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Modeling the Sociotechnical Dimensions of Urban Resilience: Community-level Microgrids

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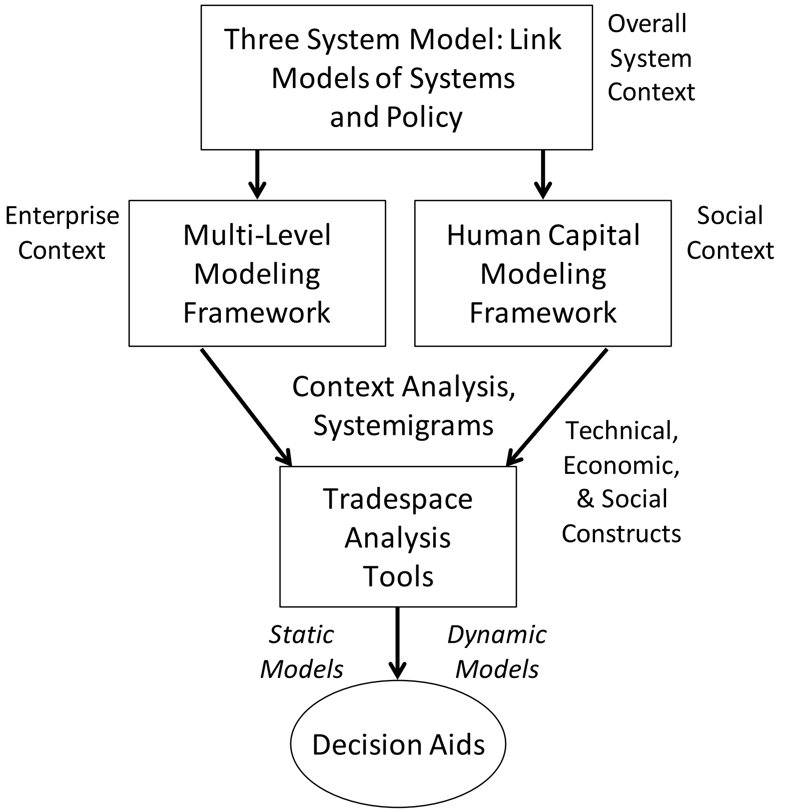
Agenda

- Motivation and Context
- Learning Goals and Outcomes
- System Context: the Three-Systems Model
- System Activities: Multi-Level Modeling
- System Outcomes: Human Capital Model
- Case Study Part 1: Conceptual Modeling
- Case Study Part 2: Tradespace Analysis
- Conclusions

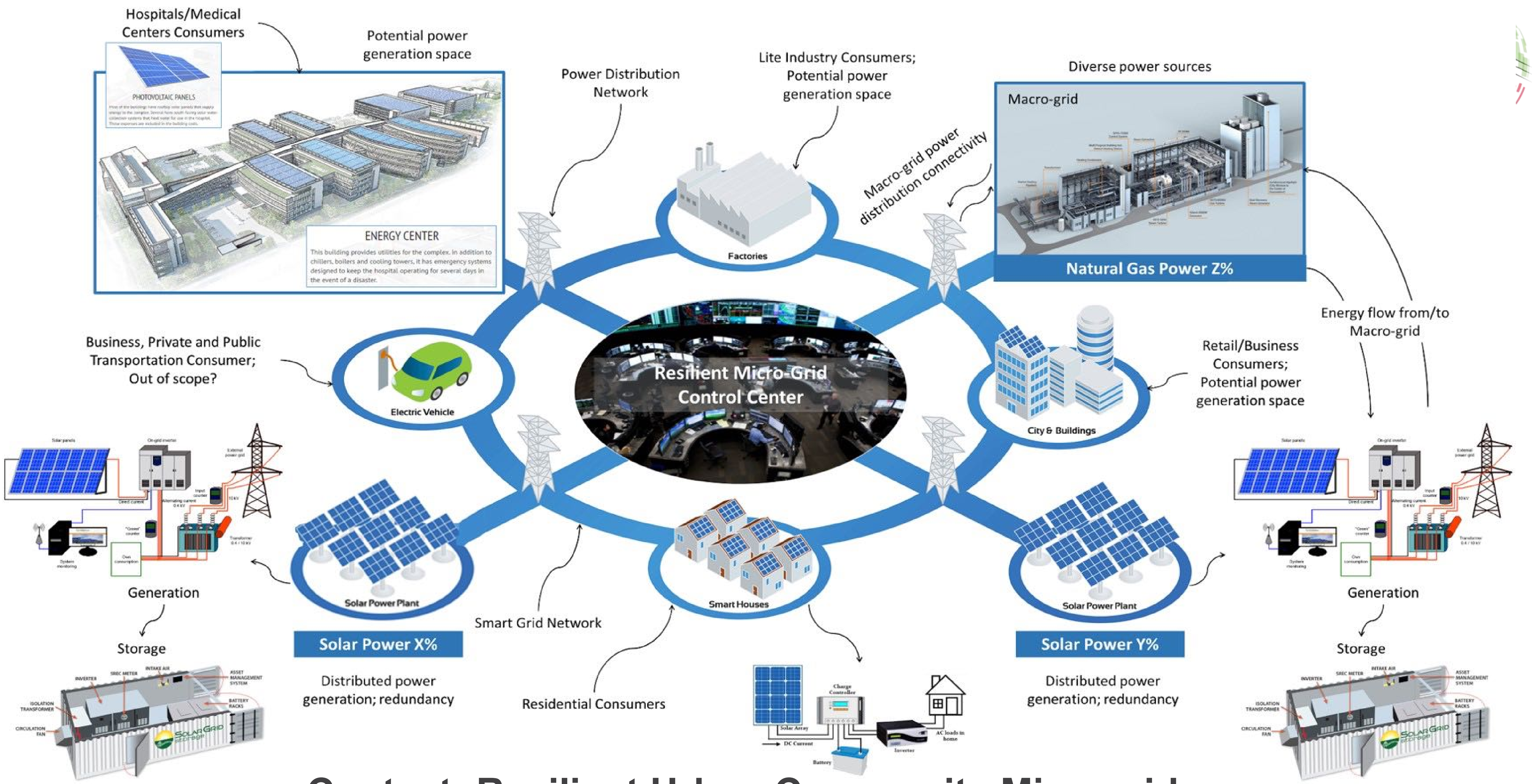


Motivation: SE Vision 2025

- A core body of systems engineering **foundations** is defined and taught consistently across academia.
- System **complexity** and associated risk is appreciated, characterized and managed.
- Systems engineering provides the analytical framework for designing and predicting the behavior for **trusted, resilient** systems.
- **Model-based systems engineering** is a standard practice and is integrated with other modeling and simulation as well as digital enterprise functions.
- Systems engineering is recognized across industries, governments, and academia as providing significant value for **innovation** and **competitiveness**.
- Systems engineering is established as an indispensable discipline for **technology assessment** and **policy analysis**.
- **Systems thinking** is taught at all levels of education.

Reference: *Systems Engineering Vision 2025*, International Council on Systems Engineering

- Sustainable
- Scalable
- Safe
- Smart
- Stable
- Simple
- Secure
- Socially Acceptable

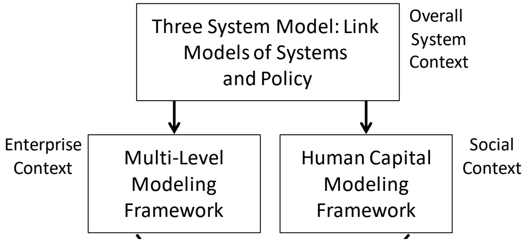


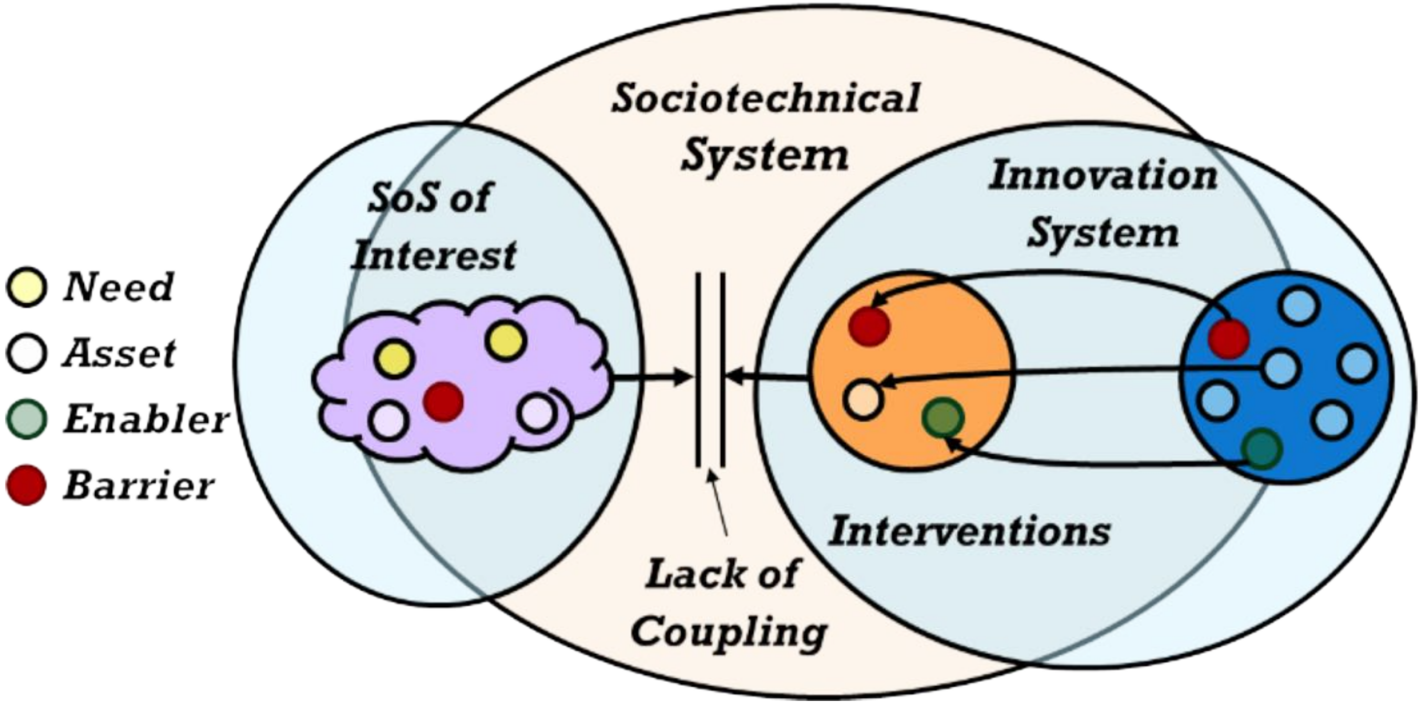
Context: Resilient Urban Community Microgrids

