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Urban governance and electricity losses: An exploration of spatial unevenness in Karachi, Pakistan

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Urban governance and electricity losses: An exploration of spatial unevenness in Karachi, Pakistan

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A R T I C L E I N F O

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A B S T R A C T

The inadequate supply of electricity in Pakistan disrupts everyday life and hampers industry and business; in this it is an emblematic indicator of the poor quality of urban governance pervasive in much of the Global South. We focus on the governance of Karachi's electricity distribution system, and its spatial unevenness across this sprawling metropolis of 15 million residents which encompasses huge informal settlements alongside upscale housing and commercial plazas. Using a dataset with granular, neighborhood-level electricity data, we apply spatial and statistical modeling techniques to understand how transmission and distribution losses, i.e., the utility's ability to bill for the electricity it supplies, vary across the city. These electricity losses provide a useful lens on the unevenness of urban governance in the city, especially where other sources of detailed socio-economic data are scarce. Our models link losses to higher proportions of residential consumers rather than commercial or industrial. Moreover, based on an analysis of model residuals, we can start to specify the degree to which urban governance is driven by the underlying characteristics of the neighborhood and bring some precision to understanding the spatial distribution of urban governance. Our findings reinforce the importance for governance reforms to be locally situated and informed, while also opening up new possibilities for visualizing electricity governance at a very local level and thus promoting democratic transparency.

1. Introduction

Electrical power is a social concern. This view is built on now-classic scholarship which establishes electrical power systems as "both causes and effects of social change" [1], as well as more recent work which approaches energy systems as "deeply enmeshed in broad patterns of social, economic, and political life and organization" [2]. At multiple scales, the importance of seeing energy systems, such as electrical power, as more than just a technical or economic concern is well established [3,4].

Within the broader context of electrical power systems, this study undertakes a social and spatial analysis of transmission and distribution losses. Losses are defined as the amount of electricity that is supplied to a system but not billed to consumers, and are typically expressed as a percentage of total power generation. Losses are crucial to managing the sector's cash flows, particularly where power is generated using expensive imported fuels, as has been the case in Pakistan. In Pakistan, the sector's historical inability to manage cash flows contributed to a chronic undersupply of electricity, resulting in rolling blackouts that have hampered economic growth despite targeted policy attention [5,6]. Due to their importance for power sector operations, utilities keep extensive records on losses at a relatively granular level, though these are typically not publicly available.[1] Losses are affected by the quality of the materials and machinery used in constructing the grid and the regularity of maintenance (i.e. technical losses), but the major component of losses results from the management and billing arrangements of the utility, and most especially the degree of 'theft' - willful efforts to avoid paying for electricity consumption (i.e., non-technical or commercial losses). We use the term losses in a sense that encompasses both technical and commercial losses, though most of our analysis will focus on

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the drivers of commercial rather than technical losses.[2] Losses, however, are not a uniform phenomenon, and using our socio-spatial analysis lens we expose the unevenness which occurs from one neighborhood to the next, represent that information visually, and ask why we might see high losses in one neighborhood, but low losses in the next one.

We treat losses as an indicator of the quality of urban governance. By governance we mean the "patterns of governing" whereby important public functions – such as electricity supply – are fulfilled [7]. Governance outcomes, such as losses, are produced through the interaction of multiple actors both inside and outside the state. Our attention is to the outcome of these processes rather than alternate meanings of governance which privilege institutional structures (as the regulatory structures are set at a national level, and don't vary at the city scale), procedures of decision making (again, these are constant at our scale of analysis), or the strategy whereby actors attempt to govern (we have no insight on this based on our data) [8]. Governance indicators typically exist at national scales rather than sub-national, particularly for data-poor environments in the Global South. It is especially unusual to have detailed data describing variations in governance at the city scale.

In this paper, we analyze the electricity losses at the intra-urban scale of Karachi, Pakistan. In doing so, we bridge two literatures that spring from different epistemologies. One is economistic, deploying statistical techniques and synoptic facts to capture how incentives and institutions can inform the neoliberal policy goal of an unsubsidized public utility separated from the central state [8]. The other is humanistic, more oriented towards a public obligation to serve citizens rather than balancing the utility's ledgers, and views the social, political, and technical aspects of the public utility's operations and its infrastructure as mutually co-constitutive dimensions of social (and spatial) justice. These are two ideal types, of course, though it is rare for studies to explicitly blend these two approaches, as they are methodologically separated (although see Bohrt et al. [9]). The economistic literature uses quantitative techniques and regional or national data from the electricity utility, while humanistic studies primarily use qualitative methods involving fieldwork which tap into the knowledge and experiences of ordinary citizens, street-level bureaucrats, and also 'key stakeholders'. In bridging these two literatures, we contribute to both. To the economistic literature, we contribute a more granular study which shows the local unevenness in electricity governance and raise questions regarding appropriate policy responses given this local heterogeneity. To the humanistic literature, we bring a broader synoptic perspective to questions of social and spatial justice in terms of the citizen's relationship to public infrastructures. By bringing them together we generate quantifiable insights regarding uneven governance across this sprawling metropolis of the Global South, and a fine-grained visualization which itself has the potential to become the basis for a pro-democratic governance intervention by publicizing service delivery records which are either hidden or known only to the utility managers.

2. Literature Review

2.1. Economistic studies of electricity losses

Electricity losses are typically divided into technical and non-technical categories, with the former concerning itself with the engineering properties of the grid as they pertain to the physical phenomena of resistance due to conductor materials, high voltage transmission over long distances, and so on [10]. Our paper is concerned with commercial losses, which incorporate a range of operational, economic, social, and political concerns connected to governance. Commercial losses are often understood as electricity theft in the economistic academic literature and among policy actors. Smith's influential paper [11] provides a thorough overview of different modalities of losses as theft, and Hussain et. al [12] provide a Pakistan-specific elaboration on this theme. A recent World Bank working paper on cost recovery in the power sector, a key element of the World Bank's 'standard package' of reforms, introduces commercial losses by giving the example of electricity theft [13]. We will complicate this view of losses in the next section by engaging with concepts of urban spatial justice from the more humanistic literature, in which access to electricity is an essential public service, and citizen claims on the electricity infrastructure are grounded in a humane perspective which resists the commercial logic of fees for service. Within the economistic literature, the reasoning behind how, why, and where losses occur has been the subject of increasing study.

