Battery Storage For Reliability Of The Electric Power Network

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About Vivian Sultan, PhD

Digital Accelerator at Southern California Edison (SCE) and a Professor of Information Systems and Business Management at California State University (CSULA). Dr. Sultan holds a PhD in Information Systems and Technology from Claremont Graduate University. She is a certified professional in Supply Management with experience in account product management, operations, and automated system projects development. Prior to her current role, Dr. Sultan served as a Senior Analyst at Edison Materials Supply, an Account Product Manager at the Walt Disney Studios. Her publications and research focus on energy informatics and the digital transformation within supply chains.

Publications

- “A Predictive Model to Forecast Power Outages,” Proceedings of the 10th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.
- “An Inclusion of Electric Grid Reliability Research through the Enhanced Energy Informatics Research Framework,” Proceedings of the 8th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.
- “A Spatial Analytics Framework to Investigate Electric Power-Failure Events and Their Causes.” ISPRS International Journal of Geo-Information, 9(1), 54.
- “How May Location Analytics Be Used to Enhance the Reliability of the Smart Grid?” Inventions, 4(3), 39.
- “Electric Grid Reliability Research” Energy informatics Journal. Computer Science, 2(3).
- “Solving Electric Grid Network Congestion Problem with Batteries – An Exploratory Study using GIS Techniques,” International Journal of Smart Grid and Clean Energy, 7(2).
- “A Conceptual Framework To Integrate Electric Vehicles Charging Infrastructure Into The Electric Grid,” International Journal of Smart Grid and Clean Energy, 6(3).
- “Analysis Framework to Investigate Power-Failure Events and Their Causes?” Proceedings of the International Conference on Data Science, Las Vegas, USA.
- “Which Grid Infrastructure Needs Utilities’ Immediate Attention to Reduce the Risk of Power Outages?” Proceedings of the International Conference on Data Science, Las Vegas, USA.
- “How May Location Analytics Be Used to Enhance the Reliability of the Smart Grid?” Proceedings of the International Conference on Scientific Computing, Las Vegas, USA.
- “Where Should a Utility Improve Tree Cutting to Reduce the Risk of Vegetation Coming into Contact with Power Lines?” Proceedings of the 9th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.
- “Is Power Outage Associated With Population Density?” Proceedings of the 9th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies, Athens.

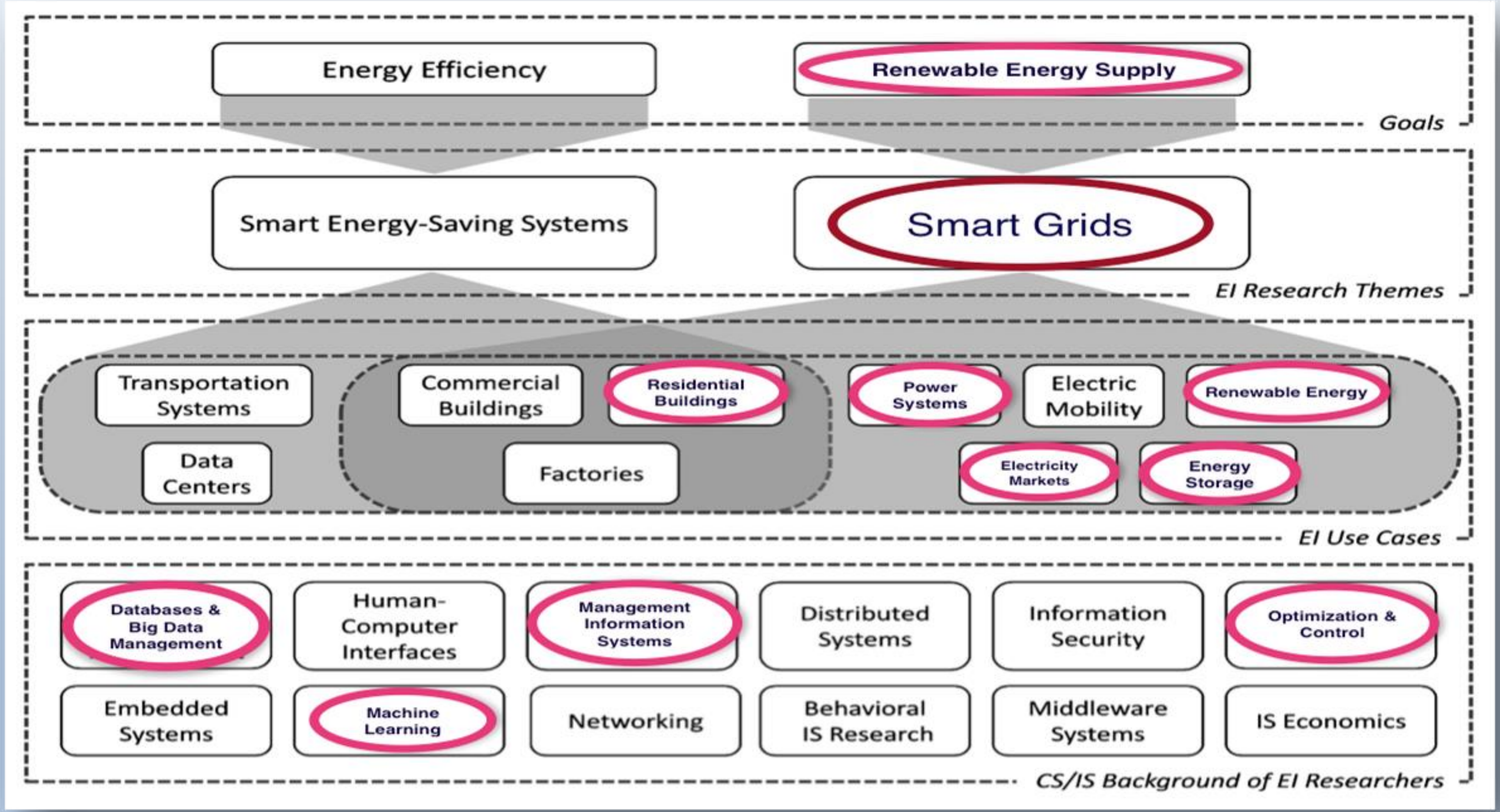
Publications – Cont'd

- “Geographic decision support systems to optimize the placement of distributed energy resources,” International Journal of Smart Grid and Clean Energy, 5(3).
- “Is California's aging infrastructure the principal contributor to the recent trend of power outage?” Journal of Communication and Computer, USA, 13 (5).
- "Exploring Geographic Information Systems To Mitigate America’s Electric Grid Traffic Congestion Problem,” Proceedings of the 4th International Symposium on Computational and Business Intelligence.
- “A Predictive Model to Forecast Customer Adoption of Rooftop Solar,” Proceedings of the 4th International Symposium on Computational and Business Intelligence.
- “Geographic Decision Support Systems To Optimize The Placement Of Distributed Energy Resources,” Proceedings of the 22nd Americas Conference on Information Systems.
- “Is California's aging infrastructure the principal contributor to the recent trend of power outage?” Proceedings of the 22nd Annual California GIS Conference.
- “A Conceptual Framework To Integrate Electric Vehicles Charging Infrastructure Into The Electric Grid,” International Journal of Smart Grid and Clean Energy, 6(3).
- “Electric Vehicles charging infrastructure integration into the electric grid considering the net benefits to consumers,” Proceedings of the 7th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.
- “Solving Electric Grid Network Congestion Problem with Batteries – An Exploratory Study using GIS Techniques,” International Journal of Smart Grid and Clean Energy, 7(2).
- “Electric Substation Emergency Disaster Response Planning through the use of Geographic Information Systems,” Proceedings of the 8th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.
- “Battery Storage Integration into the Electric Grid,” Proceedings of the 8th International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.

Battery Storage For The Grid Reliability

Grid reliability is the greatest concern resulting from the current challenges facing electric utilities. The argument is that battery storage will play a significant role in meeting the challenges facing electric utilities by improving the operating capabilities of the grid, lowering cost and ensuring high reliability, as well as deferring and reducing infrastructure investments. According to the United States Department of Energy, energy storage technology can help contribute to the overall system reliability as wind, solar, and other renewable energy sources continue to be added to the grid. Storage technology will be an effective tool in managing grid reliability and resiliency by regulating generation fluctuation and improving the grid's functionality. It will provide redundancy options in areas with limited transmission capacity, transmission disruptions, or volatile demand and supply profiles. Utility-scale storage can be instrumental for emergency preparedness because of its ability to provide backup power, as well as grid stabilization services..