INCOSE "8S" Architectural Attributes of Urban Microgrids

Attribute	Socio	Technical	Economic
Sustainable	Support community livelihoods	Incorporate more sustainable technology	Sustainable business operations
Scalable	Support urban densities/populations	Efficiency increases with scale	Scalable capital and operational costs
Safe	Minimize hazards	Minimize risks	Minimize liability
Smart	Involve community in operations	Incorporate information flows	Operate efficiently and optimally
Stable	Increase human wellbeing	Meet service quality objectives	Manage cost of service
Simple	Operate locally, create jobs	Technical architecture	Business model
Secure	Ensure privacy	Protect operation	Protect operation
Socially Acceptable	Standard of living & wellbeing	Aesthetics and equal access	Distribution of equities

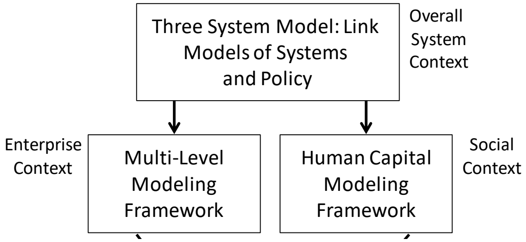
The Three Systems Model
(Inspired by Bud Larsen's Universal Mental Model)





- Context: an existing system-of-systems (SoS) that contains technology, policy, economics, social, and environmental drivers
- System innovation: occurs in a dynamic system shaped by complex interactions among the stakeholders
- The Sociotechnical System: where the SoS of interest and innovation system come together. This view supports analyses of the broader decision context

Multi-Level Modeling Framework: Context Analysis Table

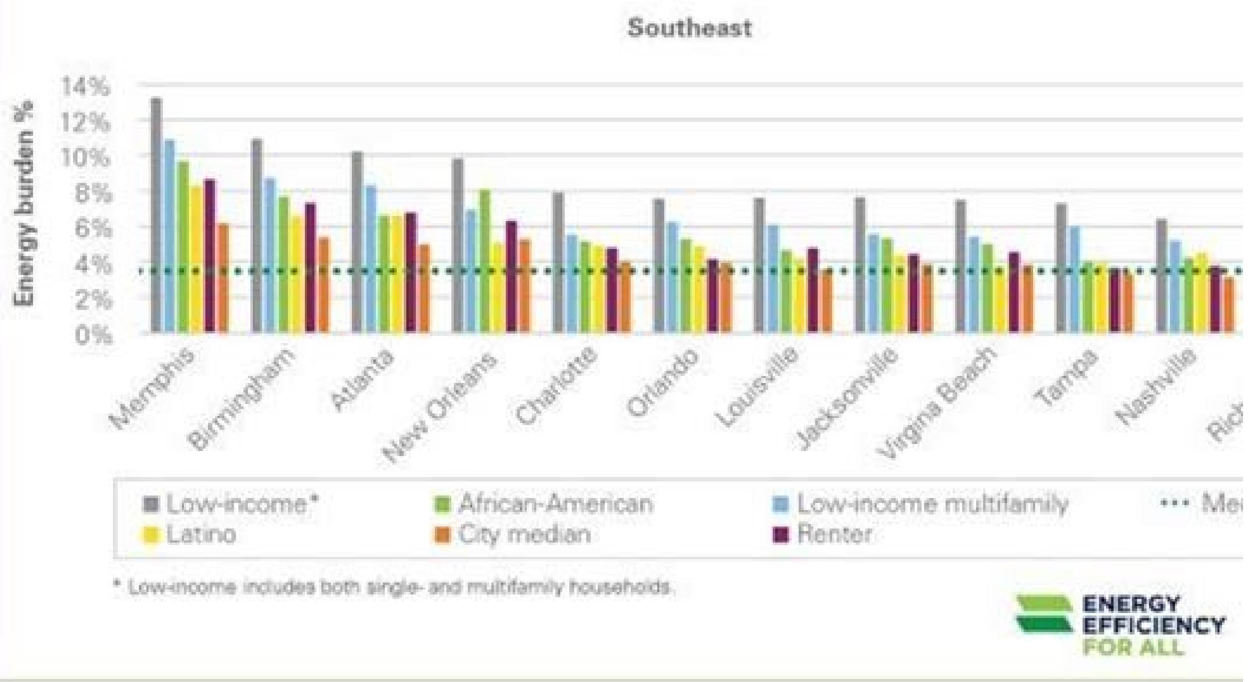


	Enabling Environment	Key Actors & Resources	Interactions/ Activities	Outcomes/ Outputs
Domain	100 Resilient Cities Initiative 100% Renewable Atlanta goal **Decreasing cost of renewable microgrid technologies**	Mayor's Office of Sustainability GA Utilities Commission	**Energy flow** **Economic flow** Conflicts between city/state energy goals Utility regulations	Increase standard of living Increased job satisfaction **Improve community and infrastructure resilience** More sustainable infrastructure
Institu-tions	City Council and Mayor's office Mayor's Office of Sustainability Atlanta Beltline Inc.	GA Power Atlanta Beltline Inc. Invest Atlanta Local Businesses	GA Power/Utility Commission agreements Neighborhood Planning Institutions (NPU) Commercial entity developing microgrid	Local microgrid managing authority **Atlanta Beltline owned microgrid** Modernization of GA Power grid
Processes	Resilience Plan **100% Renewable Atlanta Plan** Atlanta Climate Action Plan- Zoning accommodations	100% Renewable Atlanta stakeholder meetings Support for city-wide renewable portfolio standards	Microgrid interconnections with macrogrid Net metering Third party solar financing New agreements between utility and microgrid **New pricing strategies**	**Decentralized renewable energy production** Improved weather resilience via islanding Reduced water use More energy price stability
People	Community support for renewables and resilience **High city-wide energy burden**	Residents & enterprises Educational institutions	**Community support for RE and resilience** Expressed interest in microgrid participation	**Reduce energy burden** **Create local jobs** More visibility & understanding of energy processes

Specific Context Narrative

- Energy Burden and the Implications of Microgrids on Resilience

- To start the modeling process, the students conducted a thorough literature review and create a narrative description that captures the complex structure, interrelationships, and phenomena in the system
- Identification of system constructs and high-level system architecture flows initially from the narrative form, and it becomes a primary conceptual artifact for the development team to refer to



Energy Burden for median household from select groups in Southeast Cities, ordered from highest to lowest based on the average of the median energy burdens across all groups

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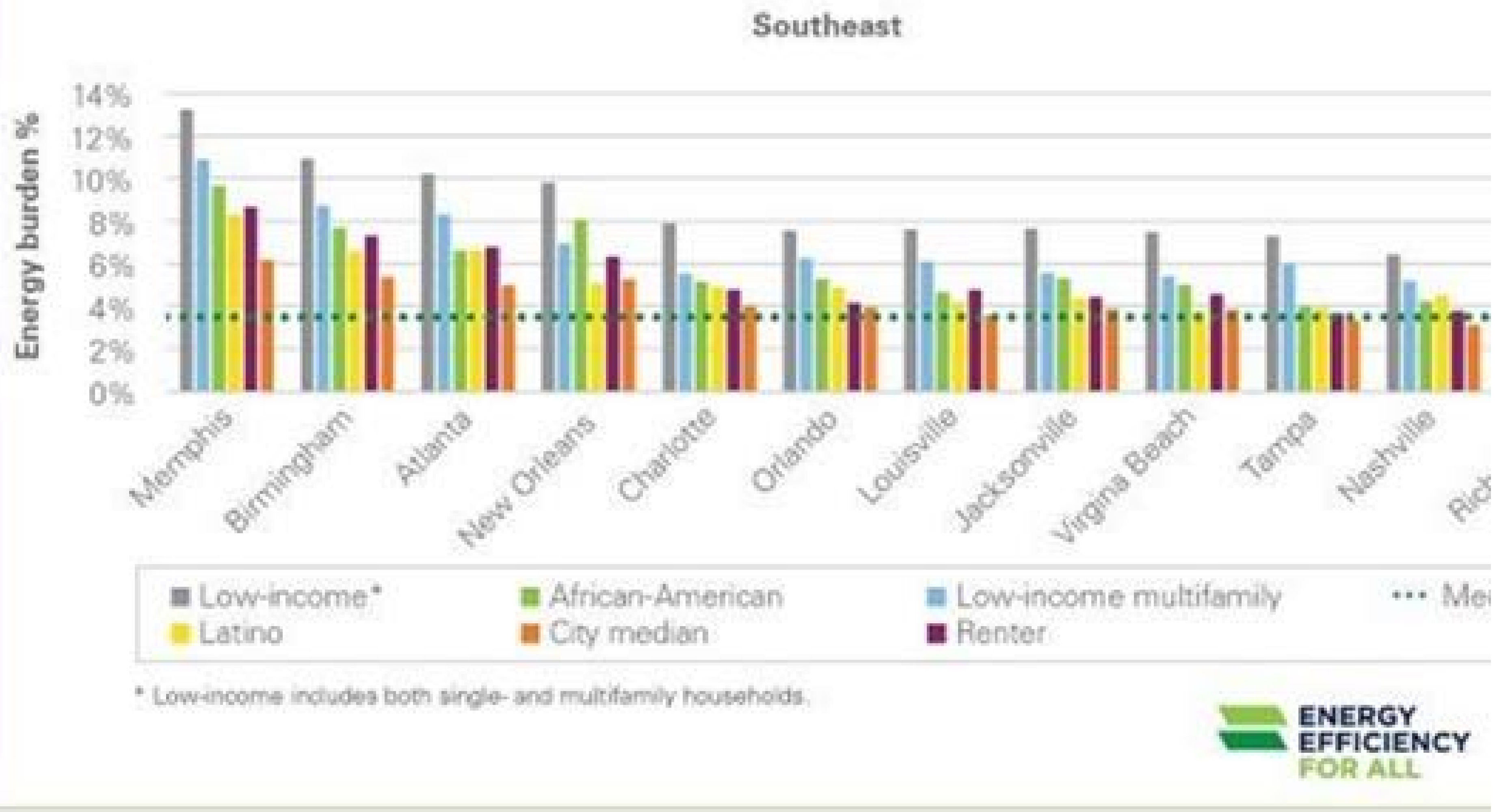
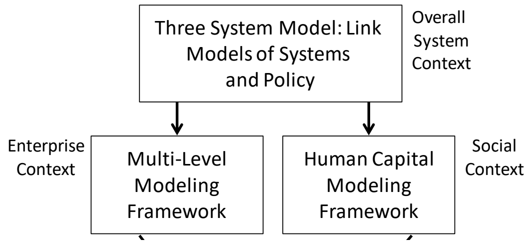
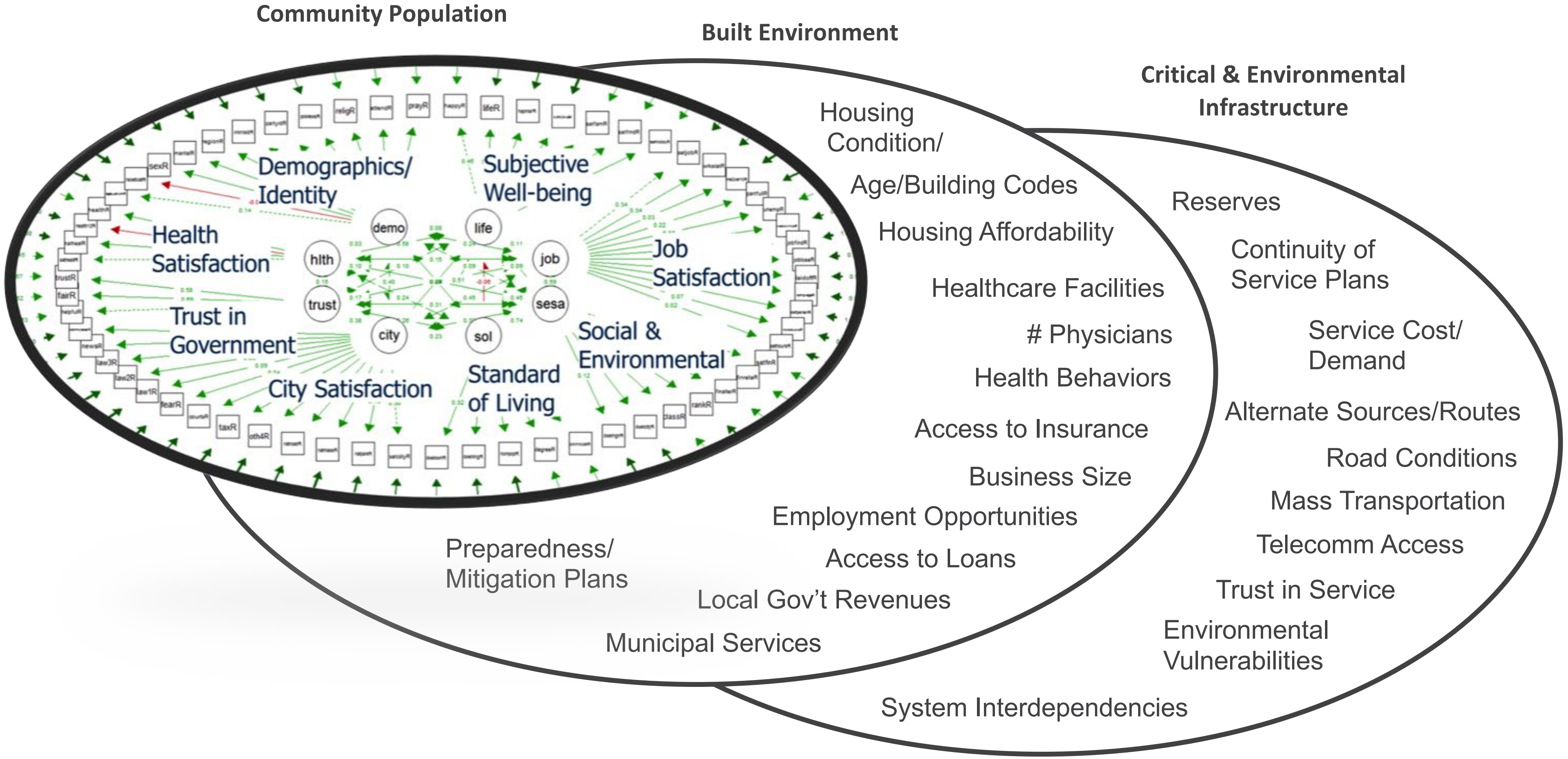