In broad, cross-national studies using statistical models, electricity provision and losses are closely linked to the efficacy of political structures. Losses have been found to co-vary negatively with income and 'good governance' (in the neoliberal sense, per the usage of international development agencies), and have even been used as a proxy indicator for institutional quality [14]. The political importance of providing electricity as a public good is shown in poorer countries which democratize, where the quantity of residential electricity consumption increases at the expense of industry's share [15]. While electricity provision is politically salient, and losses are linked to (national) governance, a qualitative comparative study of five low and middle income countries found that the challenge of addressing electricity losses was a very local issue tied to policing rather than something that could be addressed through national laws and regulations [16]. As such, electricity losses are a multi-scalar phenomenon that are simultaneously shaped by national regulatory regimes and local context.

Within countries, statistical analyses of electricity provision and losses often include socio-economic indicators as well governance indicators as explanatory variables. These studies typically use panel data for sub-national units, where the units are districts or provinces of several million people. In Uttar Pradesh, India, a machine learning model found that crime levels, literacy rates, and income levels are the three variables which explain 87% of electricity losses from 2006 to 12 [17]. Gaur and Gupta [18] identify both income levels and tax efficiency as important indicators for explaining losses for Indian states, although not the actual price of electricity. In Pakistan, regression analysis with panel data for 9 regional utilities also found income and price to be key determinants [19]. Additionally, self-reported electricity theft was found to be negatively correlated with perceptions of theft monitoring and perceptions of the honesty among utility employees (who can play a role in facilitating theft) in Rawalpindi and Islamabad [20]. Similarly, a provincial-level study in Turkey included several socio-economic terms in a regression model of electricity losses. It identified price as a key variable and argued for social tariffs as an appropriate policy response [21]. In broad terms, this literature points towards a lack of affordability as a key determinant for losses, but other indicators such as urbanization and corruption can also be relevant (see Briseño and Rojas [22] for a recent summary).

Surveys of electricity consumers also stress affordability and the perceived honesty of the utility company and its employees as key factors. Nigerian survey respondents attributed electricity theft to high prices, poor power quality, and corruption [23]. In a purely conceptual agent-based model, Jamil and Ahmad [24] argue that the decision to steal is based on a careful calculus of cost and benefit and can be addressed by increasing the likelihood and severity of punishment for theft along with higher wages for utility employees. Based on a survey of Rawalpindi residents, Jamil [20] also finds that respondents point to recent price hikes as a key factor in the incidence of electricity theft.

2.2. Humanistic literature on electricity

A new spate of anthropological studies on electricity moves beyond a rational calculus to look at the social and political relations inherent in

[2] Our dataset does not permit us to separate out commercial and technical losses. We discuss the implications of combining technical and commercial losses in the analysis section.

access to a public good that is mediated by a state bureaucracy. The state's rules and regulations surrounding electricity can be an attempt at imposing a moral code, as in colonial Delhi [25], or the grid can be an instrument of exclusion which makes and remakes social difference, as in the electrification of Palestine [26]. We build on the position that electricity infrastructures are "critical locations through which sociality, governance and politics, accumulation and dispossession, and institutions and aspirations are formed, reformed, and performed" [27]. Although we do not look at the meanings of engagement with electricity infrastructure in this study, we move beyond the reduction of electricity theft to a rational outcome based on incentives and take a more urban and contextualized perspective (in contrast to the all-seeing perspective common in the economistic literature).

Recognizing an explicitly political dimension of electricity theft is an important departure from the rational actor mode of analysis. In Latin American municipalities, selective non-enforcement for billing public services can be a vehicle for "social policy by other means" [28,29]. In South Asia, Min and Golden [30] have used night-time remote sensing imagery of illumination as a basis for arguing that successful re-election efforts for incumbents can be linked to increased losses in the period immediately prior to the election. Political leaders can selectively choose not to enforce penalties for theft both out of compassion, a lack of budget for other social welfare tools, or as a patronage ploy to win the favor of their electorate.

The emergence of an agenda for 'critical urban energy politics' is heralded by an edited volume on the 'electric city' [31]. Contributions in this volume embed energy infrastructures within "power-laden social structures" and refuse to separate managerial or technical issues from their political consequences. Within this agenda, Silver [32] analyzes the multi-scalar antecedents of power outages in Accra and their uneven incidence across the city. In Rio de Janeiro, Pilo' [33] finds that the electricity system functions as a tool to generate a certain kind of urban order initiated through top-down processes, pursuing commercial logics, and mediated through socio-technical systems of theft prevention. Verdeil [34] highlights the role of private small-scale distributors to compensate for chronic under-supply of electricity in Beirut, and the attendant rise of private mafias controlling these alternate providers. This research agenda flags the unevenness of electricity supply across cities, as well as the multiple forms of contestation (and domination) which engage with the electricity infrastructure of the city.

As we discussed in the previous section, non-technical electricity losses correlate with both socio-economic characteristics as well as the governance contexts in which they happen. Much of the existing quantitative approaches to understanding losses focus on explaining or modeling specific covariates to better understand how and where high losses occur on a *national or regional* scale. In this paper, we instead focus on the more granular intra-urban scale instead, in line with the call for critical studies of urban energy politics. But, deviating from some of the earlier work in this vein, we combine this approach with a quantitative mapping and modeling of energy losses. Part of our motivation here is that in the case of Karachi, like many other cities in the Global South which are data-poor environments, it can be challenging to gain access to systematic neighbourhood-level data on socio-economic and governance processes. That is why we turn the usual analysis of electricity losses on its head. We *start* with neighborhood-level data on electricity losses and use these losses, after accounting for some foundational covariates, to explore the uneven quality of urban governance in Karachi – for which quantitative data is not readily available.

We should note that, although Karachi has a unique profile, it parallels other large metropolises of the Global South in terms of its dynamism, widespread informality, the privatization of key public functions, and the challenges it faces due to sustained in-migration from other parts of the country. Some 55% of the world's population currently lives in urban areas, and this is forecast to increase to 60% by 2030. The welfare of $^{1}/_{3}$ of global urban residents living in slum-like conditions (i.e., lacking key services) are an important force behind the United Nations' SDG 11, on sustainable cities and communities. Partha Chatterjee described such settings as "most of the world" when he used the example of Calcutta to illustrate how formality and informality constitute *The Politics of the Governed* [35]. Mike Davis' *Planet of Slums* [36] includes Karachi alongside Lagos and Mumbai in his depiction of the global challenges involved in addressing the essential needs of humanity. While this paper focuses on Karachi, its insights are relevant to a large and hugely important segment of humanity when considering how essential services can be delivered to the world's poorest inhabitants.

In the remainder of the paper, we first provide a brief introduction to Karachi, then describe the specific electricity loss dataset we use as well as the regression modelling approach we apply to account for the basic spatial variance present within the city. In the subsequent discussion, we then specifically zoom in on the residuals of this analysis. The mapping of residuals exposes local-level variations in the socio-economic and governance context which the model cannot fully explain.

