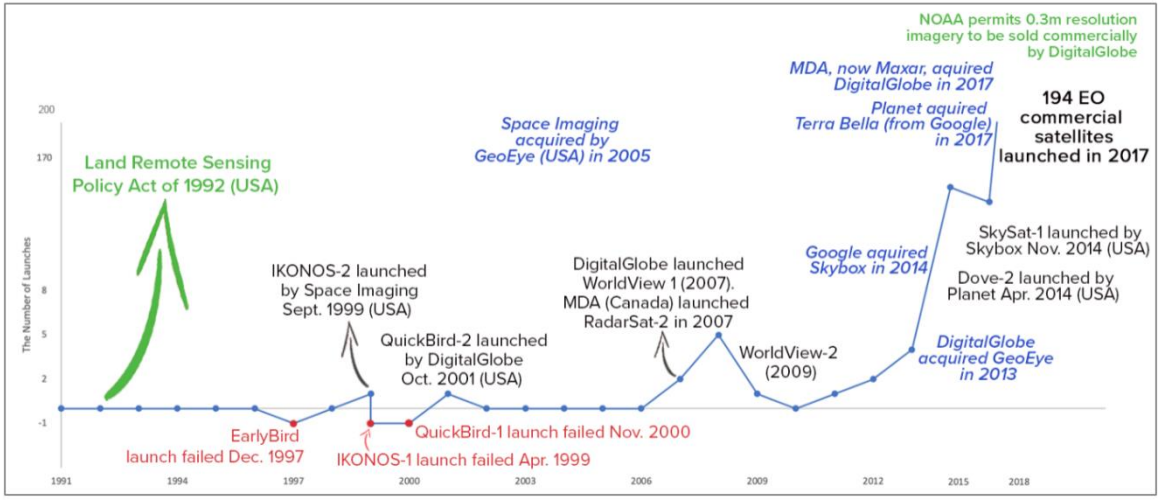
Reference Electrification Model Core (clustering, RNM, etc.)

Validation and Fine-Tuning

Optimization and Planning

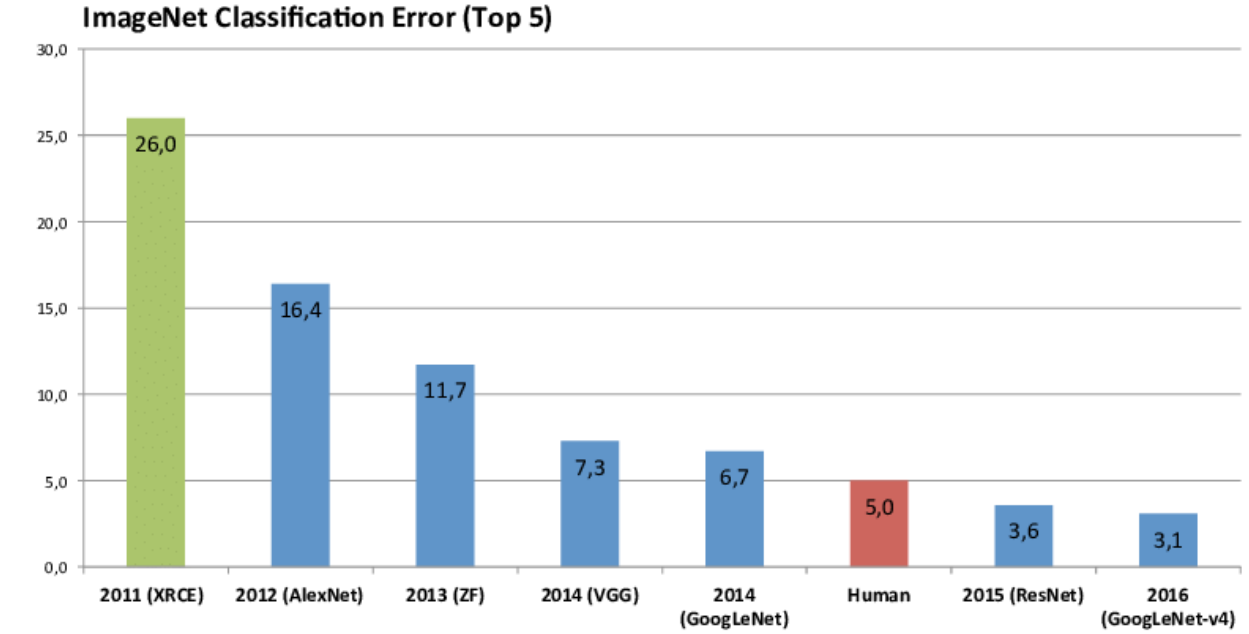
The availability of satellite imagery is rapidly improving at all spatial and temporal resolutions





Sources: https://earthobservatory.nasa.gov/world-of-change/Deforestation
http://blog.digitalglobe.com/news/frequently-asked-questions-about-worldview-4/
https://medium.com/radiant-earth-insights/commercial-entrants-are-driving-innovation-in-earth-observation-and-that-is-all-good-f755e2433ae6

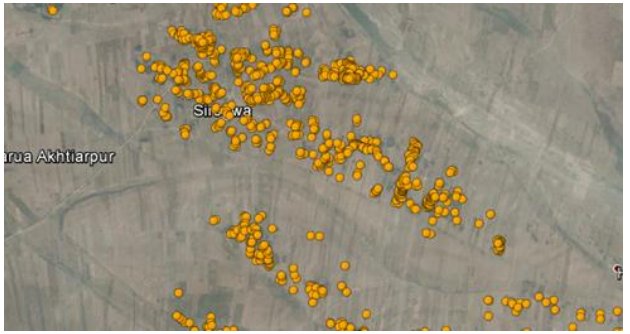
Deep learning-based computer vision systems now surpass human abilities in many applications



Sources: http://www.image-net.org/
von Zitzewitz, Gustav. (2017). Survey of neural networks in autonomous driving.

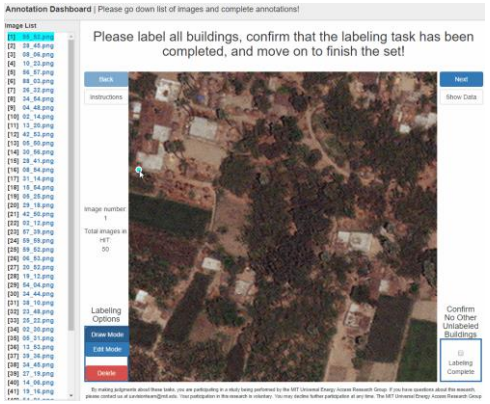
Automatic building extraction methods enable rapid planning capabilities for large regions

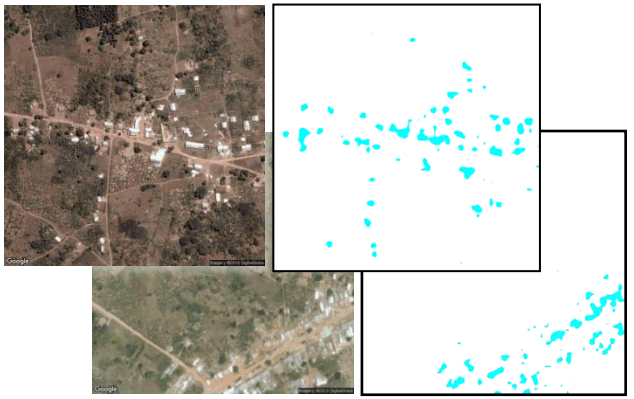
Field-based georeferencing
- $0.50-2.00/building[1]
- Months/region



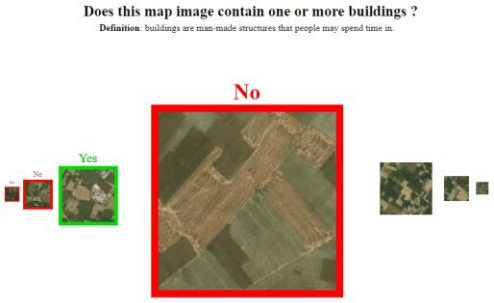
Manual image labeling
- $0.10-0.20/building[1]
- Days to weeks/region

