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Why data for a political-industrial ecology of cities?

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ABSTRACT

Despite our declared era of 'Big Data,' we lack information on the flows of energy, water, and materials that support modern societies. These data are essential to understand how ecologies and the labor of people in far flung places supply urban areas, as well as how these resource flows are used by whom, where, and for what purpose. Like other places, the state of California is struggling with issues of data privacy and access. Water scarcity and the state's commitments to greenhouse gas emission (GHG) mandates raise the issue of consumption and the unequal burdens that derive from it. These mandates have unveiled the lack of comparable and verifiable data to understand crucial production-consumption dynamics. This paper illustrates how spatially-explicit big data can be harnessed to delineate an urban political-industrial ecology of resource flows. Based on research using address-level energy and water use consumption data for Los Angeles County, the analysis reveals how the region's wealthy residents use a disproportionate share of the water and energy resources. The paper also identifies structural obstacles to increasing fees and taxes or altering property rights that would reduce this consumption and foster more equitable resource use. This study has implications for theory, method, and policy related to urban sustainability, which is unobtainable without first unraveling the political-industrial ecology of the material basis of urbanization processes.

1. Introduction

Despite the declared era of 'smart cities' and big data, we have little information with respect to the flows of resources—water, energy, food—upon which cities depend, nor how they are used by whom in cities across geographical space and for economic indicators such as level of income. Yet, consumption patterns leave indelible and uneven environmental and socio-economic imprints on the places and spaces from where these flows are sourced, processed, and consumed. Reflecting on this paucity of information while seemingly drowning in a sea of urban sustainability indicators reminds us of Kitchin's (2014a) insights about data; they do not exist independently of the ideas, techniques, technologies, people and contexts that conceive, produce, process, manage, analyze and store them. Rather, continues Kitchin, they are instrumental features of a mode of governance that asserts cities can be measured, monitored, and treated as technical problems to be addressed through technocratic solutions.

In this paper, we illustrate how purpose driven data collection that explicitly links resource use to socio-demographic characteristics, ecological hinterlands and policy regimes, can yield important insights to better understand the political, industrial, and ecological fabric of cities. This then provides the basis for developing strategies to foster urban sustainability by reshaping a city's metabolism in an informed, equitable manner.

Our approach differs fundamentally between data that is typically collected to enhance 'smart city' monitoring and top down technocratic approaches that ignore the structural conditions shaping how cities function (Graham and Marvin, 2001; Kitchin, 2014a, 2014b). This includes, for example, data gathered to implement new technologies for city efficiency, such as sensored streets or buildings connected to smart apps on mobile phones or to city bureaus and for utility energy dispatching, that is divorced from institutional and governance power dynamics that often yield uneven processes and outcomes.

Rather, we argue that big data (i.e. very large quantities of data, often trillions of records) can be joined with or matched to other datasets to yield insights into patterns of production and consumption across urban landscapes and their resulting political, industrial, and ecological implications of these dynamics. Thus, we argue for using big data that is also granular to place and spatially explicit, so that it reveals processes by connecting actors, activities, and impacts across time-space (Bair and Werner, 2011). Recognizing there are other types of big data relating to social media, we

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refer specifically to data about the resources that sustain cities as we know them, particularly in the industrialized West. It is only by tracking and tracing these flows and the regulatory regimes that structure them, that cities can develop meaningful strategies to the impacts both in the city and the 'hinterland' that such resource use can be reduced.

This big data approach we adopt and the examples of water and electricity flows that we provide nests within a broader effort to develop a political-industrial ecology of cities, which seeks to combine the critical theory and insights of urban political ecology, with mass-balance methodologies largely developed by industrial ecologists and engineers, and a sustained focus on resource consumption. This political-industrial ecology approach provides the framework necessary to assess the quantities of resource flows, to track them across space and time, and to decipher intertwined social and environmental dynamics that both reveal internal urban inequities and link the city to the distant areas from which these flows originate.

An offshoot of political ecology, urban political ecology emerged in the late 1990s and addressed a major gap in the field by drawing attention to how nature-society relations co-evolve to form the metabolism of a city and how access and use of resources are inequitably controlled and distributed (Heynen et al., 2006). Although in this theorization urbanization processes are indeed planetary, as Angelo and Wachsmuth (2015) point out, the empirical focus of much urban political ecology has privileged spatially bounded inquiries of the city (i.e. "methodological cityism"). Others have noted that a Marxist lens predominates and the approaches are largely qualitative and focus on social processes, with far less attentiveness to ecological ones (Jonas et al., 2013; Newell and Cousins, 2014).

Through urban metabolism studies, meanwhile, industrial ecologists have conducted detailed accounting exercises of the material and energy stocks and flows of cities, using methodologies such as material flow analysis and life cycle assessment, but the socio-economic and political context for how and why these stocks and flows are shaped the way they are is starkly absent, as well as matching the flows to specific geographies and residents (Kennedy et al., 2007; Newell and Cousins, 2014). Thus, urban metabolism studies in industrial ecology are largely aspatial with respect to situating these flows in specific geographies, and apolitical in the sense that the demand processes that drive urban consumption (and the infrastructures that support it) are left unexcavated.

Recently, scholars have called for combining elements of these disciplinary-bound approaches to more fully apprehend a city's metabolism (Kennedy et al., 2011; Broto et al., 2012; Pincetl et al., 2012; Pincetl, 2012; Newell and Cousins, 2014). Empirically, Pincetl et al. (2015) have carried this work forward through detailed analysis of the energy flows of Los Angeles County and matching consumption to income and built environment attributes (www.energyatlas.ucla.edu). Similarly, Cousins and Newell (2015) did so through a study of the political-industrial ecology of water supply dynamics for the city of Los Angeles. Coupling life cycle assessment with spatial data, they delineated the geographic origins of this water supply metabolism and quantified its carbon footprint. Then through interviews and historical analyses, they illuminated environmental and social justice concerns associated with these supply sources. This coupling of industrial and political ecology approaches offer an example of how to move beyond 'methodological cityism' through a mapping and analysis of a distal flow (e.g. water) of the metabolism of a city.

This paper effectively extends work on the political-industrial ecology of cities through an analysis of how urban-scale consumption patterns and institutional configurations shape the dynamics of two flows (electricity and water) in Los Angeles County. As such we seek to reframe urban sustainability of a city beyond the sensor-based smart city, not only by quantifying resource flows into and consumption within cities but also by critically asking who is using these resources to do what where. In the process, we broadly characterize the socio-economic characteristics of these flows and prod how they are embedded in the urban built environment. This entails explicitly linking political and economic power to ecological and human impacts. Of necessity this requires discussion of the regulatory structures, different actors and possible policy choices. To conduct this research we use many millions of records of use, match them to relevant variables from millions of other records such as county assessor files and census data, and careful reconstruct of regulatory regimes. All the layers form an opaque, imbricated, multi-scalar system whose future direction is being contested and whose detail is best known by the interested parties: utilities and their regulators.