The Human Capital Model

(Related GT research on complex models of human development)





- Context: an existing system-of-systems (SoS) that contains technology, policy, economics, social, and environmental drivers

Human Capital Context

Enabling Environment	Key Actors	Interaction	Outcomes/Goals	Metric (per MW)
State RE portfolio standard, tradeable renewable energy credits, feed-in tariffs, tax incentives, net metering, virtual net metering, third party solar financing	1. State of Georgia 2. Federal Government 3. State electric utilities	Policies that impact economic and legal feasibility of community renewables	*Legal incorporation of community renewable group*	N/A
		Purchase of excess electricity generated from community renewable projects	*RE credits and revenue for community renewable group*	N/A
State RE portfolio standard, tradeable renewable energy credits, feed-in tariffs, tax incentives, net metering, virtual net metering, third party solar financing	1. Local Electric utility 2. Electricity generators 3. Community HOAs 4. Community members 5. Businesses in the community	Reduction of total city-wide energy demand, which proportionately reduces the demand of non-local fuel/electricity	**Energy security**	• Diversity Index • Concentration Index
		Sale/lease of property for community renewables	**Use of marginal lands and preservation of open space**	• Deforestation loss/MW • Farmland loss/MW
		Water is collected from natural sources and used in the cooling processes usually associated with energy generation	**Use of water for energy generation processes**	• Gallons of water/MW
• A mandate to hire locally and utilize local resources for generation plant creation • Use of renewable energy- as generation source will reduce the variability of electricity price • An organizational mandate to direct profits to vulnerable populations in the community	1. Community members 2. Existing local businesses 3. Vulnerable community members	Given the opportunity to fill job positions (technical or administrative) created by community renewable project	**Local jobs**	• Direct employment/MW • Indirect employment/MW
An organizational mandate to include member outreach, through education	1. Households 2. Community Renewable group	Members of community renewable group are responsible for planning/development/financing of entire project	**Citizen participation**	• Number of registered members/ total community population
		Because member have had experience starting the community renewable group, they are more prepared to start other community initiatives	**Social entrepreneurship**	• # of social enterprises created by members of the RE co-op
		Community leaders initiating a community renewable project must educate neighbors both before and after a generation project is developed on RE and energy conservation techniques	**Energy Efficiency awareness and education**	• Energy literacy of RE cooperative members (survey) • % of members who engage in EE behavior

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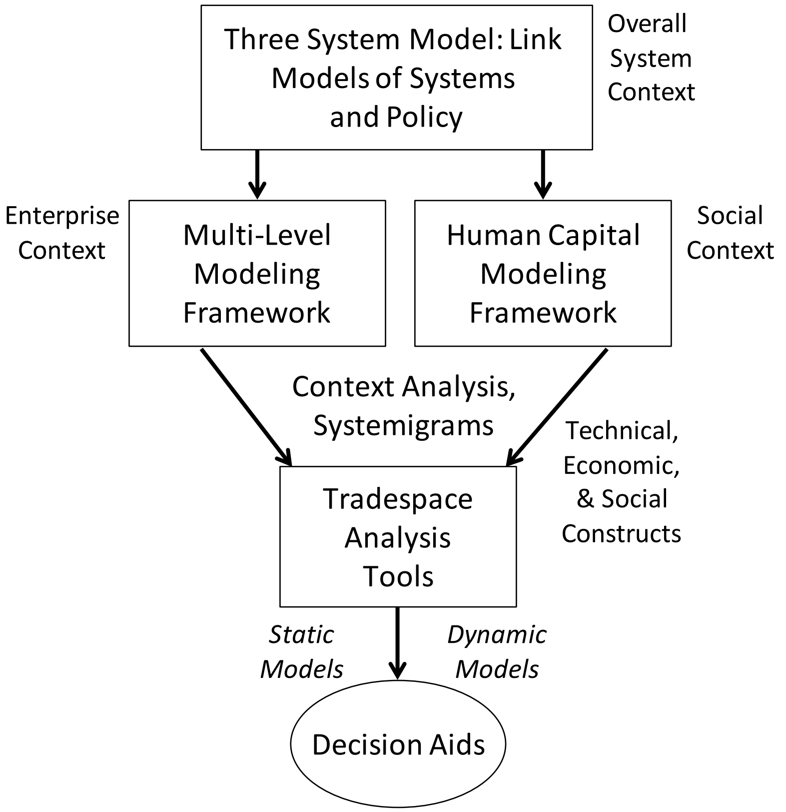


The Need to Build Resilience and Microgrids

Innovation for Disruption

Innovation by its nature is disruptive, and disruption can be destructive. The bridge between disruption and innovation is resilience. To cross that bridge leading resilient organizations are adopting innovative approaches to people, process, technology, and facilities that have the potential to create long term sustainable advantages and build enterprise resilience. This table outlines critical areas where leading resilient organizations are building innovation:

Innovator	Disruption	Innovation	Resilience Impact
ConEd	Major natural disasters destroy key transmission assets between generation and customers	Microgrid, solar energy storage	Diversify operational risk
		Mobile substations	Decreased time to restore service
PSEG	Customer expectations higher for utilities	2-way social media communication with customers during a crisis	Improved customer happiness and responsiveness
NYC Emergency Mgmt	Global shortage of human capital for resilience	High school for Emergency Management	Increase human capital available for resilience
US utilities industry	Major disasters overwhelm capabilities on hand	Mutual assistance agreements among utilities in 26 US states	Increased capability to restore services

