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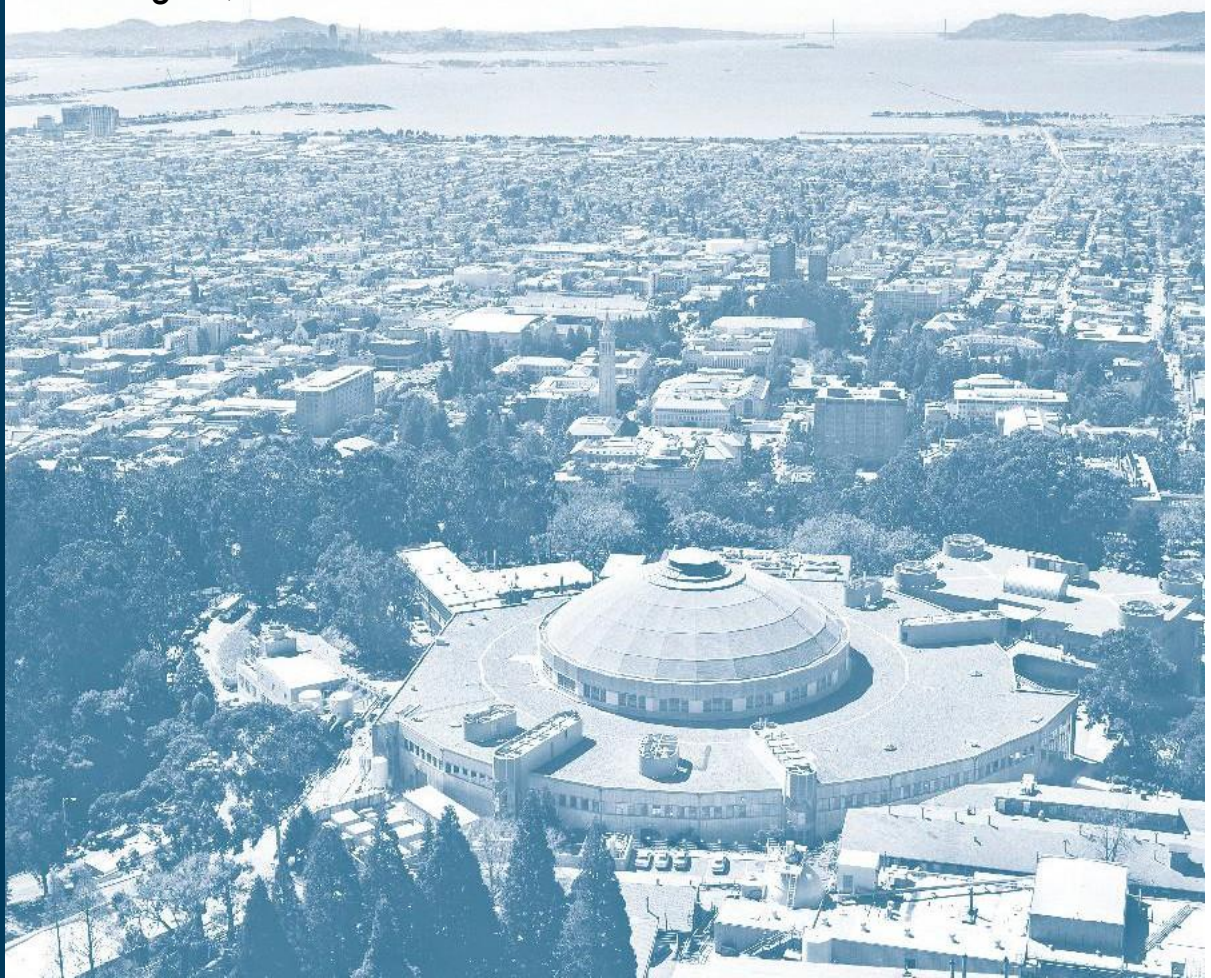

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ABSTRACT

Community and city leaders are interested in achieving sustainability goals, providing resilient energy infrastructure, and improving economic competitiveness. Community-level data acquisition and analysis can provide energy and associated benefits that are not possible at the single building level. However, there is a lack of organizational structure, common semantic data models, interoperable systems, and methods to support data-driven decision-making for community-scale energy supply and demand systems. We explored the need and opportunity for a Community Energy Operations and Planning System (Community EOPS), a potential data exchange platform. We conducted "customer discovery" interviews, and reviewed literature, public tools, and technology platforms to identify key energy data "users" and use cases in communities. The key users of the Community EOPS could be developers of mixed-use districts, corporate, defense and university campus energy managers, and city managers of cities that own their energy utility. The value could be for community planning and reporting (for energy data-integrated land use planning and community infrastructure investments in microgrids, storage, district heating and cooling), energy efficiency (leveraging optimizations for community scale energy supply and demand), flexible load management (grid-edge load management to offset, shift, and flatten loads for multiple buildings and EV fleets), cost savings and revenue generation (participating in grid services), and social benefits such as energy resilience, equity, and awareness. We developed a conceptual Community EOPS architecture with recommendations for streamlined and prioritized data acquisition, sharing, and integration driven by prioritized use cases, common metrics, and actionable visualizations that can provide value to a community's users.

Introduction

Cities, developers, communities and property owners value resilience and aggressive energy efficiency as cost-effective strategies for reducing carbon emissions, improving comfort and livability, and encouraging local economic development (Zaleski, Pless and Polly 2019). Communities are experiencing an increased penetration of community scale resources such as distributed renewables, battery and thermal storage, and developing an interest to view and control flexible community demand loads such as aggregated buildings with load diversity, electric vehicle charging stations, and district heating and cooling.