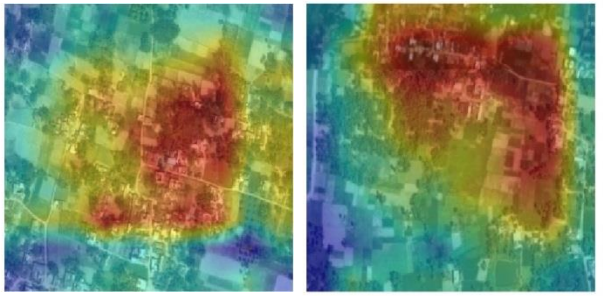
Semantic segmentation
- Negligible cost
- Hours/region
- Higher accuracies
- Poor generalizability



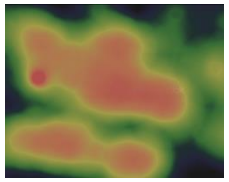


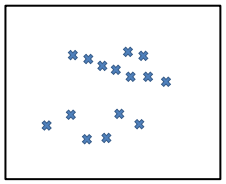
Grad-CAM heatmaps
- Negligible cost
- Hours/region
- Lower accuracies
- Improved generalizability

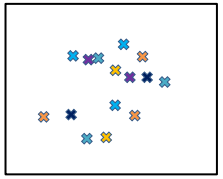


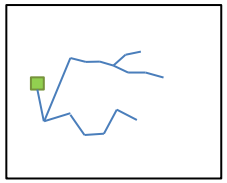


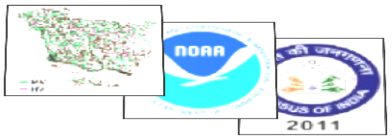
[1]Prices quoted based off of data provider, Development Maps, associated with UK-based Village Infrastructure http://www.developmentmaps.org/
Source: Lee, S., "Adaptive Electricity Access Planning." Massachusetts Institute of Technology (2018)

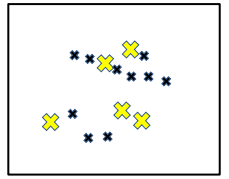












Demand Characterization

Supply Characterization

Building Extraction

Load Localization

Demand Classification

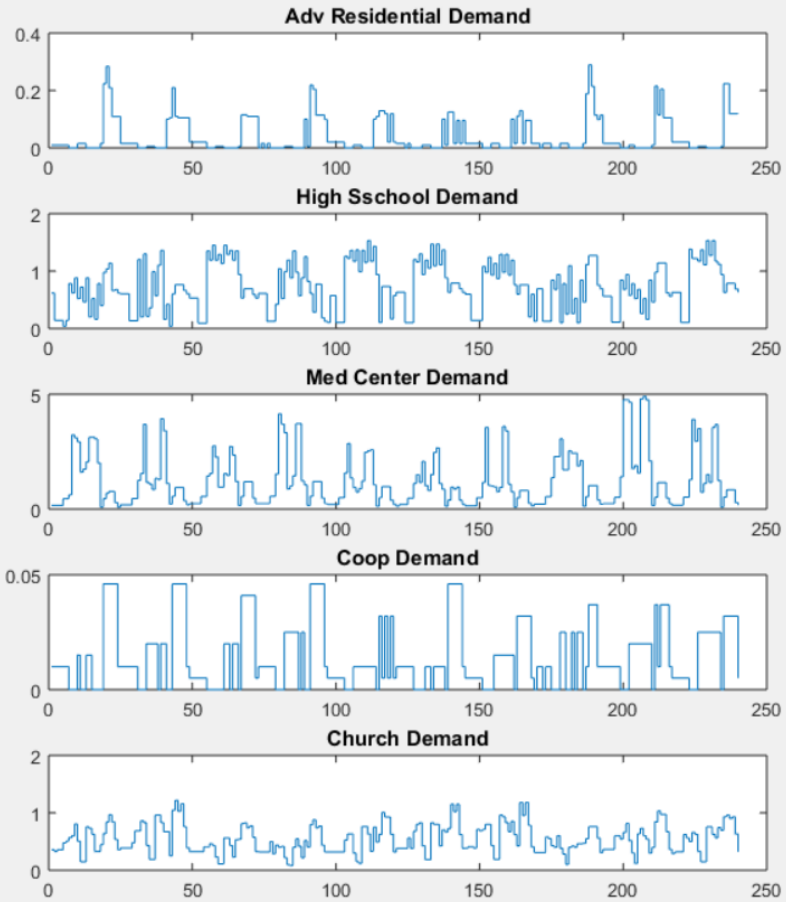
Electrification Status Estimation

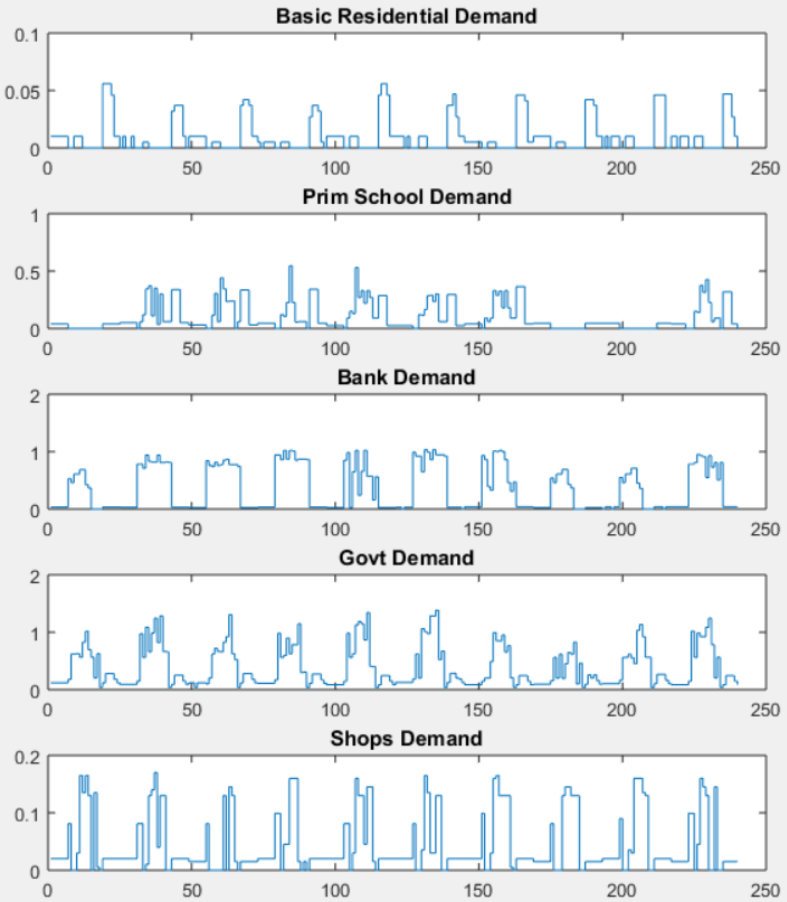
Reference Electrification Model Core (clustering, RNM, etc.)

Validation and Fine-Tuning

Optimization and Planning

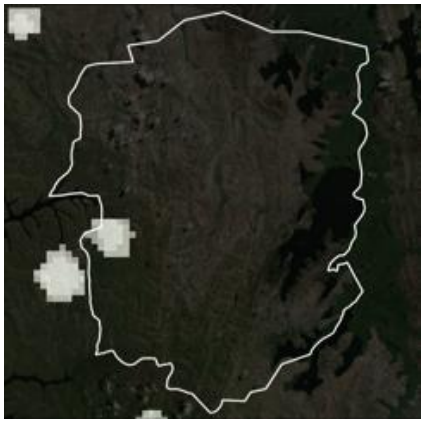
Demand inputs for the Reference Electrification Model can be collected or inferred