Data at the spatial scale necessary for this delineation is usually proprietary, and enormously complex and tedious to obtain and process. It is contained in database structures developed by agencies, often in isolation, that have both limited motivation to explore socio-demographic trends in resource flows and no mandate to do so. For example, each utility in the state of California tracks its use data and attributes of that use, differently; each county assessor organizes their parcel data differently and with a range of attributes that are not consistent county to county. Thus data important to the mission of the organizations themselves is not collected in ways that make it readily usable for exploration and comparison. More conventional smart city data is self-referential – the city as the universe – and is likely based on public activities. It is also collected with goals of efficiency and to improve services rather than a sustainability that aims toward reductions of resource flows and impacts on hinterlands, as well as greater equity.

With this in mind, the next section briefly characterizes and critiques the rise of data-analytics for so-called sustainable cities. This is followed by the electricity and water case studies of Los Angeles County. Analysis of these resource flows reveals the significance of consumption at the household level, especially wealthy households who represent a disproportionate level of use for both water and electricity. We also delineate the convoluted institutional arrangements and governance structure that inhibit transparency with respect to resource use as well as structure changes necessary to foster more sustainable and equitable outcomes. The paper concludes by reflecting on how big and spatially explicit granular data can be harnessed to broadly illuminate differences across urban landscapes and provide an empirical basis for analyzing processes and impacts.

1.1. City sustainability, institutions, and data analytics

Over the course of the 20th century, in agencies, bureaus, programs and international organizations, the use of quantitative data to generate public policies has become firmly entrenched. Different protocols are used to collect the data at different scales. Concerns about the sustainability of cities, and shifting the course of development to mitigate or curb environmental impacts, has driven data collection on city performance and efficiency. Data for sustainability indicators of all types have been collected, and utilized to create benchmarking programs, dashboards, and metrics. Such efforts are aimed at tracking progress toward goals, empowering residents to monitor how well their cities are doing, to advance transparency and accountability, as well as, of course, political careers.

This surge of data collection is increasingly enabled and joined with systems driven by information and communication technologies (ICTs). Smart meters, sensored road intersections, building management systems, and new transportation apps are just a few examples of proliferating technologies, which are often displayed digitally on the web so that users can access the information on their mobile devices or computers. This is often advocated as progress toward the 'internet of things' (Greengard, 2015). Information and communication technologies are viewed as foundational to initiatives to make cities more sustainable through efficiency metrics (and also to demonstrate fiscal responsibility). Data collection and transparency are new watchwords of good government generally. Cities such as Los Angeles, Seattle, and New York have launched open data portals to track key city metrics and outcomes. In LA, the mayor's sustainability dashboard connects metrics to the mayor's sustainability plan. ("Sustainability City Plan for Los Angeles", 2016). In NYC, this is particularly advanced, including data about payroll, purchasing, audits, and much more. As a result of the Bloomberg era and the data driven nature of its administration, NYC officials announced the online availability of more than 1300 data sets, boasting it had more open online data than any other US city (Office of Comptoller City of New York, 2014). These are important initiatives as they intend to make governmental operations more transparent and more accountable. Yet governmental operations are only a subset of activities that affect urban sustainability. In the U.S. at least, there are many publicly regulated private monopoly service providers, as well as the larger domain of economic activity that takes place in cities that have enormous resource impacts.

And thus, despite the sea of data – especially on the city administration itself – its' connection to the actual environmental, social and ecological dynamics of cities and their resource use remains remarkably obscured. The collection of data is not framed to document political or ecological impacts; it also does not connect to the regulatory regimes which structure the infrastructures that yield the dynamics. Sustainability, for example, is generally measured within the city limits and in lump quantities – e.g. amount of trash diverted from the landfill – not the organization of trash collection, the companies that do the collecting, and the garbage processing systems and their ownership and organization. Data on who produced the trash, how much, where, of what kind, or where the diverted trash goes is not collected (Murphy and Pincetl, 2013). This is similar to energy use flows, which are lumped into a single value for a city, or derived from modeled or self-reported data. Data on energy or water use in specific buildings, for example, is proprietary or simply not collected and data on energy generation or the myriad of water utilities in a single region (in California) is equally difficult to obtain. Thus the data upon which urban sustainability initiatives is to be guided is often truncated, limiting a deeper linking of urban consumption patterns to spatial impacts to far-flung places of origin and destination (like electricity generation, water sources, and waste disposal), as well as within the cities themselves in terms of distribution and urban morphology. In the emerging data rich smart city strategy, often data is collected on and for individuals who are then provided with their own data (if they wish to sign up for it), with the expectation that with that data, they will better manage their electricity, natural gas or water use in the name of efficiency or sustainability. This is a far cry from using data to ascertain larger spatial patterns that are driven by the socio-technical system itself (Pincetl et al., 2016), like the buildings themselves – that may be poorly built – and thus constraining individual capacities for using data to reduce their consumption.

Cities are complex socio-technical systems infused with history, politics and context, and the data collected reflects process-bound managerialism, codes, rules, departments, existing urban morphology, and fiscal constraints. The infrastructures guided by those socio systems need to be interpreted in that light (Kitchin et al., 2015).

For data to be meaningful, it must be matched to variables (e.g. buildings, neighborhoods, sociodemographic characteristics and more) that can help explain patterns. As Kitchin (2014b) note, cities are multiple, complex, interdependent systems that influence each other in often unpredictable ways. Thus energy and water use, in our example, are influenced by multiple variables that are important to understand, including the institutional architecture of their management. While data structuring has advanced considerably in spatial analysis, in the analysis itself the connection to the regulatory regime of city patterns is often lacking. Explanation of drivers, regulatory constraints, investments in infrastructure, are all now needed as the basis for analysis of the data. Further, actual consumption of resources at the individual level and how that is shaped by urban morphology and infrastructure, as well as the institutional arrangements for such flows which are a result of over a century of socio-technical system evolution, will be locally contingent. Changing practices, such as reducing metabolic resource flows, will then reflect local specificities.

