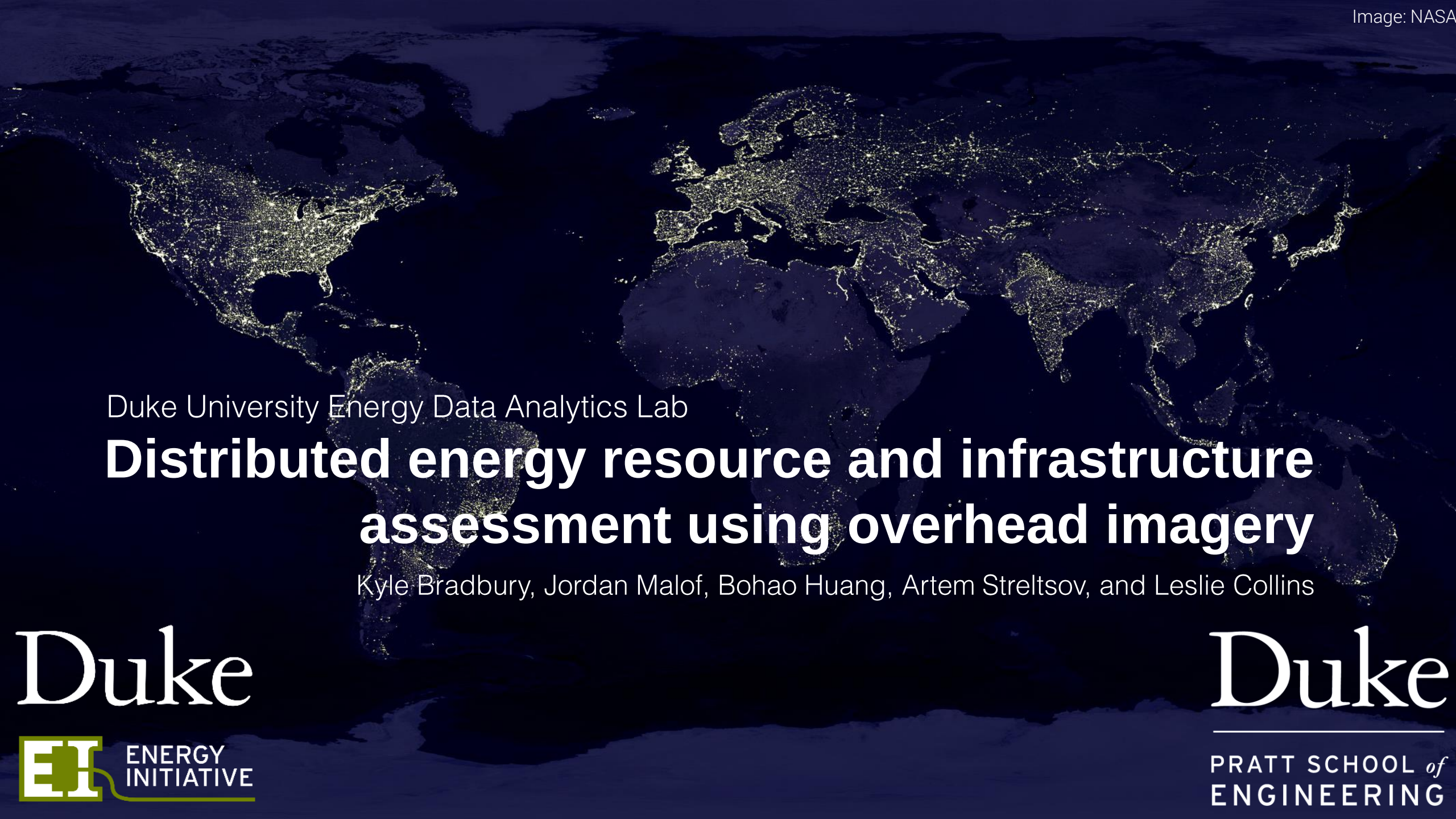


Duke University Energy Data Analytics Lab

Distributed energy resource and infrastructure assessment using overhead imagery

Kyle Bradbury, Jordan Malof, Bohao Huang, Artem Streltsov, and Leslie Collins

Duke

ENERGY INITIATIVE

Duke

PRATT SCHOOL of ENGINEERING

Research Vision

Global, automated assessment of **energy infrastructure**…

…to develop pathways to **sustainably** meet energy needs.


1 Supply


2 Transmission
& Distribution


3 Demand

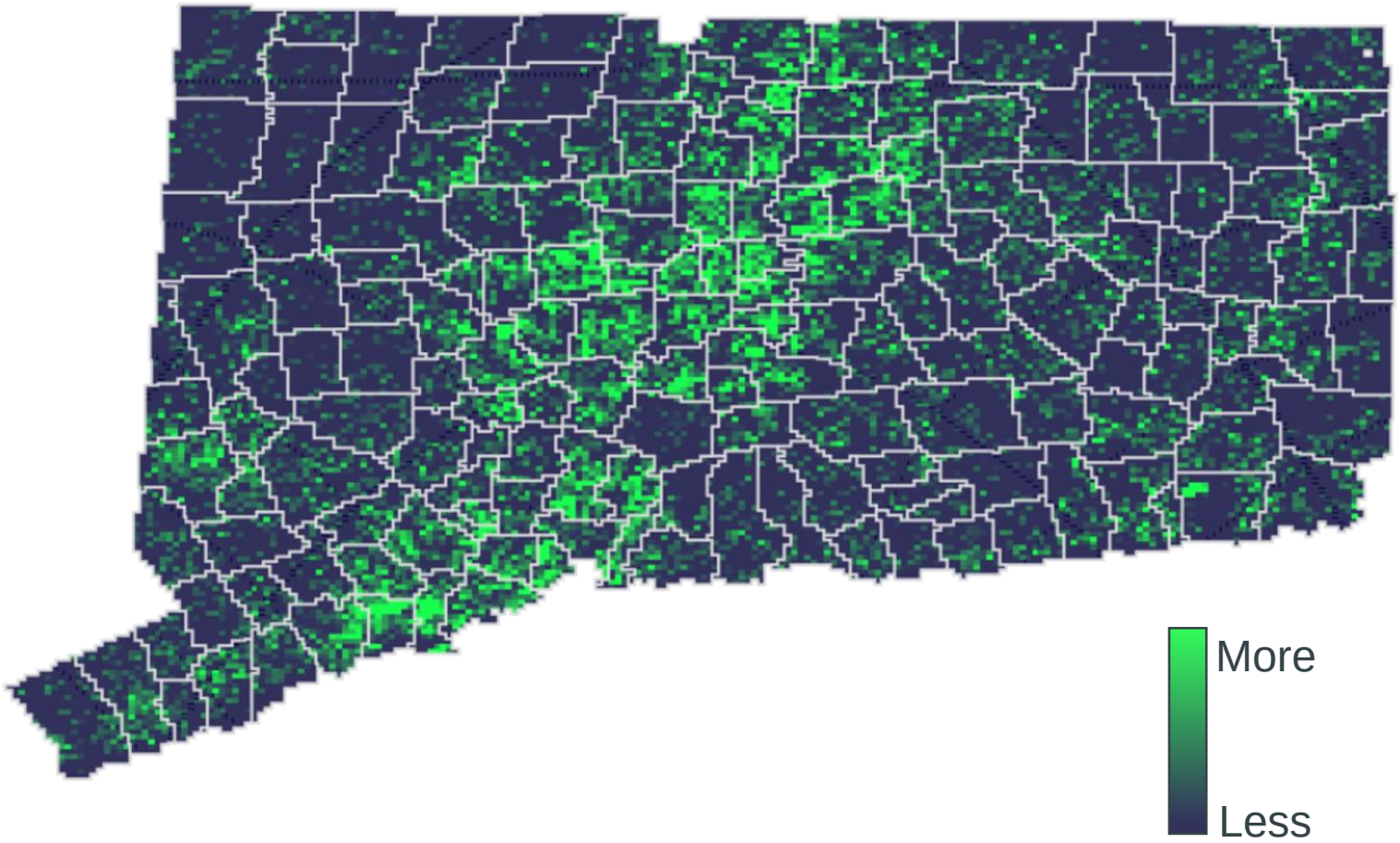

4 Access

Original image with ground truth (red)