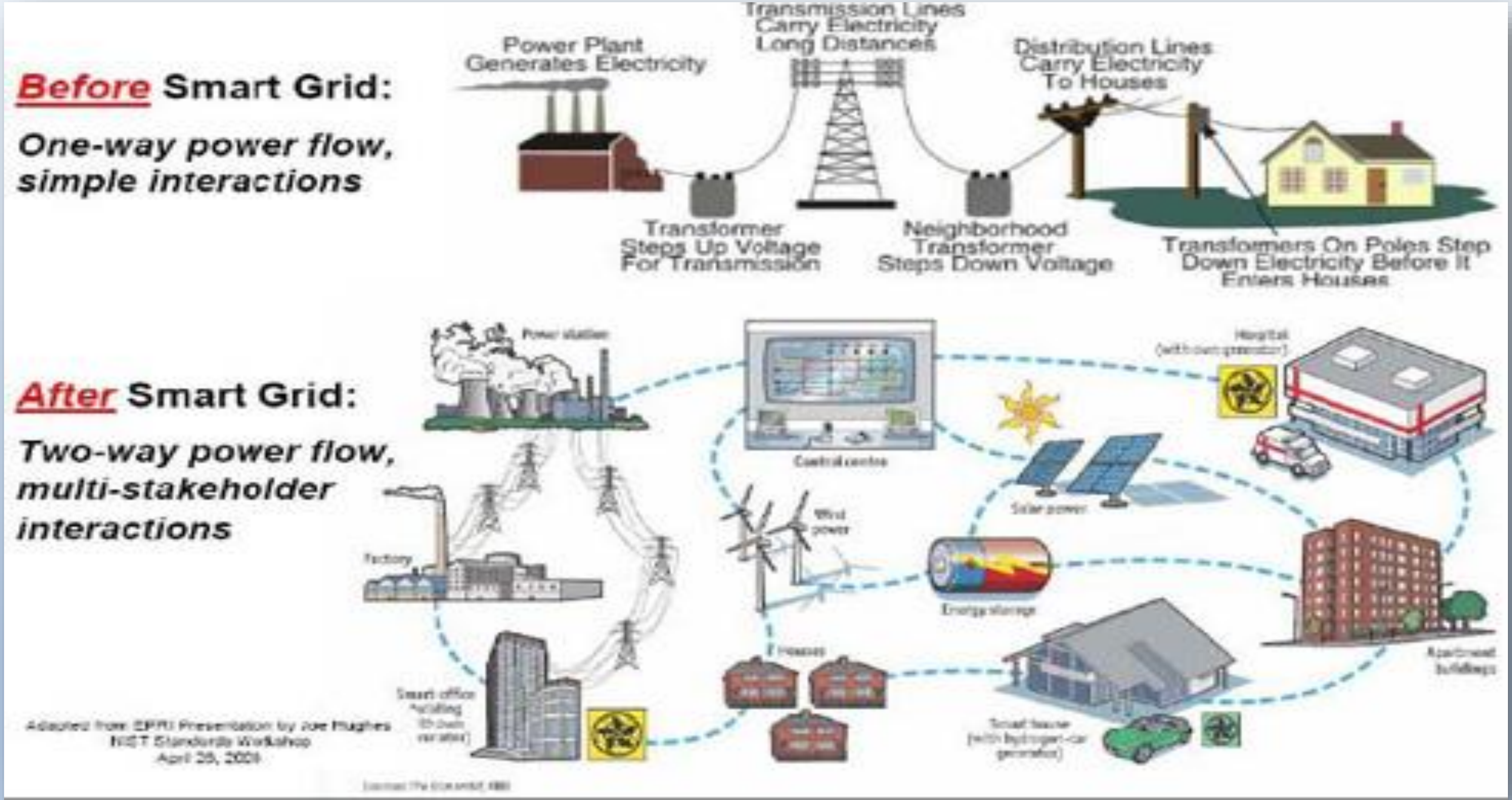
Energy Informatics Research
(Goebel et al. 2014)



Smart Grid Reliability

Smart Grid: a new class of technology to bring the electricity delivery system into the 21st century - Network technologies are the backbone of this system

- ✓ Must be adaptable, strong and responsive
- ✓ \$338–\$476 billion in the next twenty years to incorporate in DERs, intelligence technologies, advanced systems, and applications
- ✓ Tools for optimizing grid operations and to forecast future problems are crucial within the modern grid design



Before Smart Grid:

One-way power flow, simple interactions

After Smart Grid:

Two-way power flow, multi-stakeholder interactions

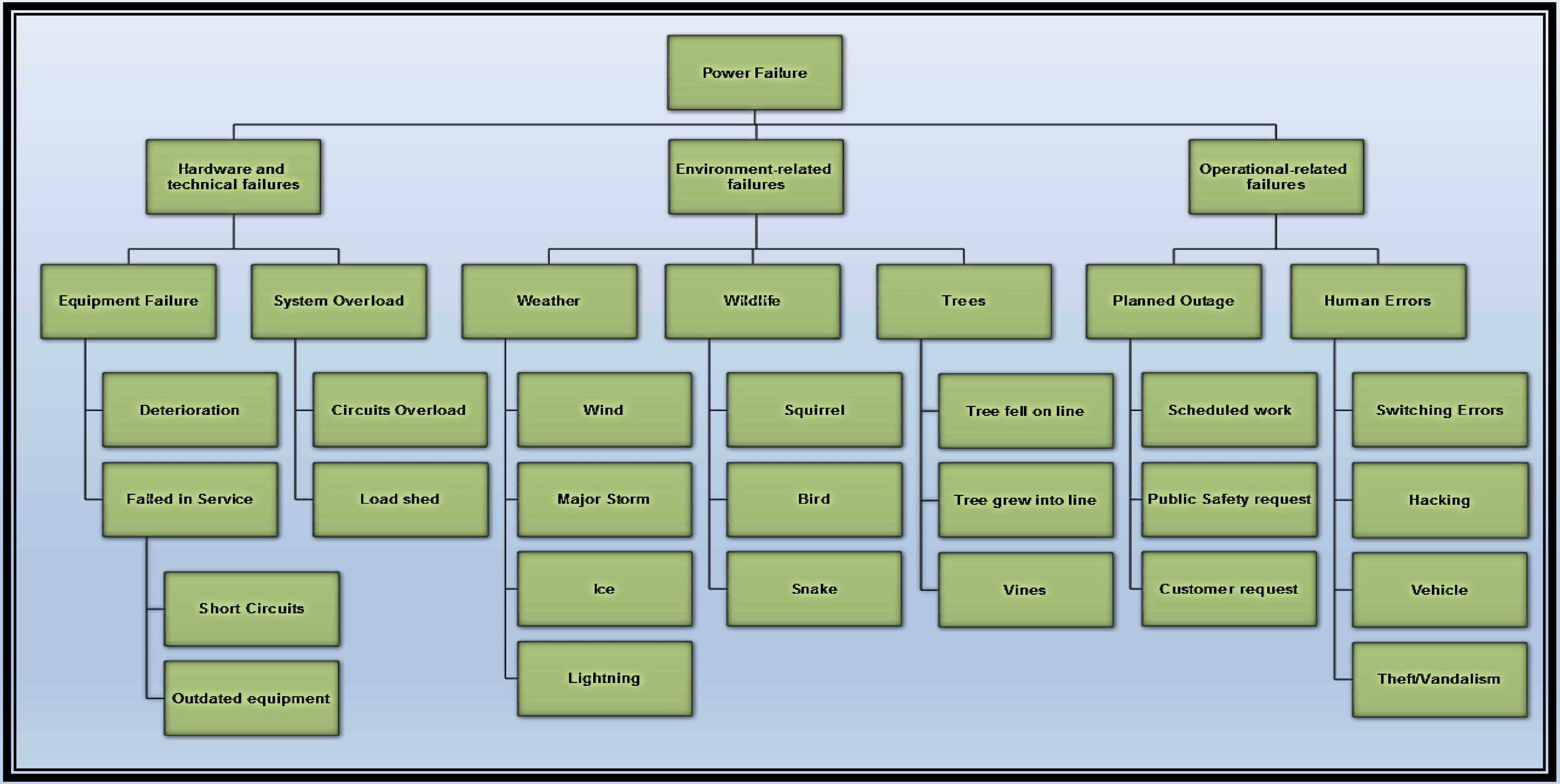
Adapted from EPRI Presentation by Joe Hughes
NIST Standards Workshop
April 28, 2008

Smart Grid Reliability

Reliability: the degree to which the performances of the elements of the electric system result in power being delivered to consumers within accepted standards and in the amount desired - Measured by outage indices

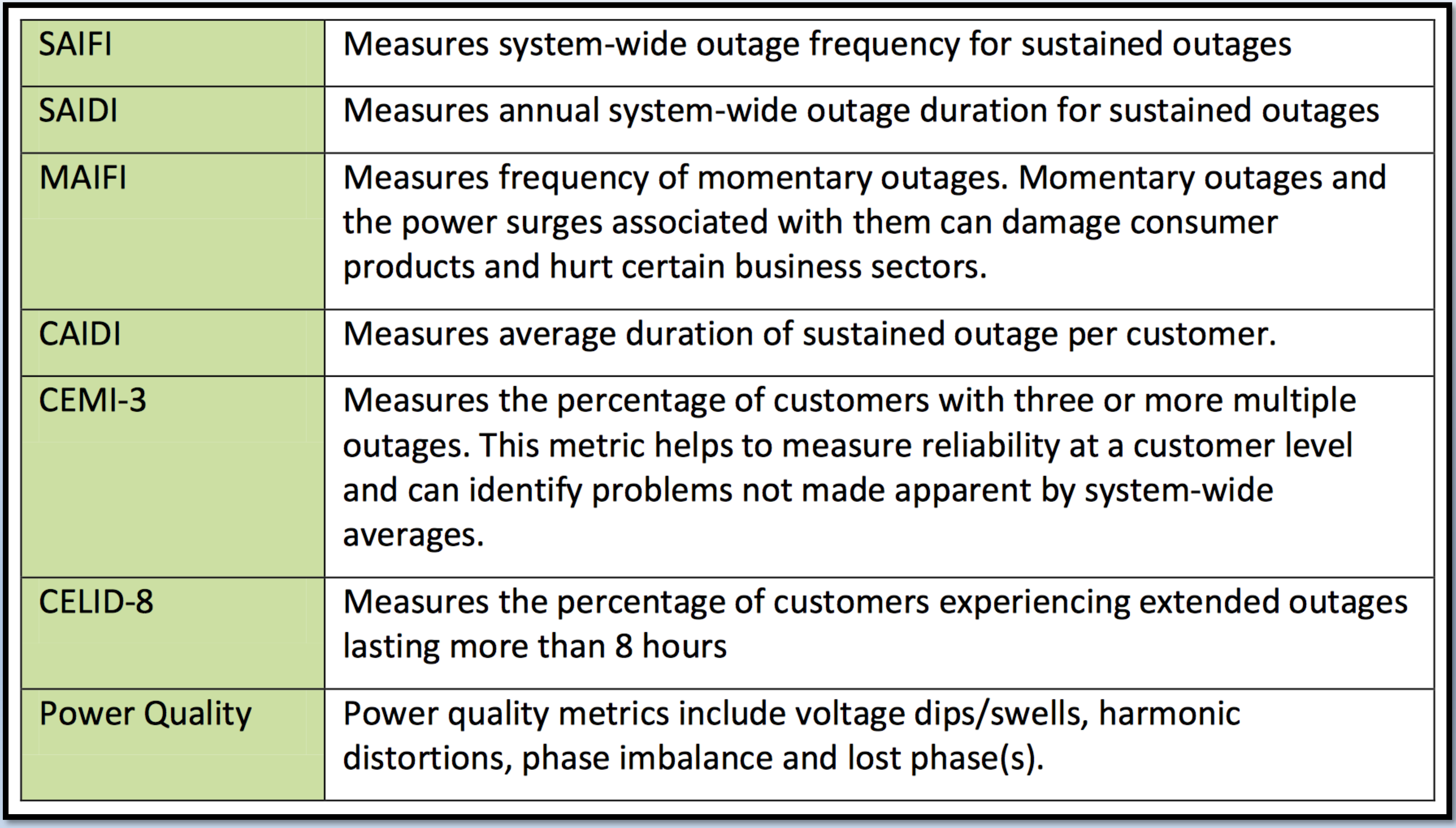
- The economic cost of power interruptions to U.S. electricity consumers is $79 billion annually in damages and lost economic activity
- Power outages can be especially tragic when it comes to life-support systems in places like hospitals and nursing homes or in facilities such as in airports, train stations, and traffic control