2. A political-industrial ecology of energy use in Los Angeles

Los Angeles County has over 10 million inhabitants and consists of 88 independent cities, dominated by the City of Los Angeles, the second largest city in the United States. The city of Los Angeles has the largest municipal water and power utility in the country—the Los Angeles Department of Water and Power (LADWP). Except for a few smaller municipal utilities, the remaining cities in the county receives electricity from the Investor Owned Utility (IOU), Southern California Edison (SCE). The use of energy is a critical component to address in order to reduce GHGs and for the greater sustainability of cities. California has particularly ambitious reduction mandates. Energy generation and conveyance brings with it significant environmental impacts and its regulation is nested and tiered in federal, regional and state institutions. These include the Federal Energy Regulatory Commission and the North American Electric Reliability Corporation (NERC). There are also regional entities such as the Western Electricity Coordinating Council (WECC) that promotes bulk electric system reliability in the Western Interconnection area that provides power to the western U. S., the Independent State Operator that dispatches energy across the California grid minute-by-minute, and the state of California's Public Utilities Commission that regulates utility rates, grid infrastructure and maintenance, energy rebates as well as establishing mandates about renewable energy resources. Each has its respective independent oversight, governance rules, and institutional procedures. The policies established by these interacting and overlapping entities create the context in which service is delivered in LA County, though decisions made by these nested interacting entities are difficult to access and hard to understand. Public participation, while possible, is extremely limited.

Understanding how energy is used over *time* and *space* requires management of big data sets as, intuitively, it is evident that there are spatial and temporal differences in that use (Widén et al., 2009). More use requires more generation, which will have greater environmental impacts (e.g. GHG emissions and air pollution) and impacts on the grid needed to deliver the energy. Shifts toward a renewable portfolio, or energy use reductions also bring spatio-temporal environmental and social impacts. But determining electricity use and its drivers requires high-resolution use data of consumption variations by building type, size, use and age as well as socio-demographic factors. In the case of Los Angeles County, while distributed generation by solar photovoltaics and utility-scale solar plants is increasing, the majority of electricity is still generated by hydro, coal and natural gas. Insight into building energy use is a first step toward developing reduction strategies. This then needs to be coupled to the regulatory frameworks that structure the grid and its assumptions, such as the importance of natural gas infrastructure for peak load electricity and as back up, even under conditions of increased renewable generation, and what might be storage alternatives to replace gas fired power plants when renewables are not online.

2.1. Data and methodological approach (Building the UCLA Web Atlas)

To understand how energy consumption differs in LA County, we obtained address-level IOU electricity use data from the state's Public Utilities Commission (PUC) under a non-disclosure agreement for a five-year period (2006–2010). LADWP provided similar electricity data, as well as water billing data (2000–2010). We developed an object-relational database containing approximately 500 million records that depict service addresses, energy consumption, and demographic characteristics for 2.4 million parcels throughout the County over the five-year period. Developed in PostgreSQL, this database spatially enabled and includes related information including building characteristics and demographics from the 2011 American Community Survey at the census-tract level (Pincetl et al., 2015). We developed: (1) a relational database of account-level energy use, building characteristics, and socio-demographic data; (2) software that aggregates parcel-level information to meet privacy requirements for wider reporting of consumption data; (3) an *Application Programming Interface (API)* to query aggregated data; (4) and a web-based user interface featuring interactive maps, charts, tables, data visualization tools, and documentation. We received data in multiple formats, including comma-separated value (csv) and data files for the statistical software SAS (SAS Institute, Inc, 2015) which required the data to be harmonized and integrated. All files were uploaded to the database as csv files and data files from SAS were converted using open-source *Python* software (Porse et al., 2015).

Validation of the data and mapping was done in several ways, focusing on geocoding accuracy and aggregate energy totals based on utility and regional boundaries.

The ability to match service addresses and consumption to the correct parcel locations (known as geocoding) is imperative for such research because parcel information is the primary source of information for building attributes such as use type, square-footage, and vintage. However, geocoding an inexact science and some measure of error is to be expected. To test the accuracy of the geocoding, CCSC researchers consulted with the UCLA Statistical Consulting Group to develop a weighted and stratified sample validation test based on account type, geography, and use type.

Researchers manually checked each sampled record to assess its positional accuracy and developed confidence intervals for estimated error rates in address placement and associated consumption. The proportion correctly matched was noted for each stratum and was used in the formulation of the weighted proportion mean and confidence interval. For confidentiality protection, no use data or personal data was included in this verification. The validation testing produced a 95% confidence rate that the percentage of accurately geocoded addresses for the entire database is between 95 and 99%. For more details on this procedure, see the Methods page on the Energy Atlas website (www.energyatlas.ucla.edu).

Additional validation work compared Energy Atlas consumption results to trusted external reporting sources like the California Energy Commission and local government reports, including aggregated totals, as mentioned, based on utility boundary and County-wide reported totals. The Energy Atlas aggregates parcel-level energy totals to neighborhood, city, councils of government, and county levels, which were then compared to reported totals from CEC reporting. Validating all aggregation levels based on external sources is challenging however, because data at these comparable levels is not publicly available.

We analyze building information derived from the 2008 Los Angeles County Assessor's parcel dataset which contains 2.4 million parcels covering the entire County of 10 million inhabitants. This dataset includes information on taxation of each property, including vintage, use code, square footage, and building design type. For the analysis, block groups were chosen as they include detailed housing information (renter/owner) and income estimates. Building energy use was examined by use type (single family, multiple family, commercial, industrial and institutional), per square foot, per parcel, by age category, and for residential buildings, by income.

2.2. Results (The Web Atlas)

Results presented in this section are based on analysis of the UCLA Energy Atlas (Pincetl and LA Energy Atlas Team, 2015. "LA Energy Atlas." Los Angeles, CA: UCLA, Porse et al., 2015). Energy use in L.A. County varies widely by geography, income, building characteristics, and climate. Across the cities in the county, median annual consumption per square foot varies by building type and age, as well as income.

2.2.1. Energy use by building use type

Residential properties consume between 11,000 and 55,000 British Thermal Units (BTUs) per sq. ft., commercial properties vary from 15,000 and 83,000 BTUs per sq. ft., and industrial buildings from 110,859 BTU per sq. ft. (all reported in medians). Institutional buildings had the highest maximum value as well as the largest range, reflecting the diverse types of buildings in the institutional sector and inaccuracies in the LA County Tax Assessor records as institutional buildings pay no taxes. Building energy use varied by type, size and age, and these are noticeably related (Porse et al., 2015).

