

# Power Islands. The geography of electricity diffusion in Indonesia, 1975–2018

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## ABSTRACT

Using the case of Indonesia, we provide novel evidence that the spatial diffusion of electricity technology in the global South is a lengthy and non-linear process that is influenced by local geographic, economic and demographic conditions. We do so on the basis of newly developed consistent time series data on installed electricity generation capacity and household electrification ratios from previously unpublished energy statistics at the (sub-)regional level in Indonesia, for the period 1975 to 2018. We identify spatial interactions in historical electricity adoption rates that are mediated by geographical distance, exploiting the spatial variation stemming from the country's size and archipelagic nature. We find that regions located farther from Jakarta experienced delayed electrification, with geographic remoteness and fragmented infrastructure emerging as key constraints. Differences in power supply development, population density, per capita GDP, and landscape complexity further explain variation in electrification speed. Using a simulation exercise, we show that some eastern provinces could have reached a 50 % electrification rate up to 26 years earlier if they had shared the structural characteristics of Jakarta. Our findings underscore the importance of within-country spatial heterogeneity in understanding electricity diffusion and highlight the policy relevance of targeting local barriers to accelerate access. The study contributes to global electrification research by documenting diffusion patterns at subnational scale in a lower-middle-income country and offers a replicable framework for assessing spatial inequality in electricity access.

## 1. Introduction

The diffusion of electricity technology is a lengthy and non-linear process, both within and across countries. It was on December 31, 1879, that Thomas Edison introduced electric light by illuminating a street in Menlo Park, New Jersey, under the watchful eye of a curious audience. After the demonstration, Edison himself supposedly said: “We will make electricity so cheap that only the rich will burn candles.”<sup>1</sup> But it took no less than eighty years to make this prediction come true for the U.S. – it wasn't until 1960 that virtually all homes in the U.S. were powered by electricity, while Edison himself commissioned the first power station already in 1882. At a global level, the actual

electrification is currently around 90 percent, meaning that almost 140 years after Edison's prophetic words, 10 percent of the world's population is still dependent on candlelight.

The remaining electricity access challenge is largest in rural areas, where approximately 84 percent of the roughly 675 million people without access reside [1]. Sub-Saharan Africa now accounts for majority of the global access gap, other regions – most notably Central and Southern Asia – have made substantial progress in recent decades [1]. The persistent urban-rural divide in electricity adoption is economically rational: expanding electricity infrastructure requires large, lumpy investments that generate higher returns in densely populated, wealthier urban areas where demand is

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<sup>1</sup> ‘We Will Make Electricity So Cheap That Only The Rich Will Burn Candles’, Thomas Edison Notebook, Wild Pages Press, 2019.

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concentrated. Geography thus plays a critical role in shaping the inherent trade-off between the economic logic of infrastructure development and the social imperative of equitable access, poverty reduction, and inclusive development in rural regions.

Rural electrification remains a critical component of achieving Sustainable Development Goal 7 (SDG7), which calls for universal access to affordable, reliable, and modern energy services by 2030. In light of this challenge, this paper uses the case of a large middle-income Asian country, Indonesia, to examine how the interaction of geographic, economic, and demographic conditions have shaped subnational variation in historical electrification trajectories. Indonesia's pronounced spatial heterogeneity and archipelagic structure offer a unique context to study the mechanisms behind uneven electricity diffusion. The electrification of Indonesia started in the early 1900s during the colonialization era and has recently achieved near-universal electricity access. We analyse long-term electrification trends across Indonesia's provinces and islands in detail, with the aim to shed light on how geography mediates the pace and pattern of electricity adoption within a single national context.

This paper advances spatial electrification research in three ways. First, we assemble and harmonize a unique, long-run (1975–2018) subnational panel dataset for Indonesia that combines household electrification rates with installed generation capacity from previously unpublished statistics. This allows us to analyse within-country variation in electricity diffusion dynamics in a major country in the global South – an angle that remains underexplored in much of the existing literature, which has largely focused either on national trends in low- and middle-income countries or on subnational patterns in high-income contexts. Second, we operationalize geographically mediated diffusion within a country by adapting Spatial Distance from Technology (SDT) and Spatial Distance from Income (SDI) indicators, originally developed to study technology diffusion at the country level [2], to the subnational scale. These indicators capture how proximity to the national adoption and income “core” is associated with provincial electrification trajectories across an archipelagic setting. Third, beyond documenting spatial patterns, we couple a two-step empirical diffusion model with a counterfactual back-casting simulation and a decomposition, quantifying how much of the electrification timing gap across provinces is associated with structural differences in local characteristics, including proximity to urban and economic hubs, population density, firm presence, and landscape complexity – factors that influence both infrastructure investment decisions and demand-side dynamics. We express these effects in intuitive “years-to-threshold” metrics (e.g., years to 25% and 50%

access).

Together, these contributions provide a replicable framework for diagnosing and decomposing within-country electrification dynamics and disparities in geographically fragmented contexts. As such, they can inform more realistic scenario building and support the design of targeted, effective electrification strategies for the regions of the world where households still rely on candles as their primary source of light. Fig. 1 presents a schematic overview of the various research steps taken in the paper along with an overview of the structure of the paper in the various sections that constitute the paper.

To put our framework and research in context, first section 2 reviews the existing literature on electricity diffusion and spatial technology adoption, highlighting the novel features of our contribution. This includes discussing the two spatial indicators (SDT and SDI) that serve as proxies for spatial inequality in access to technology and economic opportunity. Section 3 provides a brief historical overview of electricity diffusion in Indonesia, tracing its evolution from the colonial period (starting in 1897) to the present. Section 4 describes the construction of our newly developed regional dataset and presents key descriptive statistics and their relationship with electrification rates. In section 5 we use regression analysis to identify the potential role of geography in driving the speed of electricity diffusion. We use part of the regression outcomes to calculate for each province the gap between its speed of electrification and that of the early adopter (Java-Bali). In section 6 we decompose this gap into the respective contribution of the driving forces of electrification as identified by our regression framework, which we then use to simulate the number of years that are required to electrify at least 50 percent of households. Section 7 concludes.

## 2. Literature and theoretical background

The observation that electricity technology diffuses slowly across populations is well established (see, e.g., Ref. [3–10]), and holds for many other technologies (see, e.g., Ref. [2,11–15]). This has led many scholars to study why technology diffuses so slowly, and what explains cross-country differences in its speed of diffusion (see, e.g., Ref. [11,13,14,16–24]).