3. Methodology

3.1. A brief introduction to Karachi

Experiencing rapid growth after the partition of India and Pakistan in 1947, Karachi grew into a sprawling giant of 15 million people that became the industrial and economic hub of Pakistan. Notwithstanding its economic growth, Karachi became synonymous with violence as the onset of the Afghan war (1979–87) brought with it a proliferation of refugees, small arms, and drugs. Karachi grew through successive waves of migration which brought in *mohajir* migrants fleeing the violence of partition in 1947 at the founding of Pakistan, as well as domestic migrants from Balochistan and Khyber Pakhtunkhwa who came in search of economic opportunity [37]. While migrants at the time of partition became concentrated in planned areas and benefitted from urban planning measures, later waves of migrants largely populated unplanned areas and relied on kinship groups to establish local order [38]. In the absence of effective state power or a single dominant group, gangs and political parties fought for control over neighborhoods. The Muttahida Qaumi Movement political party (the MQM, formerly known as the Muhajir Qaumi Movement) became particularly associated with the protection rackets which controlled city life, destabilizing opposition groups as well as imbuing everyday life with fear and insecurity [39–41]. Although some degree of violence remained in Karachi's everyday life, the end of the gang war concentrated in Lyari – one of the city's oldest neighborhoods – in 2012 coincided with a period of broader decline in the degree of everyday violence, and, potentially, opened a window of opportunity for more systematic public service delivery.

Karachi's challenging environment for public service delivery takes a very specific form for illegal electricity connections, namely the *kunda*, an Urdu word which roughly translates to hook. A *kunda* connection will connect a household (or other premises) to the mains by attaching a metal wire with a hooked ending directly to overhead electrical wires in the street, bypassing the electricity meter. The *kunda* wire will often be passed through half of a plastic bottle so that a wooden pole can be used to push the bottle and thus move the wire, rather than directly moving the wire itself. Despite these measures, electrocutions do occur, particularly when these flimsy connections are knocked down in monsoon storms. Although a *kunda* connection is so blatant that it is easily observed, the protection rackets prevalent in Karachi's recent past meant that local authorities either hesitated to intervene or were connected to the rackets. Even now that the protection rackets have abated, the *kunda* connection is so easily reestablished that removal drives have limited efficacy. The term *kunda* is also used for illegal electricity connections common to other parts of Pakistan. Beyond the specific modality of a hooked wire, these might be facilitated by utility staff and other local authorities, whether under the influence of local notables or for a payoff [42].

K-Electric (or KE) is the rebranded name of the utility formerly known as the Karachi Electric Supply Company (KESC), which was founded in 1913 as a private entity and then nationalized in 1952. KESC was privatized in 2005, and then sold to its current owners, the private equity firm Abraaj Capital, in 2009. It is the sole provider of electricity for Karachi. KE notably reduced losses from 36% in 2005 to 20% in 2018 [43], an achievement for which KE highlights the role of its 2012 'reward and reprimand' policy that saw it preferentially supplying electricity to areas with low losses. Due to this policy the electricity supplied to high-loss areas was reduced, but this policy was also intended to serve as an incentive system to encourage high-loss areas to pay their bills in order to receive improved supply (i.e., less loadshedding, or fewer hours of outages in a day). KE also undertook combined social and technical interventions in high-loss areas, though many of these occurred after the dataset used in this paper.

4. Data and methods

The dataset at the foundation of this analysis is provided by K-Electric. The company provided two specific input datasets. First, they extracted from their billing administration a dataset that captures the amount of electricity supplied and billed at the feeder level for the period July 2015 - May 2017 across 1655 electricity feeder lines. Per feeder, this dataset also includes the number of residential, commercial, and industrial consumers, but no identifying information other than the feeder name is included. The second dataset contained the spatial locations for 25,422 pole-mounted transformers, each connected to one of 1518 feeders. This dataset also contained a numeric ID for each feeder as well as details on which administrative region (referred to as an Integrated Business Center (IBC) by K-Electric) each feeder belongs to. However, the names used for the feeders are not consistent between the two datasets, which prevents a straight-forward linking.

We selected a full 12-month period between July 2015 and June 2016 for use in this manuscript. We use a full year because this is consistent with how electricity usage is reported to the national electricity regulator and to smooth out seasonal variations as well as anomalies that may arise from month to month. Transformers in the spatial dataset that belong to the same feeder are aggregated together and Thiessen polygons are subsequently drawn around each feeder. The two datasets were joined using a fuzzy matching process [44] leaving a total of 1259 feeders with both a geographic location (as represented by a Thiessen polygon) as well as loss data for the period July 2015 - June 2016. To prevent feeders with only minimal energy consumption from affecting the subsequent analysis, we filter out feeders that consumed<10,000 kWh during the entire study period ($n = 2$; the median consumption per feeder is 11.1 million kWh). Additionally, we remove feeders that have an electricity density (kwh received / feeder area in square meters) of<1 ($n = 58$) as these consist of feeders at the fringe of the city that are sparsely populated but cover large land areas. This allows us to 'zoom in' our analysis on the urban core of the city. We also filter out any feeders that show negative losses over the 12-month period ($n = 63$). These feeders effectively see payment for more kWhs than are consumed, which is likely the result of an administrative or accounting issue. The final dataset has a total of 1136 feeders. This filtering does not substantially affect the results of our subsequent analysis and we provide a version of our analysis with unfiltered data in the Supplementary Materials.

To add as a foundational covariate in the regression analysis, we derive the population in each feeder line area based on data made available by the WorldPop project [45]. We do this by using the 100 m resolution population data and aggregating all 100 m cells that fall within a feeder area.

In the first step of our analysis, we conduct a conventional ordinary least squares (OLS) linear regression analysis. The dependent variable is percentage losses at the feeder level, calculated by subtracting from one the kWh billed divided by kWh supplied for each feeder (i.e. $1\text{-kWh}_{\text{billed}}/\text{kWhsupplied}$). Explanatory variables include the total amount of electricity delivered, the relative share of commercial, residential and industrial customers and finally the number of residents in that area. We also include a fixed-effects term for the administrative region as differences in local governance for each region might explain larger regional variations. In sum, we estimate the following model:

$$LOSSES_{ij} = \beta_1 {}^* TOT_i + \beta_2 {}^* RESI_i + \beta_3 {}^* COMM_i + \beta_4 {}^* INDUS_i + \beta_5 {}^* POP_i + \beta_6 {}^* IBC_j + \varepsilon$$

Where LOSSES are the losses for feeder i in IBC j; TOT is the total consumption in kWh; COMM is the proportion of commercial customers; INDUS is the proportion of industrial customers; POP is the number of people living in that feeder area; and IBC is a fixed effect based on a dummy variable for the IBC in which the feeder is located.