2.2.2. Energy use by building age and income

Buildings built before 1950 have the highest median annual consumption per square foot, and those built after 1990 have the lowest regardless of climate differences (i.e. temperature) across the region. Interestingly, geographic variation in median parcel energy use shows that for both single-family and multiple family homes, older, poorer neighborhoods in central Los Angeles have generally higher median values of energy consumption *per square-foot* but lower *total energy* consumption than the newer construction in coastal cities of the County. This may indicate that the energy efficiency in buildings mandates of the state have been effectively integrated into the building code and lead to better performing buildings, but this performance is undermined by building size. Further, median *total energy use* in single-family homes generally increases across income with a slight trend of increasing consumption from 2006 and 2010. Alternatively, median *energy use per square-foot* decreases as median household income increases. In the multi-family home sector, energy use per square-foot is also higher in the neighborhoods with lower median household income. Across multi-family buildings in neighborhoods, median total energy use increases with median household income in a neighborhood (Porse et al., 2015; Pincetl and LA Energy Atlas Team, 2015).

In LA County, residential buildings use more energy than other building types (Fig. 1). Single-family homes alone use more energy than every other sector, accounting for 26% of total building energy consumption (Pincetl et al., 2015). Single-family homes are also the dominant land use in the region. Residential energy use varies significantly across the county. Unit consumption of electricity differs by building type, but the differences are relatively consistent across income. Commercial buildings tend to use the most electric-

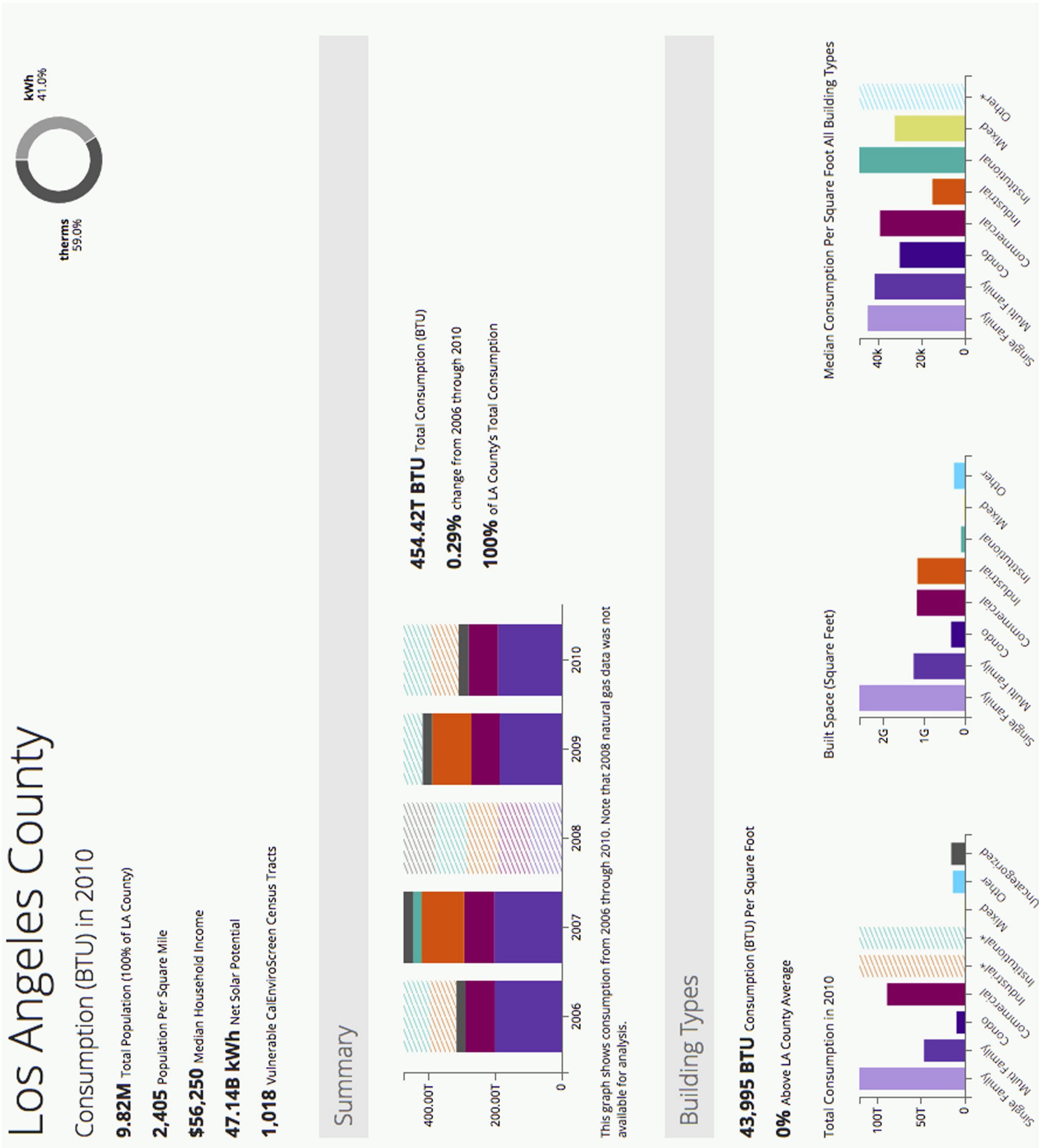


Fig. 1. Building energy consumption in Los Angeles County 2010.

ity per square foot, followed by institutional buildings and single-family homes.

2.3. Discussion

The use of big and granular energy data—individual service address billing data matched to parcel building information and census data—reveals the disproportionate use of resources by the wealthiest in the region and the relationship between building age and square foot energy use. Indeed, while California's Title 24 building code has resulted in increasingly more efficient energy use per square foot, especially since 1999, such codes do nothing to affect building size. Thus, as wealthier residents build larger houses, total energy usage increases despite the greater building energy efficiency, presenting a Jevon's paradox (Alcott, 2005). For example, in the city of Malibu, residential buildings are newer than buildings in South Los Angeles and thus significantly more energy efficient per square foot. However, residents in wealthy Malibu use ten times more energy per capita than their counterparts in South LA. There is a general trend toward larger buildings in more affluent neighborhoods and this may mean there is the need for more grid capacity to serve those neighborhoods. This results in the general rate payer subsidizing a grid that is robust enough to provide the additional energy required by larger houses, presenting a clear environmental justice issue associated with energy use. This is revealed by analyzing address-level data.

At the regulatory level, the PUC requires utilities to expend billions of dollars in rate-payer funds on conservation and efficiency programs which are created to assist building owners reduce their energy use. These programs are voluntary and utilities offer rebates that customers can apply for. PUC relies on individual rate payers to desire to reduce their energy use and service cost, and to contribute to the cost of the retrofit. The PUC relies on modeled, sampled or self-reported data to evaluate the effectiveness of the programs. Neither the utilities, nor the PUC have studied actual energy use change from these programs and, since the state's Energy Commission is responsible for Title 24 (the energy efficiency regulations), the PUC does not investigate building energy conservation standards. Thus, relationships such as building vintages and energy use, building size and consumption, energy conservation and efficiency programs, or the 'wealth effect' are left uncovered. California's energy and building code regulatory regimes are fragmented and rely on individual customers to assume the mantle of efficiency (Schiller Consulting, 2007).