Detected solar arrays

1 Distributed energy supply

Goal: estimate solar array **locations**, **power capacity**, and **energy generation**



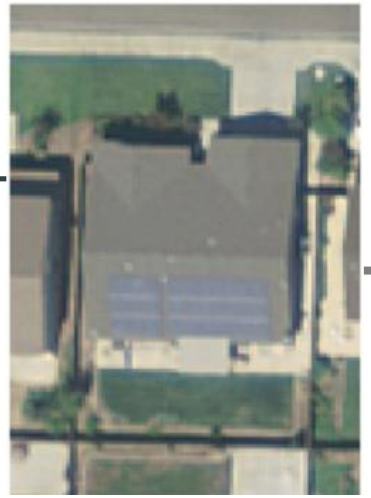
Public estimates of distributed solar are generally limited to state or national scales (U.S. EIA)

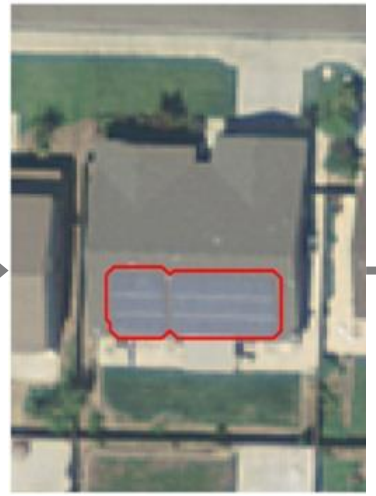
Estimating Energy from Distributed Solar Using Satellite Imagery

Process

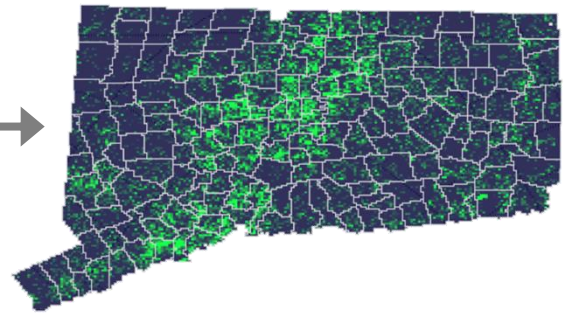
Input Satellite Imagery → Solar Array Detection → Power Capacity Estimation → Generated Energy Estimation ← Regional insolation data → High-resolution estimates of solar energy

Example





4,750 Watts → 6.94 MWh →



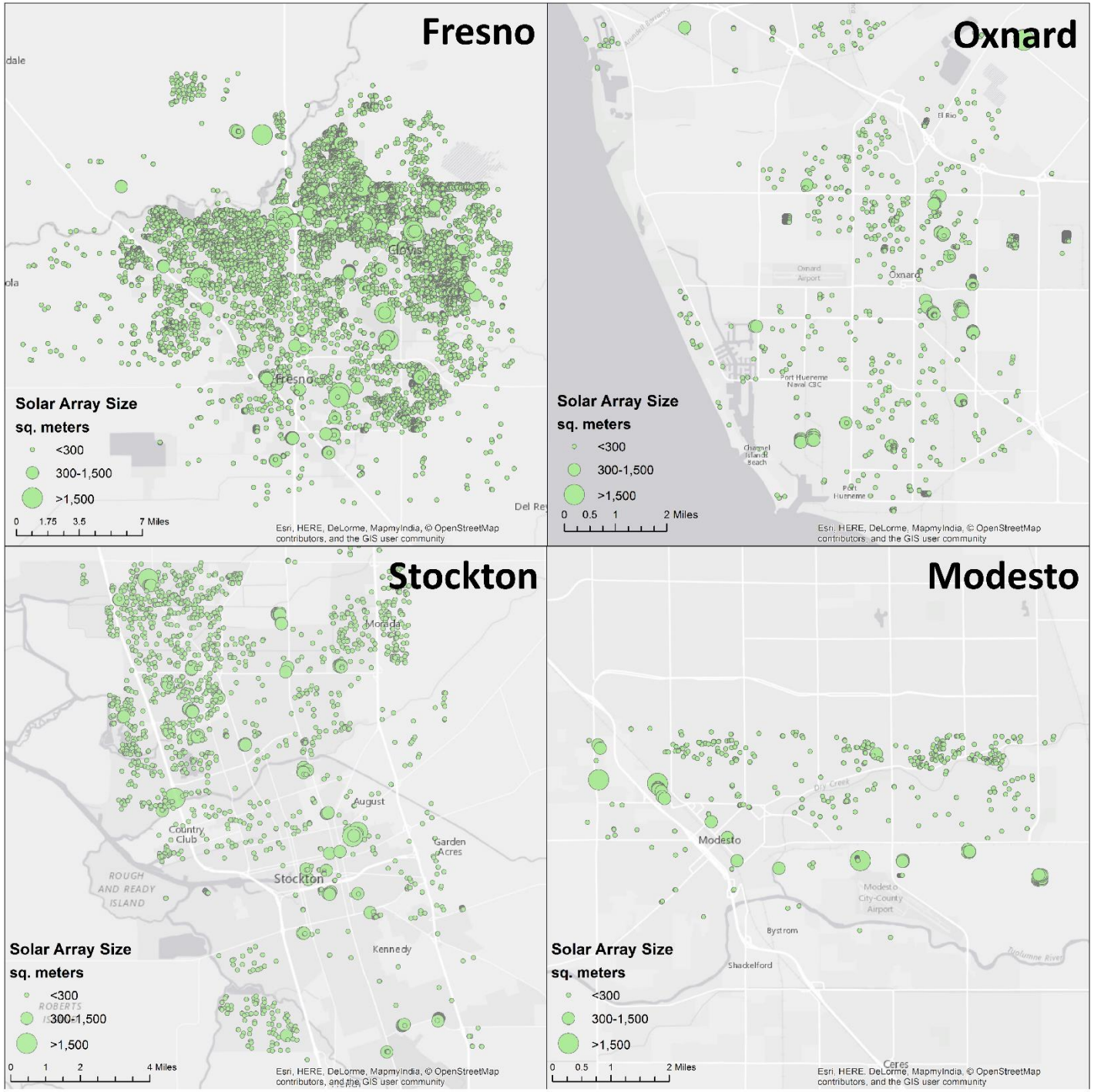
Malof et al. 2017

Solar PV Data

Dataset created by summer 2015 Data+ team and published in Scientific Data

19,000+ manually annotated solar arrays from 4 CA cities

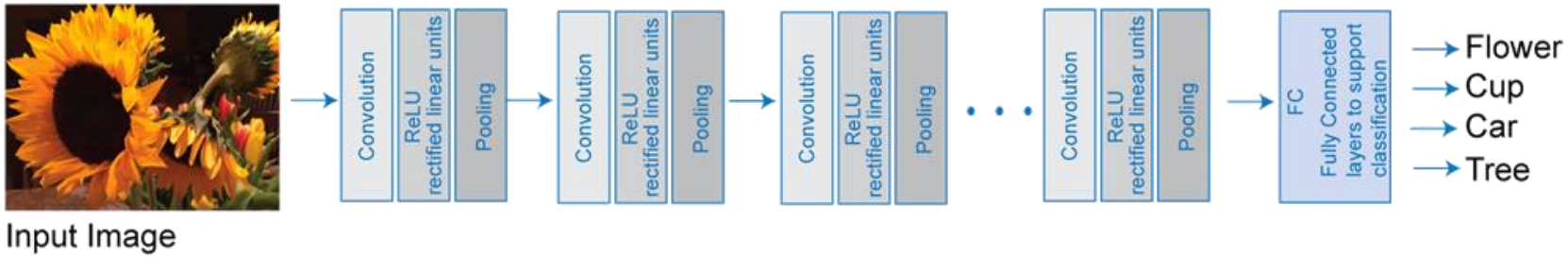
Can be used to train deep learning techniques



Bradbury, K., Saboo, R., Johnson, T., Malof, J., Zhang, W., Devarajan, A., Collins, L., Newell, R. (2016) "Distributed Solar Photovoltaic Array Location and Extent Dataset for Remote Sensing Object Identification." Scientific Data, 3. doi:10.1038/sdata.2016.106.