Fortunately, there are significant energy savings opportunities that are possible specifically at the community scale. For instance, the community scale may be the sweet spot to exploit the *time varying behavior of community or aggregated energy assets*. Connected and smart communities can leverage flexible demand across sectors, such as scheduling EV fleet charging, and shifting district thermal plant or aggregated building peak loads to be non-coincident, which

can reduce the risk of transformer burnout/equipment overload and the ensuing capital investment to replace the expensive equipment. Using macroscopic and cross-sectoral load data analytics, flexible load management at the community scale can also help increase enrollment in currently undersubscribed 'time of use' rate utility programs as well as help schedule the community's renewable use at times of high availability to flatten the duck curve. This can provide multiple benefits such as reduced operating cost for the community's asset owners, a greener fuel mix, and potentially enhanced grid/microgrid integration and energy resilience. Another opportunity is to use the *community's energy resources with increased effectiveness and reduced energy wastage*. For instance, data visibility can enable not just exploiting the diversity of loads across different building typologies, but also assessing opportunities to utilize the cumulative waste heat from certain buildings for other parts of a campus, such as a district heating and cooling plant or community thermal storage, thereby creating closed loops and significant energy and cost savings.

Community stakeholders around the U.S are expressing an interest in effective data applications that can integrate energy and complementary datasets to analyze, visualize, and support such types of data-driven decision making for planning, design and operations of the community's energy assets. Early adopters are investing in the use of "smart city" private platforms, and public tools with a desire for robust actionability from community-scale data. However, while there is enthusiasm for the concept of community energy analytics, there is a lack of common semantic data models, interoperable systems, and methods to collect and share energy data.

Several challenges exist for the development and implementation of an integrated data collection and analysis platform at the community scale. Organizational hurdles include: a lack of comprehensive energy data acquisition, clear goals and use-cases, siloed procurement and high costs of platforms, and lack of data sharing and visibility across urban or campus departments. In term of regulatory hurdles, apart from a handful of energy disclosure laws such as AB802 in CA and LL84 in NY, or voluntary programs such as ACEEE City Scorecard and LEED for Cities and Communities, few regulations trigger data acquisition and visibility across energy sectors and communities. Technical hurdles include: an absence of integration between existing technology platforms and public datasets that serve disparate sectors, combined with a lack of standardization of data formats, i.e. metadata dictionaries, schemas, and models. Risks are associated with cyber-physical security, data privacy, and inconsistent data provenance.

Given the wide spectrum of possible research areas in this fast-evolving space, we focused on three research questions as an approach to how an effective community scale energy data system could be developed and used:

1. **Who are the key stakeholders at the community scale who make energy infrastructure technology (Infratech) related purchasing and use decisions?** What is the appropriate community scale of these stakeholders and their sphere of influence?
2. **Why do stakeholders want to use an effective community scale data platform?** What energy opportunities are not being harnessed through available 'state-of-practice' platforms, that potential 'state-of-the-art' Community EOPS should aim to achieve?
3. **What can be a conceptual architecture for a potential Community EOPS data exchange platform**? How can the above-mentioned technical challenges be solved?

Contributions of the Paper

First, we identified the key stakeholders in communities of different sizes and in different regions around the country and interviewed them to determine the scale of their influence, role in decision making, and if this varied by communities' scale and type. Then, adding extensive reviews of both the existing literature, and commercial and public tools, we identified the platforms that are in use today, how organizations are using them, and what are the unmet needs, not being answered by these platforms. Last, building from these learnings, we identified key features and functionality for a proposed conceptual Community EOPS framework to address the key value propositions for stakeholders. The results of our work have been presented as 1) a description of key stakeholders, their use cases based on decision making domain by community type; 2) a description of important energy-saving opportunities with corresponding metrics, data, and illustrative visualizations to support the use cases and 3) a conceptual software architecture that utilizes publicly available datasets, metadata standards and semantic information that enables applications to be developed across different types of data. The use cases span three different phases of a community's life cycle – Planning and Policy, Design and Build, and Operations and Maintenance. We make a case for data sharing across departments and users in different roles for better visibility, monitoring and eventually better planning and control. We also address leveraging complementary data streams and non-energy drivers such as public awareness, resilience, and equity as catalysts for energy delivery and savings.

Methodology

Our methodology included three main activities: stakeholder interviews, literature review, and a review of emerging software tools and datasets.

Stakeholder Interviews

We conducted 28 stakeholder interviews to increase our understanding of the use cases and functionality that a potential community scale platform could address. This included eight cities of different sizes and levels of energy management, namely Berkeley, San Francisco, San Jose, San Luis Obispo, San Diego, CA, Dallas, TX, Orlando, FL, and Racine, WI. We included three utilities: two city-owned utilities, i.e. Palo Alto and Santa Clara CA, and one large utility Portland General Electric Utility, OR (to evaluate if the utility/regional scale is appropriate). Other stakeholders included four campus energy managers from Parks Reserve Forces Training Area (military), Lawrence Berkeley National Laboratory (research), and the University of California (educational) at San Diego and Davis, CA; two urban developers i.e. FivePoint, CA and Sidewalk Labs, Canada; four technology companies, i.e. Bosch, Enersys, Itron, and Panasonic, and seven consultants and non-profit organizations working in the urban energy sector, i.e. 2030 District Network and Natural Resources Defense Council (non-profits), Fehr and Peers, Ford Mobility (transport), Skidmore, Owings & Merrill and Urban Collaborative (urban planning), and Strategy of Things (consulting). The interviews provided us a high-level understanding of the key decision makers and energy priorities at the community scale, and how they vary by city, campus (corporate, educational, defense, etc.), or multi-use district or neighborhood. We recorded the

benefits these communities derive from the use of existing platforms, and if there are any unmet needs and data gaps to achieve their prioritized use cases.

Literature and Emerging Tools

In this section, we summarize studies on city level energy data requirements and present a review of illustrative public and private technology platforms, tools and datasets.