Most existing empirical studies focus on technology adoption in rich countries. This is especially true for process innovations or so-called general-purpose technologies (like electricity, railroads, automobiles, or information technologies), while exceptions often deal with relatively simple (agricultural) innovations such as seed adoption by farmers (see, e.g., Ref. [25,26]). Notable exceptions on electricity and other

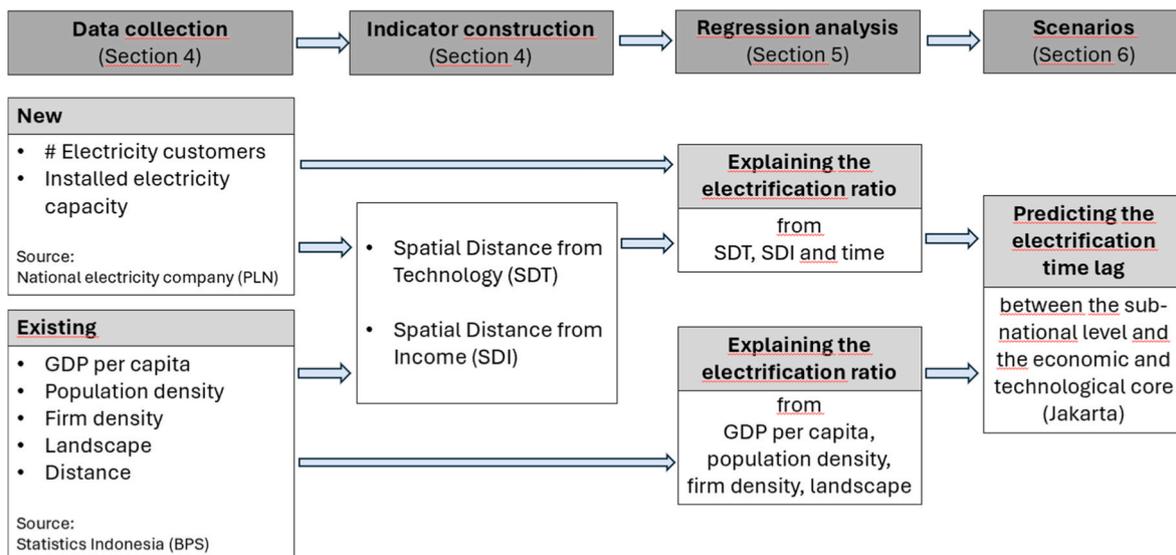


Fig. 1. Analytical framework and structure of the paper.

infrastructure include Aklin et al. [27], Kale [28] and Steckel et al. [29]. Obviously, this bias is due to the fact that new technologies indeed often spread first in rich countries, but also stems from data limitations in poorer countries. For the aim of this study, we tackled the latter barrier by constructing a consistent time series of installed electricity generation capacity and household electrification ratios across all Indonesian provinces and islands from unpublished statistics kept by Indonesia's national electricity company PLN.

In contrast, most existing empirical studies that use time series data to explain (renewable) electricity diffusion patterns, take countries as their unit of analysis and identify drivers of technology adoption from country characteristics such as per capita GDP, human capital, or institutional quality (e.g., Ref. [27,30]). In doing so, they often (implicitly) consider countries as independent, thus ignoring the possibility of cross-country interactions in the adoption process. Also, they tend to ignore the substantial spatial variation in historical electrification rates within countries, thus ignoring the possibility of within-country interactions in the adoption process. This runs counter to much evidence from the aforementioned innovation diffusion literature that technology adoption involves acquiring knowledge which often comes from interactions with other agents. In turn, these interactions are influenced by geography, because (physical and cultural) proximity facilitates knowledge spillovers – as is of course also illustrated by persistent gaps in the evolution of urban and rural electrification rates within countries. Clearly, despite being a non-rival in nature and notwithstanding a spectacular fall in transport costs over time, it often (still) takes long for ideas and technologies to travel outside centres of gravity (e.g., Ref. [31] and many studies that followed). Fadly and Fontes [32] provide a clear example of the importance of geography in electricity diffusion: they show, for a large panel of countries, that adoption of renewable energy technologies is likely to be affected by the adoption pattern in neighbouring countries – with the effect being stronger in case of tight trade relationships. In this paper, we further explore this argument by assessing the regional evolution of initial electricity adoption across Indonesia.

To test whether electricity diffuses more slowly in areas farther from the economic and demographic centres that lead in electricity adoption, we adopt the Spatial Distance from Technology (SDT) measure from Comin et al. [2]. Originally developed to capture geographically mediated cross-country diffusion, we adapt this measure to analyse provincial electrification dynamics in Indonesia. Intuitively, the SDT of an area is an interaction between the (log) of technology adoption in other areas and how distant they are. More precisely, the SDT of an area specifies the interaction between technology and distance as the scalar product of a vector of (log) technology adoption in other areas and the vector of distances (kilometres) to these other areas. Fadly and Fontes [32] applied this insight and measure to study the link between geographical proximity and adoption of renewable energy technologies across countries. In contrast we study the evolution of initial electricity adoption as a function of geographical proximity, and we do so at the regional rather than the country level. We thus take Indonesian provinces as our areas and define technology adoption in terms of the electrification ratio, which defines the SDT in province  $c$  at time  $t$  as follows:

$$SDT_{ct} = \sum_{k \neq c} d_{ck} x_{kt}, \quad (1)$$

with  $k$  being a province other than  $c$ ,  $d_{ck}$  the distance between province  $c$  and  $k$ , and  $x_{kt}$  the electrification ratio in province  $k$ . We use the capital city of the province as a point of location to calculate distance and produce a distance matrix. We take logarithms and add a technology-specific constant that ensures that  $x_{kt}$  is always positive. In particular, the minimum of  $x_{kt}$  along  $c$  and  $t$ , for the years used in the regression analysis in the next section is 1 percent.

The SDT captures geographically mediated interactions in electricity adoption by measuring a province's distance from the diffusion frontier in other provinces, consistent with the stylized fact that rural

electrification tends to lag behind urban adoption [4]. In line with a simple theory of human interactions, Comin et al. [2] argue that, in contrast to goods or investments, the effect of distance on technology adoption vanishes over time as technology diffusion proceeds. Since the matrix of distances is constant over time, time variation in SDT is generated by the diffusion of electricity. If being close to adoption leaders is beneficial for the diffusion of technology, we should observe that the SDT for a province is negatively correlated with its electrification ratio and that the value of SDT decreases over time.

Geographical interactions relevant for technology diffusion also reflect non-technology such as international trade, institutions, and markets, which correlate strongly with income [2]. We therefore control for several such factors that may influence provincial electricity adoption, including population and firm density. Because of data availability, however, it is impossible to identify all potential driving forces of electricity adoption across 33 provinces since 1975. But, as Comin et al. [2] also argue, it is hard to think of variables that affect electricity diffusion, that are geographically correlated, that change over time, and that are not correlated with income. Therefore, we control in our analyses of electricity adoption dynamics across provinces for the potential influence of non-technological mechanisms of geographical interactions by including a Spatial Distance from Income measure (SDI), like in Comin et al. [2]. Analogous to SDT, we compute SDI by using other provinces' (log) per capita income  $y_{kt}$  in terms of per capita GDP, multiplied by the distance (in kilometres):

$$SDI_{ct} = \sum_{k \neq c} d_{ck} y_{kt} \quad (2)$$

Both the SDT and SDI indicators thus quantify how geography and economic centrality mediate technology diffusion in a large, fragmented country. Hence, they operationalize the idea that the spatial diffusion of electricity access in Indonesia can be understood through technology diffusion theory and geoeconomic perspectives on spatial inequality. Classic diffusion theory predicts that new technologies spread in an S-shaped pattern: early adoption occurs in core regions with higher income, population density, and institutional capacity, followed by slower diffusion to peripheral areas as costs fall and knowledge spreads [21, 33]. This pattern closely mirrors Indonesia's electrification trajectory—rapid progress in Java and Sumatra and delayed adoption in the eastern islands. A higher SDT values represent greater distance from the technological frontier and thus higher infrastructure costs and weaker spillovers. The SDI indicator complements this by capturing economic distance from high-income provinces, linking spatial inequality in income to disparities in electricity diffusion.