Available for download at:
https://doi.org/10.6084/m9.figshare.c.3255643.v2

Convolutional Neural Networks



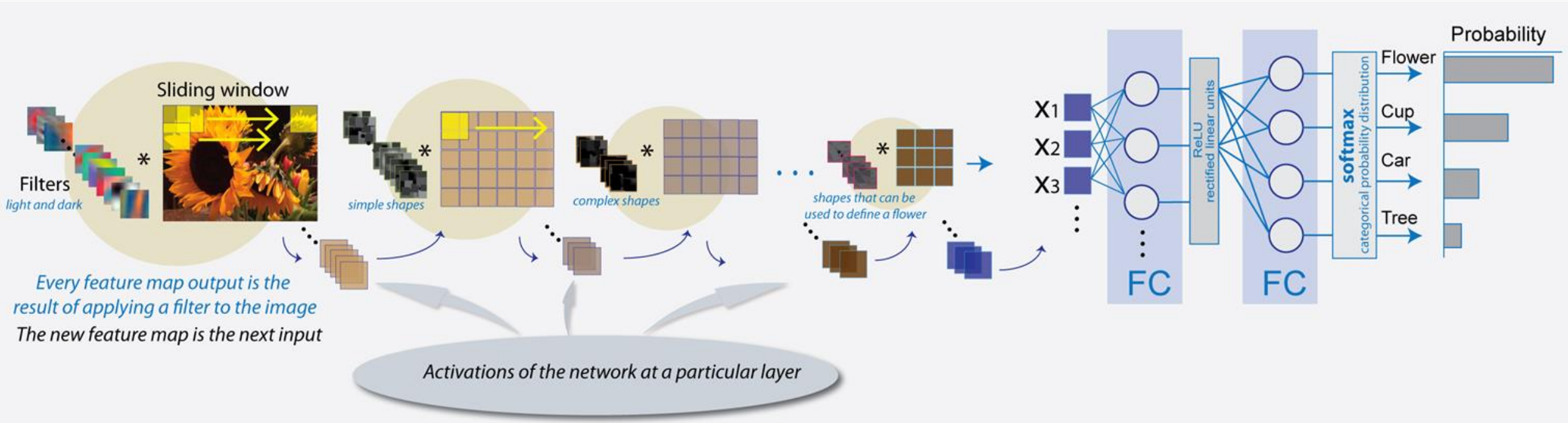


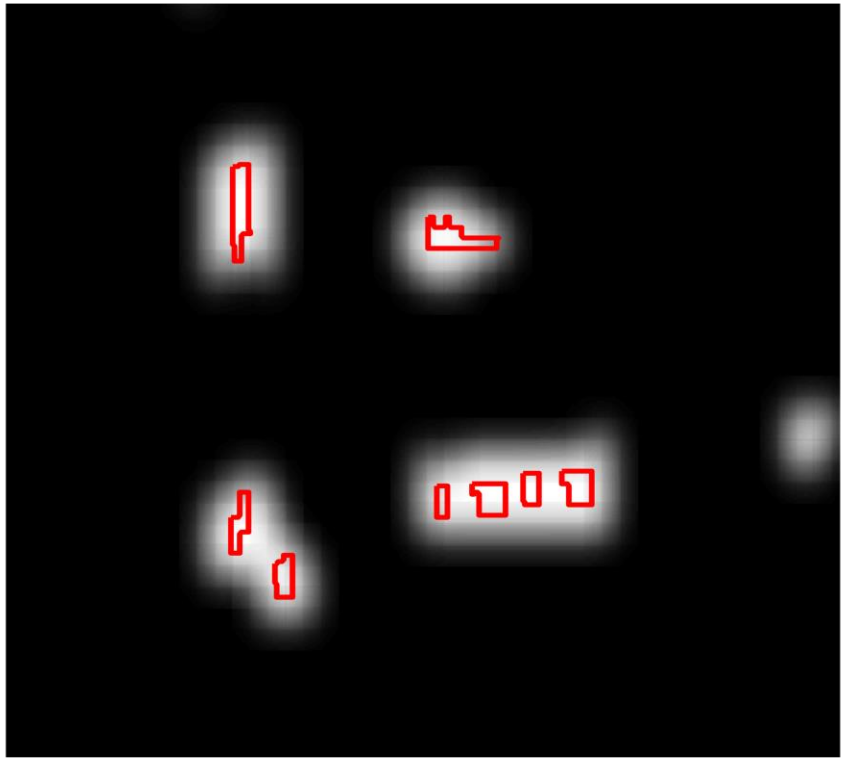
Image from the Mathworks

Sample Results

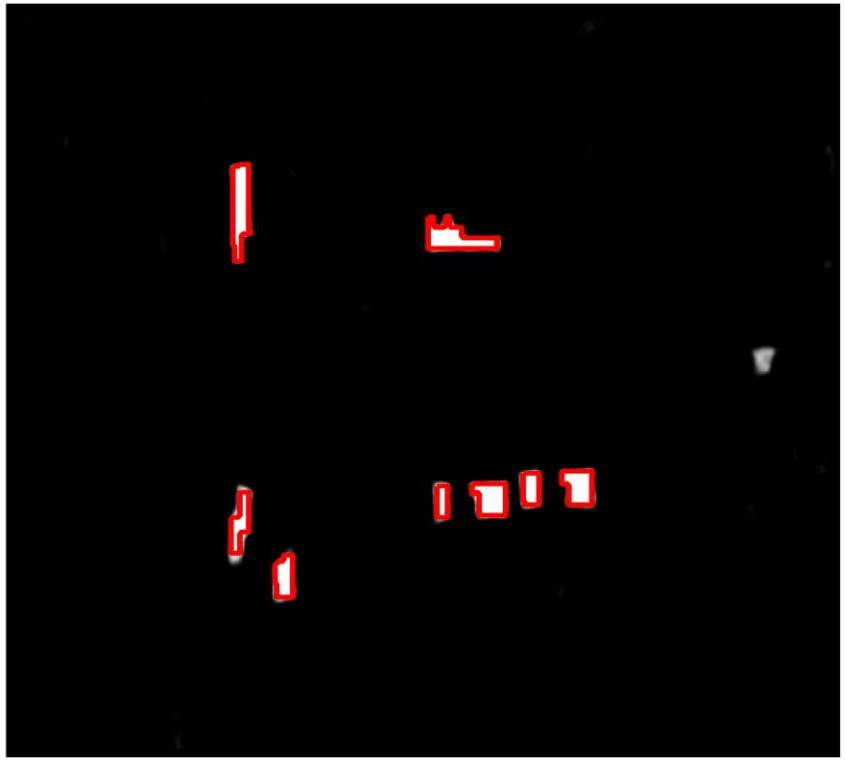
Using convolutional neural networks (CNN)