Through interviews conducted across 20 cities, Aznar et al. (2015) revealed that city and sustainability staff focus on building certifications and best practices, mixed-use community planning and distributed generation development. The authors also suggest that cities focus on Climate Action Plans (CAPs) and city's energy and greenhouse gas (GHG) reduction goals. Comparing their city's performance with other cities through cross-sectional benchmarking is a key use case of energy managers (Bull et al. 2019). They also suggest that communities would like to better understand the consumption load profiles and identify what type of infrastructure, renewable generation and storage resources to invest in. This increased interest in distributed energy resources (DERs) can be attributed both to the increasing interests in improving energy resilience and energy equity for vulnerable communities (Aznar et al. 2015). Calvillo, Sánchez-Miralles, and Villar (2016) show how communities are interested in tracking their utility grid infrastructure and the increasing EVs. Ribeiro et al. (2019) ranks the 75 largest U.S. cities based on major policy areas, including establishing stricter climate and GHG reduction goals, investing in local DERs, supporting energy code compliance and energy disclosure policies. Piette et al. (2018) conducted interviews with multiple cities to understand their needs, methods and tools being used to model energy use and evaluate GHG policies. They report that cities face challenges with collecting, managing energy data from its building stock.

Next, we reviewed available public tools and datasets. As mentioned in Table 1, some of these are mature tools adopted by users, and others that are still nascent in their adoption. Several have been developed by National Labs for potential integration into community-scale platforms.

Finally, we identified several categories of proprietary commercial energy management platforms, whose sales are directed at specific departments. For ease of framing, we have consolidated multiple stakeholders under three user groups based on their roles in the built infrastructure life cycle as described earlier: Planning and Policy, Design and Build and Operations and Maintenance. The procurement of these commercial systems is usually in siloes, which in turn leads to extra costs and lack of data sharing leverage and visibility. Unsurprisingly, no platform is comprehensive in its data acquisition across various sectors. The biggest gaps occur at the grid edges around collection and sharing of energy supply (generation, storage) and demand (buildings, transport, district thermal systems) data. Table 2 shows illustrative private platforms that are used by stakeholders that we interviewed, the benefits they derive from them and the potential unmet energy savings opportunities. These commercial platforms are classified as: Distributed Energy Resources Management System (DERMS), Building Energy Information Management Systems (BEMIS), Electric Vehicle Charging Analytics (EV), Building Energy Benchmarking (Bx), Green House Gas Reporting (GHG), Utility Analytics (UA), and Community Planning Platforms (CPP).

These tools and platforms have highly specific users and sectors, and there is an unmet need for data exchange across sectors and visibility across community users from planning to design and operations, as shown in Table 3 and discussed in the next section.

Table 1: Public energy modeling and analytics tools and datasets offered by DOE/ National Labs

Public tool/ dataset	Type: (Adoption)	User Type	Benefits (Link)	Unmet Needs
BEDES Building Energy Data Exchange Specification	Dictionary (Medium)	Operations	Schemas cover standard terms, definitions, field formats for data on building size, type, and energy use. (bedes.lbl.gov)	Expand to include multiple sector data integration – RE, electrical storage, thermal storage, buildings and electric vehicles.
BPD Building Performance Database	Open Dataset, Bldg. Analytics (Medium)	Operations	Web tool creates peer group datasets to assess energy efficiency opportunities, forecast and quantify project performance and risk. Provides building, equipment/ asset information. (bpd.lbl.gov)	
CityBES City Building Energy and Sustainability	Building. Analytics, Benchmarking (Low)	Planning	Modeling software for building energy benchmarking, retrofit analysis, renewable energy analysis, and building performance visualization. (citybes.lbl.gov)	
DERCAM Distributed Energy Resources Customer Adoption Model	Modeling (Medium)	Design	Modeling software for microgrid analysis, sizing for generation and storage. Quantifies for technology and economics for capital and operational expenses. (building-microgrid.lbl.gov)	
ESPM Energy Star Portfolio Manager	Open Dataset (High)	Operations	National online benchmarking software to track energy and water consumption, GHG. Benchmark the performance of one building/portfolio of buildings. (portfoliomanager.energystar.gov/)	
OpenEI Open Energy Information and Data	Open Dataset, Analytics, Modeling (Medium)	Operations	Multiple large databases including national utility tariffs, scenario modeling, and resource planning. (Openei.org)	
SEED Standard Energy Efficiency Data	Benchmarking, Analytics, (Medium)	Operations	Standardized format for energy data acquisition, storage and analysis for building portfolios, performance reporting, benchmarking. (seedinfo.lbl.gov)	
UrbanOpt Urban Renewable Building & Neighborhood Optimization	Analytics (Low)	Design	Tool to model design of district energy systems, heating and cooling investments, DER optimization, (http://www.nrel.gov/buildings/urbanopt.html)	

Table 2. High level assessment of illustrative private sector energy management platforms.

Platform Type	Stakeholder	Benefits	Unmet Needs
1: DERMS	Operations	Energy providers can balance and optimize DER integration	Feedback loops from operations to design and planning
2: BEMIS	Operations	Local energy management at building level, grid services, DER management, controls	Benchmarking, resilience, land use planning and investment decisions for infrastructure
3: EV	Operations	Charging data, bi-directional grid communication	Integration with other non-EV platforms
4: Bx, GHG	Planning	Climate mitigation efforts and policies	Benchmarking with other districts or cities to support planning
5: DERMS, UA	Operation	Analytics for land-use planning, DER control and management	Include cross-sectional benchmarking to augment the planning
6: BEMIS, DERMS	Operations	Customer specific apps, benchmarking, design of campus power supply	Interoperability with public datasets, benchmarking
7: DERMS, EV	Operations	Customized applications	Interoperability with buildings and public datasets, geospatial integration
8: BEMIS	Operations	Flexible, scalable and handles different time series streams and static data	Support for geospatial visualization to perform land use planning
9: CPP	Planning/Design	City planning tool	Integrate feedback loops from real time operations

Results

We analyzed information from the reviews through a five-step process summarized here:

Figure 1. The five-step process framework for research results.

1. Use cases: Identify high priority current and aspirational use cases across the three user groups
2. Metrics: Determine metrics to support the use cases, and overlaps of key metrics across users
3. Data: Identify data needs, sources, streams, and approaches to data interoperability
4. Visualization: Develop conceptual data visualization to aid various levels of decision-making
5. Software Architecture: Develop conceptual data exchange architecture for applications that address the prioritized use cases

Step 1: Use Cases

We categorized the users based on the phases of a community's life cycle into *Planning & Policy, Design & Build,* and *Operations & Maintenance*. These users expressed different desired access frequency and derived value from energy data, as shown in Table 3.