Population agglomeration—central to geoeconomics and new economic geography—further amplifies these spatial patterns. In Indonesia's archipelagic geography, agglomeration takes the form of island clusters such as Java–Bali, where dense populations and concentrated demand create economies of scale that accelerate grid expansion. In contrast, sparsely populated islands like Maluku or Papua face high per-connection costs and logistical barriers, slowing adoption despite national investments. By combining insights from diffusion theory and geoeconomics, we interpret electrification as a spatially uneven process shaped by distance, density, and economic gravity. The SDT and SDI indicators translate these abstract mechanisms into measurable variables that can be tested empirically. In section 4 we document the evolution of geographical interactions in electricity adoption (SDT) and income levels (SDI) over time as well as the regionally different patterns in SDT and SDI across Indonesia. In section 5 we control our regression analysis identifying the spatially specific determinants of electricity diffusion across Indonesia for the influence of SDT and SDI. This provides the foundation for our simulation framework in section 6, which together assess how structural differences in geography, income, and population density explain variation in electrification speed.

### 3. A short history of electricity diffusion in Indonesia

The supply and diffusion of electricity in Indonesia started in the period of Dutch colonization. Jakarta was the earliest to benefit in 1897 while other provinces with substantial economic activity, such as mining, sugar and tea factories, plantations, trading, and so on, also started electrification in the early 1900s [34]. After independence, three main private Dutch electricity companies, namely *Nederlandsch Indische Gasmaatschappij*/the Netherlands Indies Gas Company (NIGM), *Gemeentelijk Electriciteitsbedrijf Bandoeng en Omstreken*/the Municipal Electricity Works for Bandung and Surroundings (GEBEO) and *Algemeene Nederlandsch-Indische Electriciteits-Maatschappij*/the Netherlands Indies General Electricity Company (ANIEM), were nationalized by the Government of Indonesia in the early 1950s, but the process was fraught with difficulties. This complex transition was followed by political instability and hyperinflation in the 1960s. Together with a lack of funds, engineers, and qualified management, it resulted in PLN running the electricity company with poor operating conditions and a lack of expansion possibilities [34]. After several organizational changes, PLN became the only state-owned electricity company that was responsible for connecting people throughout Indonesia from 1972 onwards.<sup>2</sup> Therefore, the available PLN data that we can collect goes back to 1975.

Fig. 2 shows that early first steps in electrification as measured on the horizontal axis do not automatically imply high adoption rates later in time. The plot correlates per province the first year that electricity arrived (horizontal axis) and its percentage of districts that subsequently electrified up to 1970 (vertical axis). It can be seen that some early adopters, such as the provinces East Nusatenggara (ENT) and Lampung (LMP), stay behind in the years that follow, whereas some late adopters, such as West Sulawesi (WSI) and Southeast Sulawesi (TSI), experienced a very rapid electrification.

The electricity diffusion process was very slow until about the 1980s (the electricity rate was only roughly 10 percent by then), after which the electrification ratio grew rapidly in some provinces while remaining low in others – implying an increasing spatial variation in access to electricity over time. For example, between 1975 and 2018 the electrification ratio in the capital city Jakarta increased from 20 percent to 100 percent, whereas in the remote province of Papua, it grew from only 3 percent to 35 percent. In the same period, the total installed electricity generation capacity in Indonesia increased more than 50-fold (from about 1 to almost 58 GW), of which in 2018 no less than 65 percent is still located at the central Java-Bali islands and only 3 percent in remote Eastern Indonesia [36].

The continued slow diffusion of electricity across provinces in Indonesia since 1975 is shown in Table 1. From the table it can be seen how fast electricity has diffused across provinces since 1975. For instance, only two provinces achieved at least 10 percent access to electricity in 1975 and at least 50 percent in 1990, while only one province was fully electrified in 2010. Most of the provinces reached the threshold of a 10 percent electrification in the 1990s. The electrification trend began only to accelerate in 2000; at least half of the households in 15 provinces were connected to the electricity grid in 2000 and at least 75 percent electrification was achieved by 19 provinces in 2015. This

<sup>2</sup> On October 27, 1945, Sukarno, the first Indonesian president, established *Jawatan Listrik dan Gas* (the electricity and gas company) under the Ministry of Public Works and Power with an installed capacity of 157.5 MW. In the period from January 1, 1961 until January 1, 1965, this electricity company was changed into *Badan Pimpinan Umum Perusahaan Listrik Negara* or the General Leader Agency PLN (BPU-PLN) and its capacity almost doubled to almost 300 MW. In 1972, the Government of Indonesia issued a Government Regulation, which stated that PLN was the only company to serve electricity throughout Indonesia. Since 1994, PLN has been a state-owned company, and it operates under the Ministry of State Owned Companies and is supported by the Ministry of Mining and Energy.

relatively fast diffusion is due to the national program to accelerate electrification, that is, the fast-track programs followed by PLN's so-called 35,000 MW program to speed up electrification.

As shown in Fig. 3, Indonesia's national electricity company PLN expanded the electricity grid steadily after the 1970s but began to accelerate only after 2010, as is apparent in the increasing electrification ratio as well as the installed capacity. While about 75 percent of the districts in Indonesia were already connected to the electricity grid before 1970, Fig. 3 indicates that by 2018 the electrification ratio had only increased up to 83 percent. The Asian Financial Crisis in 1998 contributed to some delays in the electrification program, as we can see in the slowing down of the capacity expansion and the substantially smaller electrification ratio between 1998 and 2010. During the crisis, many infrastructure projects, including private power plants, were postponed while at the same time PLN encountered financial difficulties and a lack of investment funds [37].<sup>3</sup> After some renegotiations and rescheduling with the investors, PLN gradually increased its capacity further after 2005 and intensified it from 2010 onwards, incentivized by changes in the broader institutional and political context – most notably the decentralization reform of 2000 and the direct presidential elections since 2004.