Such findings are important in current debates about how to best achieve GHG emissions reductions in the electricity sector and raise questions about the future of the control of the grid, of electricity generation, of environmental impacts of that generation, and the scale and role of regulators. It raises questions about the ultimate success of increased building energy efficiency if that is negated by larger and larger buildings. Publicly-regulated utilities were the product of early twentieth century reforms which protected private monopolies in exchange for strong regulatory supervision. Entrusted with providing power, these regulated monopolies were not structured with a mission of energy efficiency or energy conservation. It must be noted that LADWP, a municipal utility has not shown significantly different strategies than the IOU private utility, both maintaining the status quo, for different reasons.

At the center of these discussions remains the issue of reducing building energy use through conservation and green building technologies; thus reducing consumption itself. Mapping energy use over space and time (i.e. year-built data) reveals important relationships across the region. There is the relationship between building construction and energy use, as well as the impact of income. Upgrading the older infrastructures may produce less additional GHGs at point of electricity consumption than new buildings built based on Title 24 standards, but it could also mean that low-income neighborhoods continue to have older building stock. Essentially, this could perpetuate continued inequality. On the other hand, little analysis has been conducted on the full life cycle cost of materials and greenhouse gases of, for example, replacing the old inefficient residential buildings with new ones.

Affluence is the most important driver of energy use in buildings. Ultimately, however, state energy policy, including rooftop photovoltaic, rests largely with the PUC, who will issue policies on feed-in tariffs, net metering, grid modifications and reliability standards for generation and back-up. This will drive electricity production toward or away from renewables. These policies will be crafted in consultation with other regulatory entities such as the FERC and the NERC, but all of this remains largely out of reach for most residents and is unknown, remote, codified, and complex. Building energy use remains the purview of an entirely different agency, the California Energy Commission, though the PUC mandates the IOUs to develop and fund conservation and efficiency programs out of rate payer funds. Rate payers have been charged billions for these programs, with no accountability of metrics like those we are constructing. Interestingly, convinced that big data will yield better behavior, the PUC has ordered the utilities to install smart meters that will provide their clients with more information about their electricity use (by hour and by appliance) convinced that big data –to the customer – will yield better behavior. Yet, as discussed above, the building itself largely dictates energy use per square foot. Investments in retrofitting are patchy due to the need for the building owner to apply for a program and to pay for it, and have not deeply improved the energy performance of the building stock since the early 2000s. One explanation is that the programs are not targeted to the most inefficient buildings. The programs have also not resolved the owner renter issue, where there is little incentive to spend money improving buildings that house tenants.

Finally, better data for customers may simply provide them information they can do little about – poor appliances, poor buildings, and few options in a fiscally constrained world (California Energy Commission, 2016; Navigant Consulting, 2014). Yet, this is the direction of the smart city instrumentation – pushing energy conservation onto the consumer who inherits a building, inherits the utility, and inherits the grid and the energy mix. More information for the consumer does little to alter this situation that offers little transformative change, other than more sacrifice by the customer, particularly low income ones.

3. A political-industrial ecology of water use in Los Angeles

Historically, water use in California has received a great deal more attention than energy use. With its Mediterranean climate, Los Angeles receives about 15 in. of rain in a 'normal' year in the winter. Summers are hot and dry. Water to the region is largely imported to the region from three main sources: (1) The Colorado River; (2) the Sacramento River and Delta region, and (3) for the city of Los Angeles alone, the Owens Valley where the city acquired surface and groundwater rights at the turn of the 20th century and subsequently built the Los Angeles Aqueduct (Cousins and Newell, 2015). The Owens Valley is surrounded by high mountains (up to 10,000 feet) that were set aside for their watershed value by President Harrison in 1893 and are now National Forests. The development of water infrastructure in Los Angeles County occurred over time as the region urbanized. The state Superior Court awarded the City of Los Angeles exclusive rights to water from the Los Angeles River and its watershed in 1903 and in 1913 the LADWP completed construction of an aqueduct that brought water from the Owens River 240 miles away (Hundley, 2001). But water in the region was predominantly developed locally with little state supervision.

While the water-energy nexus in California has received some attention (Fang et al., 2015), as moving water north-south is the single highest energy consuming activity in the state, it is the socio-technical management of water, both the large engineered systems and the enormously complex and decentralized water delivery structure, which shapes water use and the ability to develop more sustainable transitions.

The prevalence of agriculture in the region led to formation of irrigation districts such as the Covina Irrigating District (est. 1882), followed by water companies like the California Domestic Water Company (est. 1889). In 1928, the California legislature established the Metropolitan Water District (MWD) to import water from the Colorado River. This enabled the suburbanization of Los Angeles County, and later southern California. MWD's supply was bolstered by the extension of the State Water Project in 1973, a lengthy system of canals and dams that transports water from the Sacramento/San Joaquin River Delta. Currently, a 37-member agency Board of Directors governs MWD, each appointed by the local agency to represent it through a complex set of rules. Nested within the MWD are many small suppliers (public, private and nonprofit) that deliver water to consumers (Erie, 2006; Pincetl et al., 2016). The region also has substantial groundwater basins that have been adjudicated for decades (Blomquist, 1992; Porse et al., 2015).

Responding to historic drought, the CA government mandated that cities reduce water use by 25% and that senior water rights holders in the agricultural sector register these rights and be certified. These pre-1910 rights entitle certain landholders to first water rights due to their seniority.

Similar to energy, urban water consumption suffers from a lack of transparent and comparable metrics for measuring use. Outdoor water use in residential properties is the greatest single end use in many arid areas and can be 50% or more of total urban per capita consumption (Mini et al., 2014a). Yet, few studies use actual billing or smart-meter data. Instead these studies model use or have access only to sampled or self-reported data due to privacy concerns. In the U.S., water metering does not generally distinguish between indoor and outdoor water use, except in a few experimental neighborhoods or communities such as Lisle, Illinois. Numerous work-around modeling efforts exist, but these do little to help consumers understand variations in outdoor vs. indoor water use (Syme et al., 2004; Johnson and Belitz, 2012; Salvador et al., 2011; Haley et al., 2007). Therefore, agencies have limited empirical insights regarding outdoor water use by geography and socioeconomic group over time and relative to pricing. Only in 2014 did the CA State Water Resources Control Board (SWRCB) require water utilities to report monthly per capita consumption, and then it took an additional year for such information to be comparable based on population. Essentially, this is a single value per water utility, which lumps all residential users together and exempts all others.