As the underlying factors that cause electricity losses may vary across space, and this spatial variation might very well not be entirely captured by these covariates, we check the residuals of the standard OLS model for spatial auto-correlation. The residuals of the model are indeed auto-correlated with a Moran's I of 0.2232 ($p < 0.001$). This is likely caused by an uncaptured spatial covariate. To account for this, we adopt a spatial error model instead, where we replace the standard error term with a spatial autoregressive error u:

$$LOSSES_{ij} = \beta_1 {}^* TOT_i + \beta_2 {}^* RESI_i + \beta_3 {}^* COMM_i + \beta_4 {}^* INDUS_i + \beta_5 {}^* POP_i + \beta_6 {}^* IBC_j + u$$

The spatial weights matrix for the spatial error is based on contiguity, that is contiguous regions sharing one or more boundary points are considered to be neighbors. This allows spatial dependencies and variations to be captured at a granular level as defined by the feeders in the dataset.

All analyses are performed with R and make use of the "spdep" for spatial data analysis and the "tmap" package for presenting the analysis in the form of maps [46–49].

5. Analysis and findings

Fig. 1a provides a reference map of the Karachi metropolitan area. The administrative regions, or IBCs, are drawn with black outlines, while the approximate feeder areas are drawn in gray outlines. As is immediately clear from this map, smaller feeder areas generally correspond to denser parts of the city. In Fig. 1b, which zooms in only to the feeder area for which loss data exists, we display the electricity consumption per feeder in Karachi. Although no overall spatial pattern emerges, we do see a general, and obvious, tendency for larger feeders to have a higher consumption. We also see higher consumption in areas dominated by industrial customers, such as in the southeastern part of the city (e.g., Korangi and Landhi). When we switch our attention to electricity losses (Fig. 1c), some stronger spatial patterns emerge. We can clearly recognize an overall core-periphery pattern with the urban core of Karachi having much lower relative losses than the peripheral ring. However, even within the core, there are certain areas that show much higher losses than others. This qualitative assessment based on the map is also corroborated by the global Moran's I, a quantitative measure of spatial clustering, which is 0.55 ($p < 0.001$) – indicating a high level of clustering in the loss pattern.

It is this pattern of spatial clustering that we investigate more closely in this section. We ask ourselves what the main drivers behind the pattern might be. In other words, what are potential reasons for high losses in one neighborhood, but low losses in the next one? To do this, we examine the results of the linear regression analyses described above. The overall model fit, as well as the resulting coefficients, are summarized in Table 1.

Although the simple OLS model results are also displayed, we focus our discussion on the spatial error model (see previous section for justification). The regression coefficients show that feeders with higher total consumption tend to also have higher relative losses (which is also

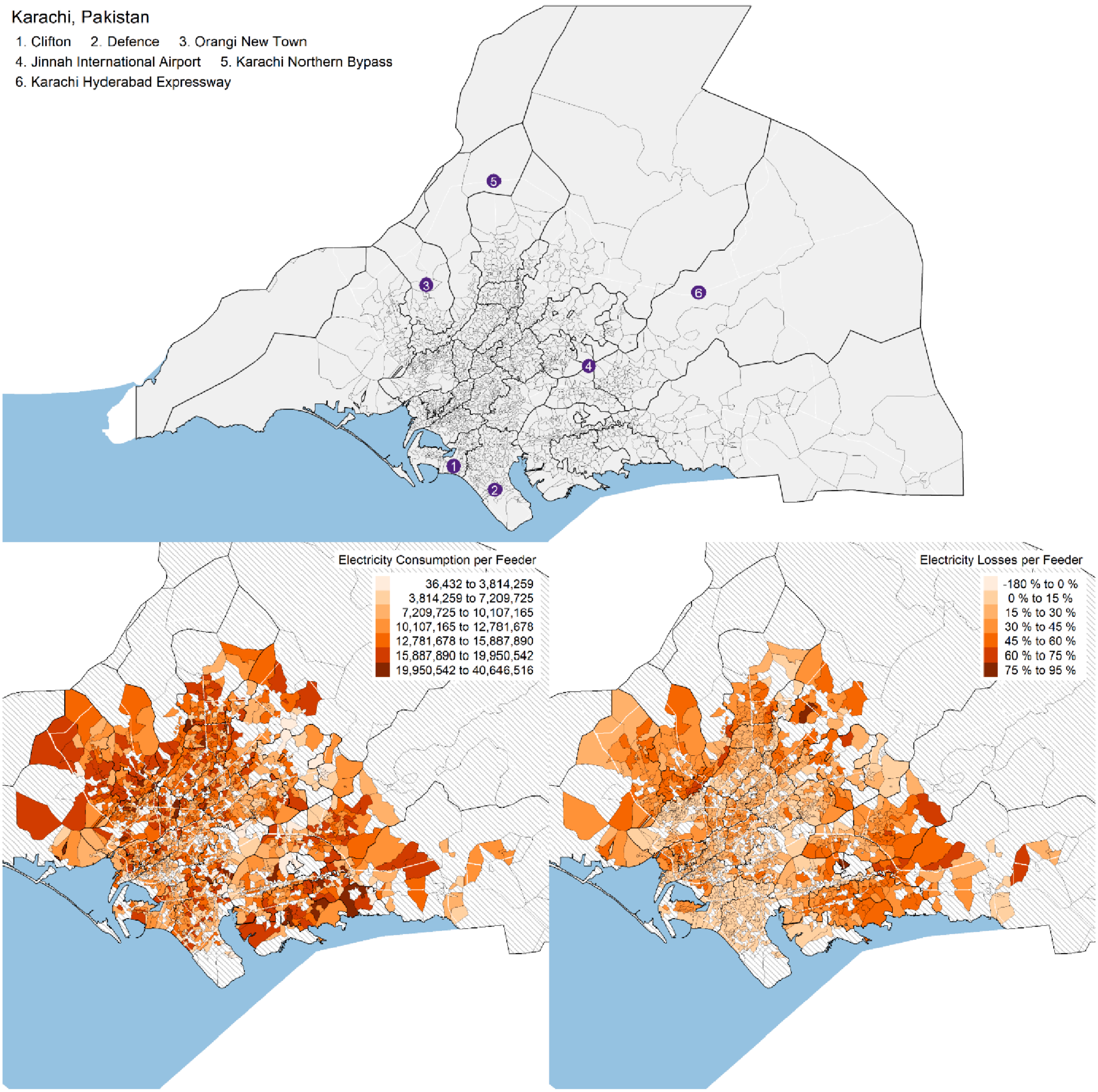

Fig. 1. Top: Karachi overview map for orientation. Bottom Left: Energy consumption map. Bottom Right: Energy losses map.