Original Image

VGG CNN



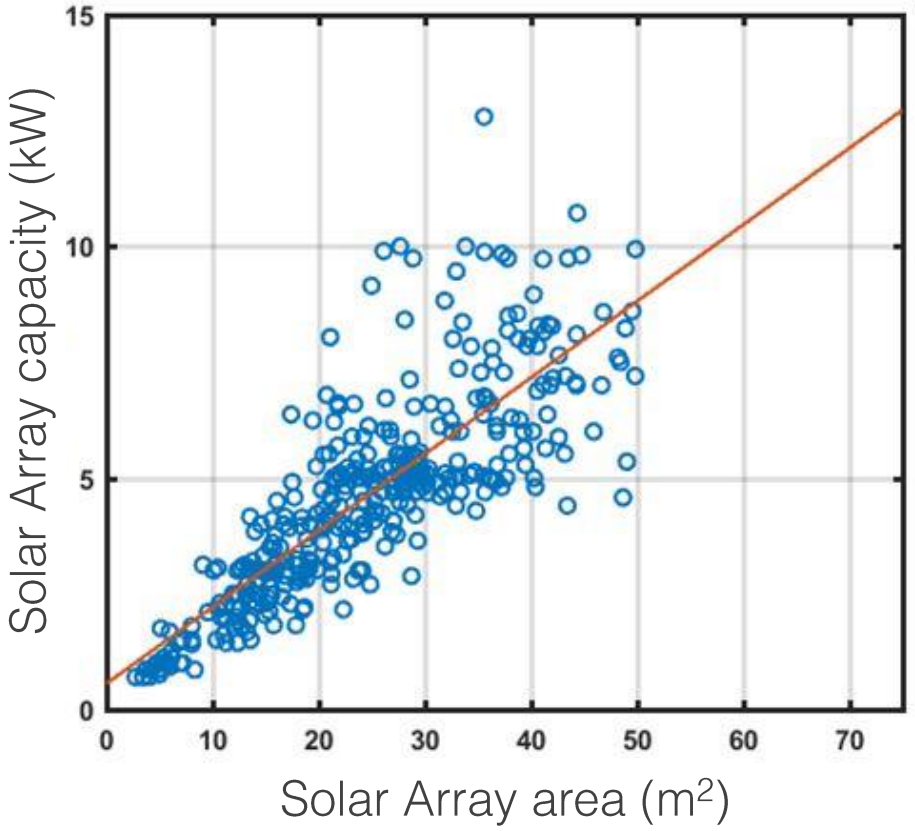
SegNet CNN



Camilo, J., L. Collins, K. Bradbury, J. Malof. “Application of a semantic segmentation convolutional neural network for accurate automatic detection and mapping of solar photovoltaic arrays in aerial imagery.” Presented at the IEEE Applied Imagery Pattern Recognition Workshop in Washington, D.C., 2017.

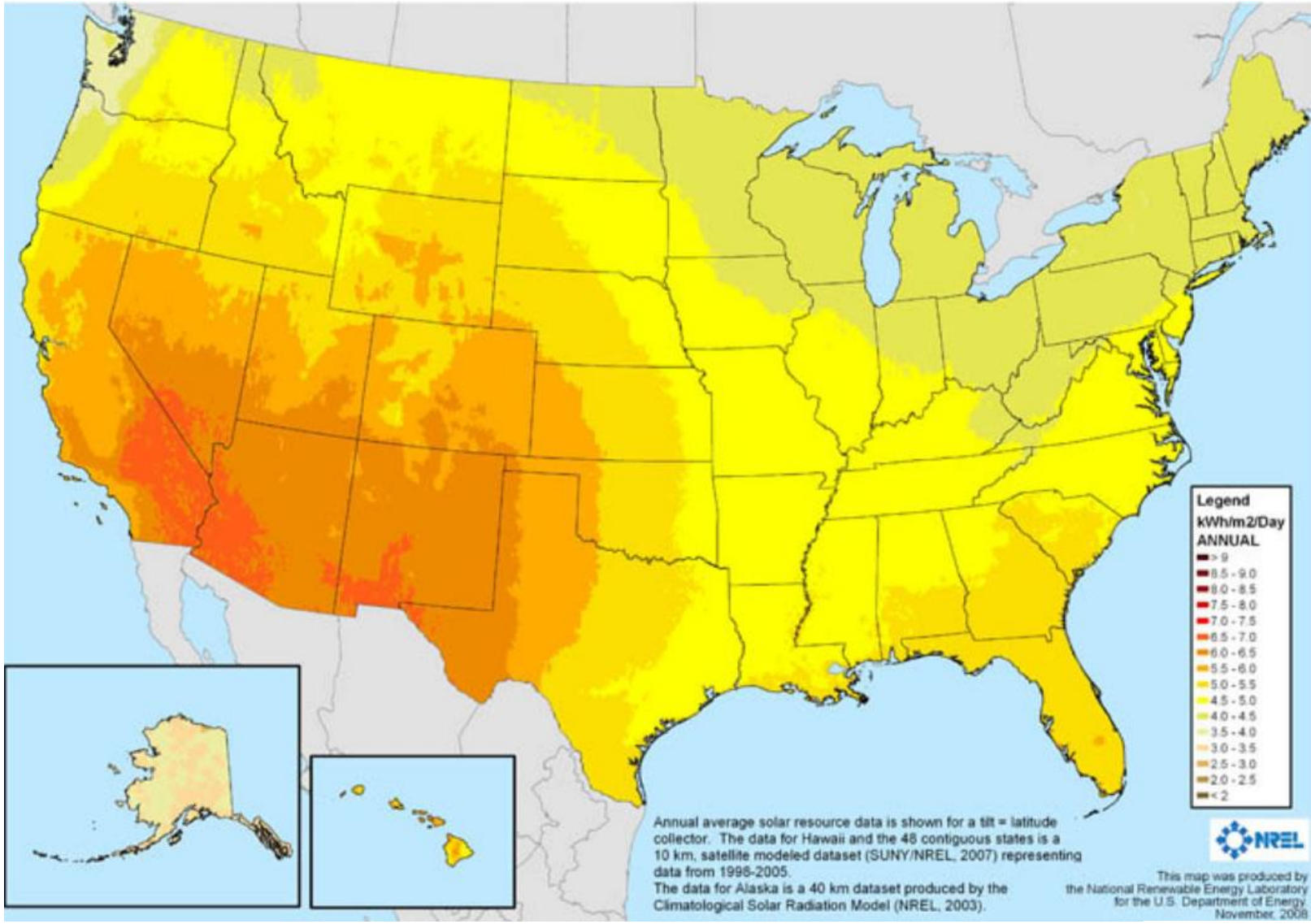
Capacity & Energy Estimation

Solar array area → capacity (kW)