Microgrids for ResilienceL

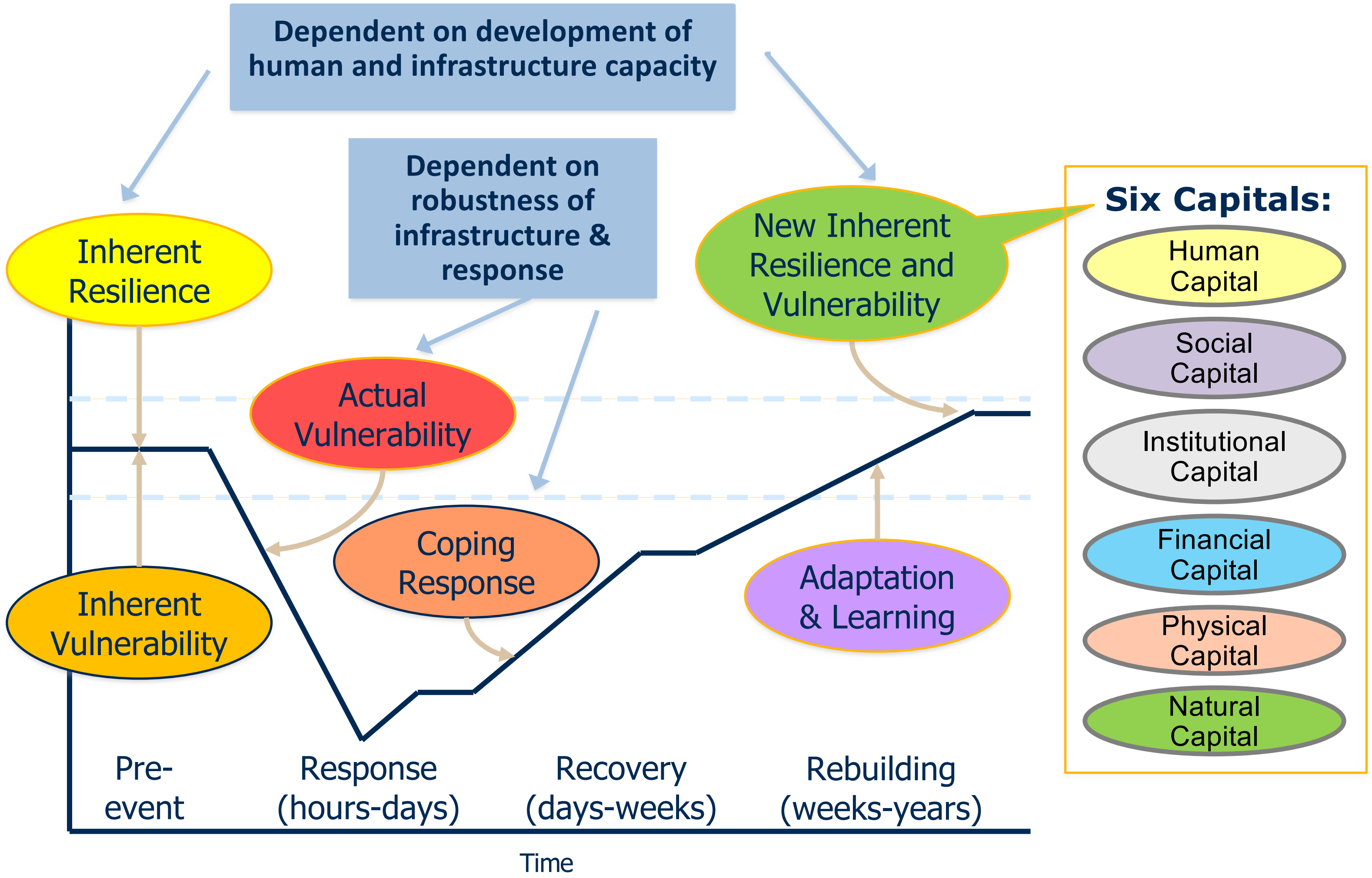
Images posted on social media and in the news showed swaths of Manhattan plunged into darkness as power outages cut off electricity to large parts of America's biggest city.

Just as striking, however, were blossoms of light visible against the otherwise black skyline. Many of these lighted outposts had separated from the grid and were now generating electricity on their own.
These microgrids were islands of light in a sea of darkness. Facilities such as hospitals were able to provide critical services both during and after the crisis because of microgrids.
The Institute of Electrical and Electronics Engineers

Perspectives

Abstractions

The Dynamic Process of Community Resilience

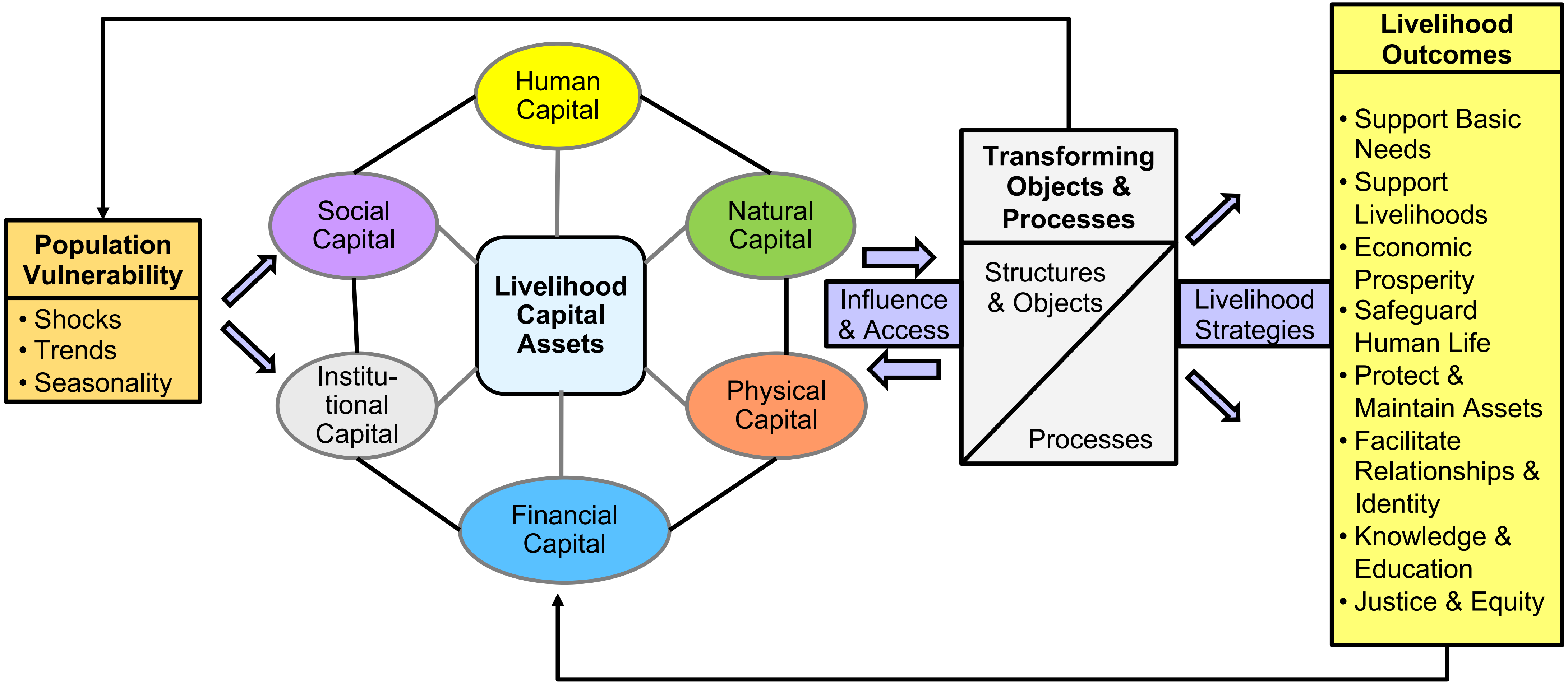


(Sources: Cutter 2008, Miles & Chang 2006)

A primary measure of ***resilience*** is the number of people and businesses that are ***not displaced***