Smart Grid Reliability (Sultan et al. 2018)



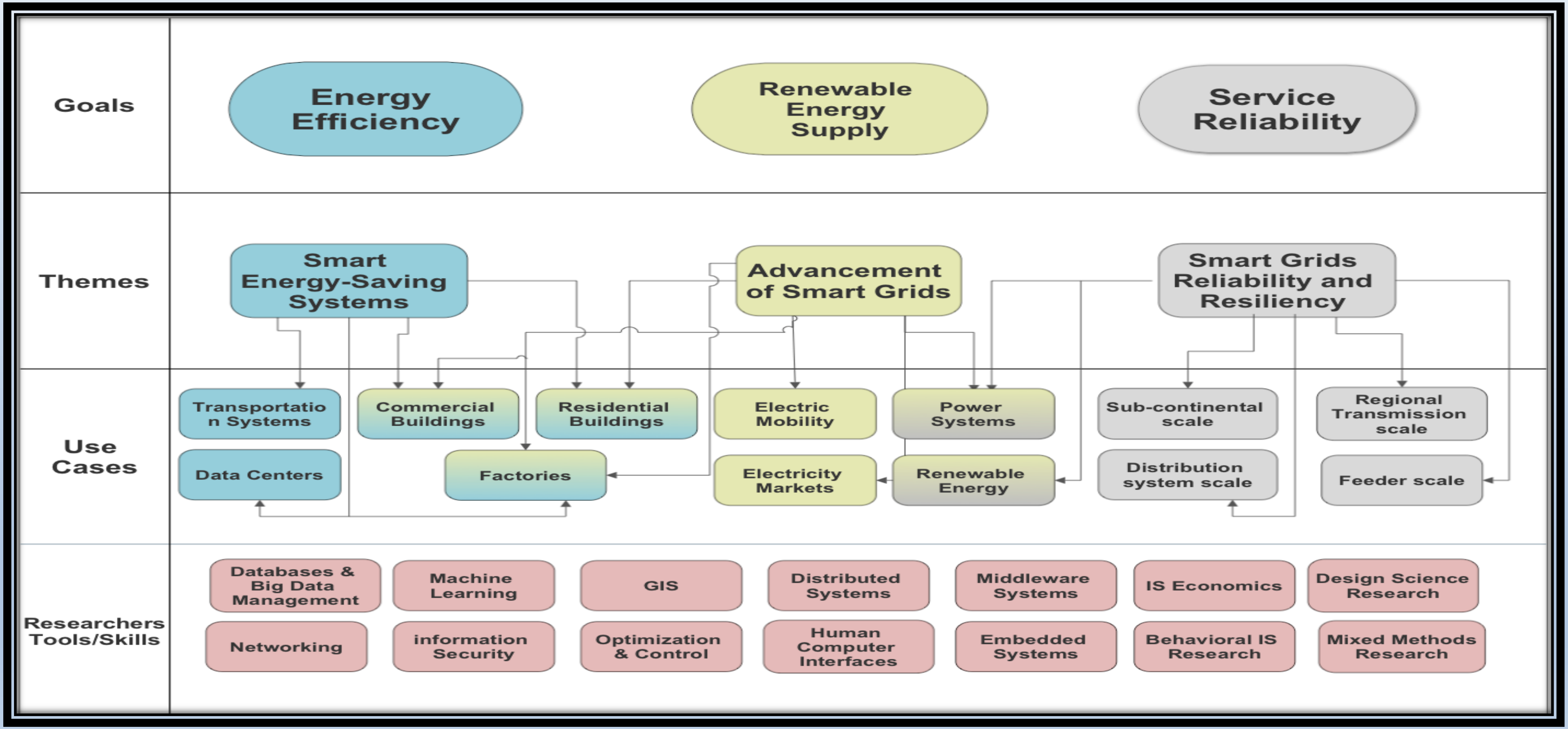
Smart Grid Reliability

Outage Indices



SAIFI	Measures system-wide outage frequency for sustained outages
SAIDI	Measures annual system-wide outage duration for sustained outages
MAIFI	Measures frequency of momentary outages. Momentary outages and the power surges associated with them can damage consumer products and hurt certain business sectors.
CAIDI	Measures average duration of sustained outage per customer.
CEMI-3	Measures the percentage of customers with three or more multiple outages. This metric helps to measure reliability at a customer level and can identify problems not made apparent by system-wide averages.
CELID-8	Measures the percentage of customers experiencing extended outages lasting more than 8 hours
Power Quality	Power quality metrics include voltage dips/swells, harmonic distortions, phase imbalance and lost phase(s).

Energy Informatics Enhanced Research Framework
Enriched with the Reliability Research (Sultan et al. 2018)



Goals

Energy Efficiency

Renewable Energy Supply

Service Reliability

Themes

Smart Energy-Saving Systems

Advancement of Smart Grids

Smart Grids Reliability and Resiliency

Use Cases

Transportation Systems

Commercial Buildings

Residential Buildings

Electric Mobility

Power Systems

Sub-continental scale

Regional Transmission scale

Data Centers

Factories

Electricity Markets

Renewable Energy

Distribution system scale

Feeder scale

Researchers Tools/Skills

Databases & Big Data Management

Machine Learning

GIS

Distributed Systems

Middleware Systems

IS Economics

Design Science Research

Networking

information Security

Optimization & Control

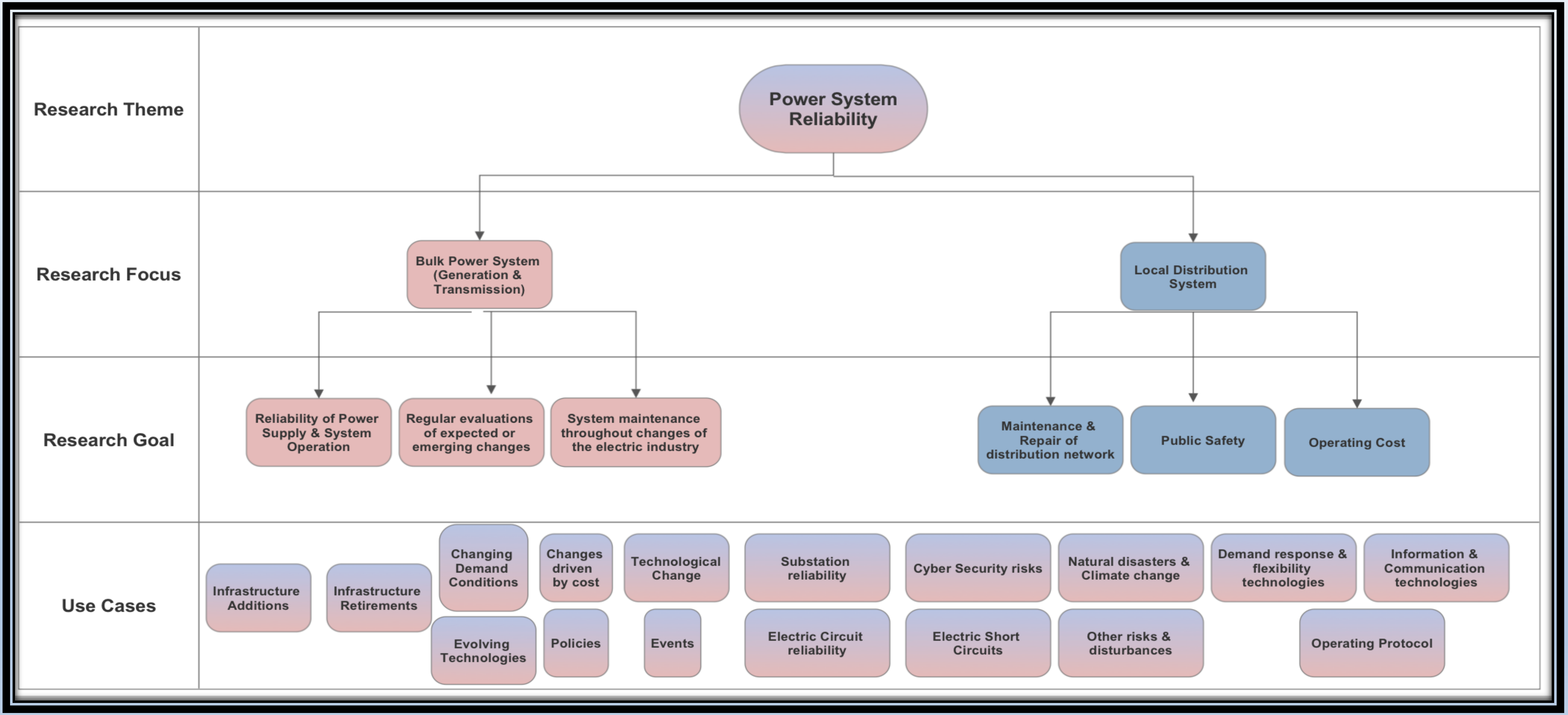
Human Computer Interfaces

Embedded Systems

Behavioral IS Research

Mixed Methods Research

Power System Reliability Research Framework (Sultan et al. 2019)