So et al., 2017

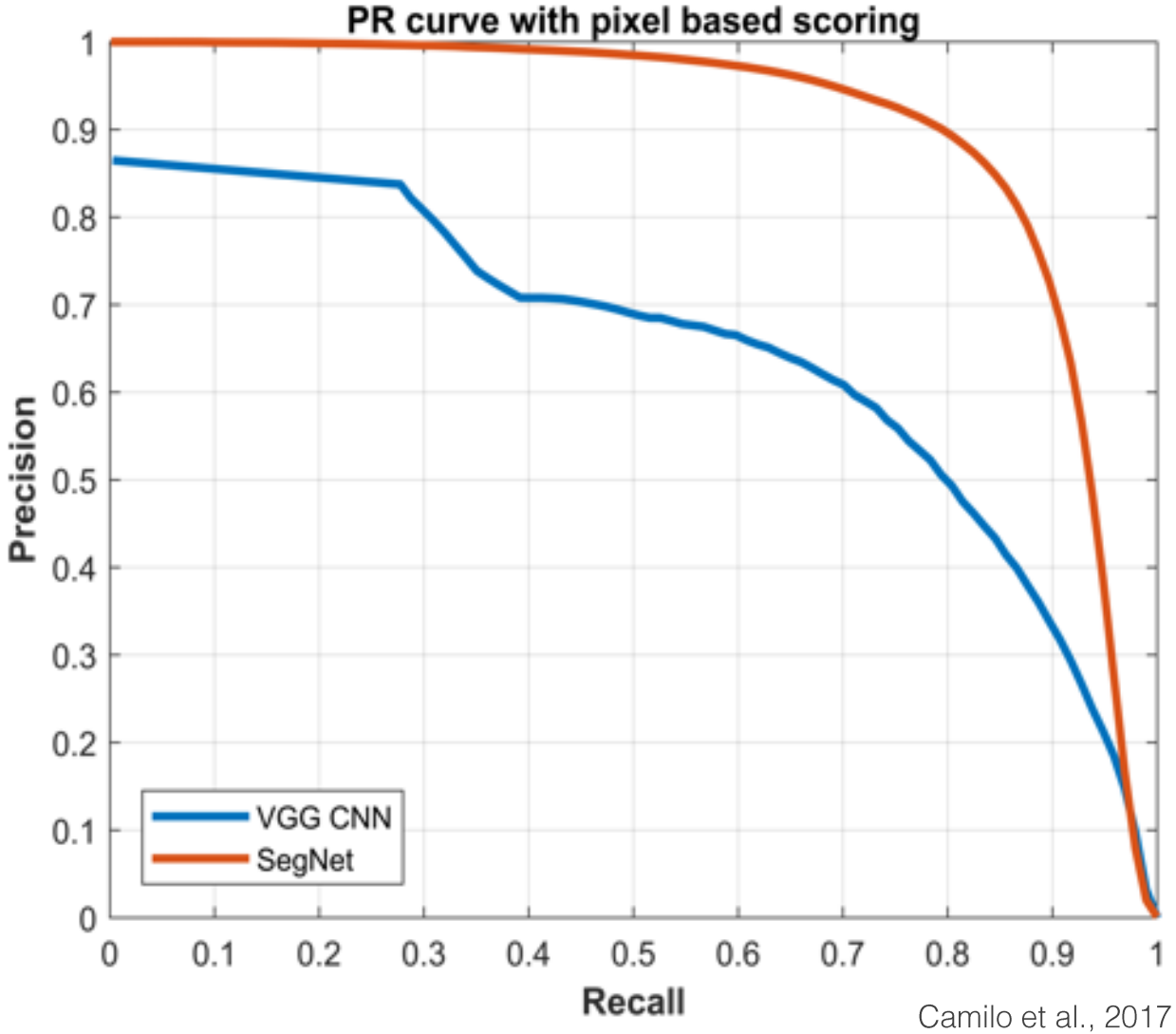
Solar array capacity → energy generation (kWh)



NREL, 2008

Results

Pixel-wise results:



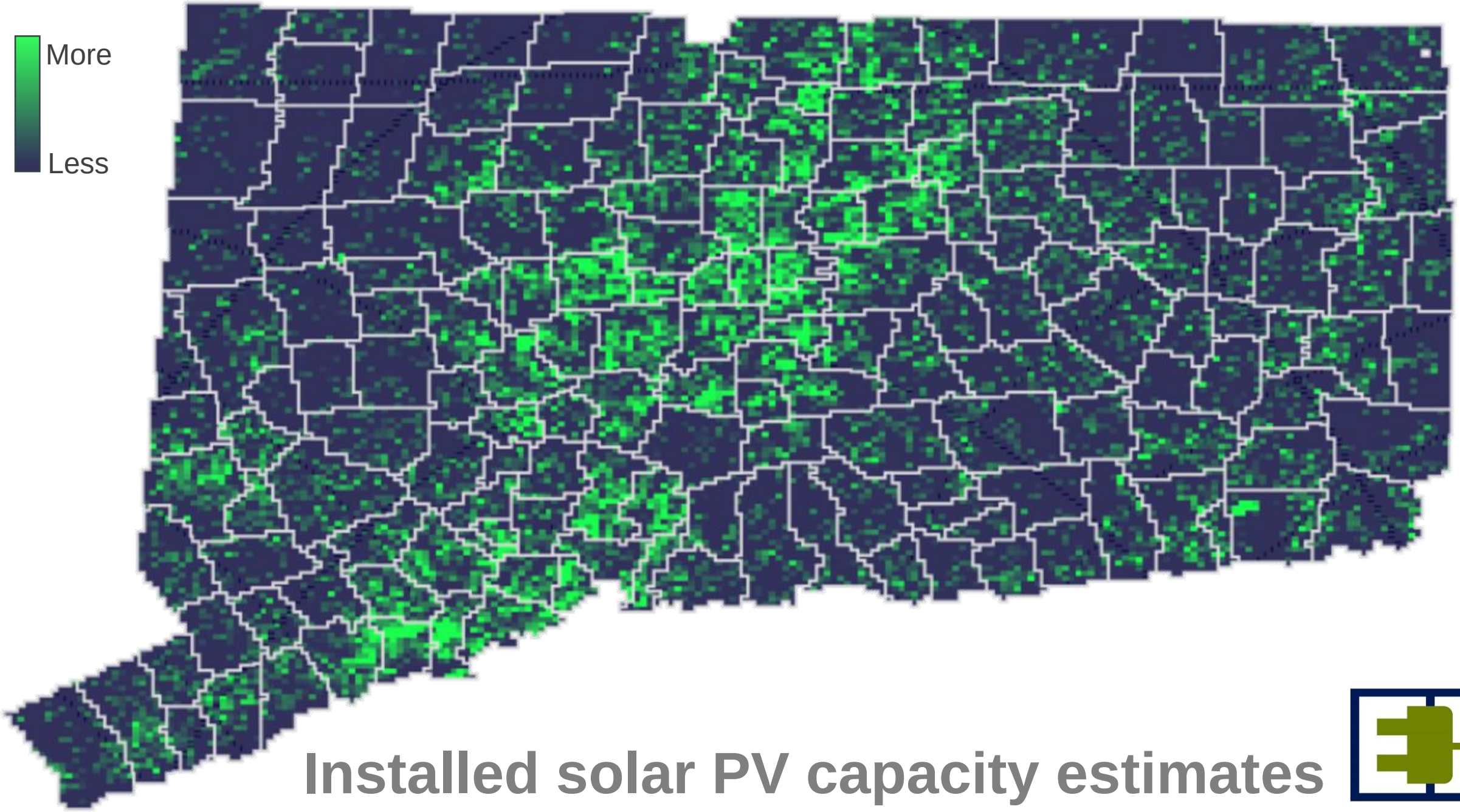
Camilo et al., 2017

Object-wise results:

City	Precision	Recall	F_1 score
Fresno	0.77	0.78	0.77
Modesto	0.73	0.75	0.74
Stockton	0.73	0.70	0.71
Overall	**0.76**	**0.77**	**0.76**