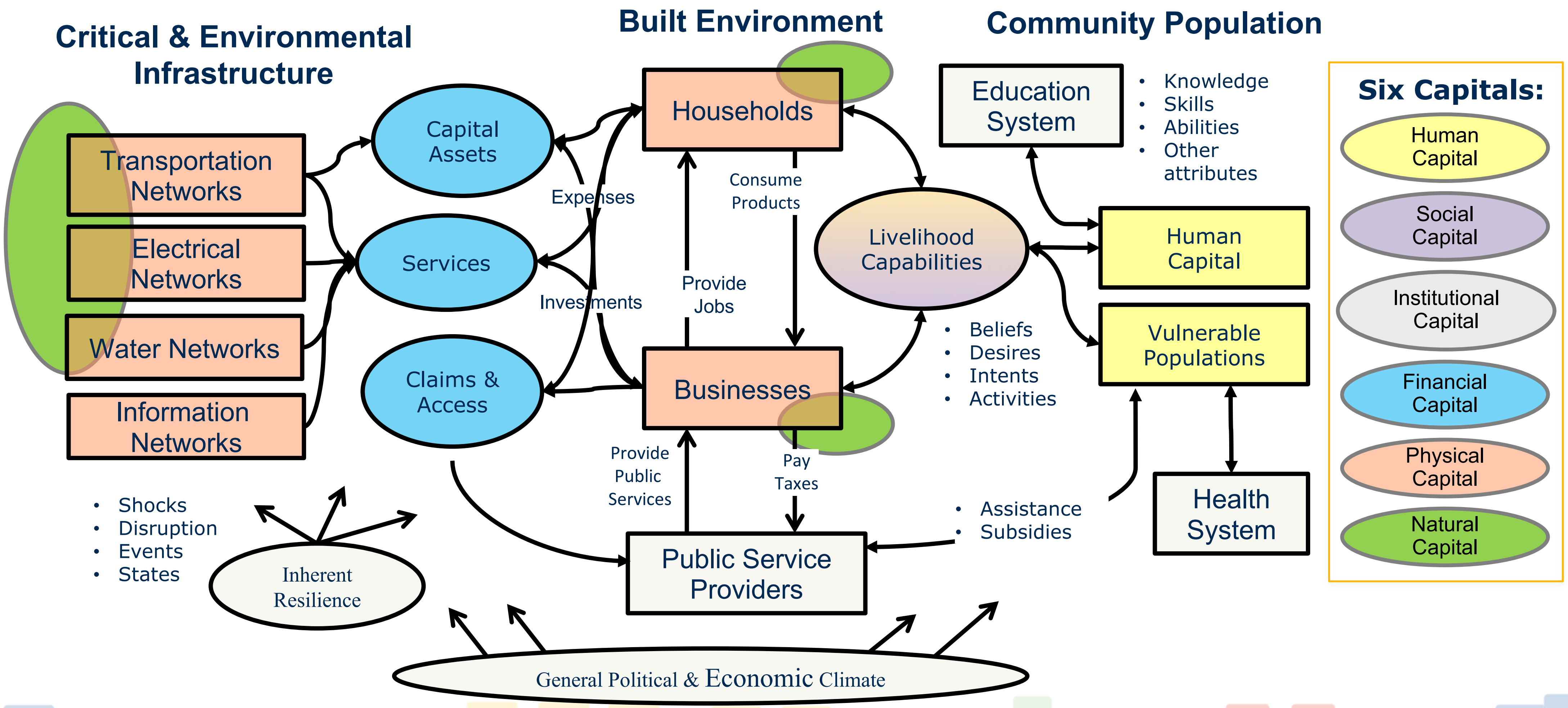
SoS Perspectives

Generally Accepted Social Model of Resilience

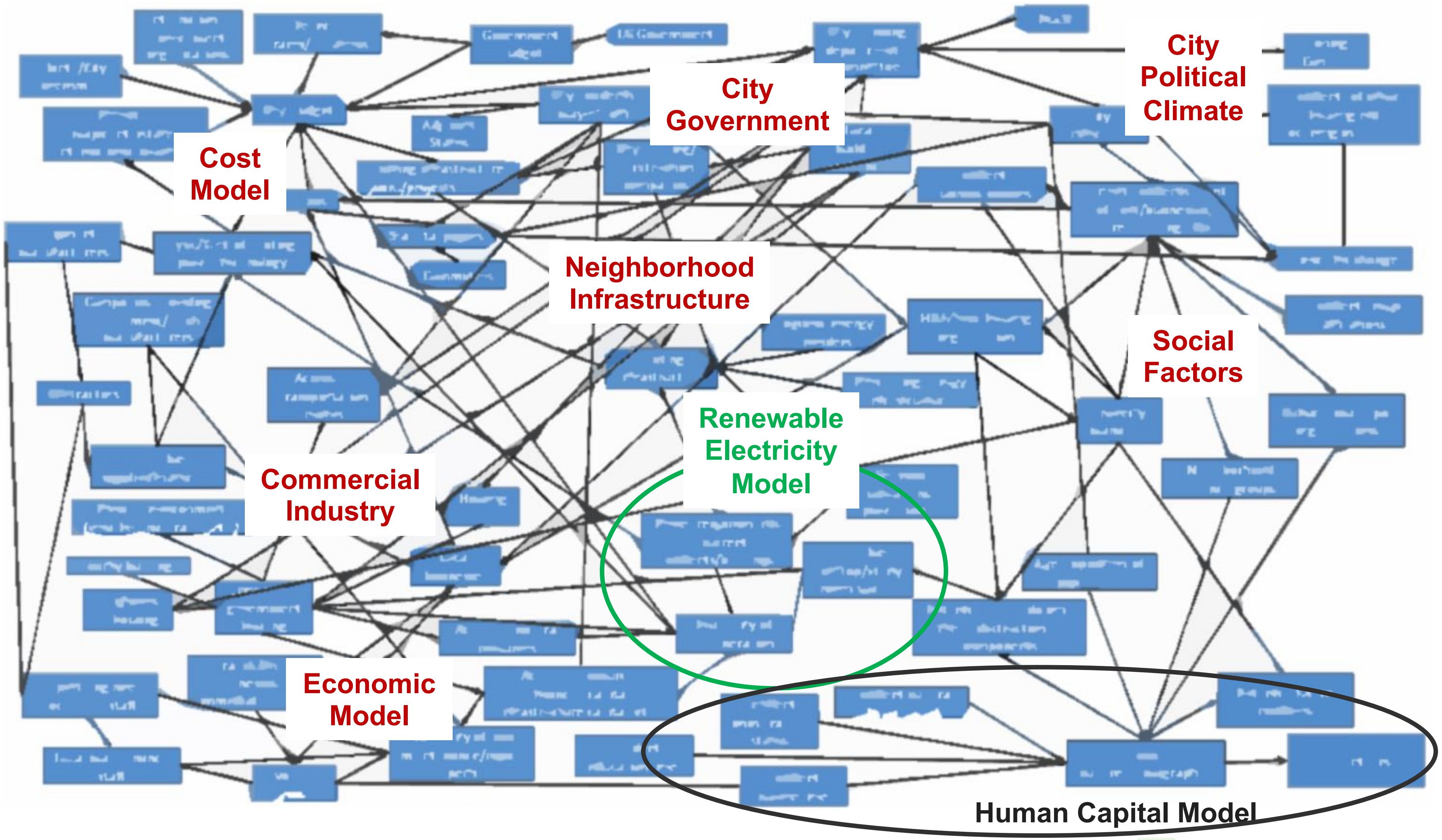


(Sources: UN Sustainable Livelihoods Guidance Sheets, ARUP 2015)

SoS Definition
Structural Architecture of Community Resilience

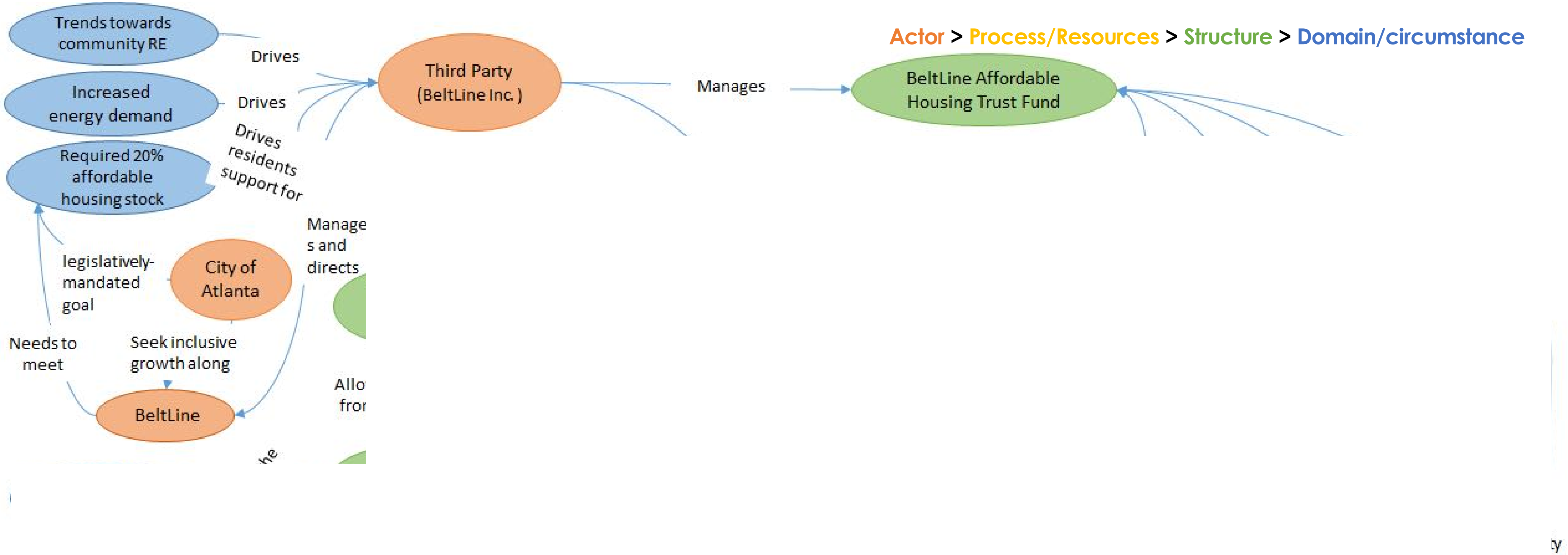


Interrelationships in Urban Microgrids



Question:
Can we optimize the human capital measures of a sustainable development project?

Systemigram Diagram of the Context Narrative



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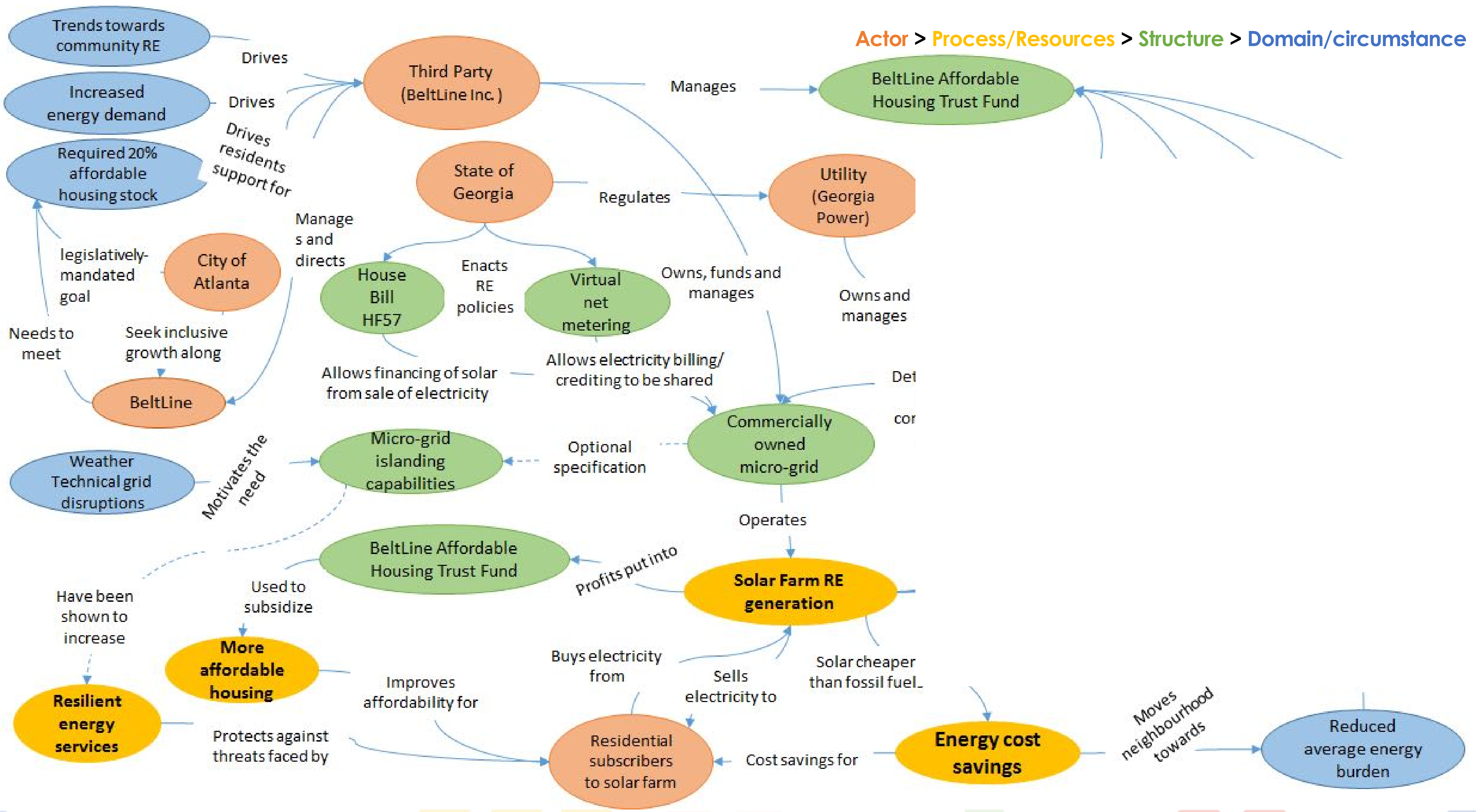