Following the decentralization reform of 2000, the authority over infrastructure development—including electricity—was delegated from the central government to provincial and district levels. This shift marked the beginning of Indonesia's democratization, including the implementation of direct local elections. These elections, starting in the early 2000s, incentivized local governments to prioritize electrification efforts, as candidates often used electrification targets as part of their campaign platforms. This motivated regions to implement rural electrification programs, frequently co-funded by the Ministry of Energy and Mineral Resources. In remote and geographically challenging areas, these programs increasingly relied on renewable energy solutions. As a result—albeit with a lag—several provinces experienced a sharp rise in electrification, including Riau, Lampung, South Sumatra, West Papua, and West Nusa Tenggara. Nevertheless, approximately 8% of households remain unelectrified, primarily in remote rural areas.

At the national level, Indonesia introduced direct presidential elections in 2004. Each elected president has launched strategic programs aimed at accelerating electrification. President Yudhoyono initiated the Fast Track Program 1 (FTP 1) in 2005, targeting increased electricity supply in 34 locations, largely outside Java. This was followed by FTP 2 in 2009 during his second term. President Jokowi further expanded these efforts with the 35,000 MW program launched in 2014. These programs, implemented by PLN, offered critical incentives for electrification, especially in under-served regions. While PLN's planning is nominally demand-driven, the FTP programs provided political and financial momentum to expand electricity access beyond Java. Typically, FTP projects followed a phased schedule: contract signing (2005–2006), construction (2006–2009), and commissioning (from 2010 onward). It is, however, also important to note that the exponential growth in electrification after 2005 was partly due to postponed power plant projects from the 1998 financial crisis that became operational in this period.

<sup>3</sup> As discussed by Sambodo [37], in the 1990s, domestic money available to finance investments in the power sector was limited, while borrowing money from international institutions was flexible. Therefore, PLN preferred to obtain long-term loans in foreign currencies as a source of financing. Moreover, to accelerate the electrification programme, PLN signed 26 power purchase agreements (PPA) with private investors to develop power generation. However, the economic crisis that hit Indonesia in 1997/1998 caused PLN to suffer not only from huge operating losses due to currency depreciation and very high interest rates but also from an international lawsuit that forced it to pay a penalty for postponed or cancelled contracts of PPAs. These financial problems lasted for six years after the crisis.

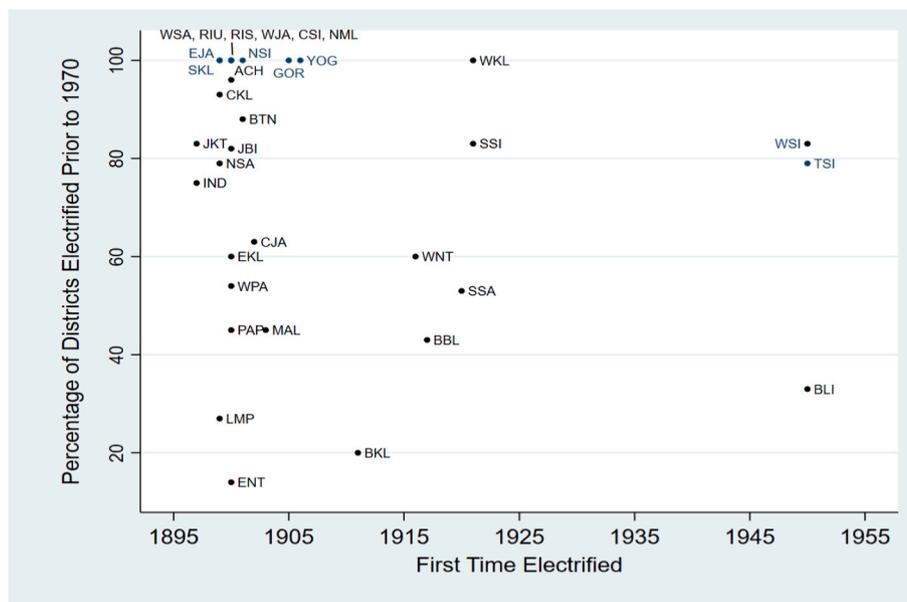


Fig. 2. Electrification Rate Per Province Before 1970.\*

\* The percentage of districts electrified before 1970 is calculated based on the first time electricity was available, recorded by PLN in the particular district, regardless of the number of connections. Therefore, a district is counted as an electrified district if there is at least one customer or one electric pole.

Note: ACH (Aceh), NSA (North Sumatera), WSA (West Sumatera), RIU (Riau), JBI (Jambi), SSA (South Sumatera), BKL (Bengkulu), LMP (Lampung), BBL (Bangka Belitung Islands), RIS (Riau Islands), JKT (Jakarta), WJA (West Java), CJA (Central Java), YOG (Yogyakarta), EJA (East Java), BTN (Banten), BLI (Bali), WNT (West Nusatenggara), ENT (East Nusatenggara), WKL (West Kalimantan), CKL (Central Kalimantan), SKL (South Kalimantan), EKL (East Kalimantan), NSI (North Sulawesi), CSI (Central Sulawesi), SSI (South Sulawesi), TSI (Southeast Sulawesi), GOR (Gorontalo), WSI (West Sulawesi), MAL (Maluku), NML (North Maluku), WPA (West Papua), PAP (Papua).

Source: McCawly [34], PT PLN [35], author's calculation from the PLN database.

Table 1

Number of provinces achieving a minimum electrification ratio, 1975–2018.

Year	Minimum Electrification Ratio				
	≥10 %	≥25 %	≥50 %	≥75 %	100 %
1975	2	0	0	0	0
1980	6	1	0	0	0
1985	14	5	0	0	0
1990	25	13	2	0	0
1995	26	21	2	1	0
2000	31	29	15	1	0
2005	32	31	16	1	0
2010	33	33	23	3	1
2015	33	33	31	19	1
2018	33	33	31	25	2

Source: PLN statistics, calculated by the authors.

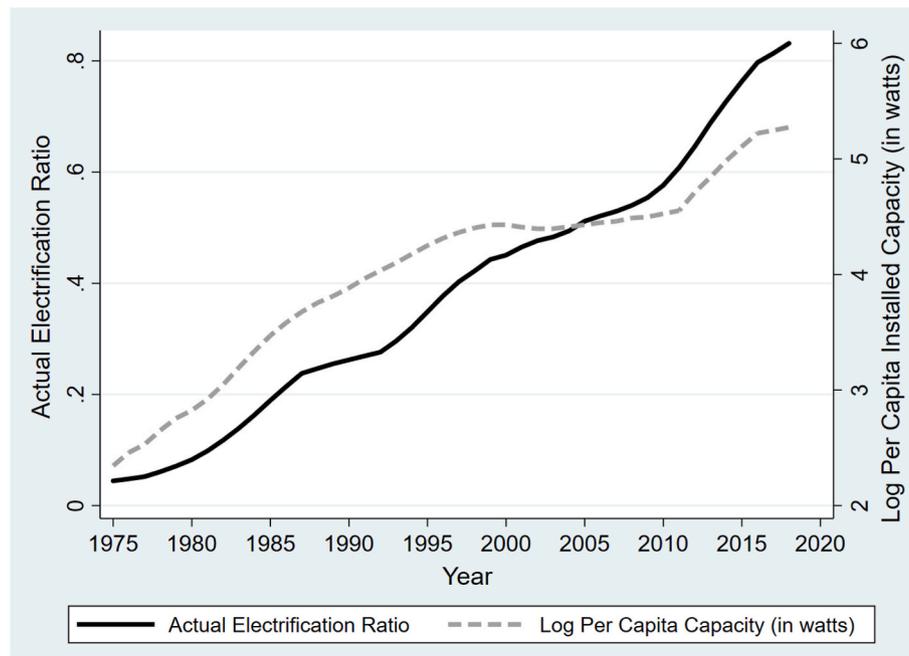
Despite the acceleration in electrification, there were still 433 villages located in Eastern Indonesia that were completely dark by 2018 [38]. Sinaga et al. [39] identified five key barriers to electrifying Eastern Indonesia, namely: (i) difficulties in reaching the location and its geographic conditions, (ii) poor inter-sectoral coordination, (iii) a lack of government funding, (iv) difficulties in land acquisition and (v) inadequacy in equipment, material, and human resources. Moreover, they found that the lack of road and bridge infrastructure, the long time required to obtain permits, and social resistance from the community exacerbate the existing initial barriers in the system.