Malof et al., 2019

Malof et al., 2019

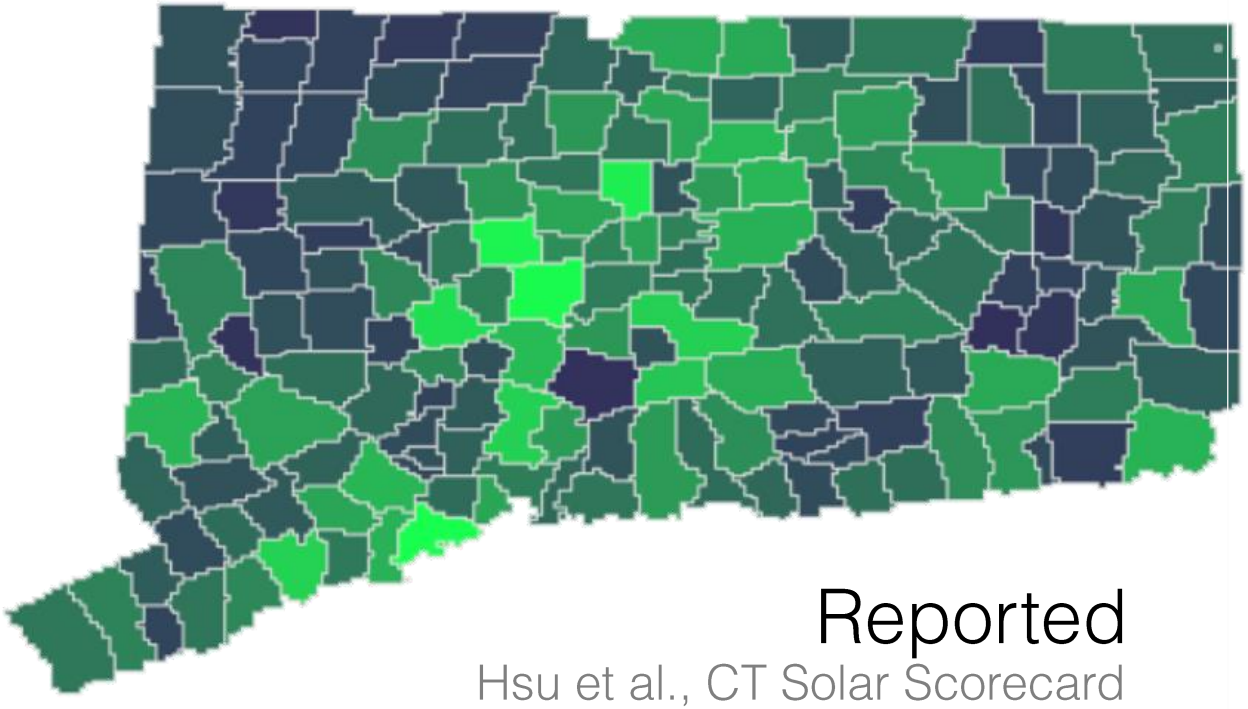


Installed solar PV capacity estimates

Automated estimates of residential solar PV capacity for CT municipalities

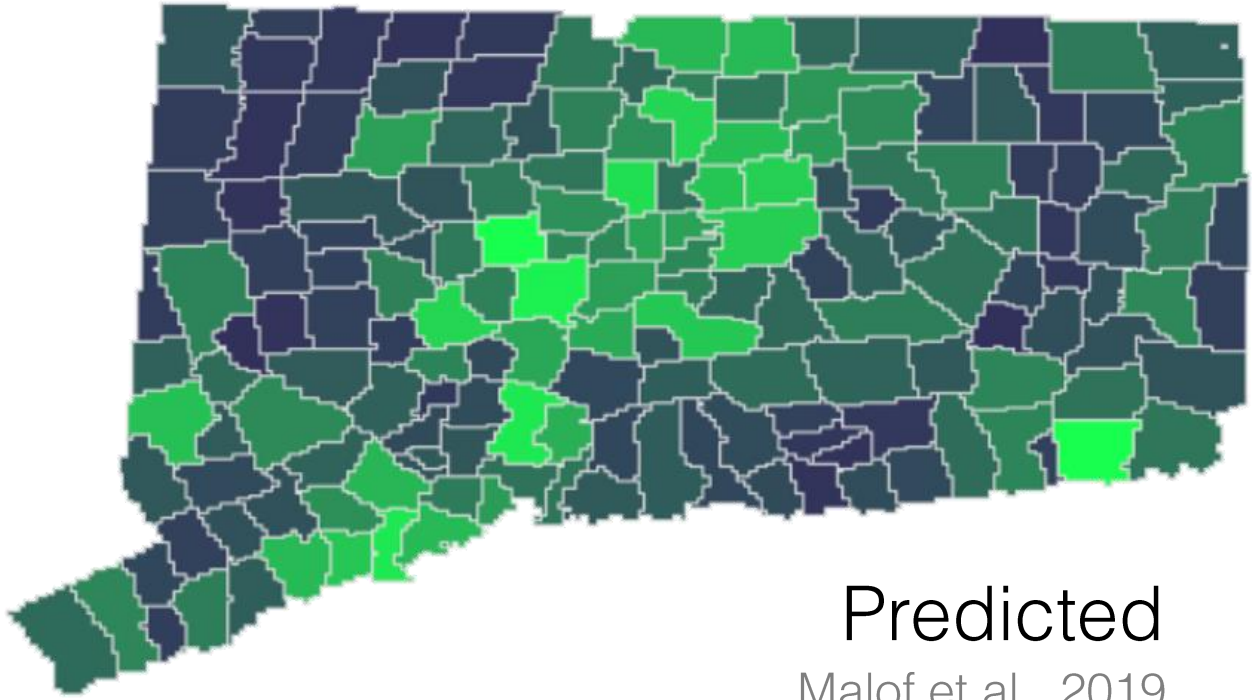
Correlation coefficient of **0.89**

(Covers over 14,000 km^2)