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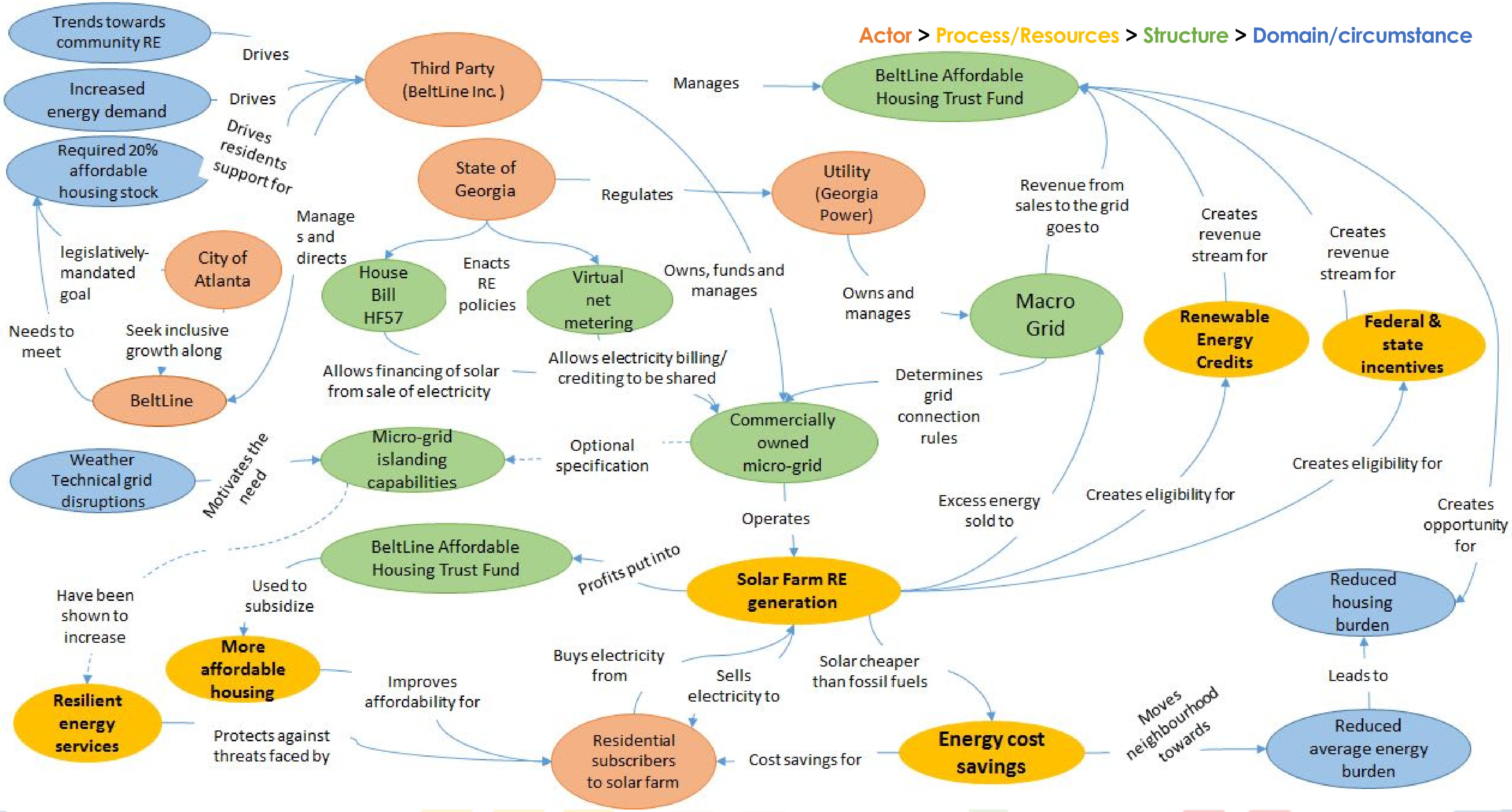

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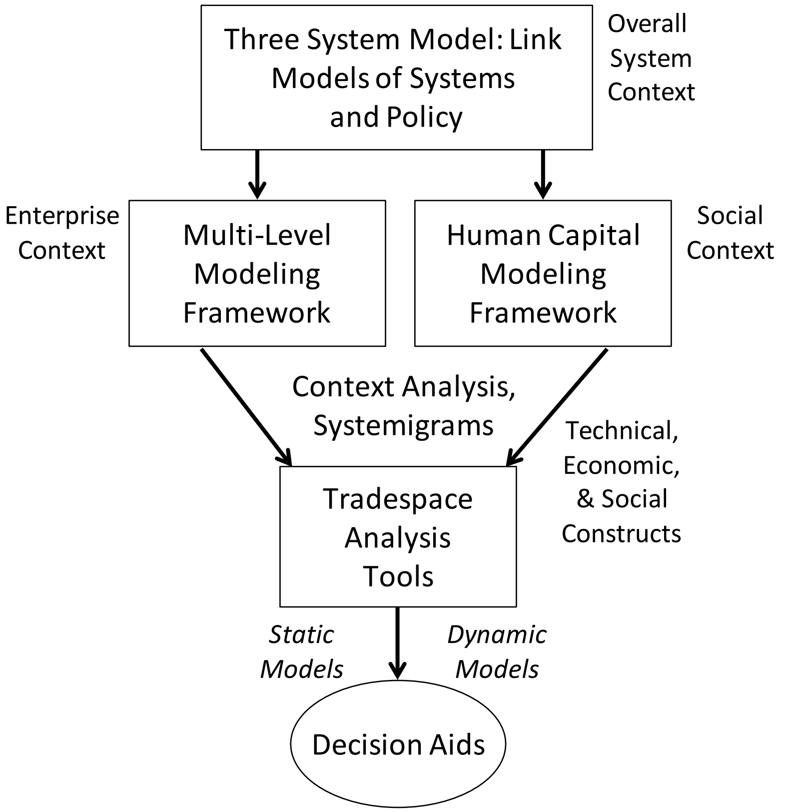
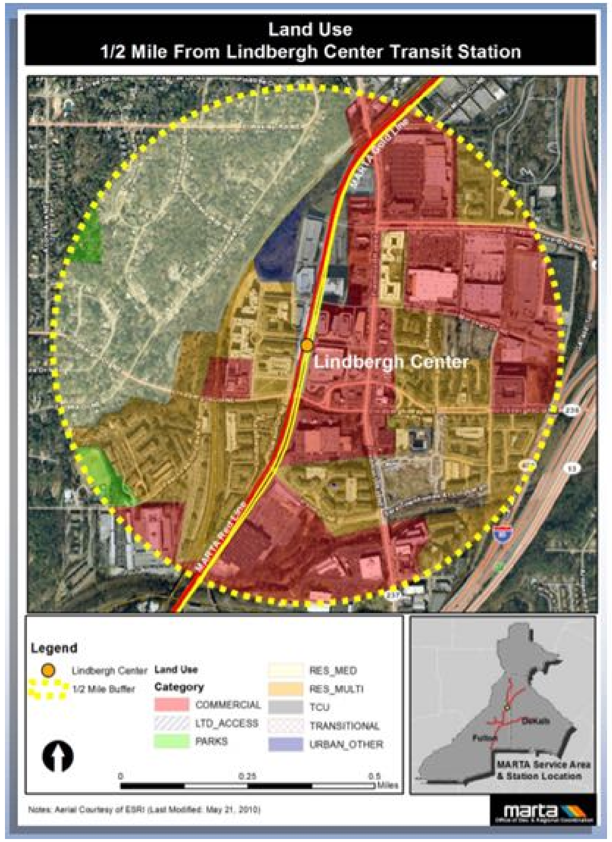


Systems Engineering Process

Activity	Focus
Stakeholder Analysis	Interview stakeholders across the context analysis, assess stakeholder impact, determine stakeholder priorities
Needs Analysis	Determine and weight requirements across the technical, economic, and social domains
System Architecture	Develop the architectural framework (various operational, system, and technical views)
Project Lifecycle	Ensure the appropriate level of definition for all stages of the system lifecycle drive the analysis
Conceptual Design	Determine structural and functional relationships, analysis of alternatives, multi-layer attribute decomposition, boundary definition, use cases
Requirements Analysis	Prioritization matrices, Options ranking, Stakeholder weighting, Quality Function Deployment
Requirements Modeling	Model system structure, function, and requirements using the Systems Modeling Language (SysML)
Business Case Analysis	Sizing and cost modeling, Financial model, Cost/ benefit analysis, Risk analysis
Tradespace Analysis	Architectural model and options analysis, Multi-criteria decision analysis using Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS), Sensitivity analysis
System Dynamic Analysis	Modeling and simulation of energy and economic flows using system dynamics modeling

Stakeholder Analysis Framework

LINDBERGH CENTER STATION ATLANTA (1/2 MILE RADIUS)

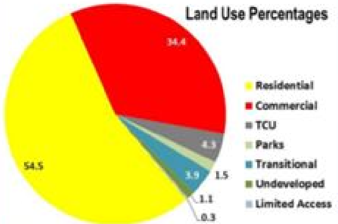


- High unemployment 10%
- Income $69.7k/year
- Young population
- Land use profile mixed
- No industrial, high residential/comm
- Energy burden 2.85%
- 2.5k < "Urban Cluster" < 50k

Neighborhoods / Region	# of households	Energy Consumption (KWh/ HH / Yr.)	Residential $/KWh	Energy Cost $/year/HH	Energy Cost $/month/HH	Median Household Income ($)	Energy Burden
Bankhead Station	1,489	17,659	$0.116	$2,048.44	$170.70	$26,165	7.83%
King Memorial Station	1,388	13,951	$0.116	$1,618.32	$134.86	$23,407	6.91%
Lindbergh Center Station	4,162	17,116	$0.116	$1,985.46	$165.45	$69,721	2.85%
Georgia	4,191,209	13,464	$0.115	$1,553.75	$129.48	$61,250	2.54%
South Atlantic	26,787,726	13,416	$0.117	$1,575.04	$131.25	$55,030	2.86%
US	129,811,718	10,812	$0.127	$1,367.72	$113.98	$56,500	2.42%

Station Area Profile

Land Use Within 1/2 Mile



Sources:
MARTA GIS Analysis 2012 & Atlanta Regional Commission LandPro 2009.

Residential Demographics 1/2 Mile

Population	7,640
Median Age	30.7
Households	2,436
Avg. Household Size	3.14
Median Household Income	$69,721
Per Capita Income	$28,567

Business Demographics 1 Mile

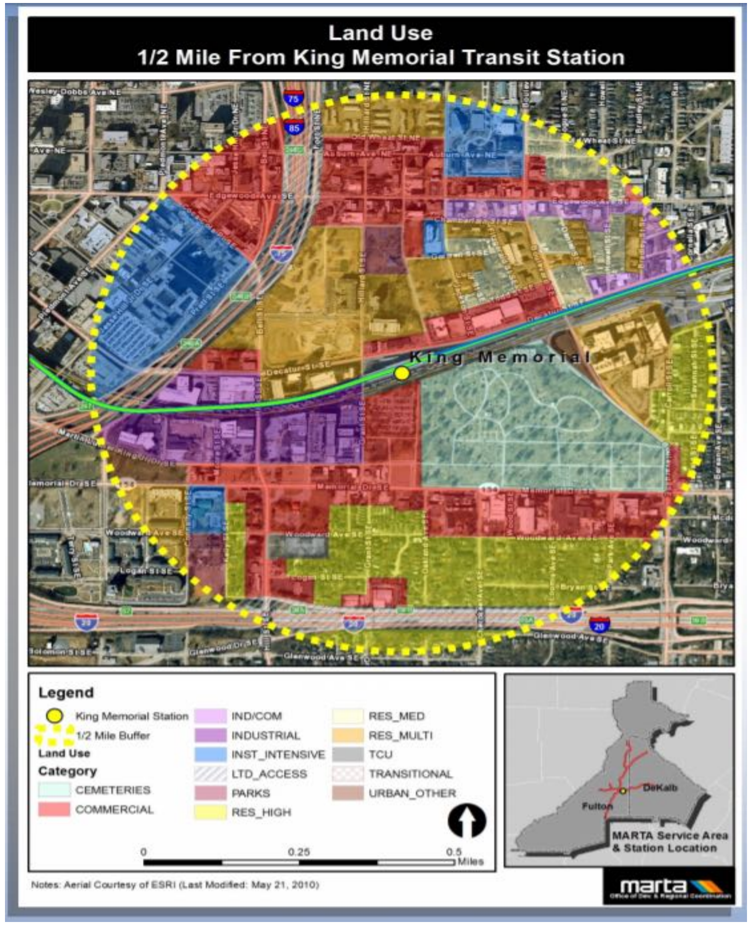
Businesses	1,135
Employees	12,137
%White Collar	67.8
%Blue Collar	10.5
%Unemployed	10.0