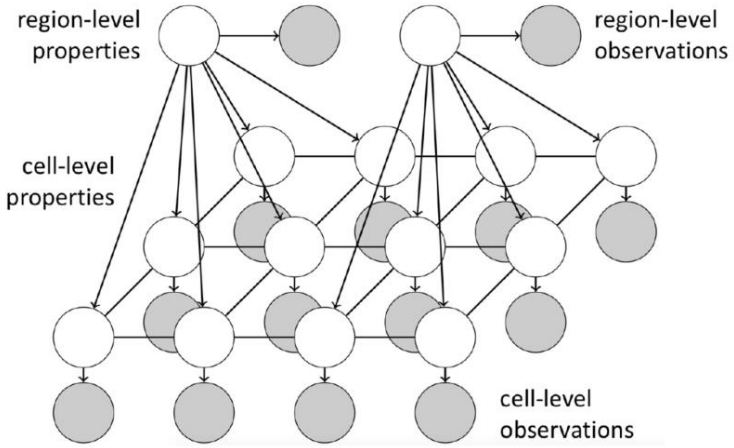


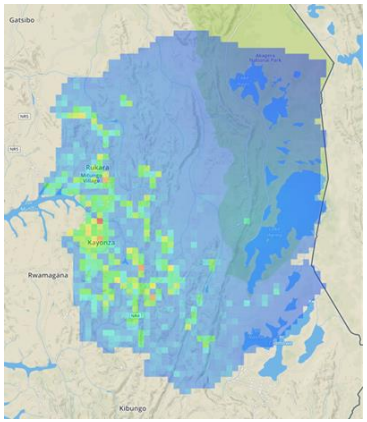


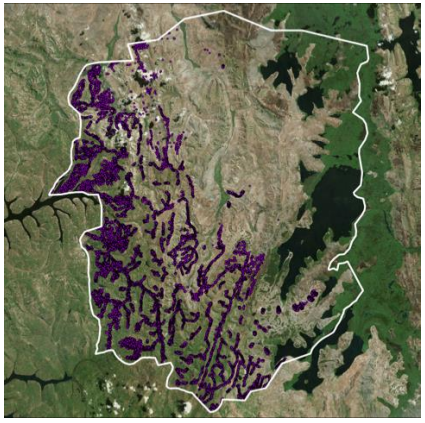
Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

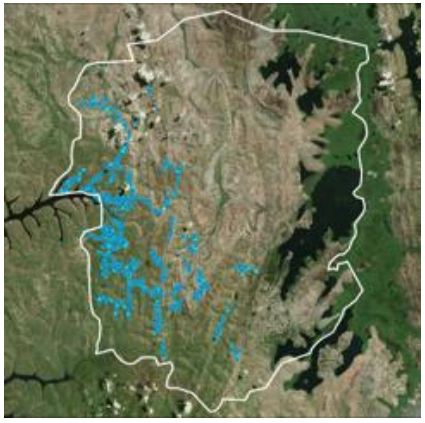
Nighttime lights, building density, and transformer location data enable electrification status estimation

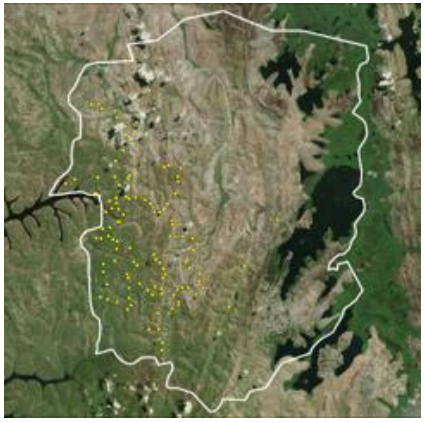


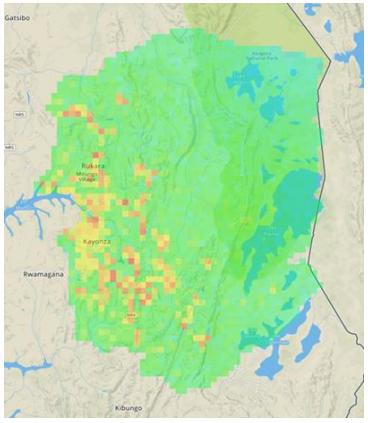




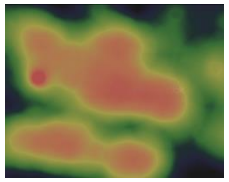


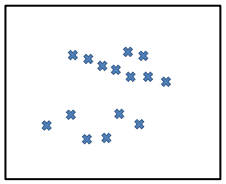


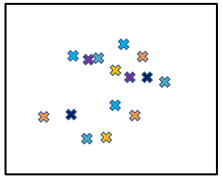


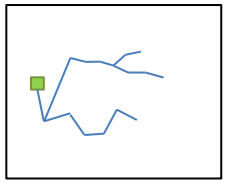


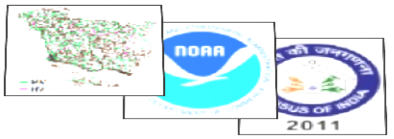
Source: Lee, S., "Adaptive Electricity Access Planning." Massachusetts Institute of Technology (2018)

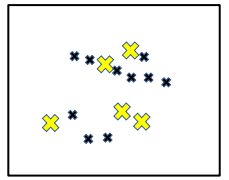












Demand Characterization

Supply Characterization

Building Extraction

Load Localization

Demand Classification

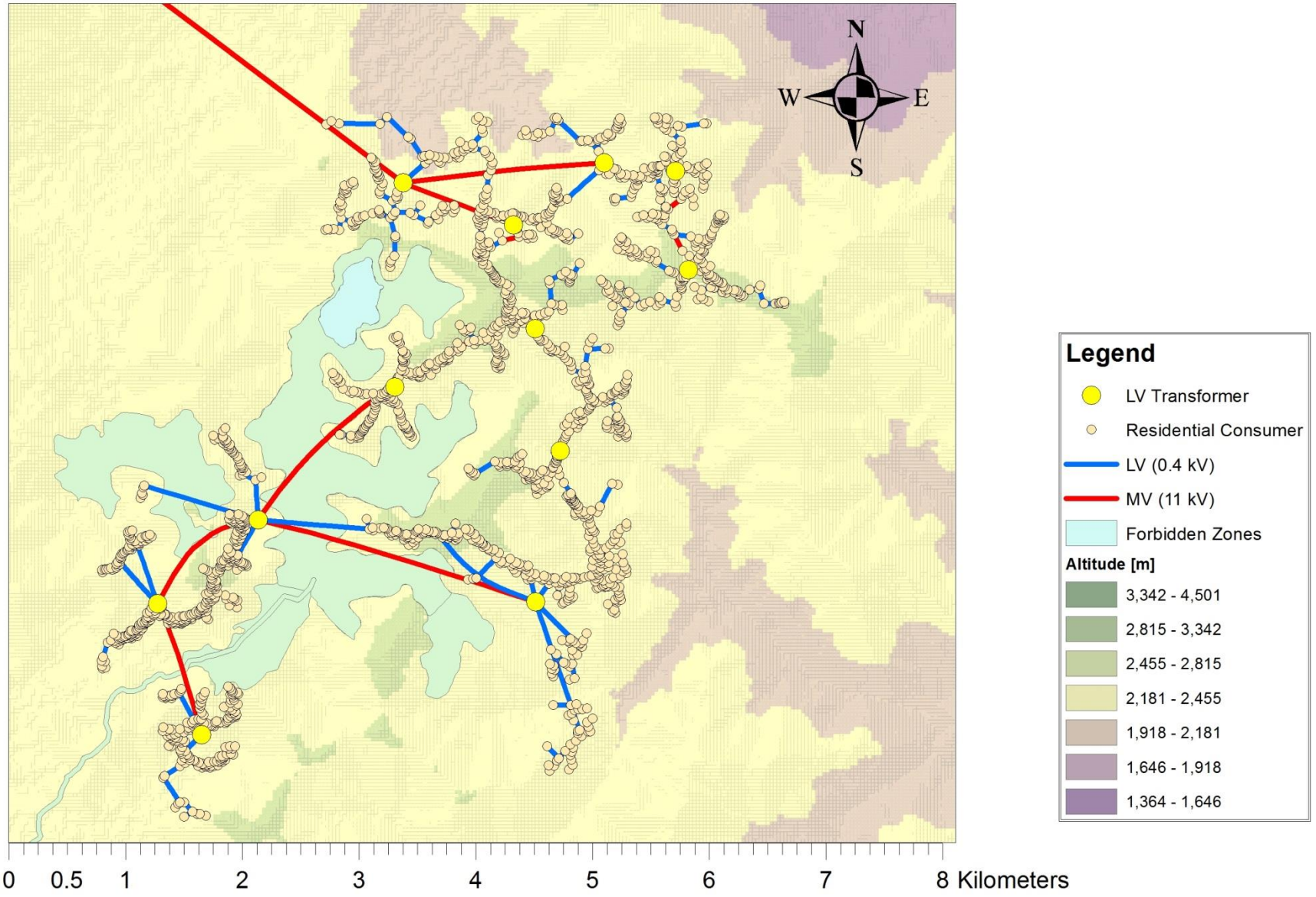
Electrification Status Estimation

Reference Electrification Model Core (clustering, RNM, etc.)