Reported

Hsu et al., CT Solar Scorecard



Predicted

Malof et al., 2019

Substation

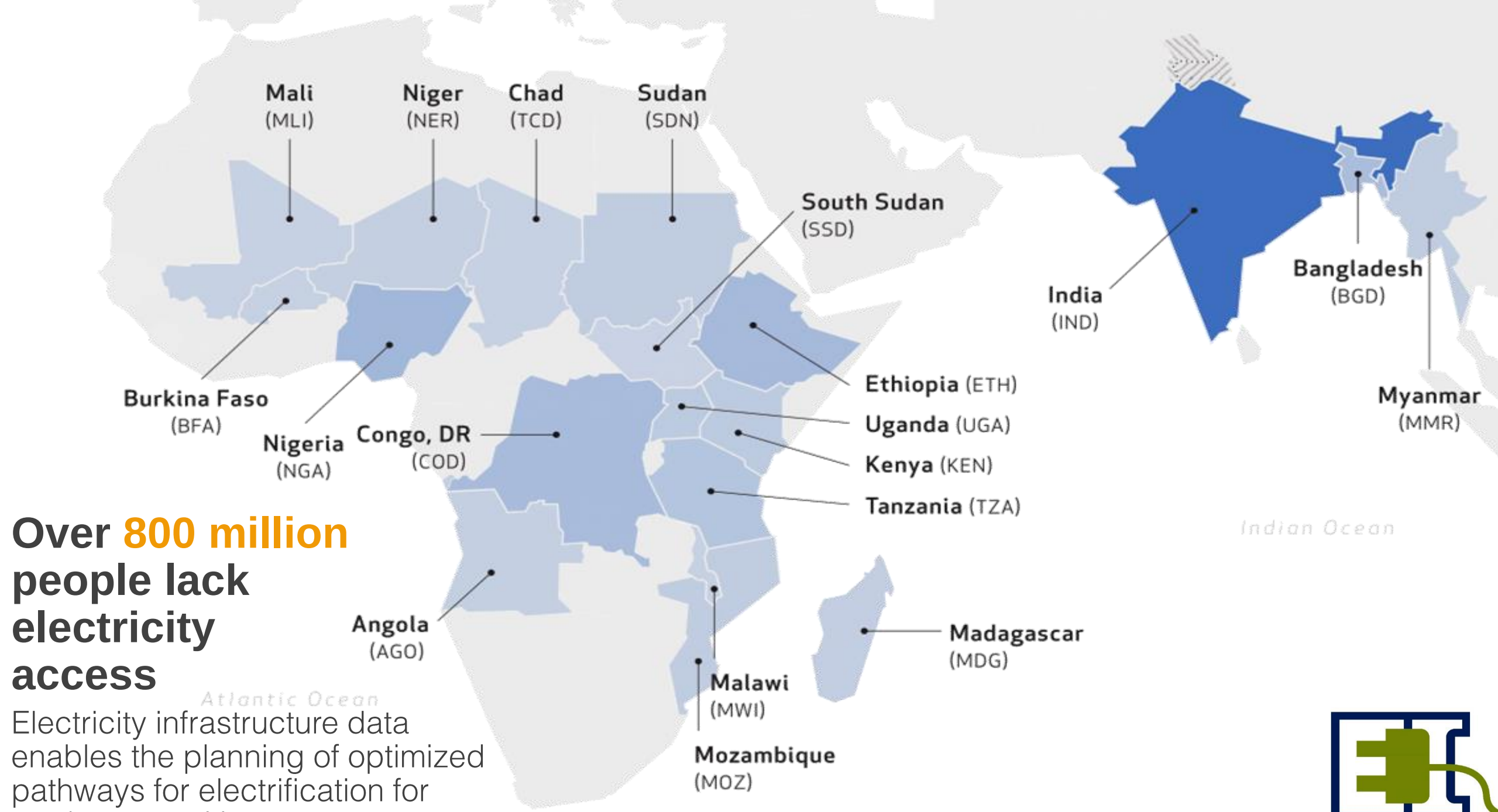
Transmission

Distribution

Sample images from Google Maps for demonstration purposes

2 Transmission & Distribution

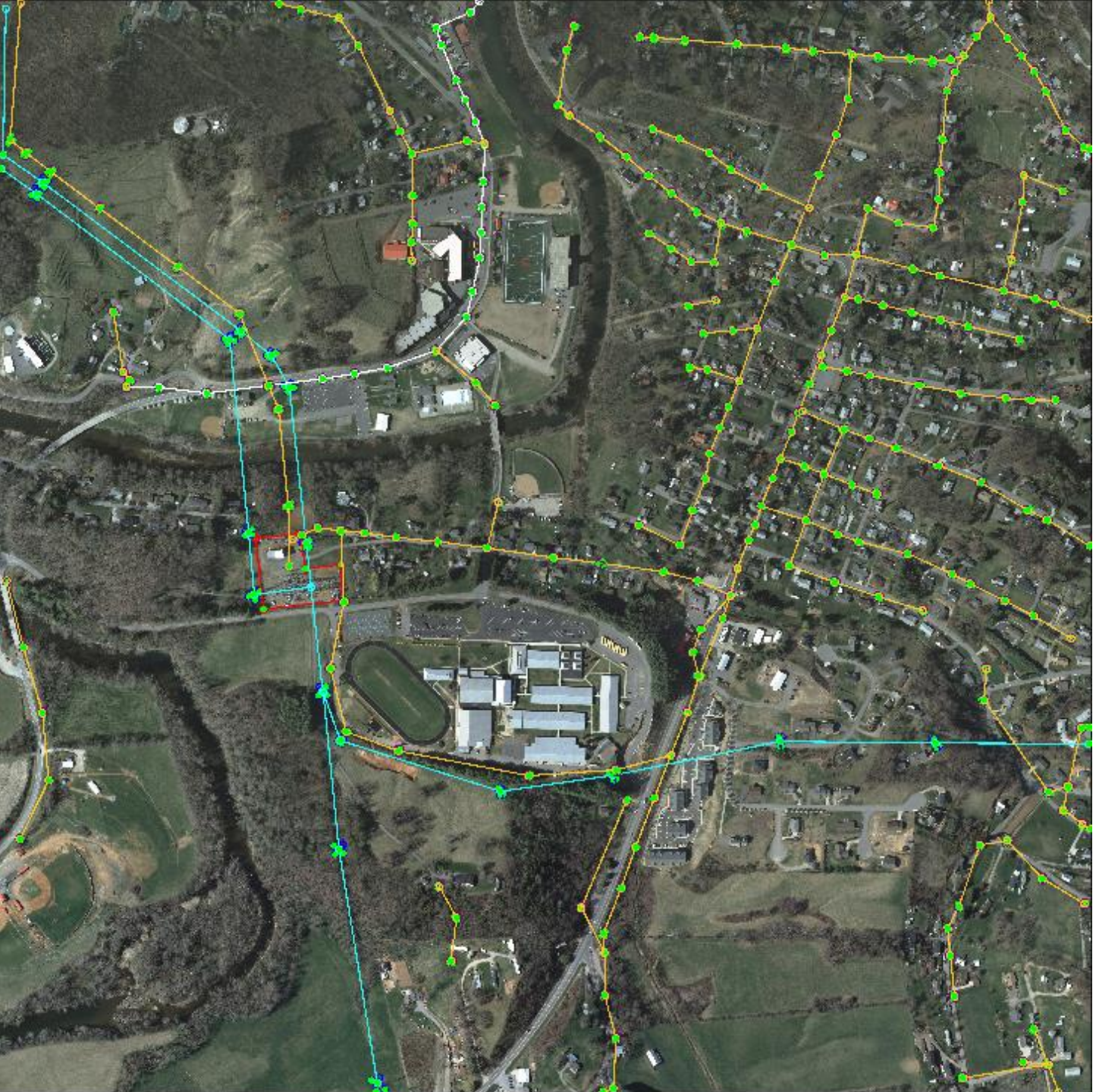
Bohao Huang, Artem Streltsov, Kyle Bradbury, Jordan Malof, *Submitted 2019*



Over 800 million people lack electricity access

Electricity infrastructure data enables the planning of optimized pathways for electrification for rural communities