visible in Fig. 1b/c). More importantly, a higher percentage of either commercial (-0.06941) or industrial customers (-0.22779) leads to lower losses. When a feeder’s share of industrial customers increases by 10 percent points, on average losses will decrease by 2.3 percent points. On the other hand, an increase of residential customers of 10 percent points will on average increase losses with 0.6 percent points. This is in line with what we would expect based on how the electricity market in Karachi operates and also corresponds to the literature on losses. For example, we know that income and other socio-economic characteristics are likely to affect losses. For residential customers, there is likely to be a larger amount of variation in these characteristics and thus feeders with a high percentage of such customers are more vulnerable to losses. Similarly, commercial and industrial customers generally consume larger amounts of energy which makes it more challenging to rely on an illegal connection as well as more difficult to avoid detection. And if electricity supply is essential to business operations – as it almost invariably is - then commercial and industrial enterprises would put their continued existence at risk by using illegal electricity connections. Beyond data related to the customer type, we find no evidence that the population density in a feeder area has an effect on losses.

To account for variation in the governance of each IBC[3], we have

[3] The IBC’s are named as follows: 1. Bahadurabad, 2. Baldia, 3. Bin Qasim, 4. Clifton, 5. Defence, 6. F.B Area, 7. Gadap, 8. Garden, 9. Gulshan-e-Iqbal, 10. Johar-I, 11. Johar-II, 12. Johar II, 13. KIMZ, 14. Korangi, 15. Landhi, 16. Liaquatabad, 17. Lyari-I, 18. Lyari-II, 19. Malir, 20. Nazimabad, 21. North Karachi22. North Nazimabad, 23. Orangi-I, 24. Orangi-II, 25. Saddar, 26. Shah Faisal, 27. SITE, 28. Surjani29. Tipu Sultan, 30. Uthal

Table 1
Main coefficients and model fit metrics for both OLS and spatial error. Fixed effects for each IBC are displayed in Fig. 2 instead.

Coefficient estimates from different modelling approaches						
Term		OLS Model		Spatial Error Model		
	Estimate	p	95% CI	Estimate	Pr(>|z|)	95% CI
Intercept	0.16383	0.00000*	0.11599, 0.21168	0.19414	0.00000*	0.13807, 0.25021
Total	0.00001	0.00000*	1e-05, 2e-05	0.01723	0.00006*	0.00881, 0.02566
Commercial %	−0.07015	0.00357*	−0.11728, −0.02302	−0.06941	0.00225*	−0.11394, −0.02487
Residential %	0.06307	0.00186*	0.02339, 0.10276	0.05770	0.00202*	0.02107, 0.09433
Industrial %	-0.23013	0.00000*	−0.30302, -0.15725	−0.22779	0.00000*	−0.29741, −0.15816
Population	0.00035	0.44562	−0.00055, 0.00125	0.00049	0.28222	-4e-04, 0.00139
Summary Statistics						
Adjusted R-Squared	0.57060			0.62390		
Moran's I	0.22320			−0.01750		
AIC	-1738.63690			-1853.80530		
Log-likelihood	904.31840			962.90260		
* p < 0.05						
* Pr(>|z|) < 0.05						

added a fixed effect term for the IBC to the model. The coefficients for this term are summarized in Fig. 2. We find IBC-level effects with low p-values for a few key areas. For example, we find high negative coefficients in the affluent neighborhood of Clifton (4) and Defence (5) in the south, as well as Gulshan Town (9), which is home to the University of Karachi. In other words, being located in such an IBC generally leads to losses that are 7–10 percentage points lower – holding other variables constant. On the other hand, we find high positive coefficients (i.e., a feeder in such an IBC generally experiences losses that are 2–4 percentage points higher) in the southeast (3, 14, 15), where a lot of industry is located,[4] and Orangi (23–24) in the northwest. Within the urban core, the northern part Lyari (18) seem to be the only IBC with a positive effect on losses ($p = 0.0230$).

The overall model accounts for a sizable part of the total variation in electricity losses in Karachi (adjusted R-squared of 0.62). In some cases, the fixed effect added through the IBC administrative area is able to capture some of the underlying spatial processes within the city as well. However, the model used here has a limited number of covariates, which is partly inherited from the overall challenge to find granular, neighborhood-level data on socio-economic characteristics in a city like Karachi. In sum, while the model explains a foundational level of variation in electricity losses within the city, it also leaves ~ 40% of the variation in losses yet unexplained. As we know from the prior literature, it is likely this unexplained variation is correlated with the underlying socio-economic and governance context of Karachi's neighborhoods.

To explore this further, we map the residuals (or model errors) for each feeder in Fig. 3. This highlights areas in which the model either over- or underpredicts electricity losses.[5] Due to the nature of the spatial regression model, no spatial clustering is present in the residuals at the city scale. However, at a more local scale, we can see some specific patterns where the model over- and underestimates losses. In some ways, it is this map that is the main 'finding' of our research. Where the model deviates from the actual losses, we might find an indication of something else happening in the underlying urban fabric. In other words, areas with high (positive or negative) residuals are deserving of a closer inspection.

6. A focus on Lyari

Many high-loss feeders can be found in and around the area of Karachi called Lyari, which has a population of some 662,000 people (per the 2017 census). Lyari is one of the oldest and densest parts of Karachi. It has a history of criminal gangs closely intertwined with city politics, though this subsided after the end of the gang war in 2012. Fig. 4 shows the electricity losses in the area of Lyari in greater detail. The shading on the map corresponds to the residuals from our statistical model predicting losses based on the limited demographic data we have, as well as the spatial location of the individual feeder relative to the rest of Karachi. The orange shades indicate a negative residual, meaning that the area has lower losses than predicted in our model. Purple shades indicate that losses are higher than predicted. The numbers on the map correspond to specific neighborhoods which are discussed in more detail below.

1. *Machar Colony*. Machar Colony lies on the western waterfront of Karachi and is a site for fishing related activities including boat construction and fish processing. This densely populated area is home to Rohingya and Bangladeshi migrant populations who have never been fully recognized by the Pakistani state and thus lack basic documentation which would allow them – or their descendants – to fully access state facilities [50]. The area lacks paved roads or sewage and sanitation infrastructure. This area has a high positive residual in our model. It fits the stereotype for an area where losses are rampant, with the unaffordability of power as the presumed key driver of losses, although the administrative and political marginalization of the population most likely compounds the area's marginality from the perspective of the state. Although there was a 2017–2018 initiative to improve service to Machar Colony and reduce losses,

[4] The global coefficient for industrial customers indicates that a higher percentage of these customers leads to lower losses. However, the fixed effect of the IBC measures the effect of that IBC region on losses, holding all other variables constant. In other words, some IBC regions with a high degree of industry when compared with other IBC regions might indeed have higher losses, when other variables are held constant. This is apparent paradox is not contradictory in practice. One is a global effect of industry customers on losses, the other is a regional effect incorporating many other factors not directly captured in our model.