Table 3. Types of community energy data users and desired value from energy data.

Type of user	Desired frequency and value from energy data analytics
Planning ● City/ Campus Manager CM ● City/Campus Sustainability Manager SM ● City/ Campus Planner CP ● City Council and Committees CC	Frequency for high-level data visibility: Annual/quarterly ● Improved Informational Awareness ● Intelligence on environmental benchmarks, targets; streamline reporting ● Data driven energy land use/ energy infrastructure investments ● Data driven policy decisions
Design ● Developer and Builders DB ● Architect/ Engineer AE ● Build Own Operate Maintain Developer BOOM	Frequency for Periodic data visibility: Seasonal/ monthly/ ● Data driven, cost-effective land-use energy infrastructure investments ● Feedback loops from operations data for next design phase ● Reduce capex and Opex on distributed energy infrastructure
Operations ● Campus Energy Manager CEM ● Public Works Department Manager PWM ● Distributed Energy Resource/Municipal Utility Manager DERM	Frequency for real time data visibility: 15-minute, hourly, daily, weekly ● Macroscopic supply and demand energy use and opportunities ● Track to reduce operational expenses on energy, minimize capital expense on new equipment ● Lower capex and Opex for community energy generation and storage, better focused services and incentives, minimize outages and shutoffs

We categorized 22 use cases gleaned from interviews and reviews, into 'Current' - those under current consideration and 'Aspirational'- those that users would like to develop and acquire data for, in the next 3-5 years. We clustered these use cases into five use case groups (UCs) as

shown in Table 4, with relevance across the phases of a community's life cycle Planning and Policy (P), Design and Build (D), and Operations and Maintenance (O).

Table 4. Potential use cases and benefits of a City EOPS platform.

	Use cases	Description	Pain Points	Benefits
UC1 Community Planning, Benchmarking, and Reporting	P1. Energy inventorying, reporting, and compliance	Inventorying for energy demand and supply, building portfolio benchmarking, and code compliance	● Inventorying and reporting require significant effort and cost due to multiple data sources and tech solutions ● Planners and designers lack access to feedback loops from operational data	● Streamlined community-wide energy inventorying and reporting ● Data-driven target setting and tracking ● Cost effective land- use and infratech capital investments ● Evidence-based policy and design decisions
	P2. Sustainability Planning	Providing interoperability with sustainability platforms for carbon disclosures and credit reporting e.g. ICLEI,[1] CDP,[2] AB802,[3] LL84,[4] ACEEE (Ribeiro et al. 2019), Leadership in Energy and Environmental Design		
	P3. Target setting and tracking	Setting goals and tracking for e.g. increase renewable fuel, integrate electrified technologies, EV fleets		
	P4. Longitudinal benchmarking	Identify trends and comparing vs. previous time periods		
	P5. Cross-sectional benchmarking	Benchmark compared to other buildings, cities, communities, districts		
	PA1. Land use planning	Scenario planning and analysis for effective land use		
	PA2. Infratech investments	Decision making for energy infratech		
	D1. Design opportunities	Optimize equipment design, site, sizing		
	DA1. Design codes and permits	Accelerate permitting process using data, for DERs, energy efficient bldgs..		
	O1. Improve operations and maintenance policies	Reduce capex and opex through policies e.g. planned and predictive maintenance performance-based contracts		
UC2 Social Benefits	PA3. Public awareness	Citizen centric data visibility, e.g. for behavior change	● Limited visibility about energy ● Inequitable delivery of energy resources ● Risk of grid outages	● Public awareness ● Energy equity ● Energy resilience
	PA5: Energy equity	Create data-driven programs to reduce burdens like high energy bills, and enhance energy reliability for vulnerable or low-income populations in the community		
	OA4. Energy reliability	Enable reliable, regular supply of energy and contingency measures in the event of a power failure		
UC3 Energy Efficiency	O2. Improve energy efficiency	Avoid energy waste by using performance data	● Low savings persistence	● Energy tracking of community assets
	O3. Optimize electric loads	Transact/schedule building electric loads, equipment, demand response		

[1] ICLEI Local Governments for Sustainability
[2] Carbon Disclosure Project
[3] California Legislature Assembly Bill 802
[4] New York City Mayor's Office of Sustainability Local Law 84: Benchmarking

UC4 Flexible Load Manage-ment	O4. Optimize thermal loads	Transact/schedule district heating, cooling, thermal storage	● Siloed load optimization ● Limited response to energy trends e.g. increased renewable, EV and DER	● Cross sector flexible load optimization of community energy assets ● Capex reduction
	OA1. Cross-sector load optimization	Reduce the energy consumption, peak loads across sectors by utilizing assets such as district energy system, DERs, flexible buildings etc.		
UC5 Cost/ Revenue Benefits	PA6. Revenue generation	Identify opportunities such as excess capacity, grid services, EV charging	● Missed cost reduction opportunities ● Missed opportunities to avail of incentives and generate revenue through grid services	● Opex reduction ● Revenue generation
	PA7. Incentives/rebates	Enable decision-making to incentivize uptake of certain technologies		
	O5. Reduce cost	Use energy data for more informed load forecasting and scheduling to reduce peak load and to implement effective demand side management		
	OA2. Billing verification	Verify billing, based on benchmarked peer buildings, EV charging and smart meter interval data		
	OA3. Rate case justification	Determine unit charge to the public utilities commission (aggregation of load)		

Highlights from the five key use cases are summarized as follows:

- **UC1 Community Planning, Benchmarking, and Reporting**: Stakeholders from the Planning and Policy (P), Design and Build (D), and Operations and Maintenance (O) user groups indicated lack of feedback loops from operational data to the planning and policy process, that could benefit decision-making for land- use planning, Infratech, such as siting and sizing of shared community energy resources, and O&M policies. They also expressed a need for streamlined community-wide energy inventorying, benchmarking, and reporting
- **UC2 Social Benefits**: Stakeholders from the user group Planning and Policy (P) indicated the need for future tools and digital applications for better provision of energy services to vulnerable communities, improve islanding capabilities and virtual power platforms, and enhanced community participation in energy conservation and environmental action.
- **UC3 Energy Efficiency**: Stakeholders from the Operations and Maintenance (O) user group expressed that community-scale energy opportunities remained untapped without adequate cross-sector energy data sharing, including enhanced shared thermal and electrical resources serving building portfolios and EV charging and data utilization to enhance the adoption of energy-efficient technologies such as direct current equipment.
- **UC4 Flexible Load Management:** Stakeholders from the Operations and Maintenance (O) user group expressed interest in opportunities enabled from community data platforms to offset, shift and flatten loads such as optimizing DERs, building, EV charging, district heating and cooling systems loads. Examples include using renewables or preheating with heat pumps, energy storage in ice/chilled water systems or high-density batteries at times of higher energy resource availability and optimizing public EV charging duty cycles to be non-coincidental with building peak loads.
- **UC5 Cost/Revenue Benefits:** Stakeholders from the Operations and Maintenance (O) and Planning and Policy (P) user groups desired greater participation by community members such as home energy management, or community owned assets, public-building, charging stations in grid services such as demand response, incentive/rebate programs etc.

Step 2: Metrics

We developed 25 metrics quantifying the types of data of interest in a Community EOPS. As shown in Table 5, several metrics are pertinent across use cases, highlighting the need for data sharing and visibility across user groups.

Table 5. Metrics mapped to community-level use cases.

Metrics	Use Cases				
	UC1 Plng.	UC2 Social	UC3 EE	UC4 Load	UC5 Cost
M1. Energy generation and consumption (therm or MWh)	X		X		
M2. Fuel mix (% e.g. Renewables, grid electricity, gas)	X		X		
M3. Green certified buildings (#, sf)	X				
M4. Number/capacity of public EV chargers (#, kWh)	X				
M5. Generation asset installed (MW)	X	X			
M6. Energy storage asset installed (MWh)	X	X			
M7. GHG emissions per sector (CO2e)	X				
M8. Urban heat stress (Max daily temperature in C/F)	X	X			
M9. Air Quality Index (value between 0-500)	X	X			
M10. Capital Costs ($)	X				X
M11. Operating Costs ($)		X	X	X	X
M12. Return on Investment (%)	X				X
M13. Costs saved or revenue generated ($)		X	X		X
M14. Energy Saved (MWh)	X	X	X	X	X
M15. Peak load reduction (MW)				X	X
M16. Pollution reduction (ppm)		X			X
M17. Environmental Disability Adjusted Life Years		X			
M18. Shared energy services (MWh, miles proximity)	X	X			
M19. Aggregated Energy Use Intensity (kWh/ft^2)	X				
M20. Aggregated Energy Star score (value 1-100)	X				
M21. System average interruption duration index (SAIDI)		X			
M22. System average interruption frequency index (SAIFI)		X			
M23. Demographics (#, %)	X	X	X		
M24. Gross monthly family spend on energy bills (%, $)		X			
M25. Energy use per capita (kWh)		X	X		

Step 3: Data

Next, we identified the top ten energy data streams necessary to quantify the 25 metrics. These data streams are: Energy Generation (DS1), Energy Use (DS2), Emissions (DS3), Weather (DS4), Geographical (DS5), Asset/Land-use (DS6), Cost (DS7), Demographics and Public health (DS8), Outages (DS9), and Income (DS10) (Table 6). The interviews revealed that there is a wide variation how much access communities may have to these data streams. Once we identified the relevant data streams, the next question we tried to answer is what are the data opportunities, for e.g. what are the publicly available datasets that would be available to all communities, and what are the paid and private data sources available to some communities. We also identified ways of acquiring the data (e.g. through drivers, application programmable interfaces (APIs)) and potential formats in which data could be standardized for better integration. The compilation presented in Table 7 focuses on open datasets, or paid services, and does not include data that are owned by private entities that probably may not be shared with the community.

Table 6. Data streams mapped to the metrics.

Metrics	Data Streams									
	DS1 En. Generation	DS2 En. Consumption	DS3 Pollution/ Emissions	DS4 Weather	DS5 Geographical	DS6 Asset/ Land use	DS7 Cost	DS8 Demographic, Public health	DS9 Outage	DS10 Income
M1. Energy generation/consumption per sector (therm/ MWh)	X	X								
M2. Fuel mix (%)	X									
M3. Green certified buildings (#, sf)						X				
M4. Public EV chargers (#, sites)						X				
M5. Generation asset (MW)						X				
M6. Energy storage (MWh)						X				
M7. GHG per sector (CO2e)			X							
M8. Urban heat stress (Max C/F)		X		X						
M9. AQI (value between 0-500)			X							
M10. Capital Costs ($)						X	X			
M11. Operational Costs ($)	X	X					X			
M12. ROI (%)	X	X					X			
M13. Costs/revenue ($)	X	X					X			
M14. Energy Saved (MWh)		X								
M15. Peak load reduced (MW)	X									
M16. Pollution level (ppm)			X							
M17. Public health DALY								X		
M18. Shared energy (MWh, mi)					X	X				
M19. Aggregated EUI (kWh/ft^2)		X				X				
M20. Aggregated Energy Star		X				X				
M21. SAIDI									X	
M22. SAIFI									X	
M23. Demographics (#, %)								X	X	
M24. Gross family inc. spent ($)							X			X
M25. Energy use per capita (kWh/p)		X								X

Table 7. Data streams and illustrative publicly available data sources (free or paid services).