Interestingly, the huge expansion of the national electricity generation capacity did not substantially change the spatial distribution of this capacity. The share of islands in the national capacity has remained roughly the same over time, with Java-Bali accounting for the largest share (70 percent) followed by Sumatera with 20 percent, Kalimantan and Sulawesi with around 6 percent and the Eastern islands with around 3 percent. Using our new dataset, we find that, on average, the electrification ratio in Indonesia increased by 6 percent per year from 6 percent

in 1975 to 83 percent in 2018. However, this ratio varies substantially across provinces. Jakarta (excluding the Seribu Islands district) has reached a 100 percent electrification ratio by 2008, followed by Bangka Belitung Island in 2017, while the three lowest electrification ratios in 2018 are found in Papua, Jambi, and East Nusa Tenggara with the corresponding figures of 35 percent, 47 percent and 55 percent, respectively (see Fig. 4).

#### 4. Data and descriptive statistics

We obtained data on the number of electricity customers and installed electricity capacity from the PLN annual electricity statistics at the (sub-)regional level. We collected these statistics from various sources, including PLN's website, PLN's headquarters, and PLN's archives. Most of the historical data were only available in the form of hard copies that we had to digitize, record, and clean. In constructing a consistent dataset, we dealt with a series of challenges, especially regarding variation in the nomenclature of business units, area coverage, and tariff classification over time – we refer to Appendix B for details. After decentralization, there were three provinces split in 2001: the Bangka Belitung islands separated from South Sumatera, Banten from West Java, and Gorontalo from North Sulawesi. The split of Papua whereby West Papua became a separate province took effect in 2004 (although the Law on Special Autonomy for the Province of Papua was enacted in 2001). However, this administrative change was not immediately reflected in the internal regional classification system of the state electricity company PLN. Specifically, both Papua and West Papua continued to fall under PLN's regional office “Wilayah X”, which includes six districts in Papua (Jayapura, Biak, Nabire, Wamena, Timika, Merauke) and two districts in what is now West Papua (Sorong and Manokwari). To address the absence of separate electrification data for West Papua prior to the split (1975–2003), we applied a backcasting approach using trends from the parent province of Papua, as recorded by “Wilayah X”. For example, to estimate the electrification ratio (ER) of



**Fig. 3.** Electrification ratio and per capita installed capacity in Indonesia, 1975–2018. Source: PLN statistics, calculated by the authors.

West Papua in 1975, we took the ER for Papua in 1975, divided it by Papua's ER in 2003, and then multiplied that ratio by the ER for West Papua in 2003. This method allowed us to generate consistent and plausible estimates for West Papua's electrification levels for the entire pre-split period. In sum, we finally managed to gather 44 years of electricity data covering the period from 1975 to 2018 at the province level.

This electricity data is supplemented with data on per capita GDP, population density, firm density, geography, and landscape complexity from Statistics Indonesia (BPS); long term data availability at the province level served as a guiding principle here. We include these variables in our analysis because they evidently influence both infrastructure investment decisions and demand-side dynamics—thereby shaping the speed and sequencing of electrification across space. Data on per capita GDP and population density from 1975 to 2018 were drawn from various editions of the publications ‘Statistics Indonesia’ and ‘Provinces in Figures’. Firm density is defined as the number of manufacturing firms per 1000 population in each province. We use data from the Large and Medium Manufacturing Statistics issued annually by the Central Bureau of Statistics of Indonesia, with the following definitions: firms with 100 or more employees are classified as large, while those with 20–99 employees are classified as medium. We measure the role of geography and landscape in terms of population distribution across islands and the share of households living in flat areas; data are taken from the so-called Podes Village Potential Statistics 1986–2018. We addressed missing geographical and landscape data for the period 1975–1985 using the Next Observation Carried Backward (NOCB) method, which replaces a missing observation with the next available non-missing value. This approach assumes that the number of islands per province and the percentage of villages located in flat areas remained constant over the preceding ten years. Accordingly, we used 1986 as the reference year to impute missing geographical and landscape values for 1975–1985. Finally, we calculate the per capita installed electricity capacity (in Watt) at the province level by combining population statistics and PLN statistics on the installed capacity for the period 1975–2018 (see Appendix B.3 for a detailed explanation).