[5] Our analysis focuses on commercial losses. In doing so we assume that either technical losses are constant over space, or that technical losses are less variable than commercial losses, and - to the extent that technical losses do vary across space - they will vary across space for the same reasons that commercial losses vary, i.e., if technical losses increase with poor maintenance, than maintenance quality will be worst in those areas where commercial losses are higher (which are typically the poorest neighbourhoods). These assumptions are testable, but only if we could separate out technical and commercial losses, which isn't possible with the current dataset.

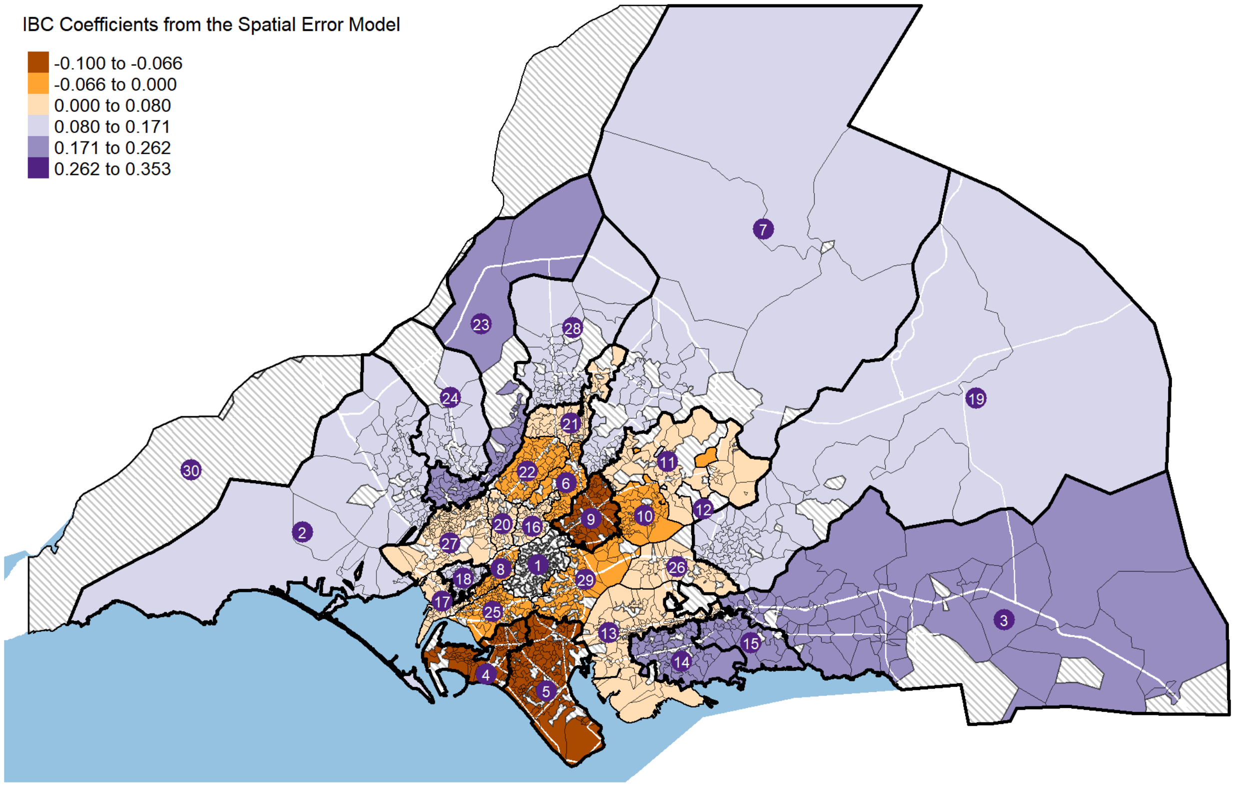

Fig. 2. Map of IBC coefficients. Black outlines indicate effects with p values < 0.01.