Data Stream	Data Source
DS1. Energy generation data	o Municipal Utility generation /Local DER generation meter data o Orange Button data: for solar generation o Energy Information Administration's electric system operating data
DS2. Energy consumption data	o Interval meter data for buildings, EVs, water treatment, district energy systems o Green Button data o Operational schedules o Audit data o Municipal Utility/DER o Energy Disclosure Data o Benchmarked data e.g. Building Performance Database, Energy Star Portfolio Manager o Energy Information Administration (EIA) datasets
DS3. Emission data	o Purple Air o Statewide open data, e.g. CalEnviroscreen o Disclosure data (e.g. Carbon disclosure project, CAIT Climate Data Explorer, C40's Global Protocol for Community-scale GHG Emission Inventories)
DS4. Weather data	o National Oceanic and Atmospheric Administration (NOAA) o Paid weather data service (e.g. Weather Underground, Dark Sky)

DS5. Geographical data	○ Satellite images (e.g. Microsoft, Google) ○ Geographical information system (GIS) maps ○ Charging station location (e.g. PlugShare, Chargepoint data)
DS6. Land use and asset data	○ Assessor data: e.g. Building type, size, year built, retrofits conducted etc. ○ Building permit data ○ Building typology e.g. North American Industry Classification System (NAICS) data ○ Green building/ LEED certification data ○ Energy equipment asset data ○ DER assets (e.g. on-site/rooftop solar, storage) capacity data ○ EV charging station data ○ Shared community energy assets
DS7. Cost data	○ Utility Tariffs (e.g. OpenEI) ○ Utility billing data ○ Energy Information Administration's electric system operating data ○ Asset cost ○ O&M retrofit
DS8. Demographic, Public health data	○ Developer's plans, city census (Occupancy: residents, day-workers, event surges) ○ Census (Public health records) ○ CalEnviroscreen
DS9. Outage data	○ Outage Municipal Utility/DER data
DS10. Income data	○ Public income e.g., neighborhood/city median income (Census data)

Step 4: Visualization

As the next step, we generated a few conceptual visualizations that can be used to portray the data and metrics as usable information. Each use case may need a different subset of the ten data streams and 25 metrics possible from a Community EOPS data exchange platform. Figures 2(a-f) are illustrative dashboards for each of the prioritized use case groups

- Figure 2a enables emissions and energy consumption reduction target-setting. The energy data provides inputs into land use planning and community energy infrastructure investments into microgrids, storage, district heating and cooling systems. It also provides upward and downward trend and benchmarking charts
- Figure 2b utilizes aggregated data on power outages, as well as near real time data on public health-related environmental data such as air quality index or urban heat island. It could be integrated with GIS data, income data, and potential environmental events to assess vulnerable neighborhoods' energy resilience, equity, and public awareness
- Figure 2c visualizes the aggregated energy use (could be normalized based on weather, community occupancy etc.) of various sectors such as commercial, residential, industrial, EV charging etc., to enable improved scheduling, controls and maintenance.
- Figure 2d presents power demand contribution of sectors/neighborhoods accounts on a daily or weekly basis. The intent is to enable better scheduling for load shifting, peak shaving, grid balancing services, and determine low-cost or no-cost operational savings.
- Figure 2e provides insights into the monthly energy costs for energy purchase, revenue generated, from market participation in grid services, incentives, and rebate programs.