To better understand how water is used and distributed in the city of Los Angeles, UCLA researchers collaborated on two studies. The first used residential parcel-level water use data over a ten-year period (2000–2010) to examine the relationship between greenness, parcel size, income, and the price of water for the LADWP (Mini et al., 2014b). We map LADWP electricity data in the Energy Atlas, and the 2006–2010 portion of the residential water analysis, overlaps with this Atlas and associated data set. The second effort was to construct a compendium of all water purveyors at the county level to understand how water is distributed and governed (Porse et al., 2015; Pincetl et al., 2016).

3.1. Data and methodological approach

As with energy use data, LADWP provided researchers with monthly single-family residential (SFR) water billing data for approximately 480,000 residential customers. Irrigated, non-irrigated and impervious areas across the city were mapped using a land cover database derived from high-resolution satellite imagery (McPherson et al., 2011). This was combined with Landsat NDVI and water delivery records to determine urban vegetation greenness. The 2000–2010-time series was then used to estimate outdoor water consumption based on the minimum month's use (winter), average minimum use months and remote-sensing approaches. Residential water use (indoor and outdoor) by neighborhood was analyzed by land use type, size of property, water rate, and income level (Mini et al., 2014b). The analysis included voluntary and then mandatory water use restrictions implemented during the 2008–9 drought (Mini et al., 2014a).

Constructing the compendium of water purveyors, beyond LADWP, entailed developing a water agency typology (public, private and non-profit) using databases from relevant agencies, including the California Department of Water Resources (DWR), the State Water Resources Control Board, the Public Utilities Commission, MWD, the Local Agency Formation Commission (LAFCO - in charge of incorporations of special districts at the county level), and trade associations for the Mutual Water Districts. Data to construct GIS boundaries came from the Department of Public Health (and its Water Boundary Tool), the CA Drinking Water Information System, LAFCO and the MWD. Overlaps and gaps were frequent among the different sources. The Urban Water Management Plans were examined to determine the amount of water supplied among different agencies. Suppliers providing over 3000 acre-feet of water annually, or serving more than 3000 urban connections must prepare this document every five years. Using these data, a database of water purveyors was assembled. Groundwater adjudications and their historical evolution, including water quantities, management, and rights, were also reconstructed to understand the contribution of this resource to regional water supply. Water use data per capita was unavailable.

3.2. Results

In this section, we divide the results into an analysis of the socio-economic determinants of water use and the related governance arrangements associated with the supply of this water.

3.2.1. Water Use – consumption and income

Analysis of the address-level water use data reveals that lot size and wealth are the major drivers in water use. Wealthier coastal areas tend to have larger lots and more landscaping, as well as cooler weather. Over the 2000–2010 period, wealthier coastal areas consumed three times more water than less affluent neighborhoods, even though these coastal areas is milder in the summer (Fig. 2). This 'wealth effect' was also apparent for energy use. Just ten percent of customers consumed 30 percent of total water consumed in single-family residential areas (Mini et al., 2014b).

Due to increased irrigation in the summer, neighborhoods with high water use exhibit higher seasonal fluctuations. Stringent mandatory outdoor water restrictions led to a 23% decrease city-wide among single-family residential area during the summer of 2010. While all groups reduced water use, lower income residents reduced comparatively more due to the price increases (Mini et al., 2015). Note that our water data was only for the Los Angeles Department of Water and Power while electricity data included both the Department and Southern California Edison, the investor owned utility.

3.2.2. Water Governance – historically accreted regional complexity

Governance structures of the water purveyors vary by type and date of establishment, resulting in a dizzying array of institutional forms and entities (Fig. 3). Many cities have water utilities that are supervised by city councils or appointed city commissions. Special districts often oversee larger areas that encompass smaller utilities for a specific purpose, such as groundwater recharge. They are governed by appointed or elected boards, but the district boundaries often do not coincide with city boundaries. Private utilities establish water rates and infrastructure maintenance procedures based on regulations by the PUC (similar to the energy IOUs), while private non-profit Mutual Water Districts are managed by aboard elected by its users. These boards tend to be small (maximum of 3000 service connections) and are largely unregulated (DeShazo and McCann, 2015; Pincetl et al., 2016). Clearly the challenge in this instance for big data is to not only delineate the system by combining disparate data sources, but also to populate this system

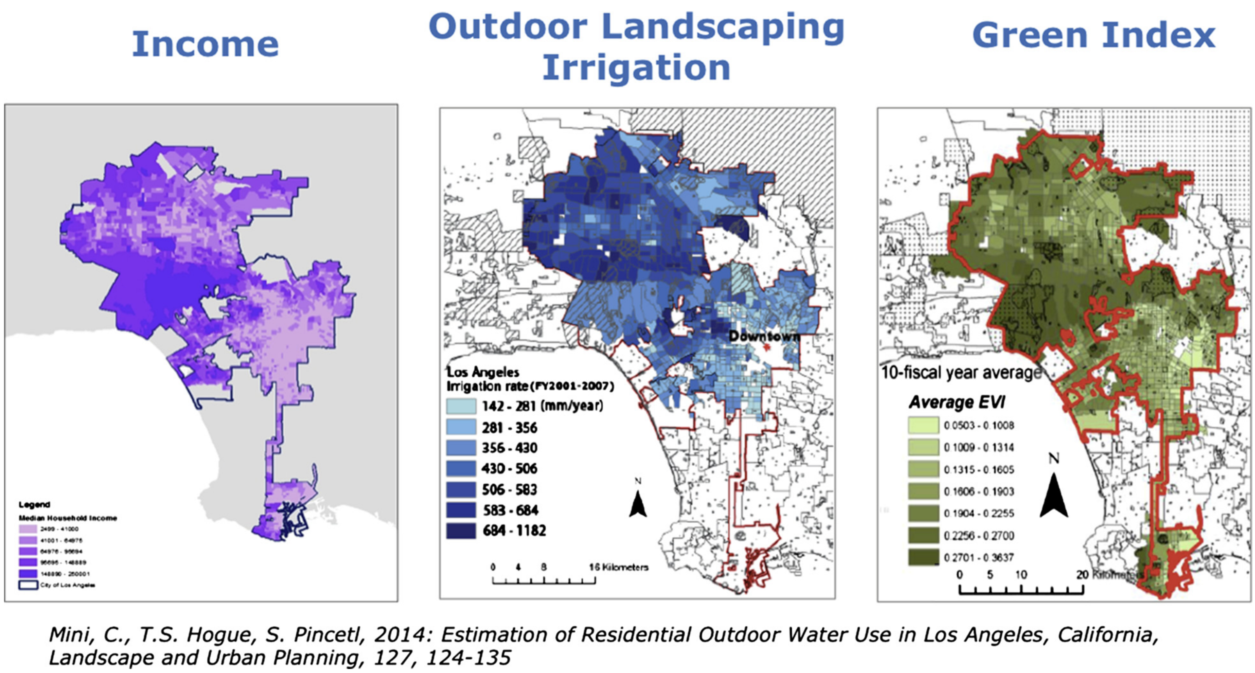


Fig. 2. Water use green index and income across Los Angeles.

with actual water use data. To do so – and to thus understand patterns of water use in the service areas and over time – would require getting each water entity to agree to provide the data under nondisclosure agreements. Such an effort would be Herculean, and private water companies would have no reason to provide the data. Unlike for electricity, none of the private water utilities (IOUs) have programs that require some reporting of individual water use to the PUC, unlike for electricity.