Source: Site To Do Business on-line, 2011

- Data driven analysis used to develop sizing models
- Includes demographic information
- Augmented with interviews in the case study locations (and others)

Stakeholder Analysis Framework 2

KING MEMORIAL MARTA STATION ATLANTA (1/2 MILE RADIUS)



- ☞Very high unemployment 17%
- ☞Low income $23.4k/year
- ☞Young population
- ☞Land use profile mixed
- ☞Low industrial, high commercial
- ☞Energy burden 6.91%

Neighborhoods / Region	# of households	Energy Consumption (KWh/ HH / Yr.)	Residential $/KWh	Energy Cost $/year/HH	Energy Cost $/month/HH	Median Household Income ($)	Energy Burden
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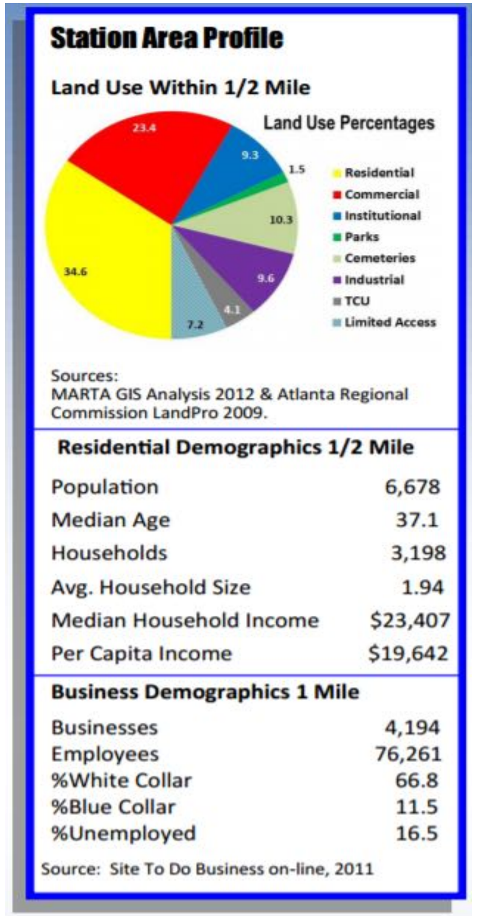


Microgrid Sizing and Cost Model

Micro-grid Selected Communities Energy Consumption.

Neighborhood	Total Households	Energy Consumption per household (kWh/Yr)	Total Energy Consumption (kWh/Yr)
Lindbergh Station	4,162	17,116	71,236,792
King Memorial Station	1,388	13,951	19,363,988

Required minimum micro-grid size in MW.

Neighborhood	Size of the Microgrid (MW)	Energy Output (kWh/Yr)	Energy Surplus (kWh/Yr)	Estimated Cost of electricity ($/kWh)	Energy Value per year ($)
Lindbergh Station	49	71,375,293	138,501	0.13	9,278,788
King Memorial Station	13.5	19,664,620	300,632	0.13	2,556,401

Minimum number of solar panels required.

Neighborhood	Power per Solar Panel (kW)	Total Solar Panels needed	Total Solar Panel Cost ($)
Lindbergh Station	10	41,620	166,480,000
King Memorial Station	10	13,880	55,520,000

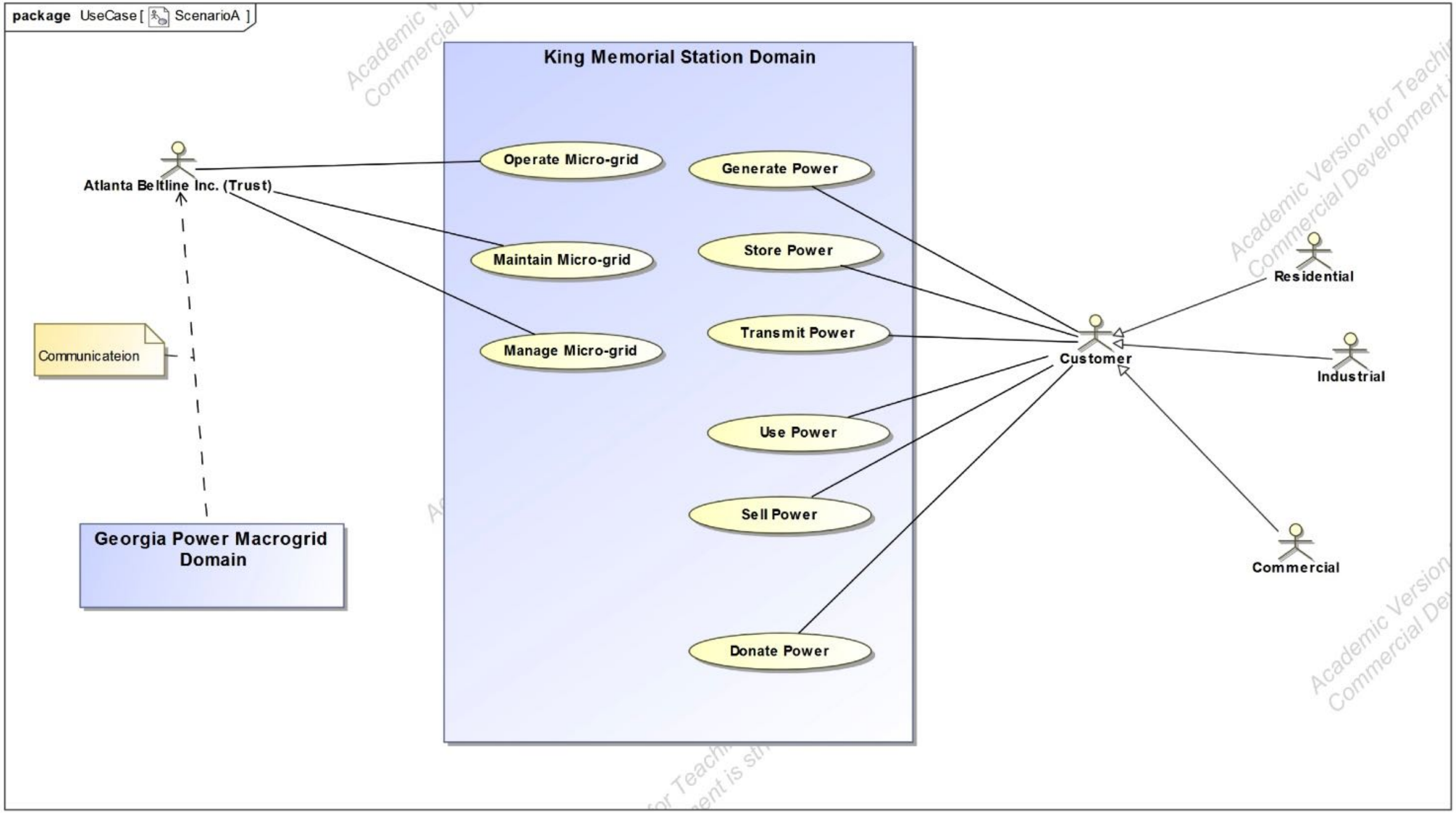
Smart meters quantity and cost.

Neighborhood	Smart Meters Needed	Smart Meter Cost ($)	Total Smart Meter Cost ($)
Lindbergh Station	4,162	450	1,872,900
King Memorial Station	1,388	450	624,600

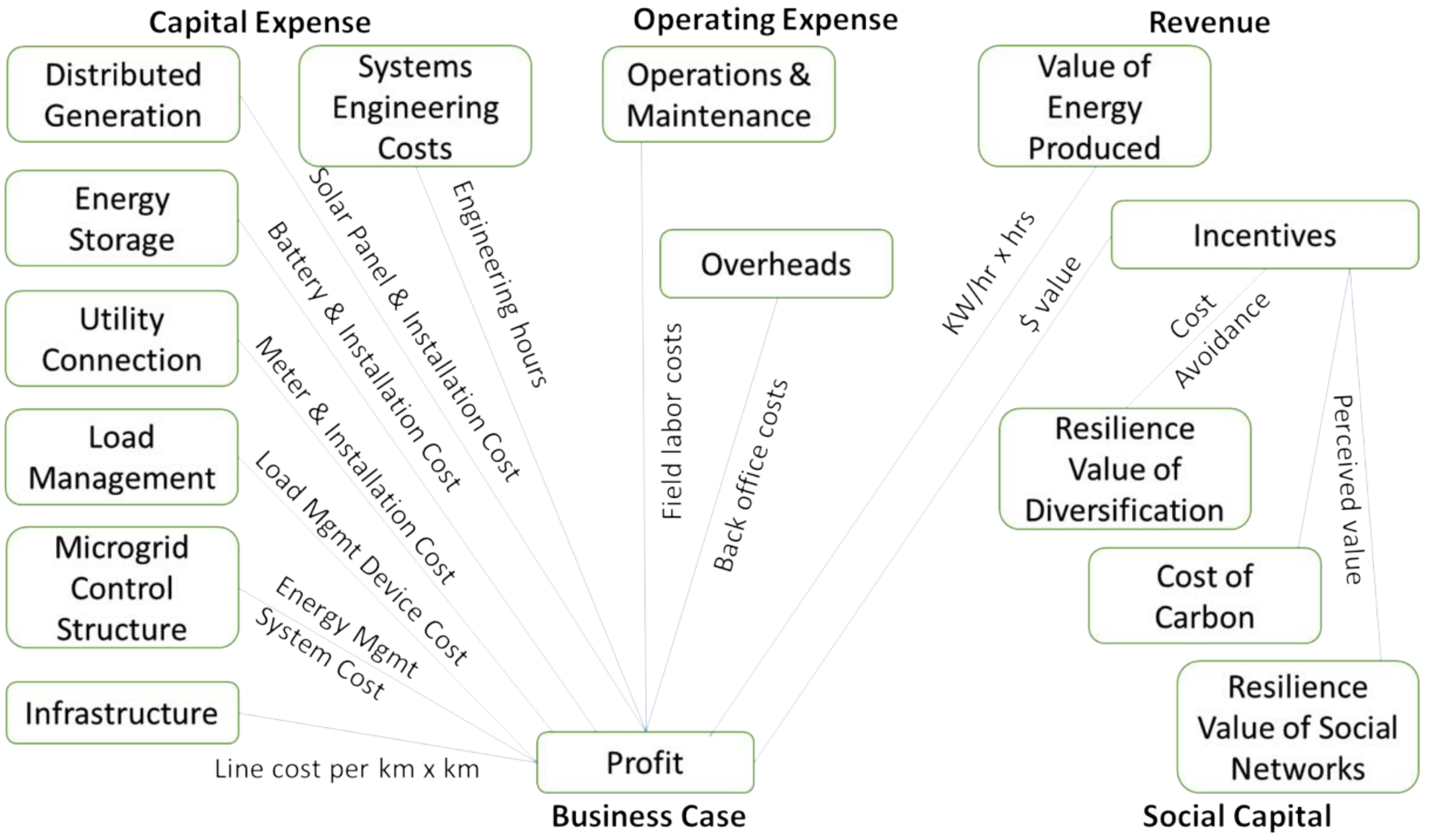
Power storage (batteries) quantity and cost.