Research Theme

Research Focus

Research Goal

Use Cases

Power System Reliability

Bulk Power System (Generation & Transmission)

Local Distribution System

Reliability of Power Supply & System Operation

Regular evaluations of expected or emerging changes

System maintenance throughout changes of the electric industry

Maintenance & Repair of distribution network

Public Safety

Operating Cost

Infrastructure Additions

Infrastructure Retirements

Changing Demand Conditions

Evolving Technologies

Changes driven by cost

Policies

Technological Change

Events

Substation reliability

Electric Circuit reliability

Cyber Security risks

Electric Short Circuits

Natural disasters & Climate change

Other risks & disturbances

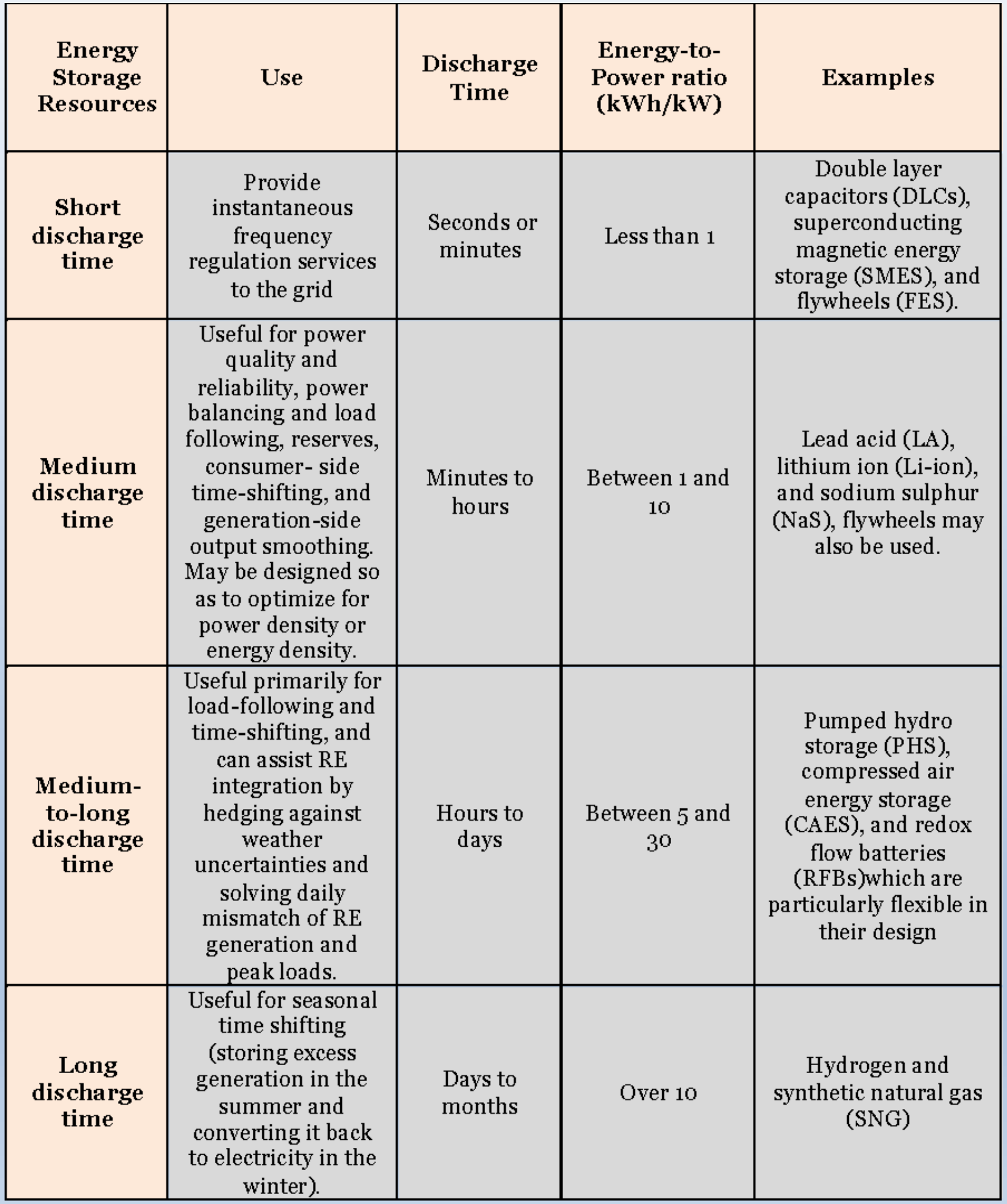
Demand response & flexibility technologies

Information & Communication technologies

Operating Protocol

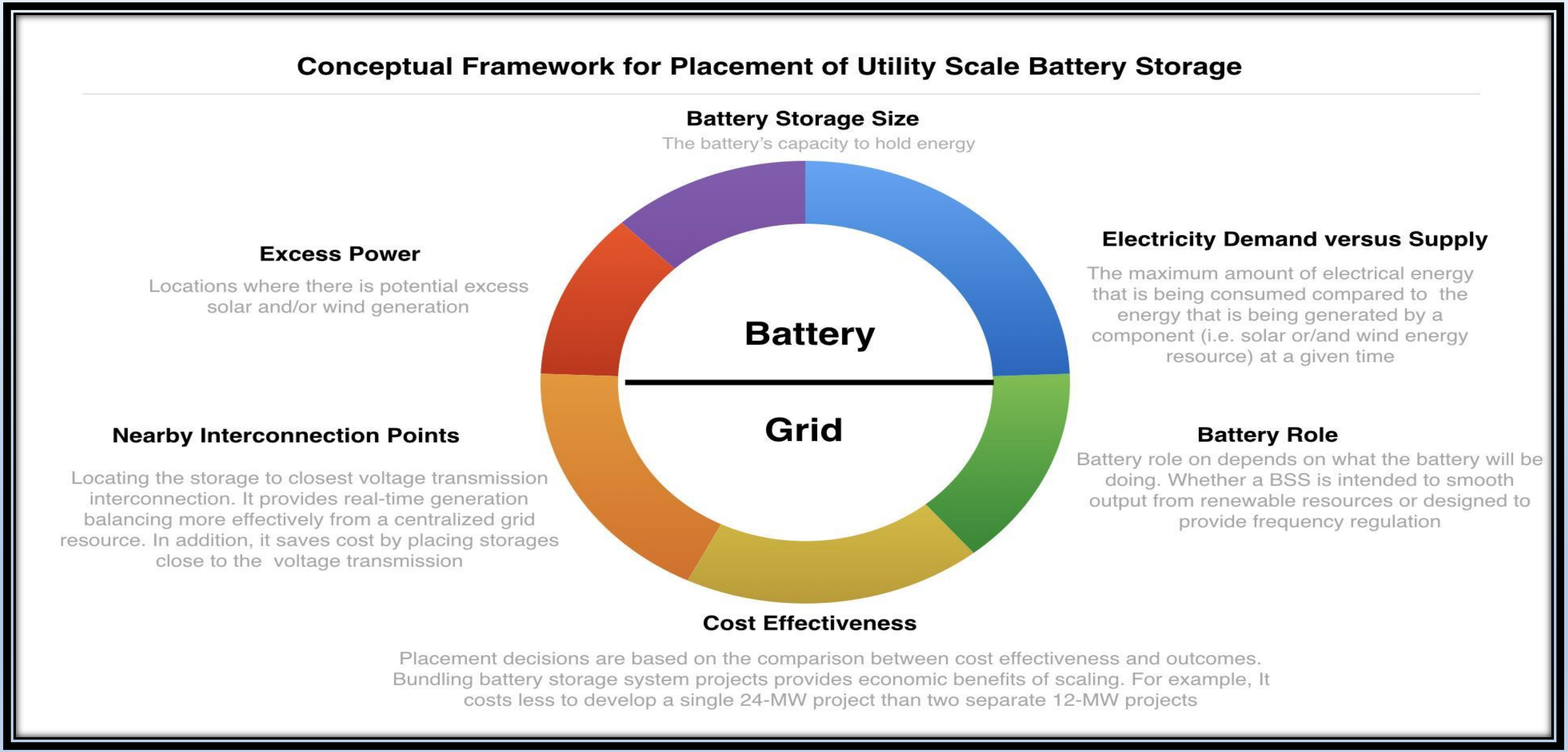
Battery Storage Integration Into The Electric Grid

- Energy storage technology to contribute to the overall system reliability
  - Regulating generation fluctuation
  - Improving the grid’s functionality
  - Providing redundancy options in areas with limited transmission capacity, transmission disruptions, or volatile demand and supply profiles
- Storage to promote energy independence and reduce carbon emissions
- Identifying optimal locations for energy storage is a challenge considering the electric grid constraints, the deployment requirements and the potential benefits to the grid