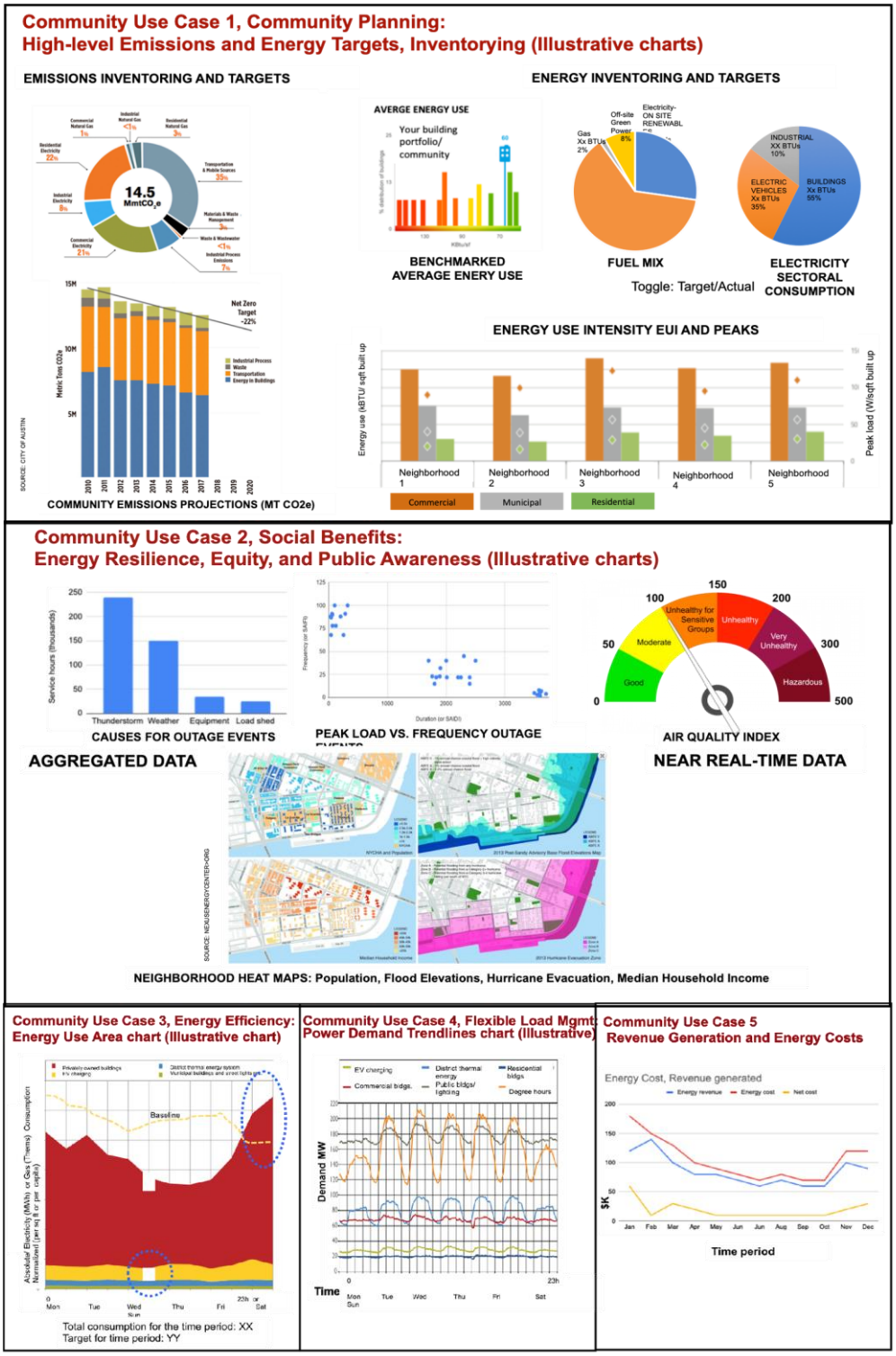

Figure 2. Illustrative visualizations from top to bottom (a) Top, UC1 Community Planning, Reporting and Benchmarking; (b) Middle, UC2 Social Benefits; (c) Bottom, left: UC3 Energy-Efficiency; (d) Bottom, center: UC4 Flexible Load Management; (e) Bottom, right: UC5 Revenue Generation/Energy Costs

Step 5: Software Architecture

The final step is identifying the various components of a Community EOPS data exchange platform (Figure 3). We consider the need for a data acquisition system using standardized data management formats from multiple sources, including near-real time, historical, and modeled supply and demand side energy data. Standard data exchange models are essential for data sharing and building scalable applications. We discuss some of these efforts:

- CityGML (CityGML 2017): XML format for representing and storing city 3D models.
- GeoJSON (GeoJSON 2020): JSON encode and represent geographic data of urban entities.
- BRICK (BRICK 2019), Project Haystack (Haystack 2020), Building Energy Data Exchange Specification (BEDES 2020), Home Performance eXtensible Markup Language (HPXML 2020) and BuildingSync (BuildingSync 2020): standardized buildings metadata representation.
- Unique Building Identifier (UBID 2019): An effort to assign unique identifiers to buildings in a city based on its geospatial information.

Figure 3 shows the different components that would be present in the Community EOPS platform. It starts with data acquisition of different data streams (DS1-DS10) from key sources. The metadata information is also stored to enable scalable applications and easy understanding of each timeseries stream. Once the data acquisition and storage part has been engineered, the next components are the applications and visualizations built on top of the stored data. Based on the data availability, these are developed to meet the stakeholders' use cases. The Community EOPS framework should support visualizations that can help a city to start using its data effectively. These could be specific to the type of user who is accessing the platform as well.

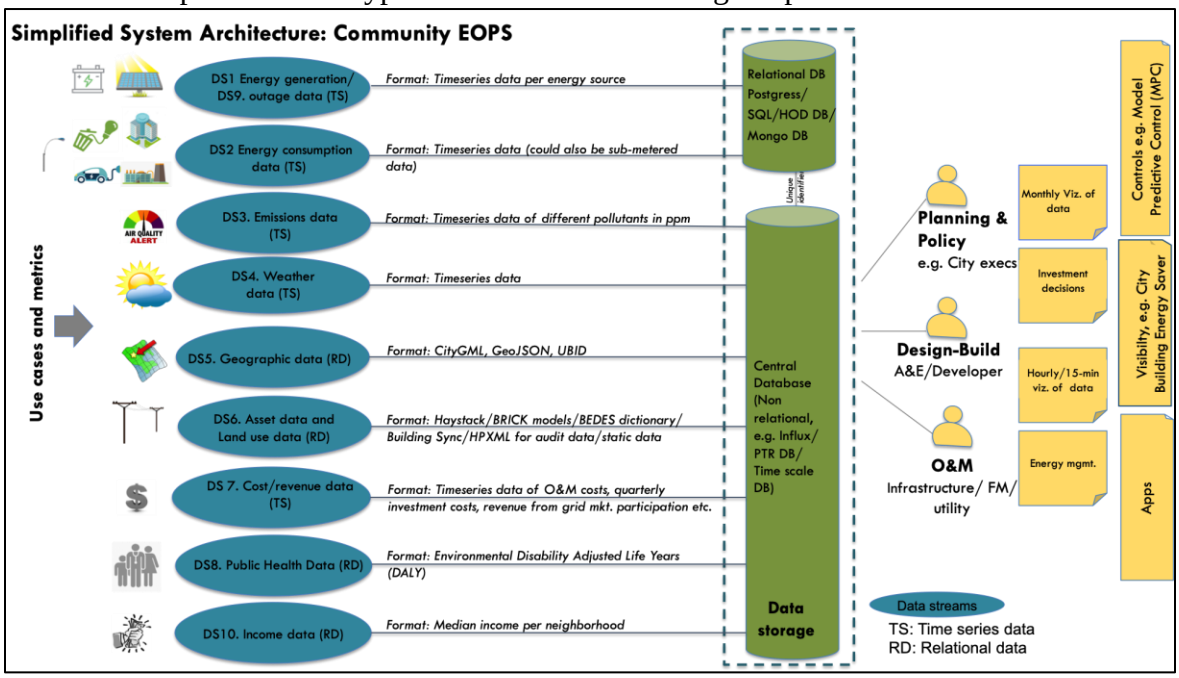

Figure 3. Conceptual architecture for a Community EOPS data exchange platform.

Discussion

A city may not be the most appropriate scale for a Community EOPS, due to the highly complex ownership and control of its built infrastructure, energy resources and data. Whereas, three categories of community scale stakeholders that could derive value from a Community EOPS, as described below and in Table 8.

High-Complexity Communities: "Green Municipalities". Cities that operate their own generation facilities or purchase power through contract, i.e. public utilities have expressed a desire for technology innovation, infrastructure improvements, and better visibility and control of their DERs. There are about 175 U.S cities that have a suitably complex stakeholder ecosystem of city departments but have a relatively smaller size (population <100,000) that may be suited to the Community EOPS concept. We regard these as "high-complexity" since the energy assets, technology, and data may be owned and controlled by multiple stakeholders.