Neighborhood	Energy needed per household per day (kWh/day	Total Tesla Powerwall needed	Cost per household ($)	Total battery cost
Lindbergh Station	47	2	11,700	48,695,400
King Memorial Station	38	2	11,700	16,239,600

Use Case Modeling



Architectural Analysis



Financial Model Overview OV-2 Diagram

Note the presence of incentives as a structural means to address energy burden, which would be created by local revenues generated from energy sales as well as from government incentive credits to the non-profit, who could then use the revenues to address inequities, create jobs, etc.

Requirements Analysis

Category	Relative Weight	Requirements	Engineering Characteristics/ Measures
Technical (50%)	**14%**	**System shall be capable of delivering power with high reliability**	Downtime (total mins/year)
	14%	**System shall be capable of delivering power with high quality**	Voltage and frequency variation and waveform distortion
	8%	System shall use multiple power sources to increase energy security	Connect to Macro-grid with islanding capability
	8%	System shall utilize solar as main power source	Commercially available solar panels
	4%	System shall have power storage capability	Commercially available power storage
	1%	System shall enable interoperable component level integration	Use non-proprietary components
	1%	System shall enable sharing of power amongst customers	Enable two-was flow of energy and information
Financial (25%)	**10%**	**System economic value shall be greater than cost**	**Revenue > Capital +Operating Cost**
	8%	Price of microgrid-generated electricity should remain stable overtime	Change in price/Time
	3.5%	The system shall engage available customer segments in the community for power generation	Power generation aggregate penetration %
	3.5%	There shall be minimal upfront capital expense for disadvantaged customers	Upfront capital expense per sliding scale
Community (25%)	**7%**	**Microgrid owner should seek local labor for pre-construction and post-construction periods of microgrid project**	**Employment/MW**
	7%	Microgrid owner should seek the use of local materials	Economic Development/MW (I/O model)
	5%	System shall reduce energy burden for disadvantaged end-users through the reallocation of profits to a subsidization program	$ gained through incentives (tax credits/ subsidies)/ selling surplus power to the grid
	4%	Microgrid owner should include an energy efficiency education and awareness component to its community outreach	% of members who engage in EE behavior
	2%	System shall locate generation plant on marginal lands	Acreage of marginal land repurposed

TOPSIS Analysis

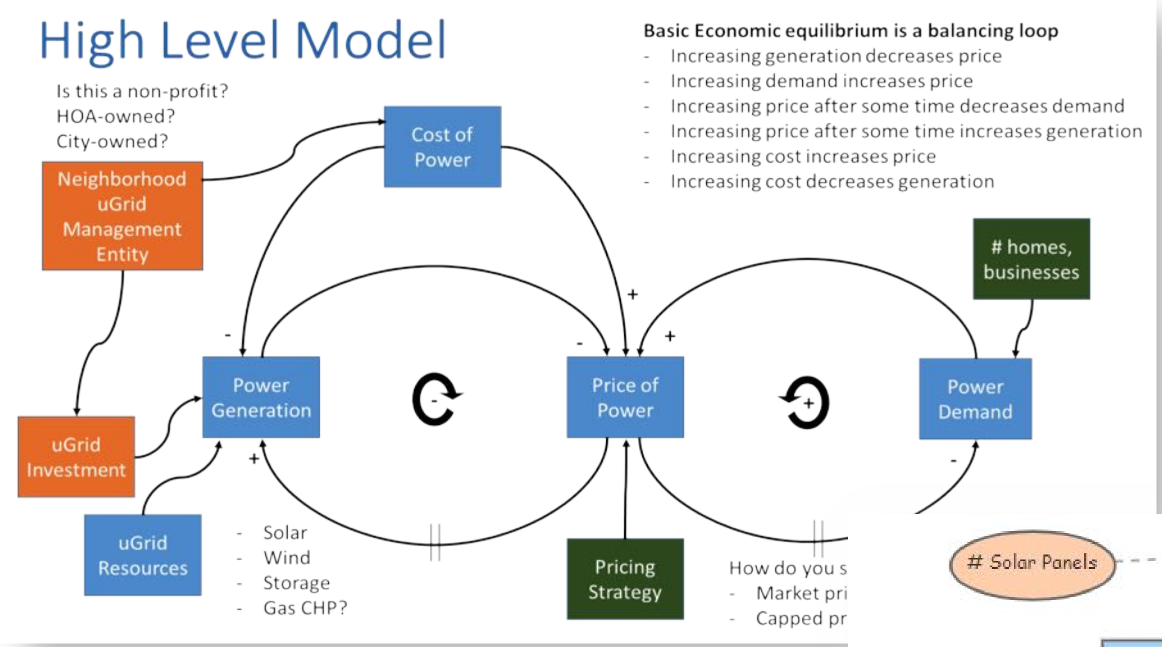
	Reliability (downtime in min.)	Quality (deviation in %)	Security (risk $? = prob. * impact)	Operation Expense ($ in mil)	Capital Expense ($ in mil)	Assistance to disadvantaged ($ in thousand)
Do nothing option (macro grid)	250	5	50	2	15	35
uGrid w/ No storage	180	15	100	4	20	15
uGrid w/ storage	290	15	100	6	27	10
Positive Net Metering	250	15	100	5	25	5
	min	min	min	min	min	max
weights	0.2	0.2	0.1	0.2	0.2	0.1
ideal	180	5	50	2	15	35
the worst	290	15	100	6	27	5

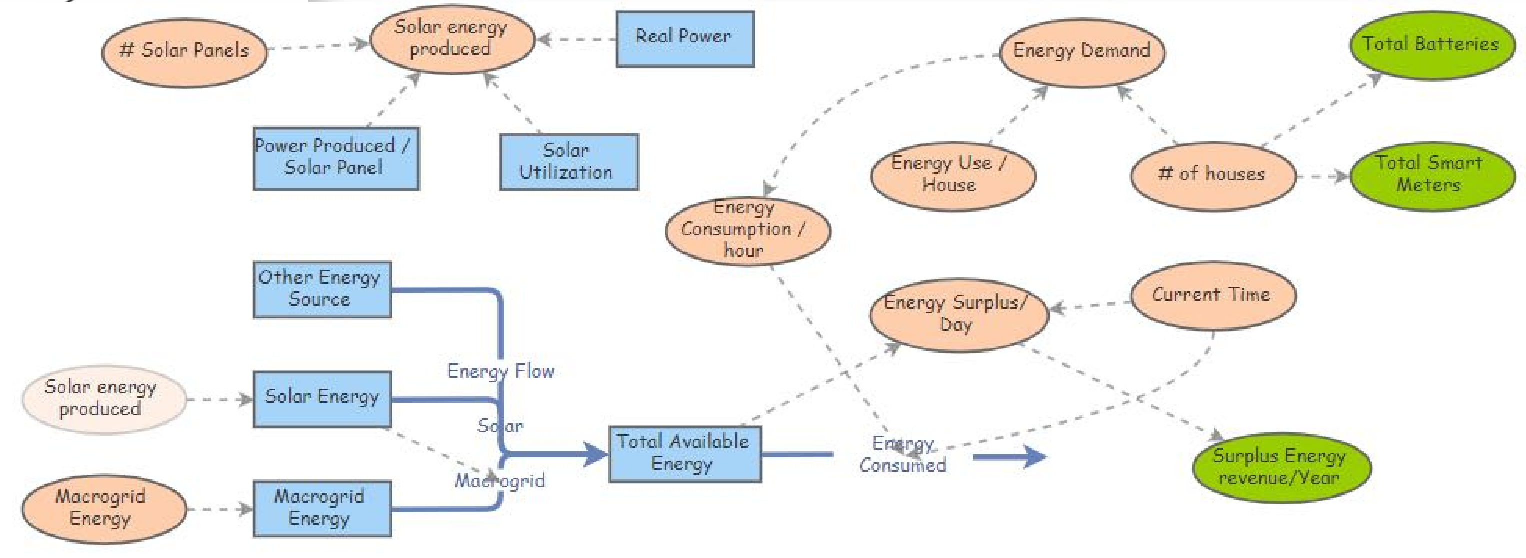
*TOPSIS: Technique for Ordering of Preference by Similarity to Ideal Solution

Analysis of Alternatives

Consideration:	Do Nothing Option	Microgrid, No Storage:	Microgrid, With Storage:	Positive Net Metering:
Description:	Maintain macrogrid status quo	Distributed Renewable Resource Generation capable of 5.2 hours of average production per day	Distributed Renewable Resource Generation capable of peak demand for 5.2 hours per day plus storage	Distributed Renewable Resource Generation Capable of producing all net power required to operate microgrid with storage
Technical: Reliability Quality Security Resilience	**Overall Tech: 1** High High High Medium	**Overall Tech: 4** High Medium Medium Medium	**Overall Tech: 4** High Medium Medium Medium	**Overall Tech: 2** High Medium Medium High
Financial: OpEx CapEx	**Overall Fin:1** Lowest Lowest	**Overall Fin:2** 3rd Highest 3rd Highest	**Overall Fin:3** 2nd Highest 2nd Highest	**Overall Fin:4** Highest Highest
Community: Assistance to disadvantaged	**Overall Comm: 1** Best	**Overall Comm: 2** 2nd Best	**Overall Comm: 3** 3rd Best	**Overall Comm: 4** Worst
Ranking	**Overall: 1**	**Overall: 2**	**Overall: 4**	**Overall: 3**

Dynamic Sizing Model





Conclusions

- Systems Engineering methods naturally support tradespace and decision analysis of complex systems with combined social, technical, and economic variables
- Need to combine qualitative analysis to conceptualize the “3 systems” and quantification of alternatives to build decision support
- Growth in use of electrical microgrids – hopefully will consider models that incorporate purely human resilience benefits
- Systems thinking frameworks are useful to get systems engineers to scope the challenge more holistically:
  - 3 systems model, to understand how innovation will change the systems
  - Sociotechnical multi-level model, capture multi-level abstractions and constructs
  - Human capital model, framework to consider human community resilience in the trades
- At this point, economic challenges constrain us – but hope to discover effective pathways in the models to inform decision makers of change strategies

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