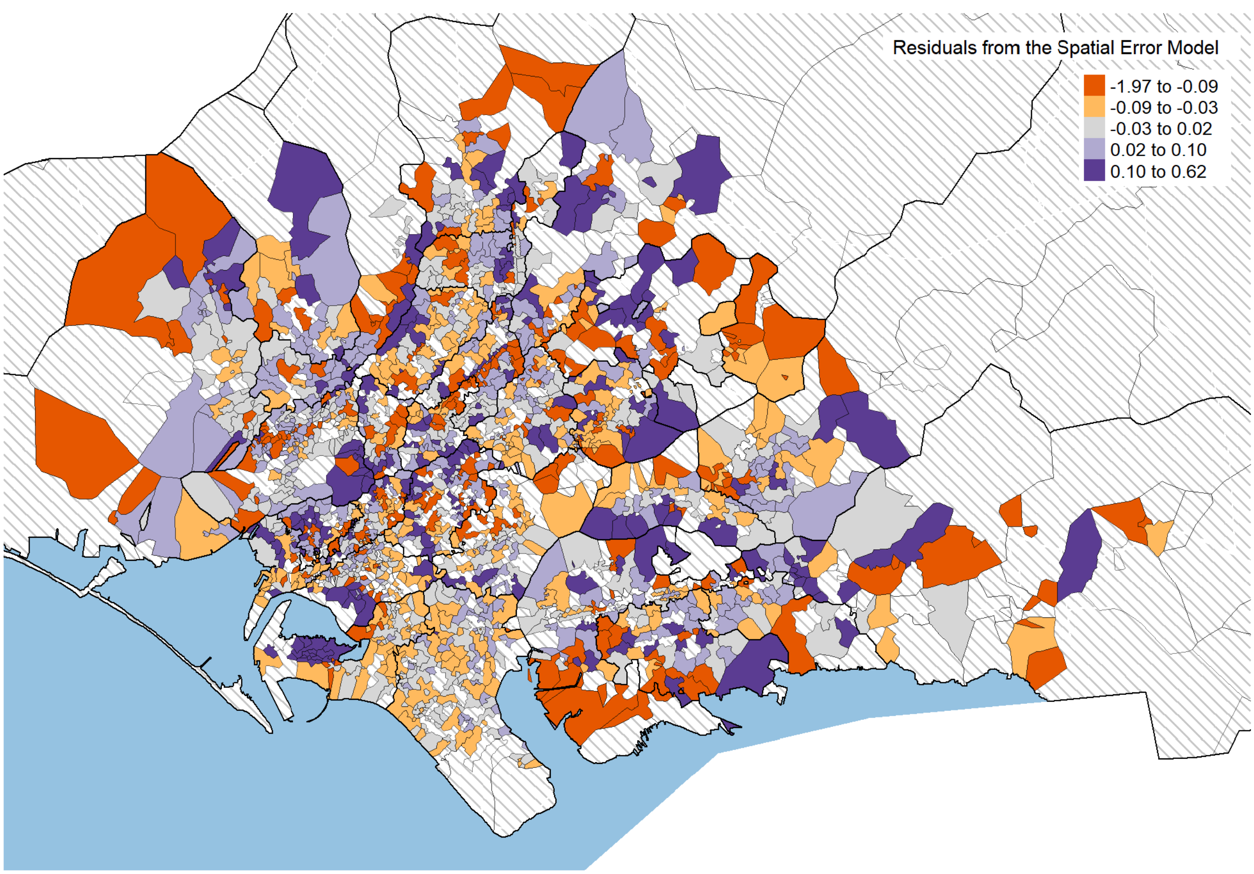

Fig. 3. Map of model residuals.

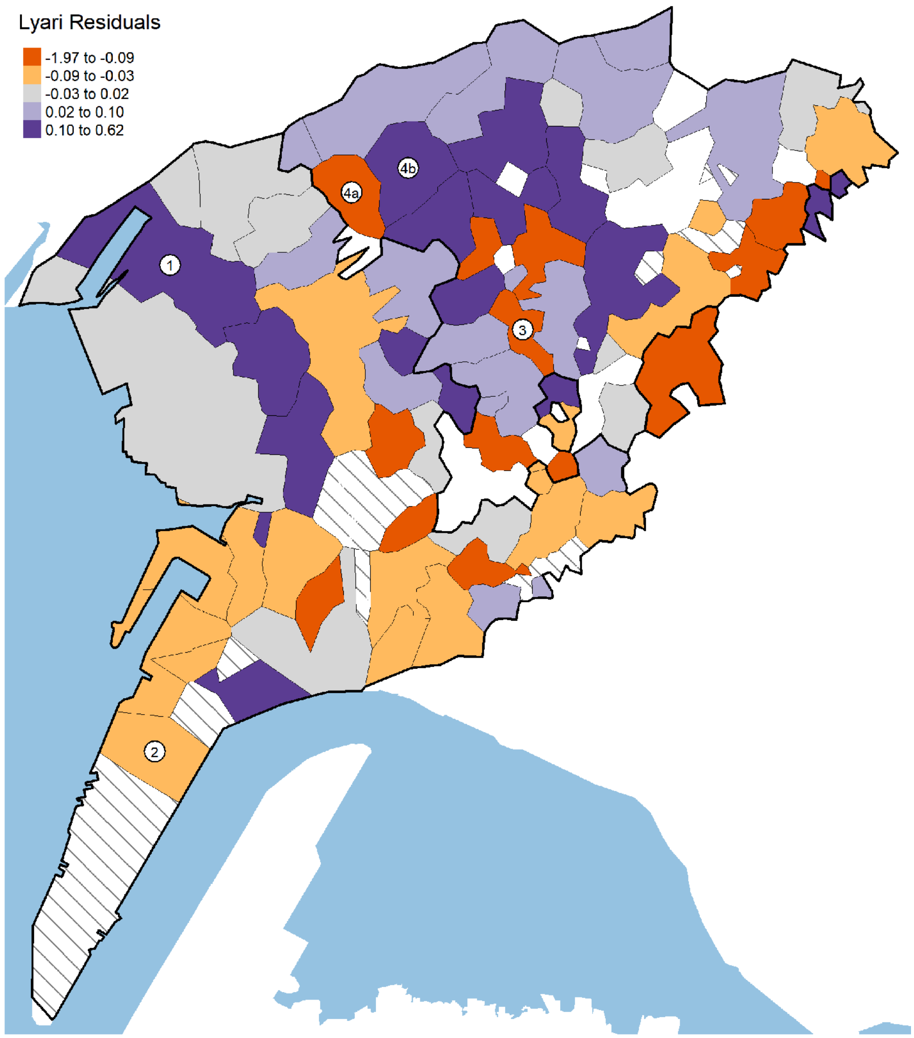

Fig. 4. Model Residuals for Lyari.

which seems to have been successful,[6] this initiative occurred after the dataset used for our analysis.

2. *KPT West Wharf*. An area with proximity to Karachi's port facilities, and home to many formal sector organizations with involvement in international trade. This area has a high negative residual in our model. We would expect that formal sector industrial activities are highly reliable consumers for the utility, and the losses in this area are indeed close to zero.
3. *Denso Road*. Denso Road is the name of a feeder whose footprint includes the commercial area of the Rose Arcade along Chakiwari Road. It stands out in our model as having a large negative residual, and indeed has lower losses (6%) than its immediately surrounding areas in Lyari. However, during the 2015–16 year of our dataset, 3 months of negative losses (i.e., the utility billed for *more* consumption than it delivered units of electricity) are recorded for Denso Road which drive the average downwards. While there are legitimate reasons for negative losses occurring, such as issuing bills to correct for past theft, it could also be an indication of overbilling, wherein consumers are falsely billed for electricity they did not consume in order to balance the utility's ledgers due to losses elsewhere in the city [51]. In the 11 subsequent months there are no such periods of negative losses, and the Denso Road figure of 27% losses for this period is far more in line with expectations based on its neighborhood. Such anomalies do occur, but a fuller explanation would require more local knowledge.[7] This is a useful illustration of reading 'too much' in the perspective provided by a dataset like this: patterns and anomalies might be indication of underlying social processes but they can also be artefacts of the data or administrative processes instead.
4. *4a Behar Colony and 4b Gulistan Colony*. Behar Colony and Gulistan Colony are two neighboring residential areas in Lyari separated by a large road, Tannery Lane. Behar Colony has a negative residual for losses in our model against a positive residual for Gulistan Colony. In the dataset they appear quite alike, with similar proportions of residential and other consumers, although each consumer account uses on average 25% more electricity in Gulistan Colony than in Behar Colony. While satellite imagery shows dense networks of 6–8 story

[6] Personal communication from KE staff (February 25, 2020). The claim that KE can successfully transform previously non-paying consumers into paying consumers is one that merits detailed further study, and would require time series data as well as more field access than was possible for this project.