Energy Storage Resources	Use	Discharge Time	Energy-to-Power ratio (kWh/kW)	Examples
Short discharge time	Provide instantaneous frequency regulation services to the grid	Seconds or minutes	Less than 1	Double layer capacitors (DLCs), superconducting magnetic energy storage (SMES), and flywheels (FES).
Medium discharge time	Useful for power quality and reliability, power balancing and load following, reserves, consumer- side time-shifting, and generation-side output smoothing. May be designed so as to optimize for power density or energy density.	Minutes to hours	Between 1 and 10	Lead acid (LA), lithium ion (Li-ion), and sodium sulphur (NaS), flywheels may also be used.
Medium-to-long discharge time	Useful primarily for load-following and time-shifting, and can assist RE integration by hedging against weather uncertainties and solving daily mismatch of RE generation and peak loads.	Hours to days	Between 5 and 30	Pumped hydro storage (PHS), compressed air energy storage (CAES), and redox flow batteries (RFBs)which are particularly flexible in their design
Long discharge time	Useful for seasonal time shifting (storing excess generation in the summer and converting it back to electricity in the winter).	Days to months	Over 10	Hydrogen and synthetic natural gas (SNG)

Battery Storage Integration Into The Electric Grid



Conceptual Framework for Placement of Utility Scale Battery Storage

Battery Storage Size

The battery's capacity to hold energy

Electricity Demand versus Supply

The maximum amount of electrical energy that is being consumed compared to the energy that is being generated by a component (i.e. solar or/and wind energy resource) at a given time

Battery Role

Battery role on depends on what the battery will be doing. Whether a BSS is intended to smooth output from renewable resources or designed to provide frequency regulation

Cost Effectiveness

Placement decisions are based on the comparison between cost effectiveness and outcomes. Bundling battery storage system projects provides economic benefits of scaling. For example, It costs less to develop a single 24-MW project than two separate 12-MW projects

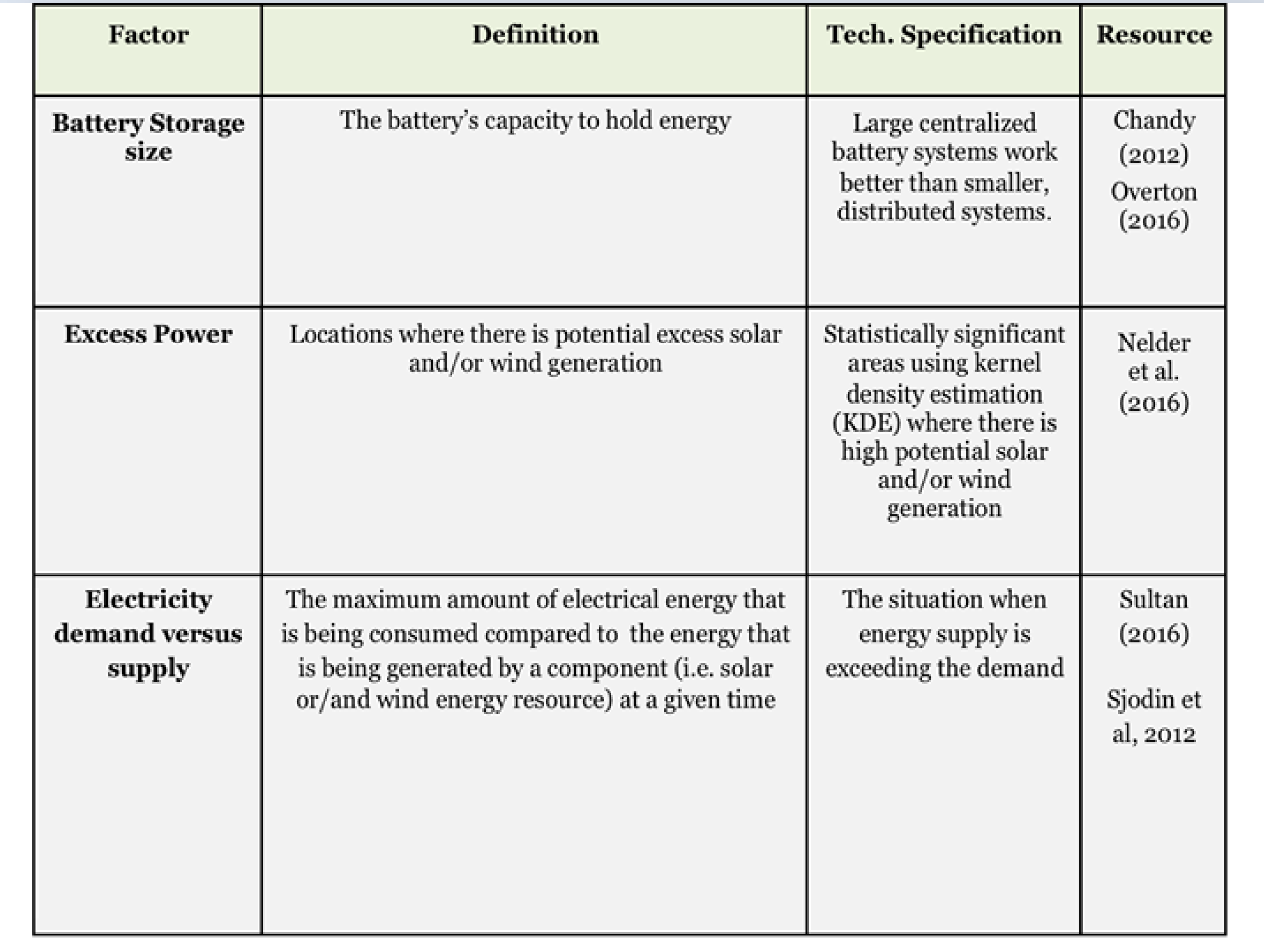
Nearby Interconnection Points

Locating the storage to closest voltage transmission interconnection. It provides real-time generation balancing more effectively from a centralized grid resource. In addition, it saves cost by placing storages close to the voltage transmission

Excess Power

Locations where there is potential excess solar and/or wind generation

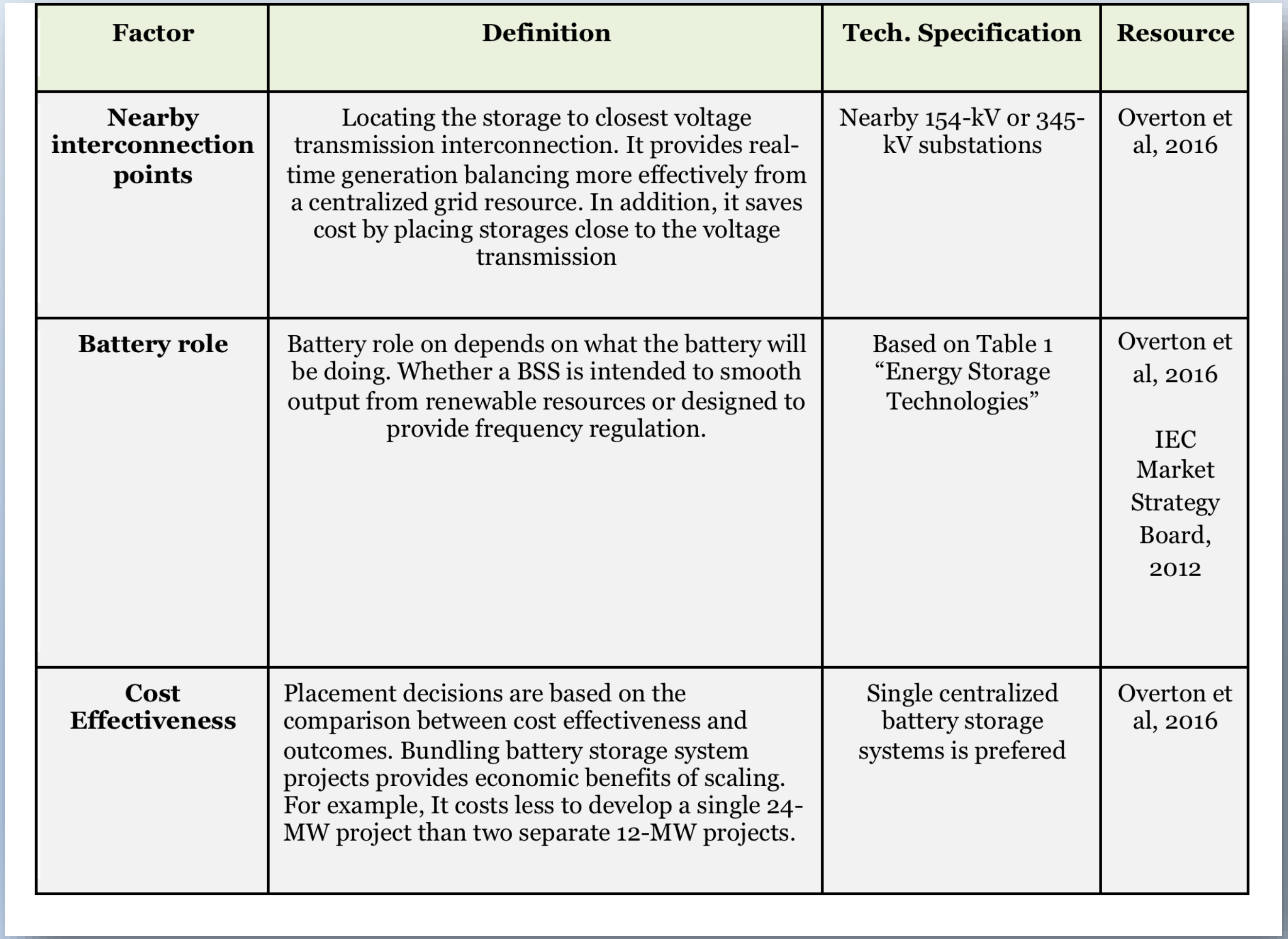
Battery Storage Integration Into The Electric Grid



Factor	Definition	Tech. Specification	Resource
Battery Storage size	The battery's capacity to hold energy	Large centralized battery systems work better than smaller, distributed systems.	Chandy (2012) Overton (2016)
Excess Power	Locations where there is potential excess solar and/or wind generation	Statistically significant areas using kernel density estimation (KDE) where there is high potential solar and/or wind generation	Nelder et al. (2016)
Electricity demand versus supply	The maximum amount of electrical energy that is being consumed compared to the energy that is being generated by a component (i.e. solar or/and wind energy resource) at a given time	The situation when energy supply is exceeding the demand	Sultan (2016) Sjodin et al, 2012

Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

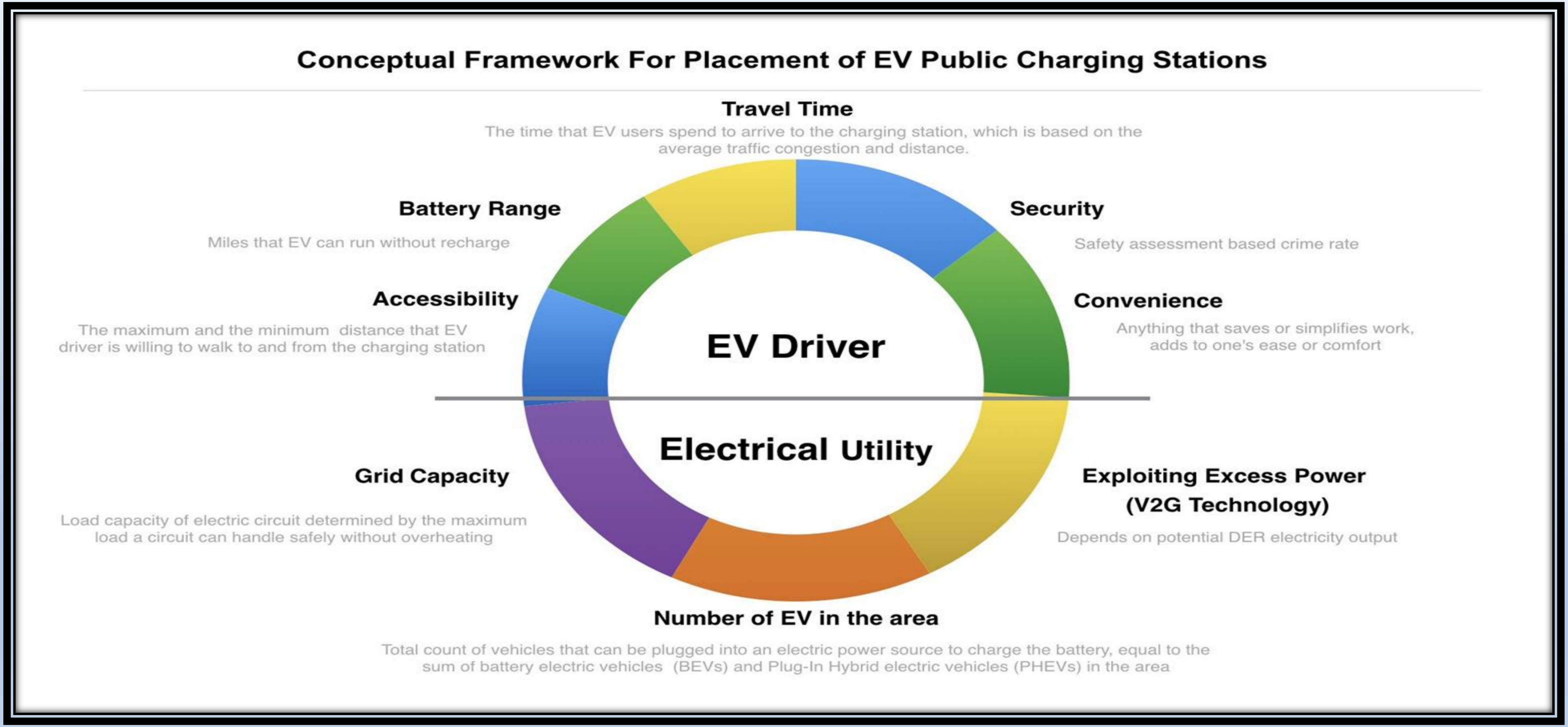
Battery Storage Integration Into The Electric Grid



Factor	Definition	Tech. Specification	Resource
Nearby interconnection points	Locating the storage to closest voltage transmission interconnection. It provides real-time generation balancing more effectively from a centralized grid resource. In addition, it saves cost by placing storages close to the voltage transmission	Nearby 154-kV or 345-kV substations	Overton et al, 2016
Battery role	Battery role on depends on what the battery will be doing. Whether a BSS is intended to smooth output from renewable resources or designed to provide frequency regulation.	Based on Table 1 “Energy Storage Technologies”	Overton et al, 2016 IEC Market Strategy Board, 2012
Cost Effectiveness	Placement decisions are based on the comparison between cost effectiveness and outcomes. Bundling battery storage system projects provides economic benefits of scaling. For example, It costs less to develop a single 24-MW project than two separate 12-MW projects.	Single centralized battery storage systems is prefered	Overton et al, 2016

ID	Substation Name	Substation Type
1	WALNUT	S -- Sub-transmission
2	ROSEMEAD	D -- Distribution
3	GOULD	S -- Sub-transmission
4	MESA	S -- Sub-transmission
5	LAGUNA	S -- Sub-transmission
6	BULLIS	D -- Distribution
7	CENTER	S -- Sub-transmission
8	CORNUTA	D -- Distribution
9	LIGHTHIPE	S -- Sub-transmission
10	HASKELL	D -- Distribution
11	STADIUM	D -- Distribution

EV Charging Infrastructure Integration Into The Electric Grid



Conceptual Framework For Placement of EV Public Charging Stations

Travel Time

The time that EV users spend to arrive to the charging station, which is based on the average traffic congestion and distance.

Battery Range

Miles that EV can run without recharge

Security

Safety assessment based crime rate

Accessibility

The maximum and the minimum distance that EV driver is willing to walk to and from the charging station

Convenience

Anything that saves or simplifies work, adds to one's ease or comfort

Grid Capacity

Load capacity of electric circuit determined by the maximum load a circuit can handle safely without overheating

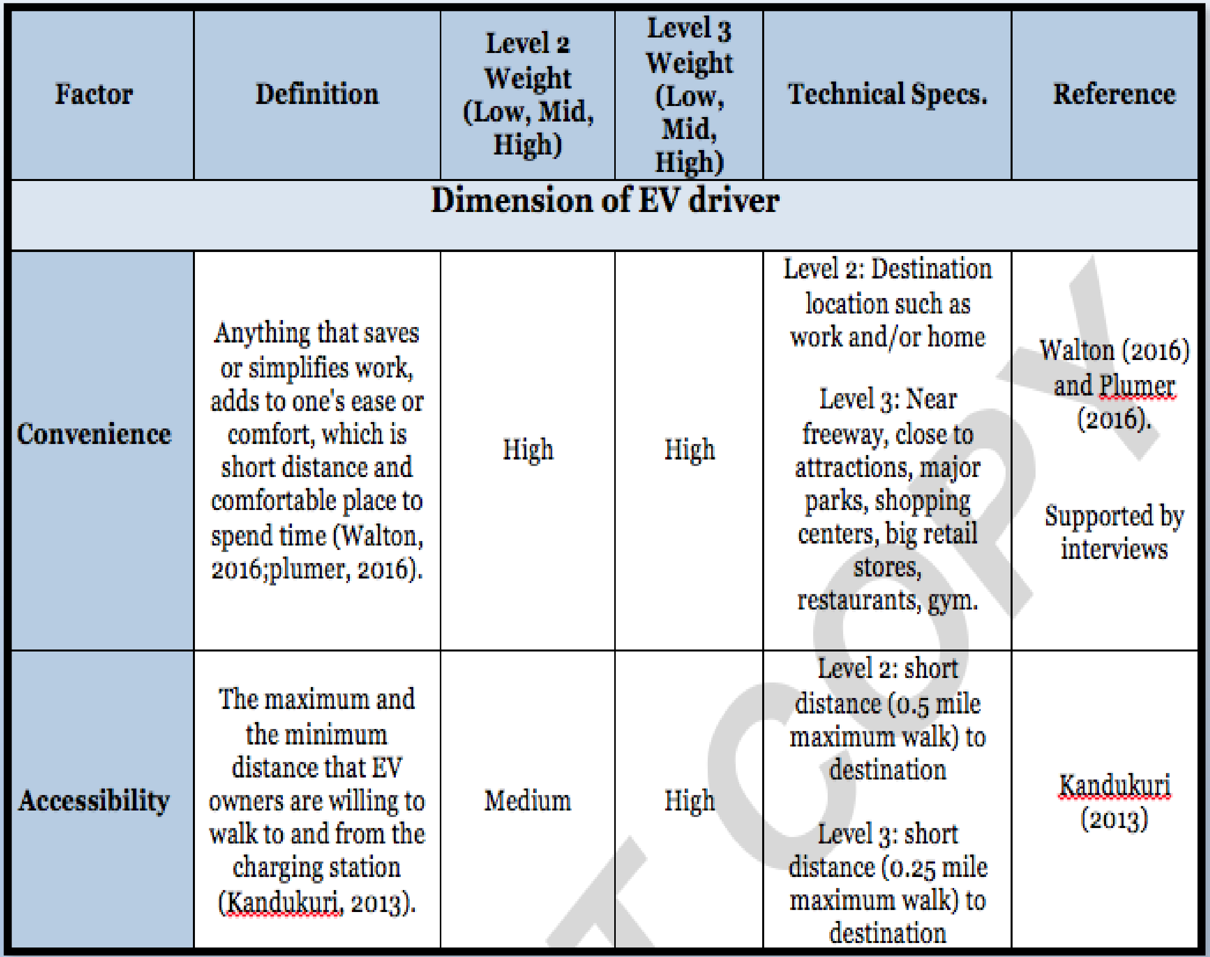
Exploiting Excess Power (V2G Technology)