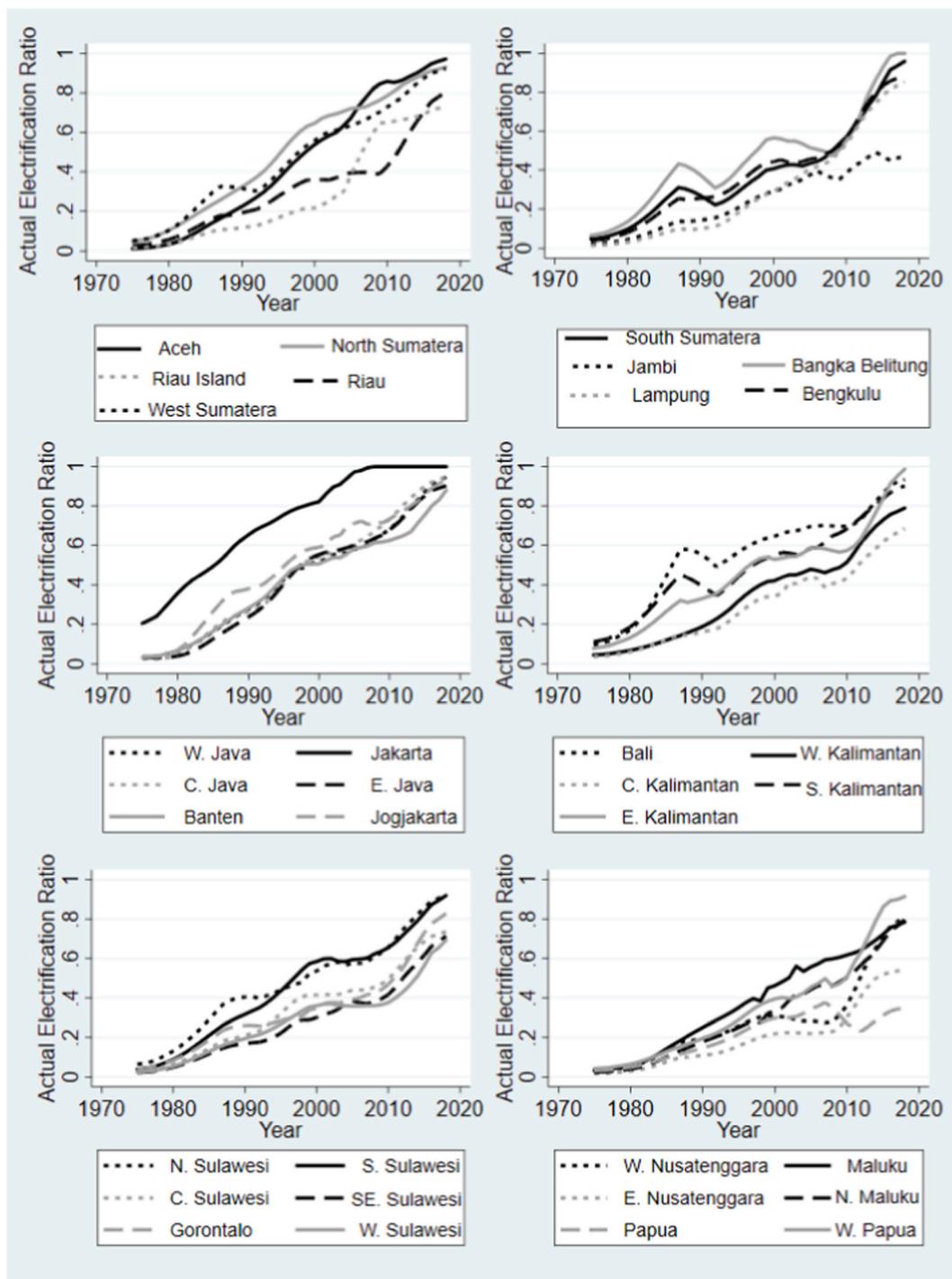
Descriptive statistics (see Table 2) show that both population density

and per capita installed capacity feature a high degree of variation across space and time, suggesting that the within-country variation in installed capacity indeed might find its cause in spatial variation in population density, with a part of the Indonesian population living in relatively small and poor communities scattered over space – which of course inhibits fast diffusion of electricity throughout Indonesia. Table A in the Annex shows that all aforementioned potential driving forces of electricity diffusion are statistically correlated with the electrification ratio. Among those variables, per capita installed capacity has the highest correlation. This table also indicates that there is no multicollinearity as none of the explanatory variables are strongly correlated with each other.

Geographical interactions in electricity adoption (SDT) and income levels (SDI), as defined in section 2 (equations (1) and (2)), show different patterns. A first finding is that cross-province differences in SDT are much higher than in SDI (see Fig. 5), implying that technology distance to the electrification adoption leader is spatially more heterogeneous than income distance to the income level leader. Fig. 5 also reveals that the variation in SDT decreases over time, confirming the hypothesis that human interaction matters in reducing the gap in electricity adoption. In contrast, the variation in SDI is increasing slightly over time since around 1998, indicating a modest but persistent divergence in income levels across provinces, consistent with various indicators of increasing inequality in Indonesia (e.g. Ref. [40]).

In line with Figs. 5 and 6 shows that in 1975 when electrification was overall still low, the electrification ratio negatively correlated with the SDT (Panel A). In other words, we indeed find that electrification adoption initially is slower in locations that are further away from the adoption leader Jakarta. By 2018, when electrification ratios were overall much higher, this correlation vanished – except for the province of Papua (Panel B). As regards the SDI, we do not find a strong correlation with regional GDP per capita, neither in 1975 nor in 2018 (Panel C and D).

Finally, to further assess the regional patterns in SDT and SDI, we divide Indonesia into three sub-regions, viz. the Western, Central, and Eastern region. Eastern Indonesia covers six province-islands, namely West Nusatenggara, East Nusatenggara, Maluku, North Maluku, Papua, and West Papua; Central Indonesia consists of the provinces at



**Fig. 4.** Actual Electrification Ratio of All Provinces in Indonesia, 1975–2018. Note: Jakarta excludes the Seribu Island district in the electrification ratio calculation. Source: PLN statistics, calculated by the authors.

Kalimantan and Sulawesi islands; Western Indonesia covers the Sumatra, Java, and Bali islands. We find for all of these regions that the variance in SDT tends to decline over time, suggesting that the gap in electricity adoption within regions becomes smaller over time (Table 3). Furthermore, we find that variation in SDT is highest in the Eastern region and lowest in the Central region. The relatively high gap in the speed of diffusion of electricity across provinces within Eastern regions may be driven by the island structure that affected the PLN distribution network in those provinces. The relatively low variance in SDT in Central Indonesia is driven by low population density and geographical

interaction, while low SDT variance in Western Indonesia originates from a relatively high speed of electricity diffusion across the included provinces due to the Java-Bali interconnected system of electricity, high population density, and high geographical interactions.

### 5. Regression analysis

In this section, we aim to identify the spatially specific determinants of electricity diffusion across Indonesia, inspired by the geographic patterns of electricity diffusion as described in Sections 2 and 3. We do

**Table 2**  
Descriptive statistics: Key variables.

Variable	Obs.	Mean	SD	Min.	Max.
Electrification Ratio (% electrified households)	1452	0.38	0.26	0.01	1.00
Per Capita GDP (in Million Rupiah)	1452	7.55	8.98	0.12	57.90
Spatial Distance from Technology (SDT)	1452	69.94	29.47	18.81	213.01
Spatial Distance from Income (SDI)	1452	422.14	130.42	229.08	985.62
Population Density (people/km <sup>2</sup> )	1286	648.8	2280	3.30	15,589
People Distribution per Island (in Thousands)	1286	43.44	62.82	0.30	366
Share of Households Living in Flat Areas (% households)	1257	0.66	0.19	0.09	1.00
Firm Density (manufacturing firms/1000 people)	1286	0.06	0.05	0.00	0.3
Per Capita Installed Capacity (in Watts)	1286	76.88	73.17	2.85	650.07
Log per Capita GDP	1452	15.36	0.94	11.73	17.87
Log Population Density	1286	4.67	1.66	1.19	9.65
Log People Distribution	1286	9.58	1.66	5.71	12.81
Log per Capita Installed Capacity	1286	3.96	0.94	1.05	6.48

so in two steps. First, similarly to the approach taken by Comin et al. [2], we explain the electrification ratio  $x$  in province  $c$  in year  $t$  from  $SDT_{ct}$  and  $SDI_{ct}$  as follows:

$$x_{ct} = \beta_0 + \beta_1 \cdot SDT_{ct} + \beta_2 \cdot SDI_{ct} + \mu_c + d_s + \epsilon_{ct} \tag{3}$$

with  $\mu_c$  representing province fixed effects to capture the differential effect on electricity diffusion in a province relative to the rest. Furthermore, we include time trends (YEAR) and island dummies  $d_s$  by classifying Indonesia's 33 provinces into five main islands  $s$ , namely Sumatera, Java-Bali, Kalimantan, Sulawesi, and East (covering West Nusatenggara, East Nusatenggara, Maluku, North Maluku, Papua and West Papua). Of these, East includes provinces with the lowest electrification ratio's due to their remoteness and low population density. If being close to adoption leaders is beneficial for the diffusion of

electricity, as argued in section 3, we expect  $\beta_1$  to be negative. By including time trends, the identification of  $\beta_1$  comes from the relative change of SDT in provinces that are close to adoption leaders versus those that are far. For ease of interpretation, we re-scaled the SDT and SDI variables.

Second, we dig below the surface of SDT and SDI to identify which spatially specific variables, that correlate with income and distance from the provincial electricity adoption leader, help to explain the observed differences in the speed of electricity adoption across Indonesia's provinces. To this aim, we apply a regression approach based on the well-known S-shaped technology diffusion curve [24] in which electricity adoption initially is low and increases slowly (stage 1), followed by rapid growth during the take-off phase (stage 2) and concluded with a low and diminishing growth rate at a high adoption level (stage 3). This pattern is loosely supported by the observed non-linear evolution of the electrification ratio over time across Indonesia's provinces (Fig. 4). More specifically, we assume that the evolution of the electrification ratio  $x$  in province  $c$  over time  $t$  can be described by a continuous logistic function between 0 and 1, as follows:

$$x_{ct} = \frac{1}{1 + e^{-\sum_{i=1}^N \beta_i X_{it} + \epsilon_{i(ct)}}} \tag{4}$$

where the parameter  $\beta_i$  determines the speed of diffusion, driven by a set of  $N$  variables  $X$  indexed  $i$ . We estimate equation (4) by using a non-linear least squares (NLS) transformation, adopted from Lankhuizen et al. [41]:

$$\begin{aligned} x_{ct} = & 1 / (1 + \exp(-1 \cdot (\beta_{-}(0) + \beta_{-}(1) \cdot \log\_GDPcap_{ct}) \\ & + \beta_{-}(2) \cdot \log\_POPDENS_{ct}) \\ & + \beta_3 \cdot \log\_ISLIDIST_{ct} + \beta_4 \cdot PCT\_HHFLAT_{ct} + \beta_5 \cdot TIME_{ct} \\ & + \beta_6 \cdot FIRMDENS_{ct} + \beta_7 \cdot \log\_WATCAP_{ct})) + \epsilon_{ct} \end{aligned} \tag{5}$$

in which the set of variables  $X$  that explain the speed of electrification are defined as follows: GDP per capita ( $GDPcap_{ct}$ ); population density ( $POPDENS_{ct}$ ); the number of people per island within one province ( $ISLIDIST_{ct}$ ); the share of households living in flat areas ( $PCT\_HHFLAT_{ct}$ );

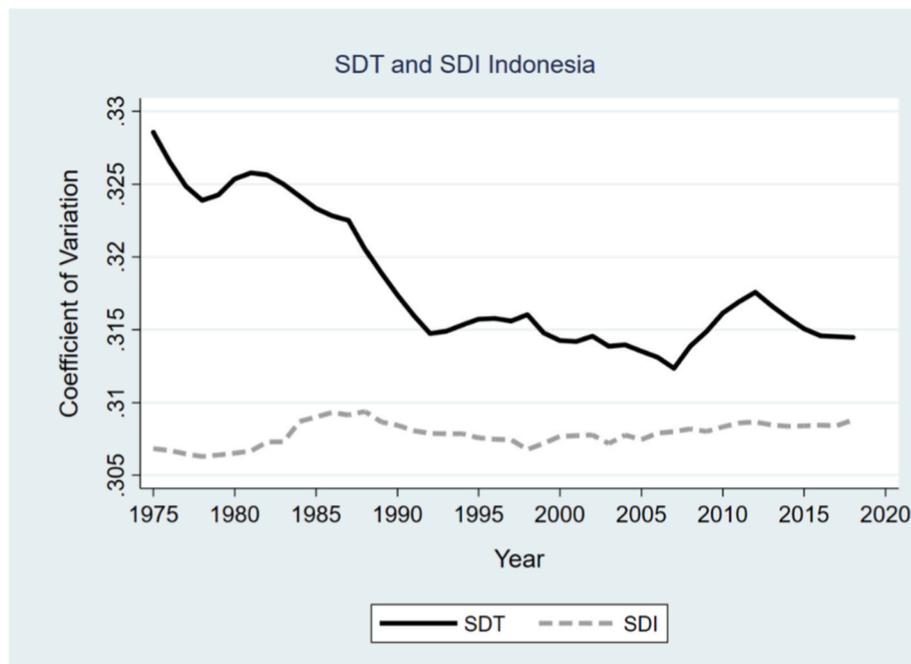
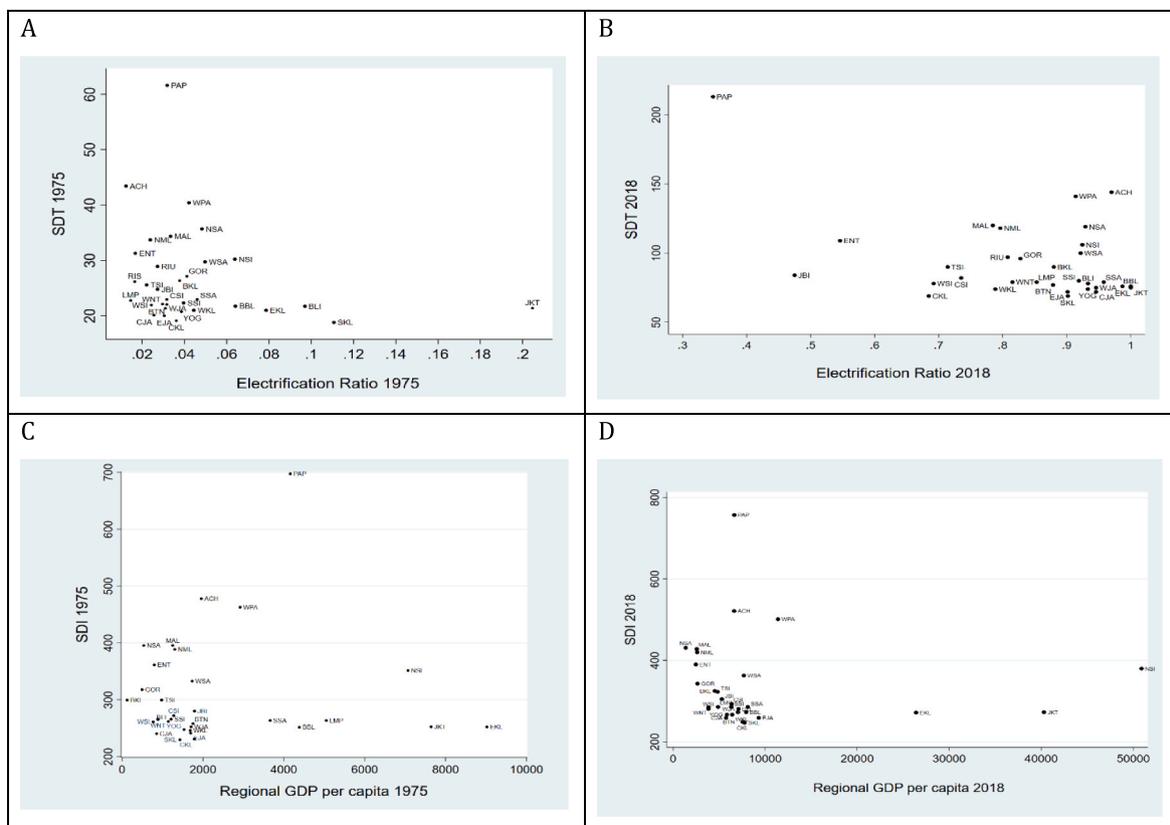