Validation and Fine-Tuning

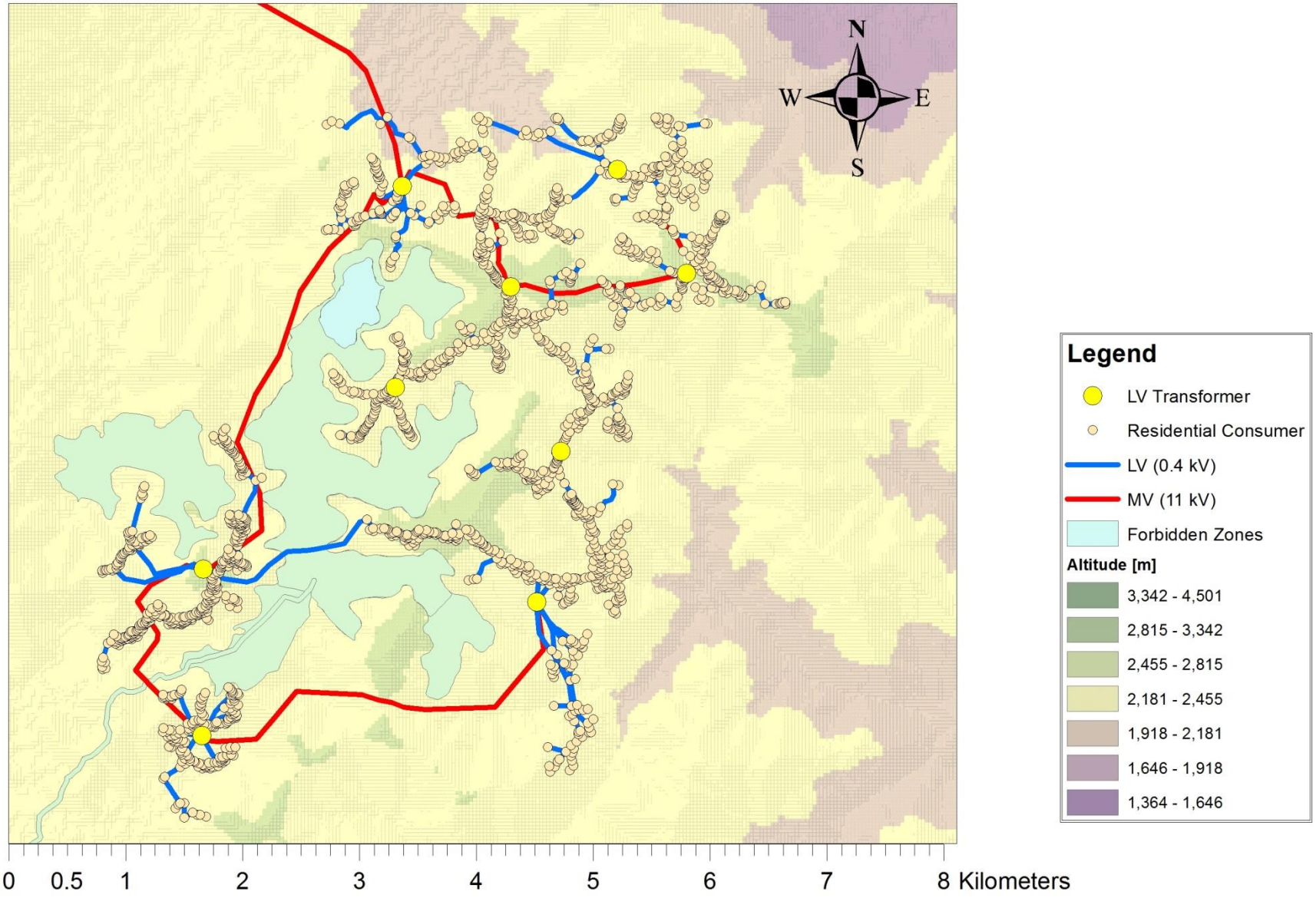
Optimization and Planning

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



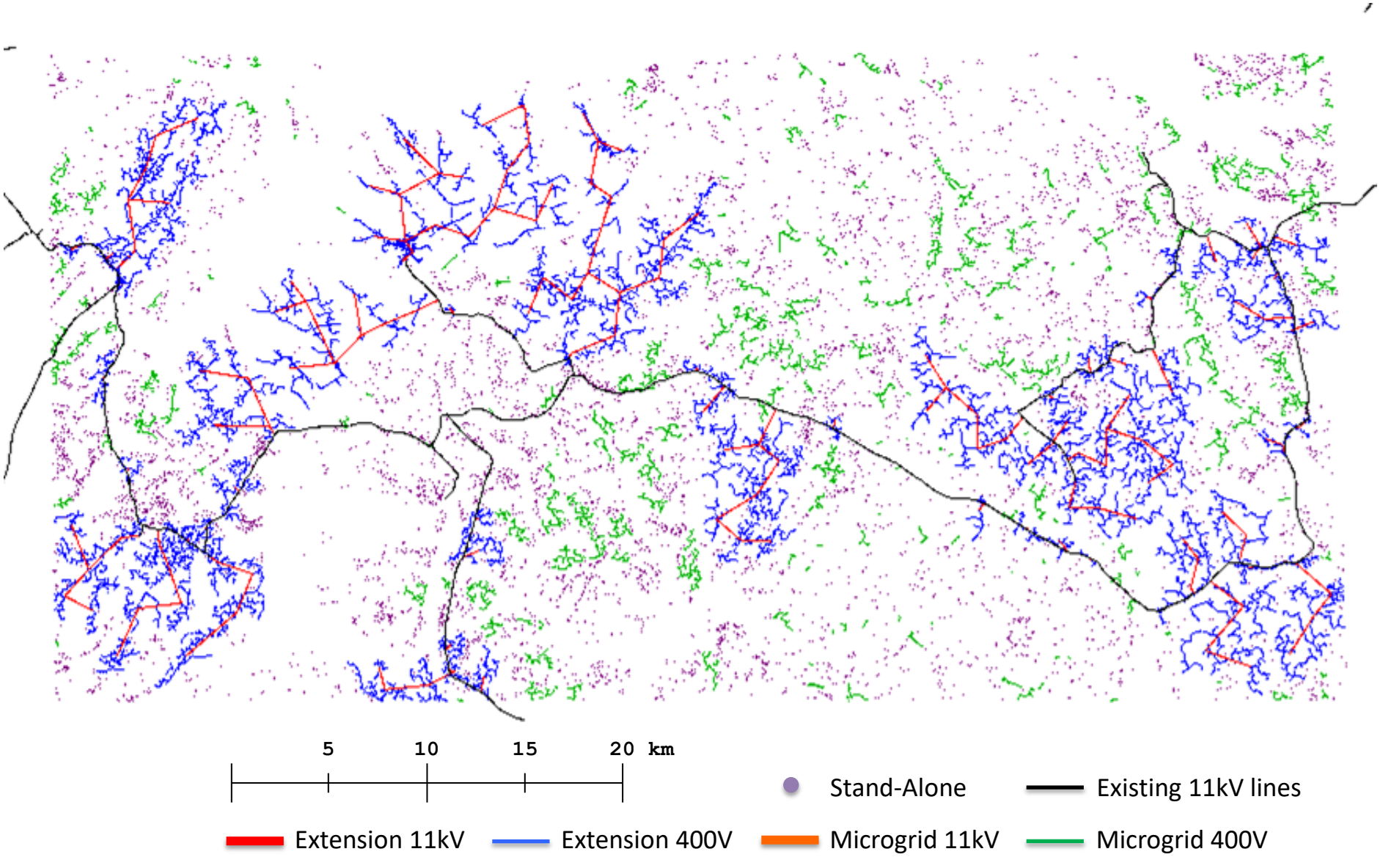
Source: Drouin, C., "Geospatial Cost Drivers in Computer-aided Electrification Planning: The Case of Rwanda", Massachusetts Institute of Technology (2018)