[7] The authors do not propose that the view of the city provided through this dataset is an unalloyed source of objective truth. Steps such as aggregating billing data for an entire year helps to smooth out smaller irregularities that occur from month to month, but it is not possible to eliminate all billing discrepancies using this dataset alone. Nonetheless, we feel that this paper demonstrates the value of such datasets in providing a meaningful lens on urban governance.

residential housing in both areas, Behar Colony has a noticeably more regular street grid. However, losses in Gulistan Colony fall drastically in July 2016-May 2017 as compared to the previous 12 months, and are only slightly higher to the figures for Behar Colony (27.5% against 24.5%) for that period, suggesting that the model results again may not be indicative of the prevalent situation in Gulistan Colony. Our analysis is further muddied by the fact that the Gulistan Colony feeder actually serves a substantial proportion of the Behar Colony side of Tannery Lane.

This focused look at Lyari reveals some potential shortcomings of our study, and of the use of such datasets at the intra-urban scale. The model itself could be improved through time-series data which would allow us to correct for anomalies such as the three months of unexplained negative losses in Denso Road. We aggregated our monthly data points to a single yearly figure to smooth the seasonal variation that takes place across the year and match the utility's reporting timeframe, but there is year-on-year variation as well which we had not anticipated.

In contrast to the more abstract view on Karachi as a whole, the zoomed-in perspective on Lyari shows the danger of putting too much credence in the insights for any one feeder, although we can still retain more confidence from the larger sample of 1100 feeders. Given that this paper's analysis is reliant on the dataset provided by KE, we have no means of tackling anomalies such as negative losses. However, as shown in the Denso road example, our model can identify the existence of such anomalies (although KE management are already attentive to such variations which show up in the data), and this dataset could lend itself to a richer set of insights if allied with local knowledge that can speak to such temporary anomalies.

7. Conclusion

As this study makes clear, despite accounting for a series of foundational socio-economic and spatial variables, electricity losses vary considerably across the fabric of a single city. These losses indicate substantial variation in the apparent quality of governance and in the utility's ability to extract payment for providing electricity. Relatively high and low-loss areas (i.e. after taking into account the model's predictions) can be found in relative proximity – sometimes right across the street from each other. In explaining these pervasive local variations in energy governance, we find that the IBC identity is an important explanator, but only because it serves as a proxy for capturing underlying socio-economic and political processes rather than spotlighting particular administrative units. When we drill still further into the specific neighborhoods, as we did with the case of Lyari, we find confirmation of the model findings regarding residential and industrial consumers as sites of high and low losses respectively[8] but also highlight a cautionary tale against an over-reliance on the dataset's seeming precision.

The visual representation of both losses and the model residuals (i.e., areas where the model does not reflect the situation on the ground) are an important output of this study, as they provide a potential for communicating the variation in the quality of governance, as well as the socio-economic fabric of the city, to a larger non-academic audience. This audience includes Karachi Electric, to whom the preliminary outputs of this study (visual mapping of losses for the entire city and the results of our spatial models) were novel when we first shared them in 2018, although they have since developed other GIS tools. However, a further non-academic audience is the city of Karachi itself, whose residents, leaders and other stakeholders remain highly exercised about the quality and consistency of electricity supply.[9]

A possible governance intervention, which would build on this study, concerns KE's use of loadshedding data for the allocation of rolling blackouts in Karachi, with areas of higher losses allocated less electricity. While KE management has this knowledge of neighborhood losses at its disposal, residents lack good information on the loss behavior of their neighborhood or other areas on which they might respond, whether in an individual or collective manner. Consistent with Archon Fung's [52] concept of democratic transparency, a visual representation of losses across the city would be an important input at multiple levels of administrative, communal, and personal decision making, as well as holding the utility to account for its provision of public goods in a manner consistent with social and spatial justice. In this way, the figures produced in our paper, which can easily be made interactive or linked to current data, could be the basis for a powerful contribution towards achieving greater democratic transparency. In the earlier discussion of the Machar Colony in Lyari, we noted that KE had undertaken loss-prevention measures that post-date this dataset. These measures combine social and technical measures and have shown some success. We could imagine using longitudinal data across the KE service area to examine the efficacy of such interventions in Machar Colony and elsewhere, and representing it visually to communicate with the general public as well as community leaders with whom KE is engaged. Such a move would be best considered through a collaborative effort of KE management, community-based organizations, and local political actors.

Several possible extensions to our study present themselves. With longitudinal data we could test whether KE's reduced losses since 2012 are due more to reducing the electricity supplied to high-loss areas or whether losses have been reduced for any given feeder. There is ample room for qualitative studies to test and probe the sources of variation in governance that we have observed in locations just a hundred meters apart. This could be particularly valuable in areas where longitudinal loss data reveals a sharp improvement – or worsening – of losses, or where interventions such as the one in Machar Colony have occurred, so that mechanisms of change can be studied and understood. Due to data limitations, our study does not divide losses into commercial and technical components. Such data certainly does reside with KE. If we were to repeat the analysis with separate technical and commercial loss data, we could test whether commercial and technical losses vary differently over space, and be more precise in understanding the variations (and, ideally, the drivers) of each. For the current study, we did not have access to a good set of socio-demographic variables as these are not available at the intra-urban scale. However, the publication of this study, alongside its replication data, could prompt others to generate such data, such as through machine learning algorithms analyzing remote-sensing imagery to identify settlement patterns. There are also potential policy implications. If, for example, the importance of class and culture for household electricity practices is taken as a potential input for climate-aware policy action, the unevenness of those domestic practices at the intra-urban scale should be factored into those policy considerations. [53,54]

Despite these limitations, our analysis here has shown that the spatial and temporal detail of electricity data has significant potential for understanding the local differences in urban governance. While not without its own set of challenges, this type of analytical approach can be especially valuable in urban contexts where data about socio-economic characteristics is scarce or not available at the neighborhood-level – as is

[8] The Covid-19 pandemic prevented the lead author from undertaking fieldwork which could have been used to develop our commentary on Lyari into a more fleshed-out case study.

[9] See, for example, news coverage of electrocutions and lengthy outages due to the 2020 summer rains. "Flooded roads, power outages and traffic jams: Heavy rain wreaks havoc in Karachi", July 18, 2020, *Dawn*. Available at: https://www.dawn.com/news/1569560

the case in Karachi. The use of electricity data, and other unconventional sources like it, might provide a catalyst for the generation of granular socio-economic data and will enable new understandings of local urban governance that bridge economistic and humanistic perspectives.

Data Availability Statement

The code and data to reproduce the analysis in this paper is available at http://doi.org/10.5281/zenodo.5052982 and https://github.com/ijlalnaqvi/electricitylossgovernance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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