Another important feature of the region's water supply is groundwater. Driven by fears of groundwater depletion and in an effort to secure long-term access to the resource, users in many of L.A.'s groundwater basins developed adjudications that allocated water rights. These adjudications, which were the first in the state, entailed legally binding agreements for individual users (Blomquist, 1992). They now serve as a template for state groundwater policy for unregulated areas. Each adjudication entity has an autonomous management structure with complex calculations regarding allowable pumping allocations, referred to as safe yields. Rights holders include cities, the county, private water companies, oil companies, school districts, cemetery districts, and individual pumpers. There are currently over 300 entities adjudicated for the basins (Fig. 3), with Central Basin having the most (112) and the Upper Los Angeles River Area the least (9), as most of the basin lies within the city of Los Angeles (Porse et al., 2015). Despite long attention and scientific study, questions still remain. How much native water is available locally remains hard to quantify due to this complex, polycentric governance system and the historic reliance on imported water to ensure the safe yield pumping levels.

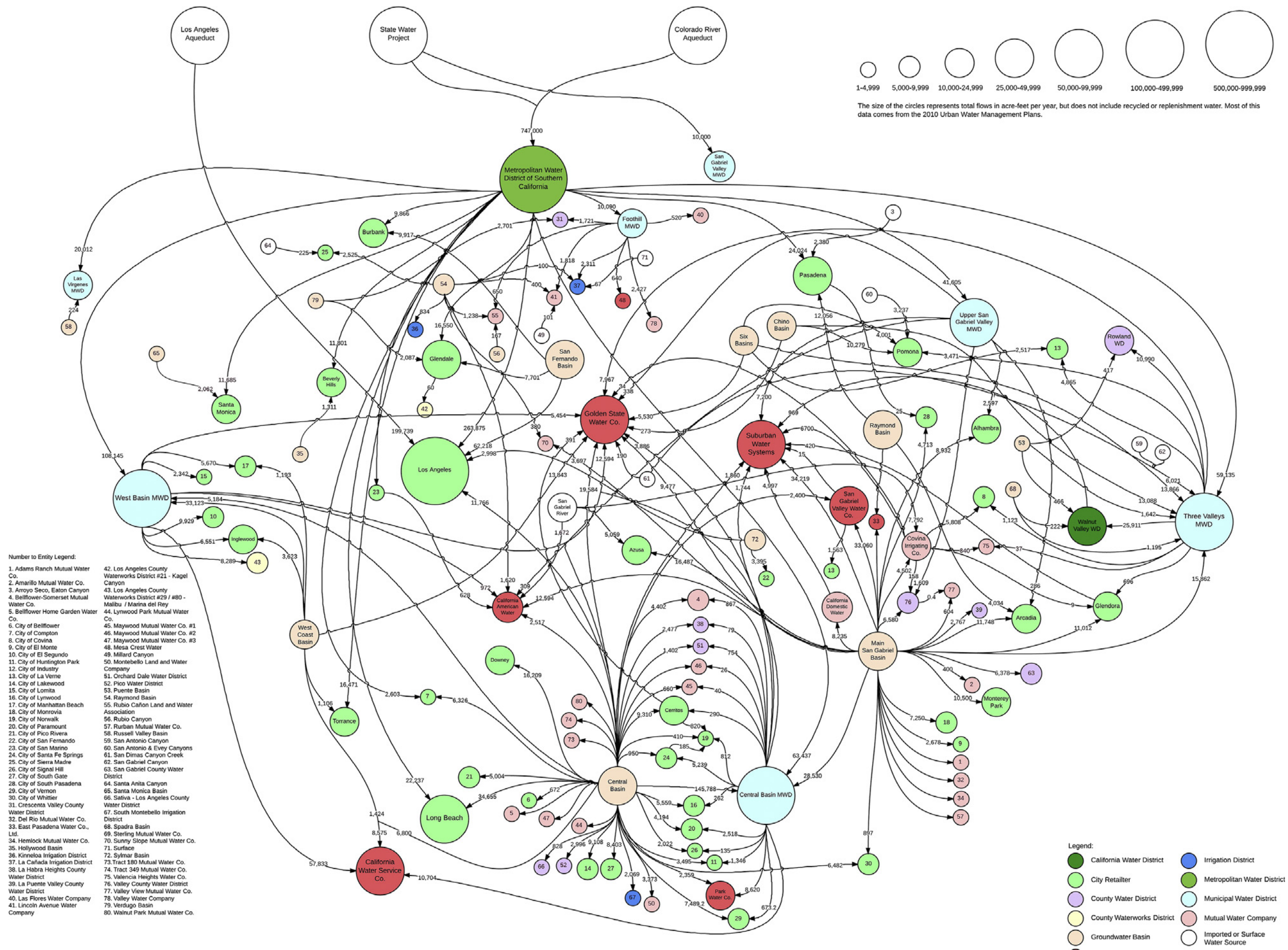
3.3. Discussion

With respect to water use at the individual parcel level, despite the on-going severe drought in southern California, little is known. While researchers were successful in obtaining the 2000–2010 dataset from LADWP, this was an exception rather than the rule, and insufficient funding was available to analyze the whole data set beyond single-family residential. Despite the City's commitment to big data and data transparency, the focus is on city operations, deemed safer than data on, for example, water use by different sectors and sociodemographic groups as there has been political push back on exposing high water users. While water resources are likely to become more scarce, the city's utility is not working to analyze water use across different sectors or users to target programs. Moreover, water use data for the other 200+ water suppliers, other than monthly residential reporting which is new, is non-existent. Therefore even under conditions of scarcity, big data has not entered into the water management regimes.

In Los Angeles County, water management is highly fragmented among over a two hundred different water delivery agencies of different sizes and institutional structures of which about one hundred are very small water purveyors. Groundwater basins show a similarly fragmented governance system, emerging from different adjudications for each basin, and hundreds of water rights holders.