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



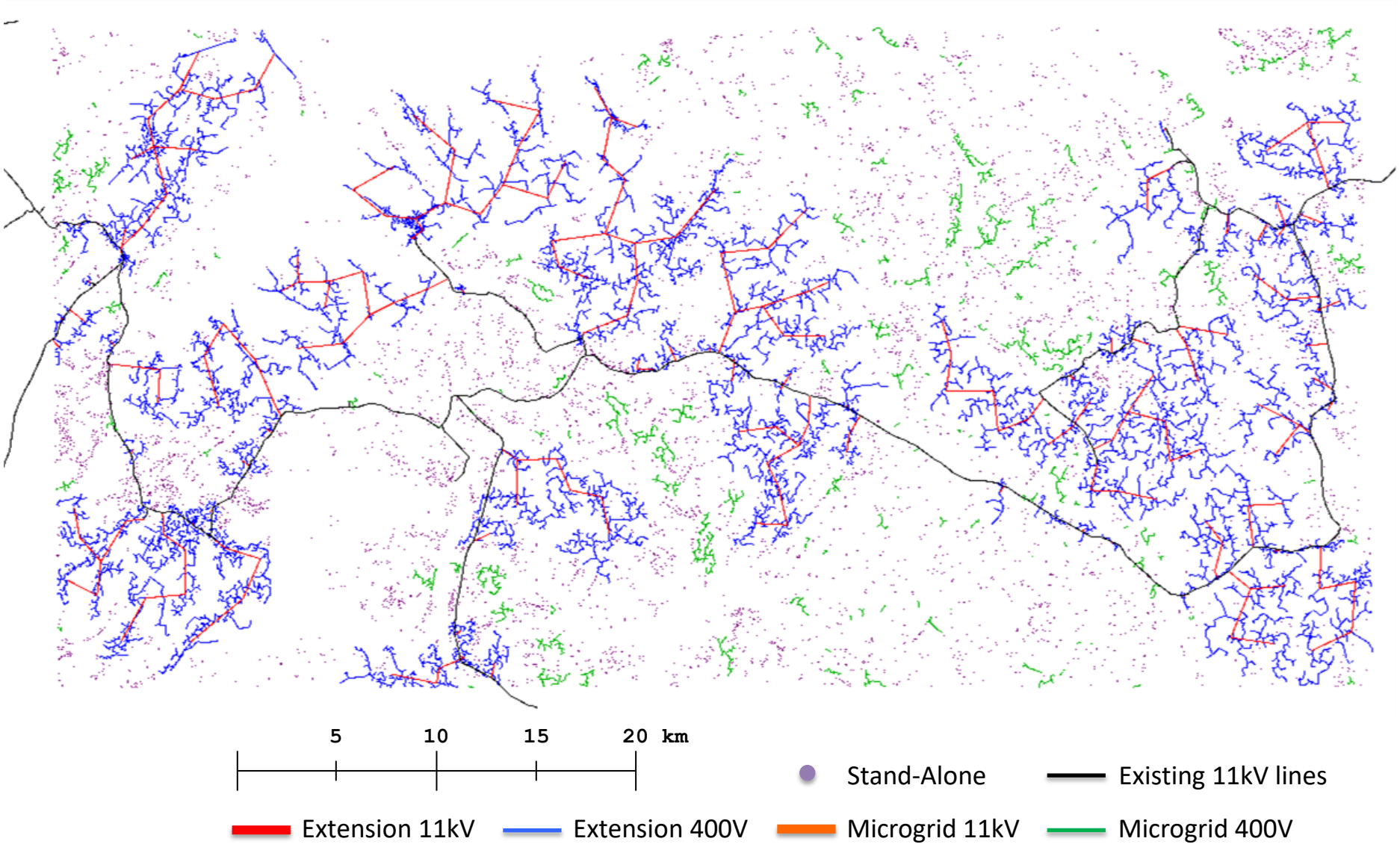
Source: Drouin, C., "Geospatial Cost Drivers in Computer-aided Electrification Planning: The Case of Rwanda", Massachusetts Institute of Technology (2018)

85% Grid Reliability



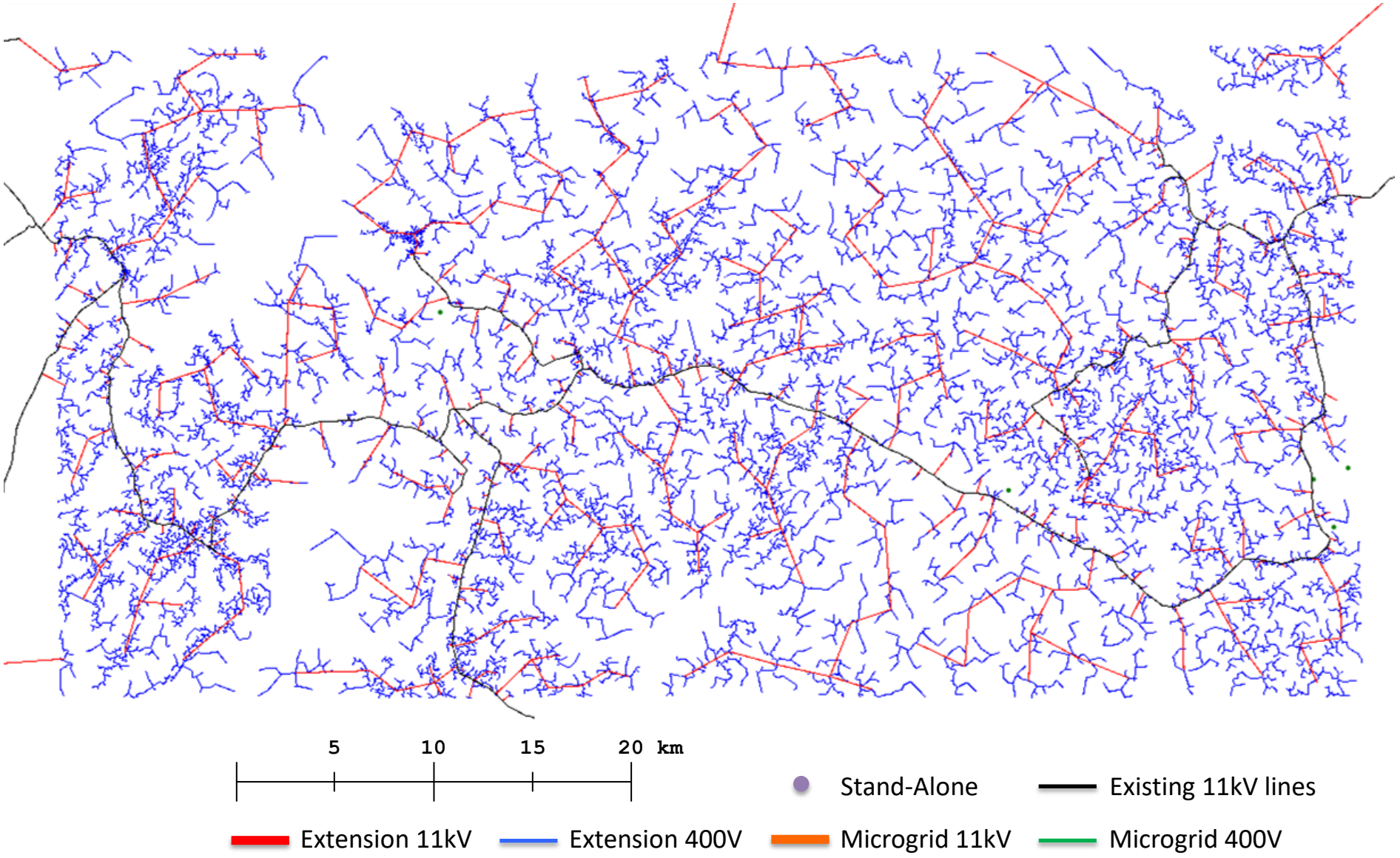
Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