Depends on potential DER electricity output

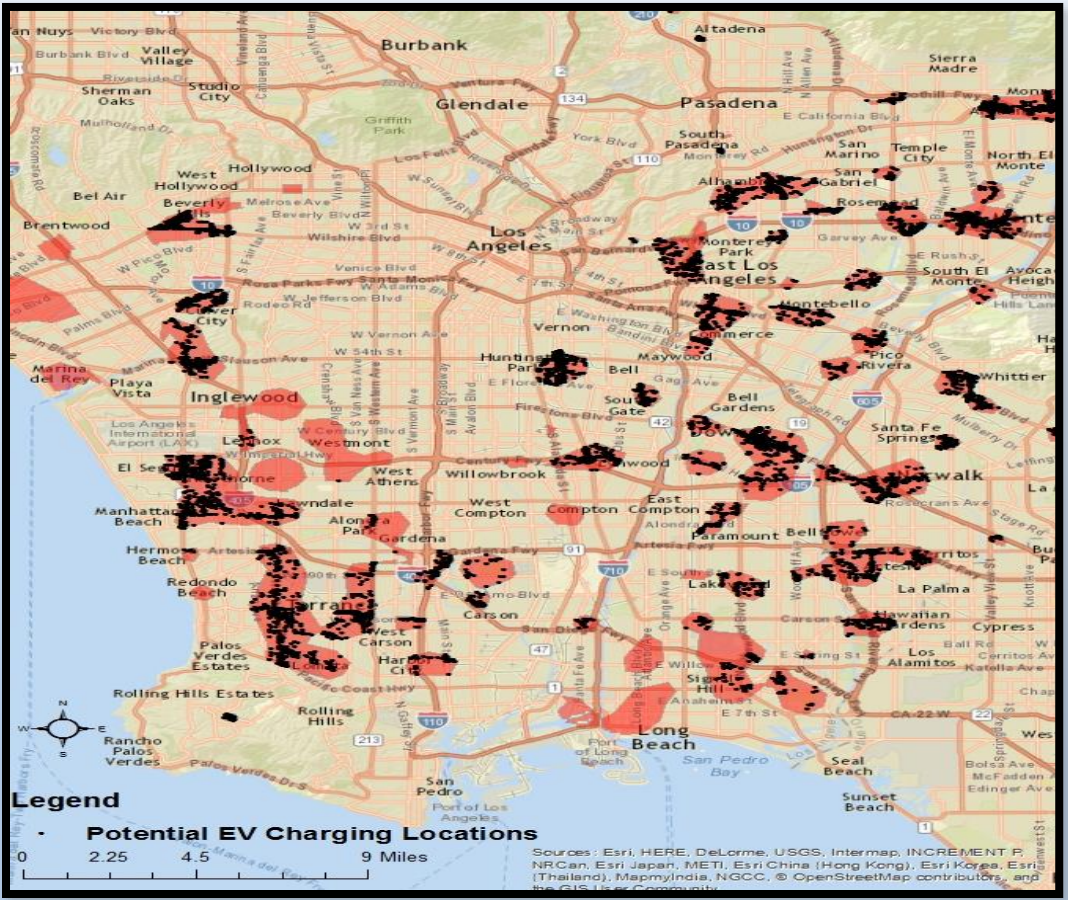
Number of EV in the area

Total count of vehicles that can be plugged into an electric power source to charge the battery, equal to the sum of battery electric vehicles (BEVs) and Plug-In Hybrid electric vehicles (PHEVs) in the area

EV Charging Infrastructure Integration Into The Electric Grid



Factor	Definition	Level 2 Weight (Low, Mid, High)	Level 3 Weight (Low, Mid, High)	Technical Specs.	Reference
Dimension of EV driver					
Convenience	Anything that saves or simplifies work, adds to one's ease or comfort, which is short distance and comfortable place to spend time (Walton, 2016;plumer, 2016).	High	High	Level 2: Destination location such as work and/or home Level 3: Near freeway, close to attractions, major parks, shopping centers, big retail stores, restaurants, gym.	Walton (2016) and Plumer (2016). Supported by interviews
Accessibility	The maximum and the minimum distance that EV owners are willing to walk to and from the charging station (Kandukuri, 2013).	Medium	High	Level 2: short distance (0.5 mile maximum walk) to destination Level 3: short distance (0.25 mile maximum walk) to destination	Kandukuri (2013)



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Geographic Decision Support System Model To Optimize DERs' Placement

Probability of event, P (event) =

$$\frac{1}{1+e^{(a+b1*x1+b2*x2+\cdots+b10*x10)}} =$$

$$\frac{1}{1+2.718^{(1.832+-2.516*x1+.193*x2+-.543*x3+0.543*x4+-1.592*x5+.297*x6+-1.039*x7+.261*x8+.006*x9+-0.579*x10)}}$$

$$E=A*r*H*PR$$

E = DER's total energy output

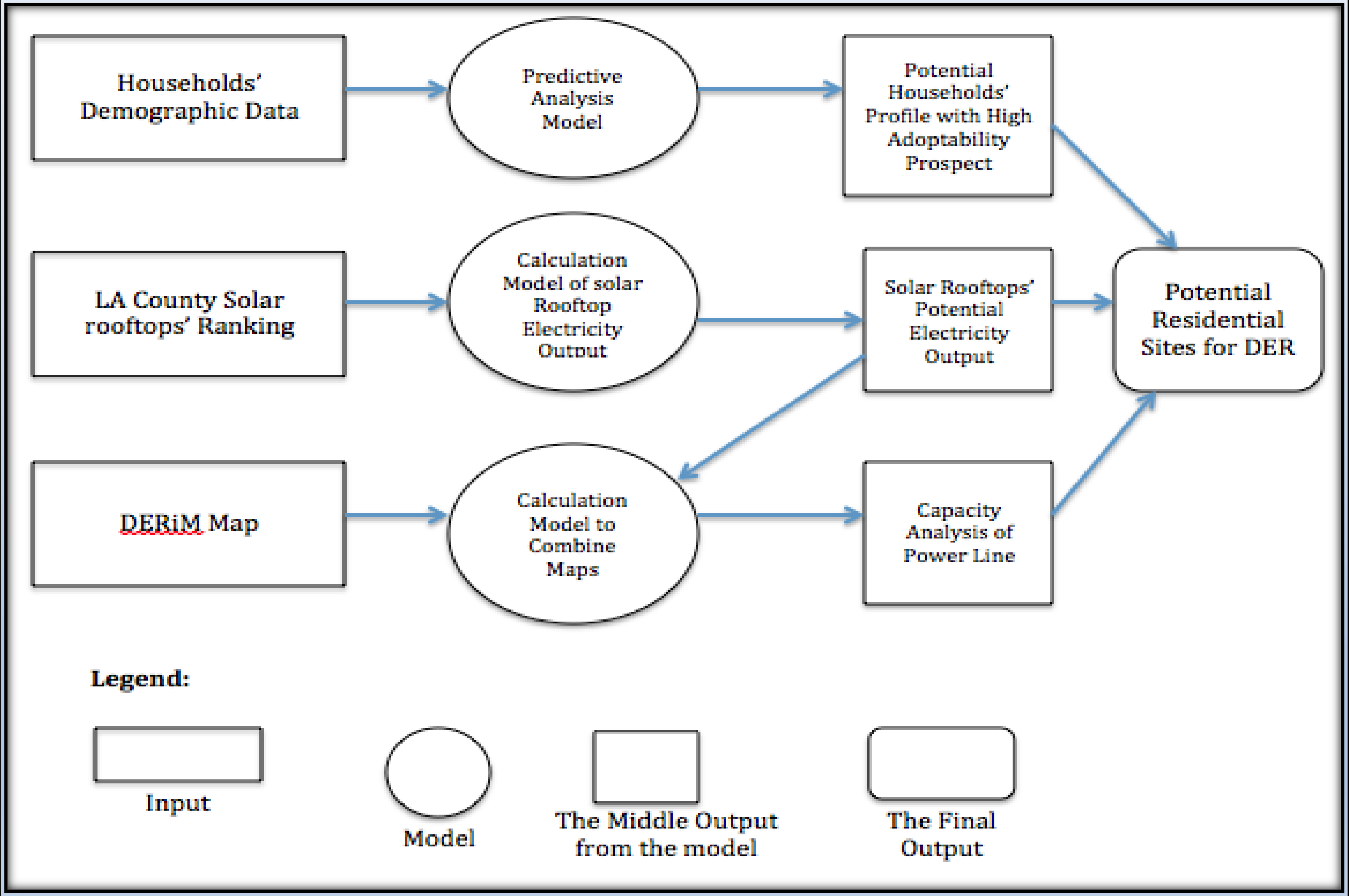
A = Total solar panel Area

r = solar panel yield

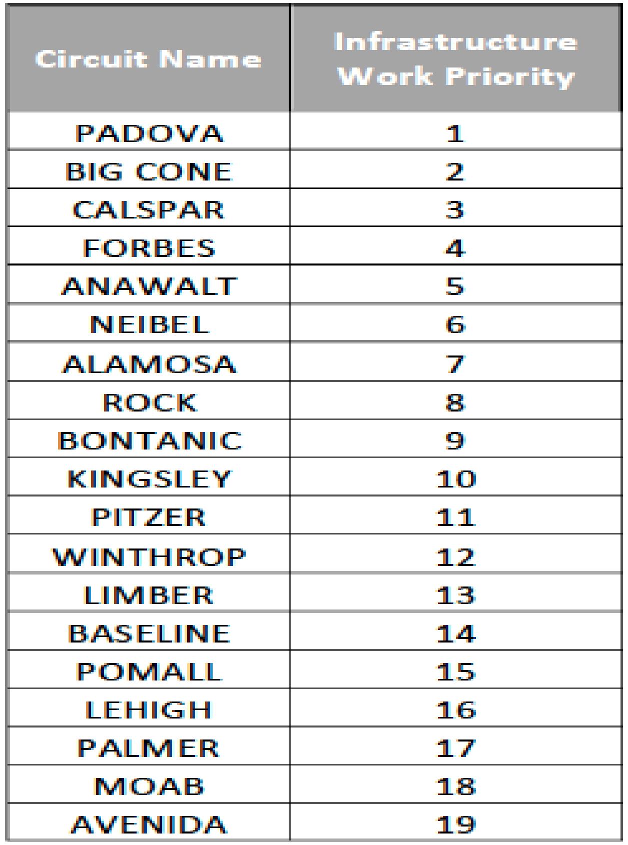
H = Annual average solar radiation on tilted panels