Image from Sustainable Energy for All, 2014

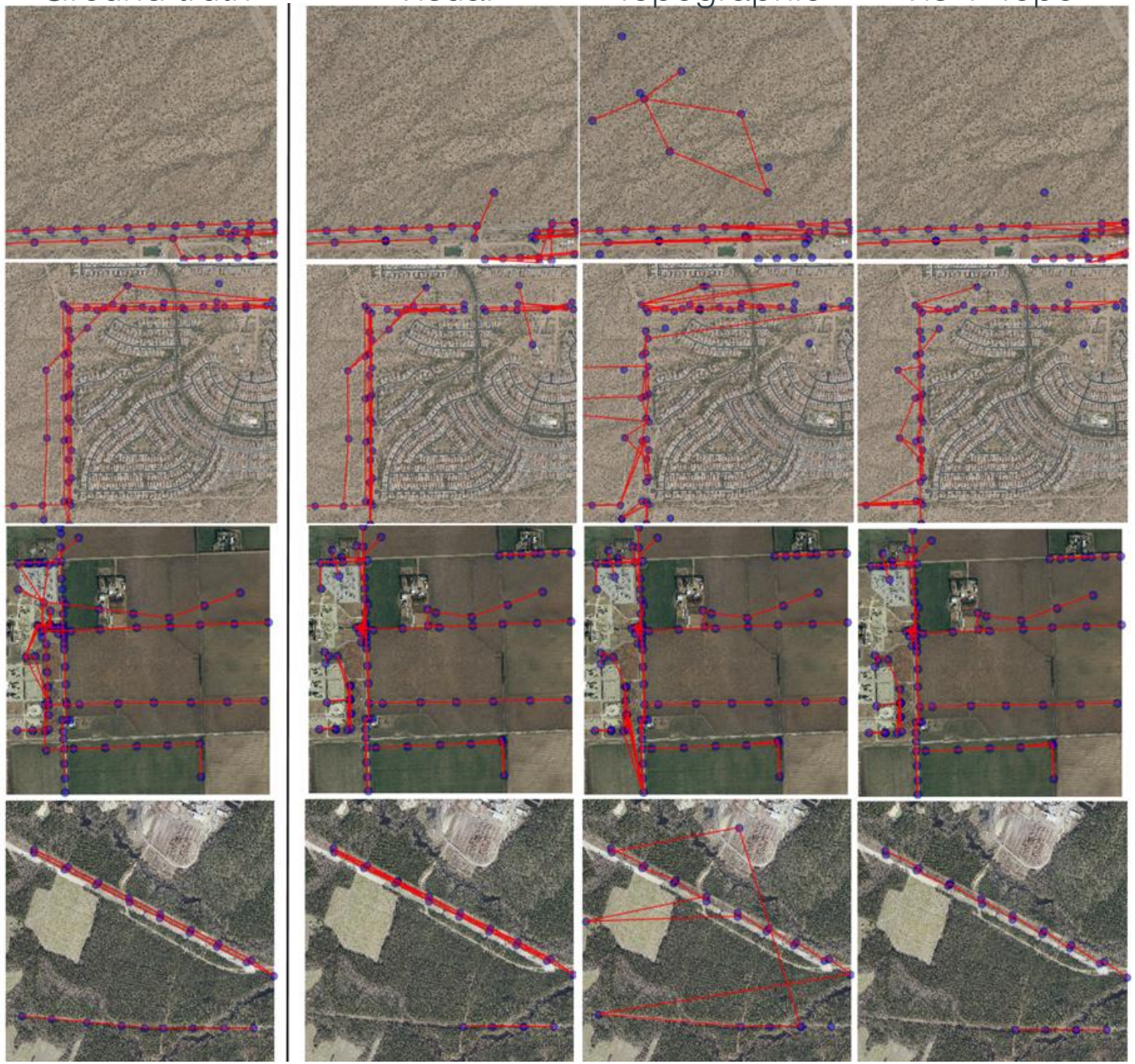


Transmission Data

Annotated transmission, distribution, substation, and power plant imagery data

Data are available at:
http://bit.ly/2jy7WvL

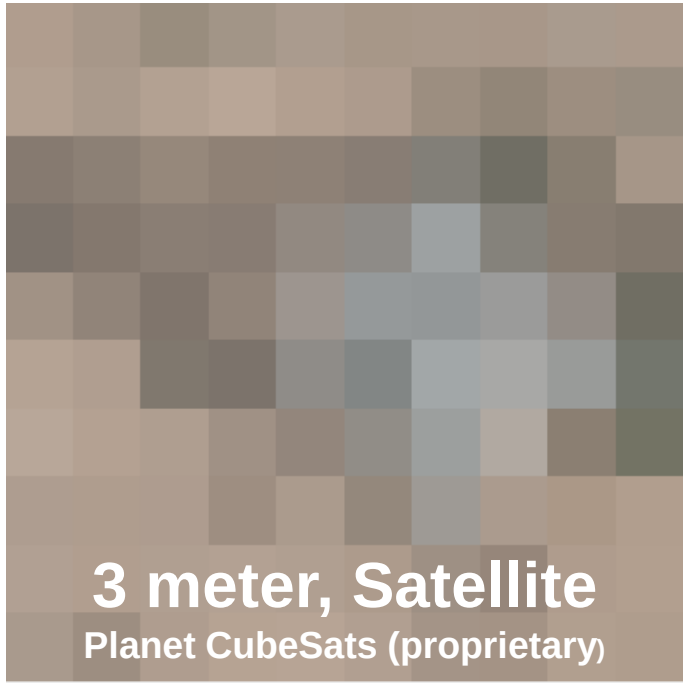
Results

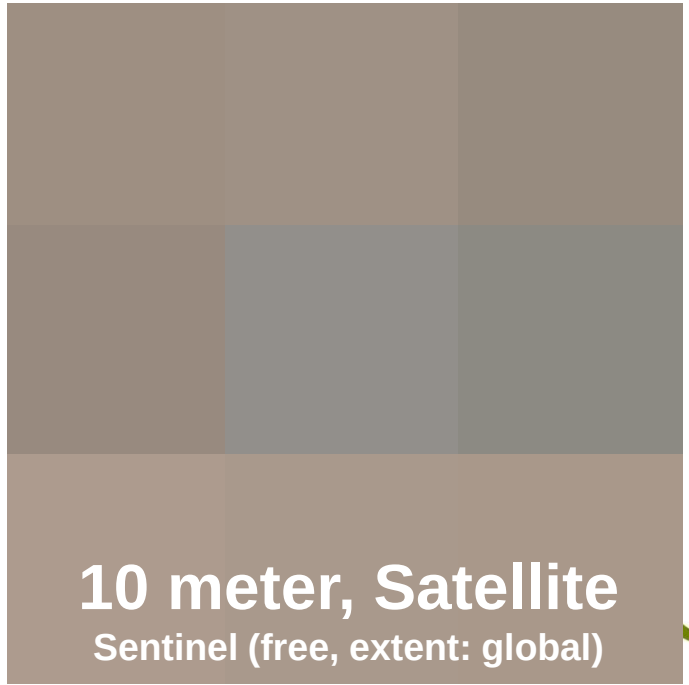


Huang, Bohao, Artem Streltsov, Kyle Bradbury, and Jordan Malof. “Automated Power Grid Mapping using Deep Learning and Overhead Imagery.” *Submitted 2019*

Challenge #1

Data resolution and availability





Ben Alexander, Wendell Cathcart, Yutao Gong, Atsushi Hu, Varun Nair, Lin Zuo. Duke University Bass Connections 2019

Tucson, AZ

Hartford, CT

Colwich, KS

Clyde, NC

Challenge #2
Geographic
diversity

ENERGY
data analytics lab

Duke ENERGY INITIATIVE

Duke PRATT SCHOOL of ENGINEERING

iiD SOCIAL SCIENCE RESEARCH INSTITUTE

For questions, contact Kyle Bradbury (kyle.Bradbury@duke.edu)

References

Bradbury, K., Saboo, R., Johnson, T., Malof, J., Zhang, W., Devarajan, A., Collins, L., Newell, R. (2016) “Distributed Solar Photovoltaic Array Location and Extent Dataset for Remote Sensing Object Identification.” Scientific Data, 3. doi:10.1038/sdata.2016.106.

Camilo, J., L. Collins, K. Bradbury, J. Malof. “Application of a semantic segmentation convolutional neural network for accurate automatic detection and mapping of solar photovoltaic arrays in aerial imagery.” Presented at the IEEE Applied Imagery Pattern Recognition Workshop in Washington, D.C., 2017.

Huang, Bohao, Kangkang Lu, Nicolas Audeberr, Andrew Khalel, Yuliya Tarabalka, Jordan Malof, Alexandre Boulch et al. "Large-scale semantic classification: outcome of the first year of inria aerial image labeling benchmark." In IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium, pp. 6947-6950. IEEE, 2018.

So, Brenda, Cory Nezin, Vishnu Kaimal, Sam Keene, Leslie Collins, Kyle Bradbury, and Jordan M. Malof. "Estimating the electricity generation capacity of solar photovoltaic arrays using only color aerial imagery." In 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1603-1606. IEEE, 2017.

Streltsov, Artem, Kyle Bradbury, and Jordan Malof. "Automated Building Energy Consumption Estimation from Aerial Imagery." In IGARSS 2018-2018 IEEE International Geoscience and Remote Sensing Symposium, pp. 1676-1679. IEEE, 2018.

Malof, Jordan M., Boning Li, Bohao Huang, Kyle Bradbury, and Artem Stretslov. "Mapping solar array location, size, and capacity using deep learning and overhead imagery." arXiv preprint arXiv:1902.10895 (2019).

Huang, Bohao, Artem Streltsov, Kyle Bradbury, and Jordan Malof. “Automated Power Grid Mapping using Deep Learning and Overhead Imagery.” *Submitted 2019*