100% Grid Reliability



Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

Forced 100% Grid Extension



Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

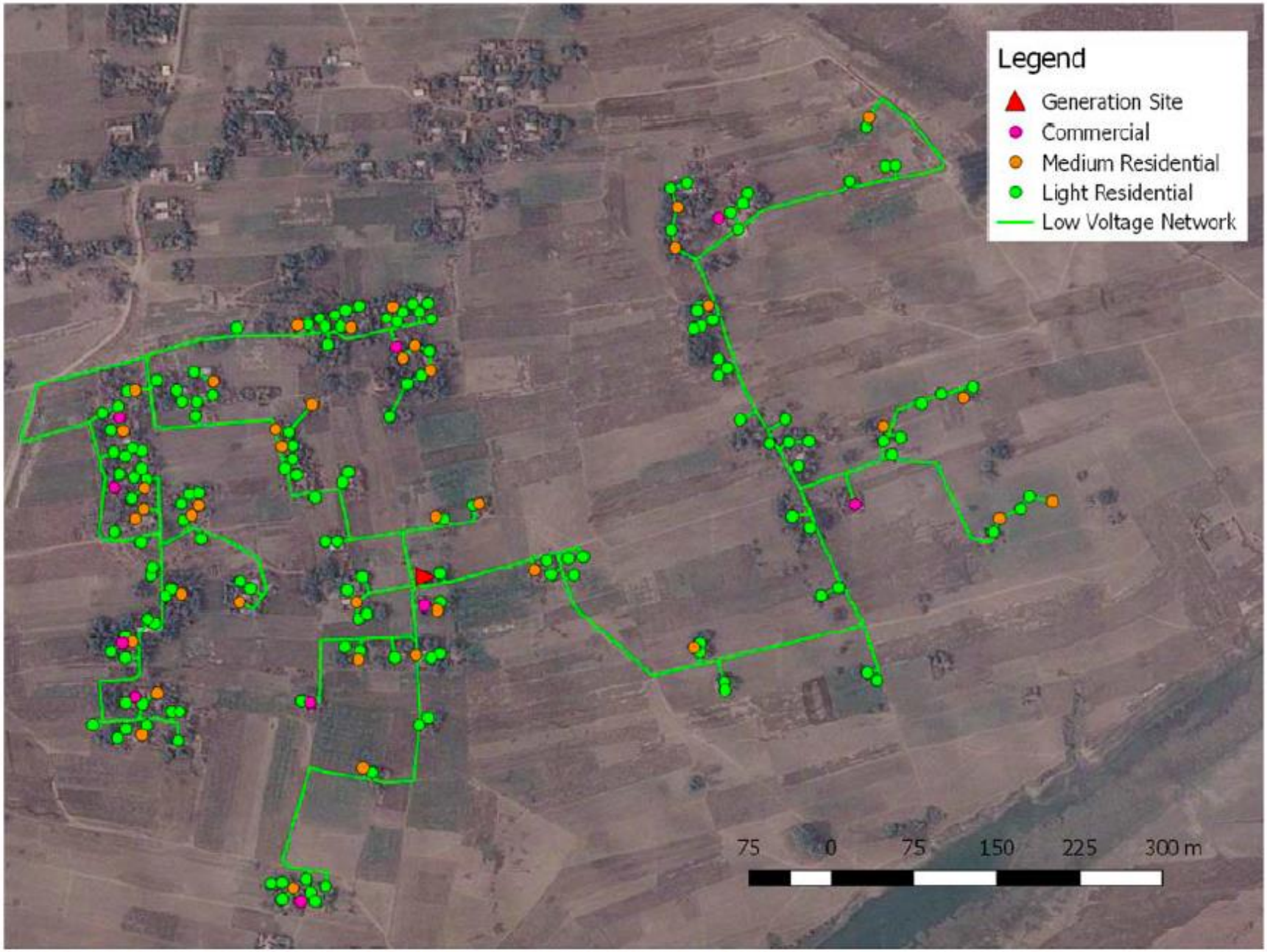
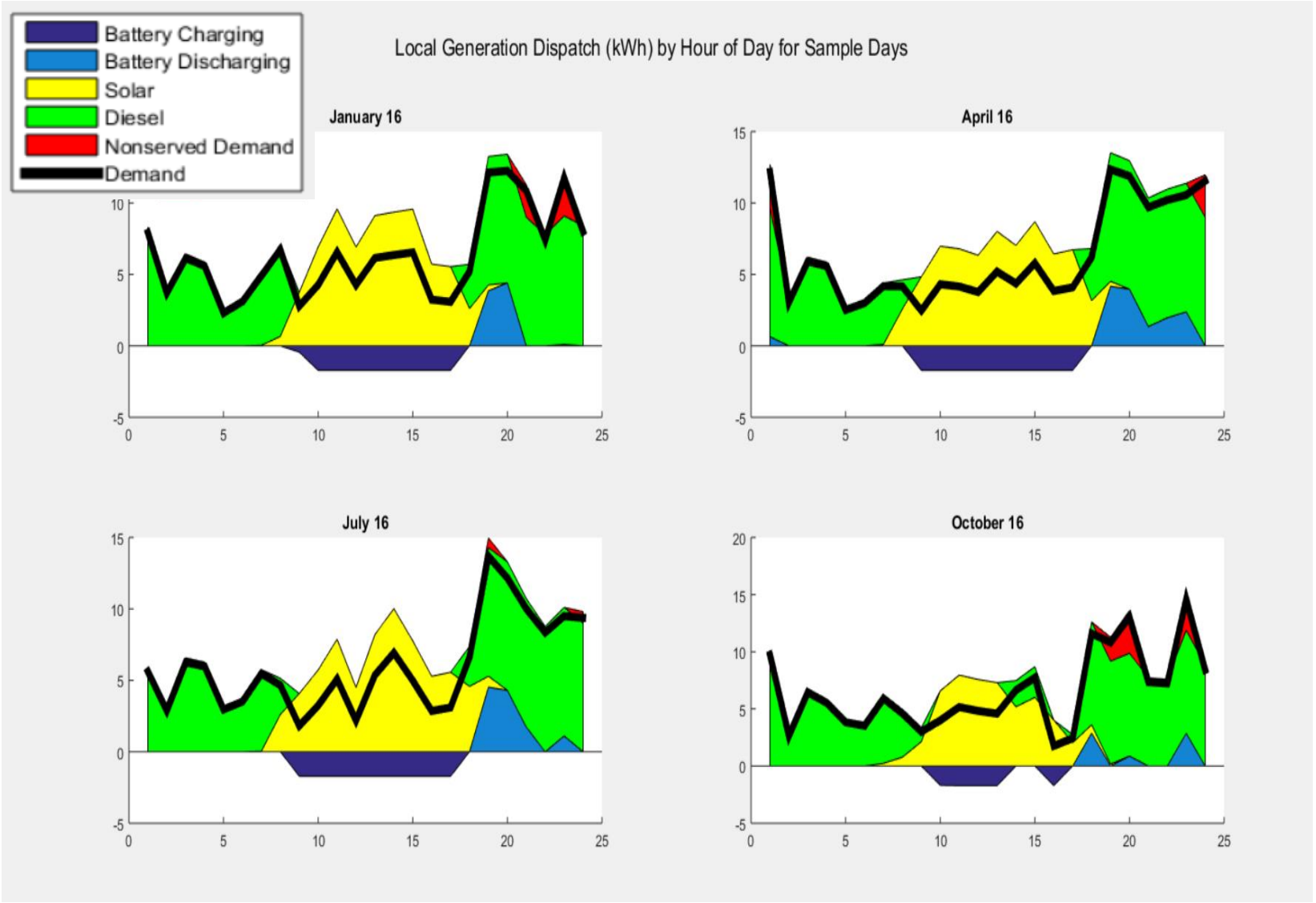


Figure 48. Network design in which the generation site and streets are designated

Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

For each microgrid, REM optimizes the mix of generation and storage



Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

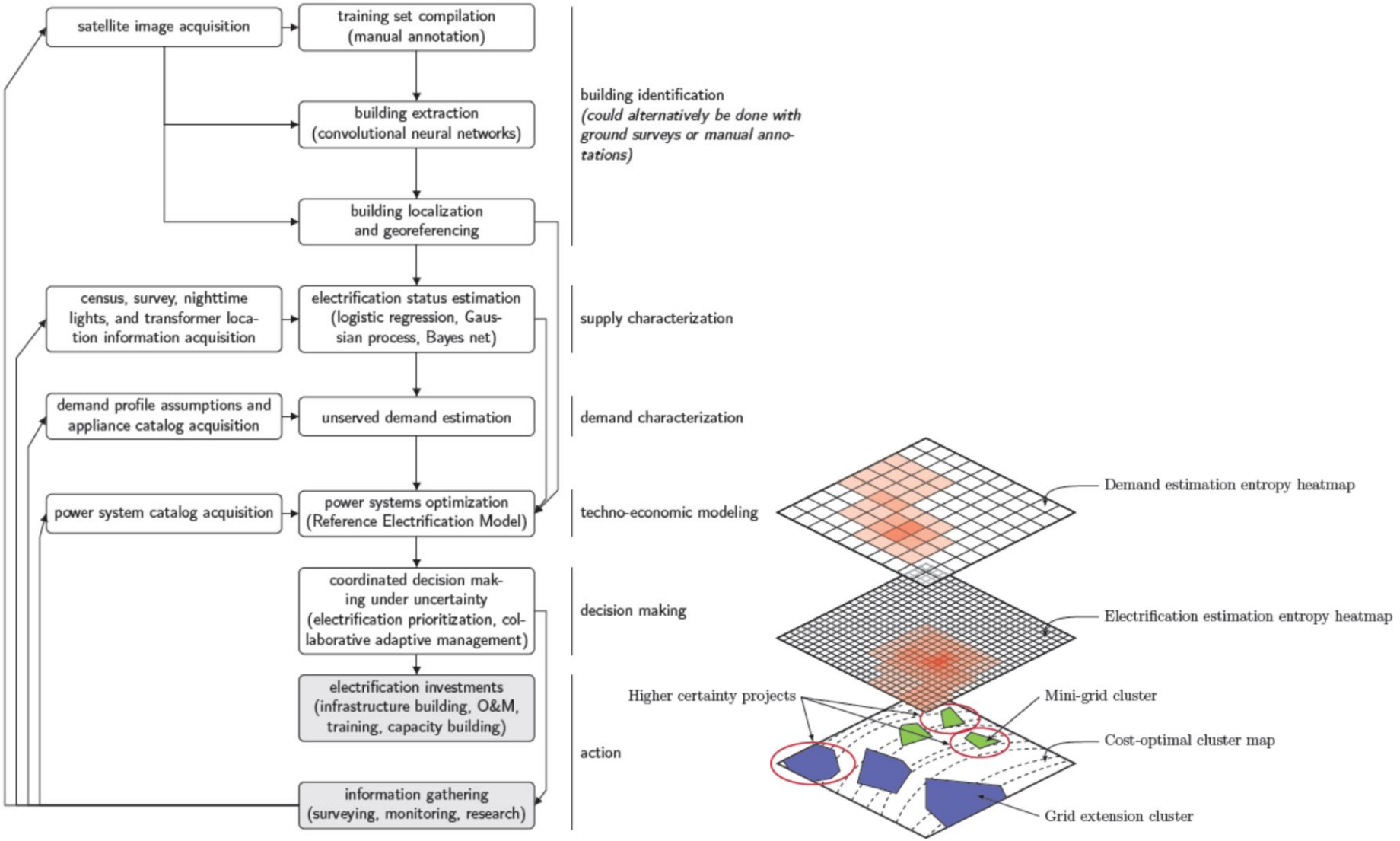
REM provides statistics of cost & performance for each type of supply in the considered region

	Mini-grids	Isolated	Grid Extensions	All
Number of Customers	8,903	17,148	26,658	52,709
Fraction of Customers	0.17	0.33	0.51	1.00
CAPEX Per Customer ($/yr)	191.69	173.38	94.23	136.44
OPEX Per Customer ($/yr)	49.83	49.50	141.73	96.20
Non-served Energy Cost Per Customer ($/yr)	5.28	53.99	66.90	52.29
Final Cost Per Customer ($/yr)	246.80	276.87	302.87	284.94
Total CAPEX ($/yr)	1,706,576	2,973,177	2,512,065	7,191,818
Total OPEX ($/yr)	443,677	848,847	3,778,261	5,070,785
Total Non-served Energy Cost ($/yr)	47,041	925,818	1,783,549	2,756,408
Final Cost ($/yr)	2,197,293	4,747,841	8,073,876	15,019,011
Fraction of Demand Served (p.u.)	0.986	0.903	0.900	0.911
Cost Per kWh of Demand Served ($/kWh)	0.312	0.313	0.206	0.245

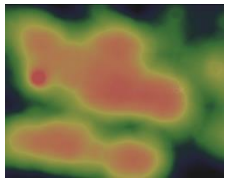
Table 4: Case study electrification: solution summary

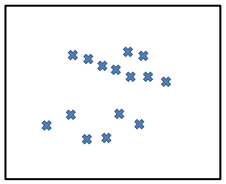
Source: MIT-Comillas Universal Energy Access Lab, "Computer-aided electrification planning in developing countries: The Reference Electrification Model (REM)," IIT WP 188 112-A (2018)

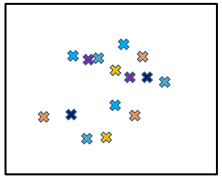
Adaptive planning methodologies for infrastructure and information are facilitated

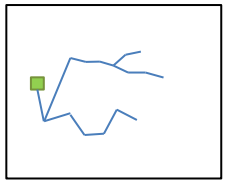


Source: Lee, S.J., "Adaptive Electricity Access Planning." Massachusetts Institute of Technology (2018)









Demand Characterization

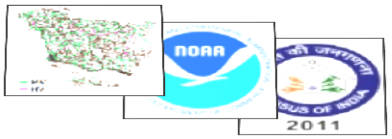
Supply Characterization

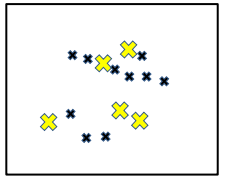
Building Extraction

Load Localization

Demand Classification

Electrification Status Estimation



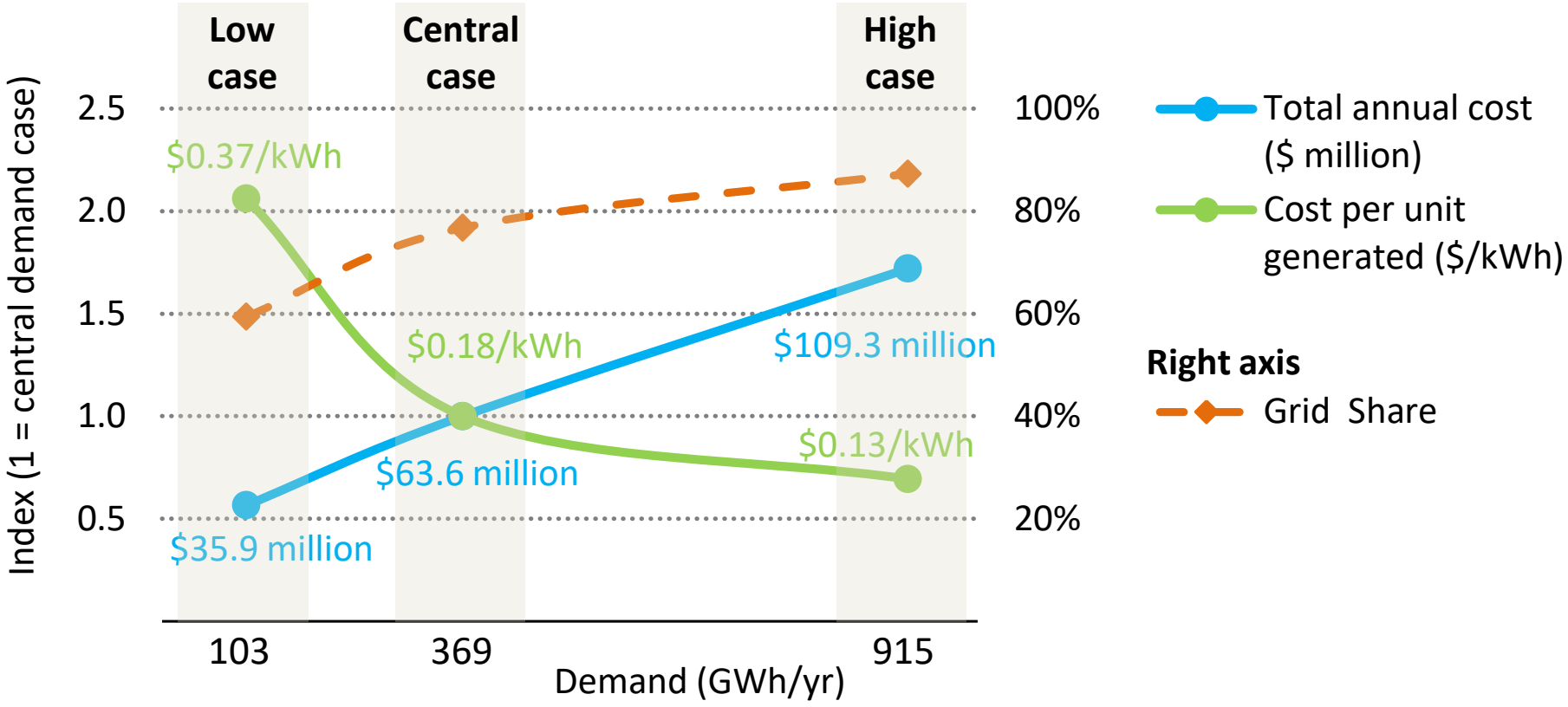


Reference Electrification Model Core (clustering, RNM, etc.)