The number of water delivering agencies creates an opaque system. No central authority responsible for collecting such data exists at the county or state level. To track compliance with the Governor's urban water use reductions, the SWRCB began requiring monthly water use reporting in 2014. But no system has yet been established in the service areas of each entity can be explored or other data can be found, including governance structure, sociodemographic profile of the service area and so forth. Nor does the new policy require an analysis of institutional type or ability to implement new programs related to fiscal health. Further, regulatory oversight of operations varies widely: private utilities are under the regulatory oversight of the PUC, city utilities report to city councils, and Mutual Water Districts are run by boards comprised of the property owners. Each has different governing mechanisms to establish programs (elected versus appointed governance structures, shareholder driven entities, or property owner-decision making), as well as varying fiscal capacities to implement programs. Fragmented governance due to water purveyors of different institutional capacities raises serious questions about the ability of retailers, especially smaller agencies, to respond to challenges associated with climate change and reduced water availability.

Big data (e.g. per capita consumption by address for each customer in the region, like for electricity) would reveal patterns across the landscape that are essential to devising water use



Potable water governance in Los Angeles County. Image created by Paul Cleland.

Pincetl S., Porse E., Cheng D. 2016. Fragmented flows: water supply in Los Angeles County. Environmental Management DOI 10.1007/s00267-016-0707-1: 1-15, 58:208-222.

Fig. 3. Water purveyors in Los Angeles County.

reductions and effective water pricing to correspond to future water scarcity. Patterns in commercial, institutional and industrial water uses could be discerned as well. To effectively reduce water use, utilities need to understand the end use of this water. Instead there is a move toward metering apartment buildings so that individual renters can have better data about their use (Stevens, 2015). Unfortunately, this is not being linked to water conservation technologies such as low water use appliances.

4. Conclusion

This paper has shown how big data – the millions of service account records of electricity and water use, matched to the millions of records of county assessor data, census data and the architecture of governance and management of institutions – were used to delineate the consumption for two resource flows (water and energy) that form part of the complex metabolism that is the city and county of Los Angeles. We make the case that moving toward more sustainable urbanization hinges on coupling detailed understanding of consumption patterns within and across the city, the material interdependencies of cities on far-flung regions, the infrastructures that bring resources to market, and the institutions that regulate flows and their uses. Comprehending how systems are organized to deliver services such as water and electricity is essential for a political-industrial ecology of cities and regions.

As the analysis shows, for electricity and water flows, affluence is the primary driver of resource use in both cases. With respect to energy use, the age and type of building is also an important factor. Similar to energy use, urban water consumption suffers from a similar lack of transparency. Our use of parcel-level billing address water data for reveals that more wealthy households often have larger lot sizes and use more water use. This is particularly true in the coastal areas of Los Angeles, whose residents are comparatively wealthy and whose properties are on larger lots with manicured lawns and landscaping. These wealthy coastal areas consumed three times more water as other neighborhoods, despite a comparatively cooler climate. Thus far, in southern California, there has been no limit to water availability, only regulatory restrictions on use. Some residents have flaunted restrictions, causing significant publicity. For example, the so called 'wet prince of Beverly Hills' was found to use 11.8 million gallons of water in one year in the midst of the drought (Williams and Mieszkowski, 2015).

That the PUC is the regulatory authority for private electricity and water utilities signifies that findings correlating address-level data on consumption of energy use with socio-demographic and building characteristics can only be actionable at that level. Water, with its highly fragmented and complex regulatory framework raises a more difficult set of challenges to fostering actionable reform. Each water utility would have to implement change or the state legislature would have to pass new measures.

Yet, big data is necessary for both systems and its analysis yields valuable insight about resource use. Big data that encompasses the institutional and ecological context of urban activities provides a framing to explore questions of equity and policy development. Such analysis can point to very different policy tools for curbing resource use and entail different actors that need the political will to enact measures. Greater urban sustainability must be coupled with an understanding that supplying large amounts of electricity and water drastically changes landscapes and environmental systems. While it is impossible for cities to entirely curb impacts, big data – with the intention to reveal resource use across space and categories – can help enable reform by identifying patterns and drivers of use.

As this paper has demonstrated, big data can also useful to probe the institutional arrangements that guide, regulate, and distribute the urban flows. The regulatory infrastructure for energy, for example, creates monopoly control of electricity and natural gas, regulated by the California PUC. But such regulated monopoly power that has ensured reliability also means that the PUC may be risk averse – fearing market and flow disruptions by new technologies and new producers. Well-regulated private utilities have proven effective at providing reliable electricity at generally affordable rates. That model, which depends on large centralized power plants, may not be sufficient to reduce GHGs. A more diverse portfolio of generation and storage will be necessary, but the regulatory framing and oversight of that new system is still unfolding and a context for struggle; and developing new community-owned -utilities must contend with a century of rules, codes and conventions and nested and tiered regulatory agencies to develop an alternative. These are all being debated in front of the PUC.

Clearly the same risk adverse situation pertains with water. Large engineered systems have increased dependency on distal water sources, rendering the urban system highly dependent on them and vulnerable to drought, though at the time of construction the rationale was to ensure sufficient water at all times. The highly engineered systems importing water to myriad distributors has meant that it is less necessary to develop more finely tuned systems calibrated to local supply availability. The seeming abundance of imported water – predicated on a different climate and fewer people – has enabled an artificially high level of urban water use. Longstanding water consumption patterns need to change, but current water use is often seen as a right rather than an exception made possible by enormous infrastructure projects. Again, big data that can show these patterns of use clearly and may lead to innovations such as indoor and outdoor water meters that will enable water to be priced differentially and thereby reduce use. In the end, only reducing demand will make the region more water resilient. Using big data can enable a more equitable transition pathway.

Big data in and of itself is simply that – lots of data. Without collecting it for a clear purpose and coupling consumption data with information on hard and soft infrastructures and institutions of governance, its usefulness is limited. Further, the trend toward smart and sensored cities seems to be devolving responsibility onto the consumers. Smart meters digitally connected to telephones that convey messages about electricity use and changes of pricing during the day to incentivize turning off appliances when electricity is expensive, is quite different than using big data to address the sociotechnical baked in structural factors that perpetuate unsustainable resource use.

Using a political-industrial ecology approach to excavate patterns using big data offers an alternative approach. As Kitchin (2014a) argue, explicit methodologies leading to complex, politically-infused, and socio-technical systems analysis to actively frame and produce cities – more sustainable and equitable ones – can be a pathway to advance greater urban sustainability. More granular data is essential to unpacking urban political-industrial ecologies and their metabolic inputs, outputs, and processes.

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