Medium-Complexity Communities: Build-Own-Operate-Maintain (BOOM) or "Ecoblock" developers. A growing number of new mixed-use developers own and operate shared district energy resources such as heating and cooling systems or DERs, or intend to do so. We regard them as potentially "medium complexity" since the size, energy assets, technology, and data are owned by fewer number of stakeholders compared to a city**.**

Low-Complexity Communities: Educational, Corporate, and Military campuses. We regard these as potentially "low complexity" since a single stakeholder typically owns the energy assets and data. There are thousands of such campuses, and they may have lower organizational barriers for Community EOPS adoption.

Table 8. Three customer segments that could derive value from a Community EOPS.

Customer segments	Key User	Key Value Streams
Low-Complexity Communities: University, Corporate, Military Campuses	- Campus Energy Managers	- Data-driven target setting and tracking across all energy supply and demand assets - Cross-sector load optimization - Reduction in capital and operational costs - Revenue generation
Medium-Complexity Communities: Multi-use districts	- BOOM Developer	Additionally, - Cost effective infratech decisions - Energy reliability - Public awareness for tenant retention
High-Complexity Communities: Municipalities with utilities	- City Manager - City Council - Public Works Department - Planning, Design & Transport Dept.	Additionally, - Streamlined inventory and reporting - Energy equity - Public awareness for citizen behavior change - City policy decisions

Conclusion

The Community EOPS is a concept for a data exchange platform with streamlined energy data acquisition, integration, and user interfaces that could provide value to communities' energy systems across their lifecycle, from planning to design to operations. New interest in Connected Community platforms is emerging at the US Department of Energy and the national laboratories. Surveys conducted in this study suggest that the scale of a Community EOPS may be best suited for municipalities with publicly owned-utilities, campuses, and multi-use district developers. Additionally, from our initial hypothesis that a single energy-monitoring platform for multiple buildings is of value to multiple stakeholders, we found that an architecture that can acquire cross-sectoral datasets and provide a series of application-specific data exchanges may be more appropriate. The most valuable opportunities may occur at the grid nodes, at the intersection of sectors, and through integration with complementary non-energy or publicly available data streams. These are gaps that current technology platforms don't typically address.

The Community EOPS is intended for operational energy and cost reduction as a core benefit, as well as to track energy reduction targets as a co-benefit of other use cases that stakeholders are most interested in, such as sustainability tracking, infratech planning, resilience, equity, public awareness, and revenue generation.

The concept of a Community EOPS is to provide actionable data for community planning, i.e. for energy-data integrated land use planning and community energy infrastructure investments in microgrids, storage, district heating and cooling. The tool could also be useful for load management, optimizing cross-sectoral electric and thermal loads and revenue generation related to tracking participation in utility or whole demand response programs. Finally, we see value in building energy benchmarking and GHG tracking and reporting.

Future work is needed to evaluate the data workflow on how related technology is used in community scale energy systems today and details about what level of interoperability is present in the emerging systems. Overcoming the barriers of a centralized data collection from hundreds to thousands of different data generating systems would be a common protocol (and communications connections from each site), as well as permissions to share data to the central repository or exchange are key gaps to be addressed. Additionally, the value of the Community EOPS lies in the potential optimization that could lead to higher performance of the integrated systems. But the relative rewards to risks issues, such as higher system and data management costs, latency, points of failure, and overall complexity of an integrated system need to be evaluated. Research is also needed to evaluate business models for these technologies and the cost-benefit frameworks for campus, community and city stakeholders.

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References

Aznar, A., Day, M., Doris,E., Mathur,S., and Donohoo-Vallett,P. 2015. "*City-Level Energy Decision Making: Data Use in Energy Planning, Implementation, and Evaluation in U.S. Cities. National Renewable Energy Laboratory*". NREL/TP-7A40-64128 July 2015. https://www.nrel.gov/docs/fy15osti/64128.pdf

Bull,R., Ozawa-Meida,L., Stuart,G. and Dooley,K. 2019."*Sufficiently engaged? How Smart Metering Systems Help Local Authorities Become Smart Cities. International Conference on Electronics, Computer Engineering and Electrical Engineering"*. Eceee Summer Study Proceedings.www.academia.edu/39514757/Sufficiently_engaged_How_smart_metering_systems_help_local_authorities_become_smart_cities

Calvillo,C.F., Sánchez-Miralles,A., and Villar,J. 2016*."Energy Management and Planning in Smart Cities. Renewable and Sustainable Energy Reviews",* Elsevier, vol. 55(C): 273-287. www.researchgate.net/publication/284360137_Energy_management_and_planning_in_smart_cities

Piette,M.A., Pass,R.Z., Singh,R., and Hong,T.2018. "Review of City Energy and Emissions Analysis Needs, Methods & Tools." 2018 Summer Study on Energy Efficiency in Buildings. www.researchgate.net/publication/326825411_Review_of_City_Energy_and_Emissions_Analysis_Needs_Methods_and_Tools

Ribeiro,D., Samarripas,S., Tanabe,K., Bastian,H., Cooper,E., Drehobl,A., Vaidyanathan,S., Jarrah,A., and Shoemaker,M.2019. "*The 2019 City Clean Energy Scorecard. American Council for an Energy Efficient Economy".* Report U1904. www.aceee.org/sites/default/files/publications/researchreports/u1904.pdf

Zaleski,S., Pless,S., and Polly,B. 2018. "*Communities of the Future: Accelerating Zero Energy District Master Planning: Preprint.*" National Renewable Energy Laboratory. NREL/CP-5500-71841. www.nrel.gov/docs/fy18osti/71841.pdf

CityGML. 2017. "CityGML - City Geography Markup Language". www.citygmlwiki.org.

GeoJSON. 2020. "GeoJSON". www.geojson.org

UBID. 2019. "Unique Building Identifier (UBID)". www.energy.gov/eere/buildings/unique-building-identifier-ubid

BRICK. 2019. "Brick: A uniform metadata schema for buildings". www.brickschema.org

Haystack. 2020. "Project Haystack". www.project-haystack.org.

BEDES. 2020. "BEDES: The Building Energy Data Exchange Specification".www.bedes.lbl.gov

HPXML. 2020. "HPXML: An open data standard". www.hpxmlonline.com

BuildingSync. 2020. "BuildingSync: Standardizing Energy Audit Data Collection". www.buildingsync.net