Validation and Fine-Tuning

Optimization and Planning

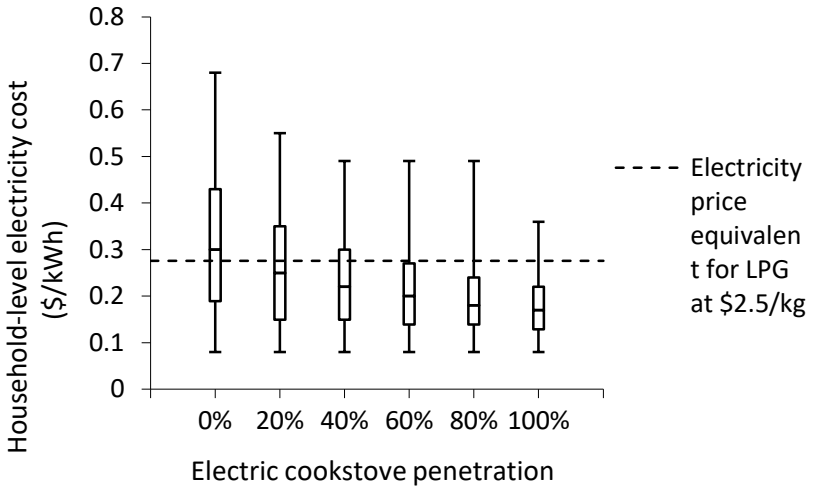
Sensitivity analyses demonstrate the criticality of estimating demand over the planning horizon



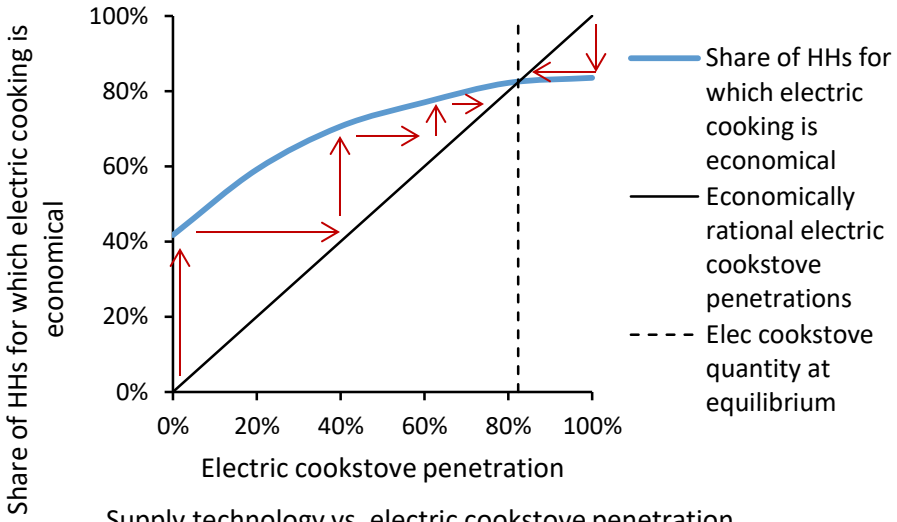
Source: Lee, S.J., Perez-Arriaga, I.J., et al. contributions to IEA, World Energy Outlook 2018. OECD (2018).

REM studies show that jointly planning clean cooking and electricity access lead to economic co-benefits

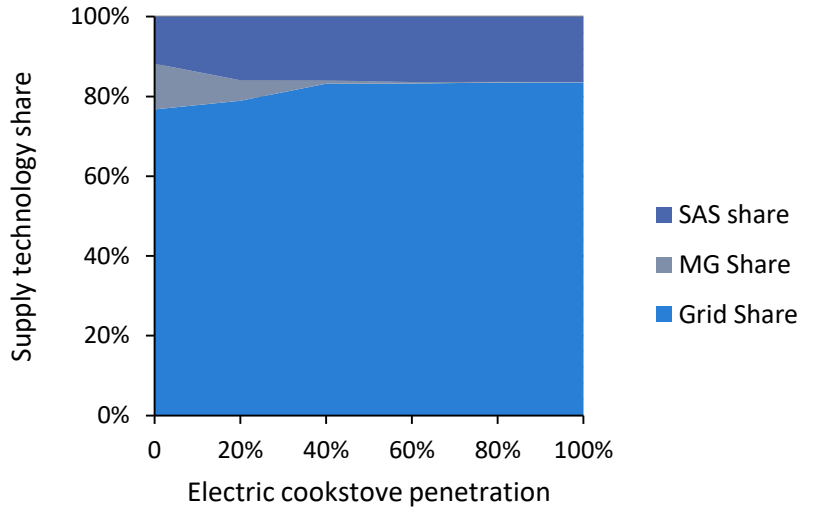
Increasing electric cooking penetrations increases electricity consumption and decreases per kWh costs



Positive feedback is observed with increasing electric cookstove penetrations

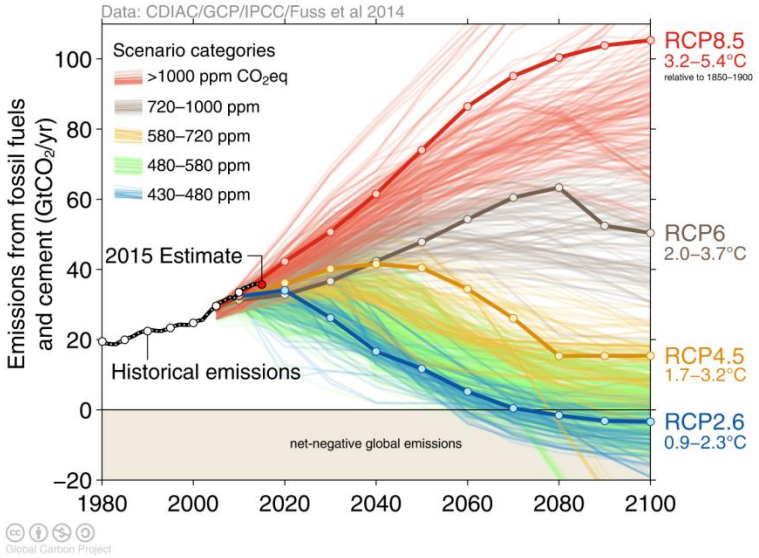


Supply technology vs. electric cookstove penetration

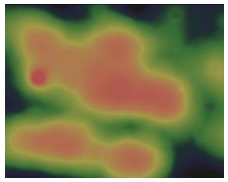


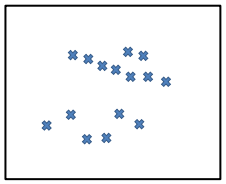
Source: Lee, S.J., Perez-Arriaga, I.J., et al. contributions to IEA, World Energy Outlook 2018. OECD (2018).; Lumbreras, J., "Session 23.- Heating, cooling, and cooking technologies ," MIT (2018)

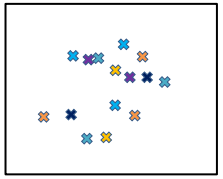
Prospects for coordinated electrification, climate, and agricultural sector planning

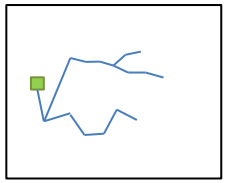


Google Maps API
(DigitalGlobe) imagery
2018 February
0.6 m spatial res
biennial temporal res









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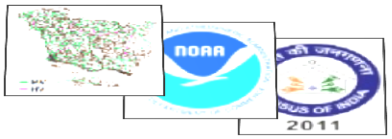

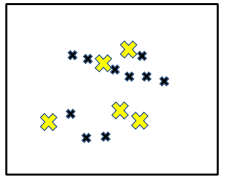

Reference Electrification Model Core (clustering, RNM, etc.)

Validation and Fine-Tuning

Optimization and Planning

Thank you! Questions?