PR = Performance ratio

Maximum Remaining Generation Capacity = Current Capacity Load - (Solar Potential + Existing Generation)

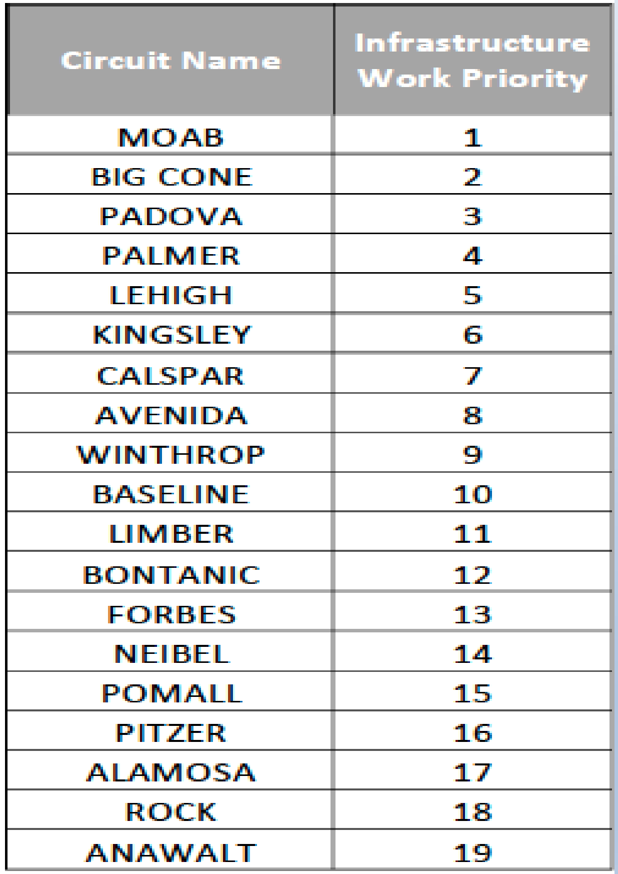


Geographic Decision Support System Model To Optimize DERs' Placement



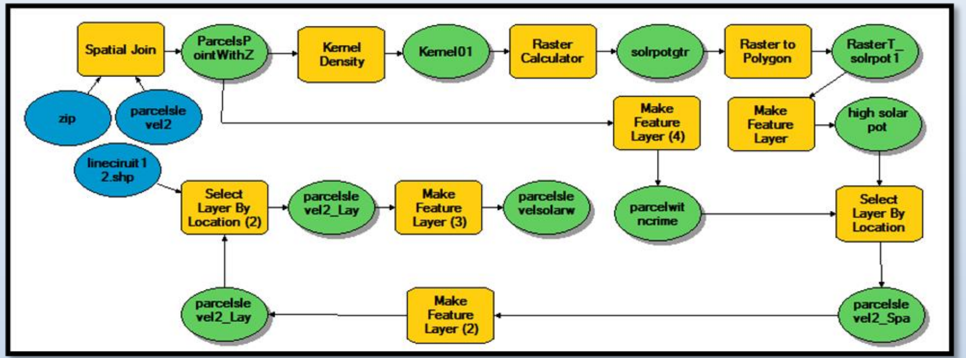
Circuit Name	Infrastructure Work Priority
PADOVA	1
BIG CONE	2
CALSPAR	3
FORBES	4
ANAWALT	5
NEIBEL	6
ALAMOSA	7
ROCK	8
BONTANIC	9
KINGSLEY	10
PITZER	11
WINTHROP	12
LIMBER	13
BASELINE	14
POMALL	15
LEHIGH	16
PALMER	17
MOAB	18
AVENIDA	19

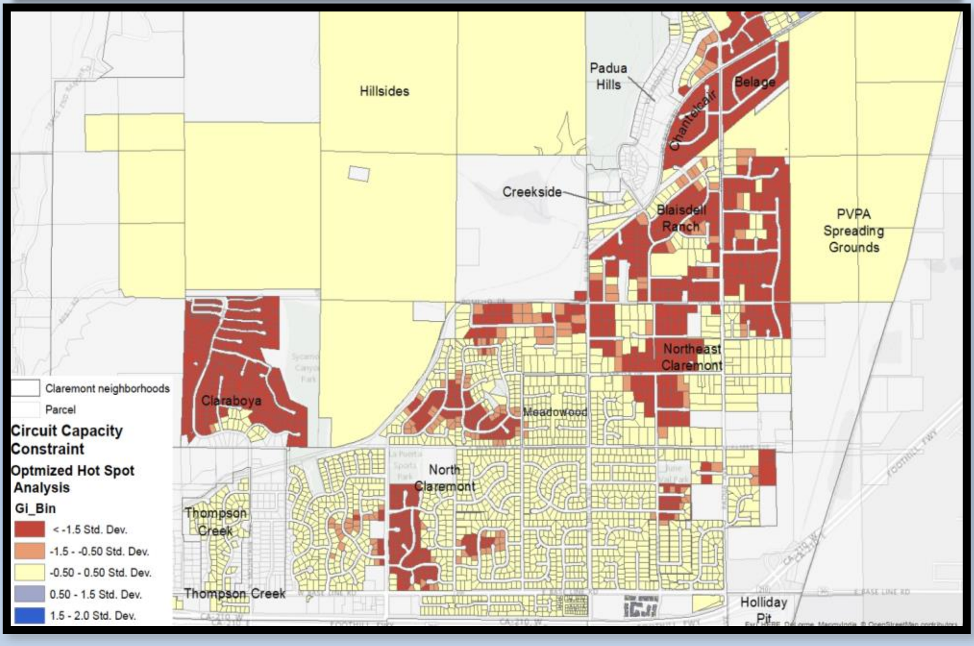
Table 1: The Maximum Residential Solar Rooftops Adoption Scenario



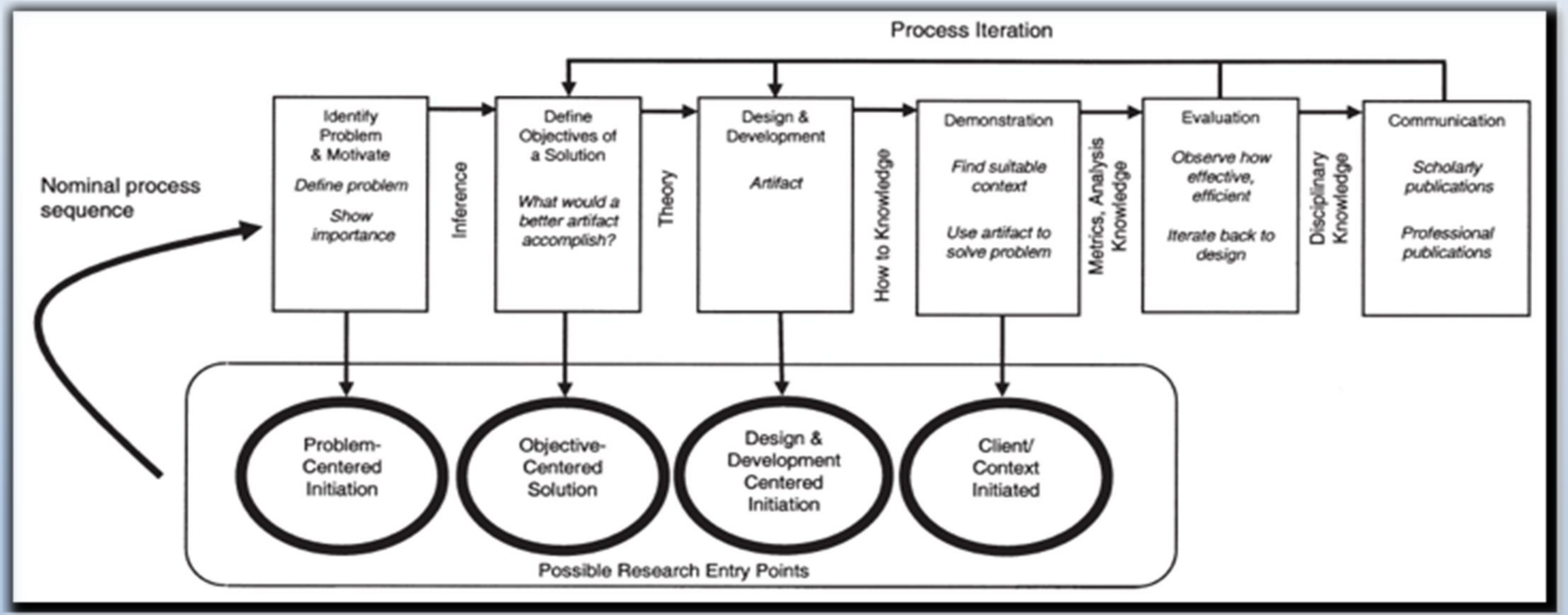
Circuit Name	Infrastructure Work Priority
MOAB	1
BIG CONE	2
PADOVA	3
PALMER	4
LEHIGH	5
KINGSLEY	6
CALSPAR	7
AVENIDA	8
WINTHROP	9
BASELINE	10
LIMBER	11
BONTANIC	12
FORBES	13
NEIBEL	14
POMALL	15
PITZER	16
ALAMOSA	17
ROCK	18
ANAWALT	19

Table 2: The Existing Scenario





Study Design and Methodology:
Design Science Research Method (Peffers et al., 2007)



Battery Storage locations can be assessed geographically to improve the grid reliability
A decision-making framework is essential in the problem resolution

Together…. Shaping the Future of Electricity