Fig. 5. Variance SDT and SDI across provinces, 1975–2018.



**Fig. 6.** Correlation between SDT and the electricity ratio (Panel A and B) and between SDI and regional GDP per capita (Panel C and D), 1975 and 2018. Note: Panel C and D without outliers of Riau and Riau Islands. We exclude these two provinces because those are income-poor but resource-rich provinces.

**Table 3**  
Variance SDT and SDI across provinces within regions in Indonesia, 1975–2018.

Coefficient of Variation		1975	1995	2008	2018	Changes (%)	
						1975–2018	2008–2018
<b>Spatial Distance from Technology (SDT)</b>							
Indonesia (all islands)	SDT	0.3286	0.3157	0.3139	0.3145	-4.29	0.19
	SDI	0.3068	0.3076	0.3082	0.3088	0.64	0.20
Western Region (Sumatera, Java, Bali)	SDT	0.2476	0.2242	0.2190	0.2217	-10.45	1.23
	SDI	0.2174	0.2188	0.2203	0.2208	1.56	0.22
Central Region (Kalimantan, Sulawesi)	SDT	0.1575	0.1494	0.1489	0.1478	-6.21	-0.73
	SDI	0.1439	0.1438	0.1439	0.1442	0.25	0.25
Eastern Region (Nusa Tenggara, Maluku, Papua)	SDT	0.3582	0.3491	0.3457	0.3491	-2.54	0.98
	SDI	0.3418	0.3436	0.3445	0.3447	0.86	0.06

time ( $TIME_{cd}$ ); firm density defined as the number of firms per 1000 inhabitants ( $FIRMDENS_{cd}$ ); per capita installed capacity in watts ( $WATCAP_{cd}$ ). Following much previous evidence (see, for example, [4,42]), we thus hypothesize that electricity diffusion is faster in provinces with more economic activities, more densely populated areas, a less scattered population living across islands, more people living in flatter areas, more firms operating and a larger power supply. As regards the latter, Indonesia comprises a series of autonomous self-contained electricity systems, as the islands are not connected in terms of electricity infrastructure (except for Java-Bali). Hence, cross-island differences in the timing of the arrival of power supply (i.e., investment in the first power plant by PLN) are an obvious determinant of cross-island differences in the speed of electricity diffusion; after all, PLN did not install first-time electricity generation capacity in the same year across all islands. A detailed description of the calculation of the installed capacity can be found in Appendix B3.

It is important to note that our analysis does not aim to identify causal relationships between GDP and electricity access, as this would

require a different methodological approach focused on causal inference. Instead, we focus on comparing the relative pace of electrification across regions and assessing the relative importance of several drivers, including GDP, population density, and firm density. The estimated regression model is therefore not intended as a stand-alone causal model, but as a tool to capture correlation patterns relevant for the simulation analysis in section 6.

Table 4 presents the results of our first regression model (equation (3)), in which we identify the role of SDT and SDI in determining electrification ratios. Column (1) in Table 4 reports only the effect of SDT and SDI without island dummies. We introduce island dummies and their interaction with SDT and SDI to see how electricity adoption varies across islands as shown in columns (2) and (3), respectively. We find a negative statistically significant effect of both SDT and SDI on a province's adoption in all specifications, confirming that distance to the economic core indeed imply slower electricity adoption and lower income. The results also show that controlling for SDI does reduce the estimate of geographic interactions in technology as indicated by SDT,

**Table 4**  
Identification of geographical interactions in diffusion electricity.

Variables	Dependent Variable: Electrification Ratio ( $x_{Ci}$ )				
	(0)	(1)	(2)	(3)	(4)
SDT	-1.620*** (0.219)	-1.240*** (0.237)	-1.340*** (0.225)	-1.130*** (0.237)	-1.420*** (0.230)
SDI		-0.352*** (0.086)	-0.493*** (0.080)	-0.622*** (0.137)	-0.303** (0.132)
SDT_SMTR			2.380*** (0.223)		2.580*** (0.247)
SDT_JVB			4.200*** (0.312)		4.220*** (0.341)
SDT_KLMT			0.794** (0.386)		1.040** (0.424)
SDT_SLWS			0.661** (0.273)		0.829*** (0.299)
SDI_SMTR				0.454** (0.184)	-0.354* (0.191)
SDI_JVB				0.125*** (0.247)	-0.0243 (0.253)
SDI_KLMT				-0.314 (0.318)	-0.469 (0.327)
SDI_SLWS				-0.148 (0.232)	-0.324 (0.238)
YEAR	0.0201*** (0.0003)	0.0198*** (0.0003)	0.0177*** (0.0004)	0.0196*** (0.0004)	0.0177*** (0.0004)
Constant	-39.67*** (0.668)	-38.89*** (0.691)	-34.74*** (0.755)	-38.52*** (0.693)	-34.68*** (0.757)
Province FE	Yes	Yes	Yes	Yes	Yes
Observations	1452	1452	1452	1452	1452
R-squared	0.916	0.917	0.929	0.919	0.930
No of province	33	33	33	33	33

but to a limited extent. Hence, non-technological mechanisms of geographical interactions that are correlated with income (captured by SDI) indeed do play a role in explaining electricity diffusion, but by no means overrule geography as a force of its own.

When we control SDT for interactions with dummy islands (column 2), the net effect of SDT on electricity adoption in Sumatera and Java-Bali is positive while it is negative in Kalimantan and Sulawesi islands. Thus suggests that the speed of electricity diffusion of the provinces within Java-Bali and Sumatera islands is faster compared to the provinces located within Kalimantan and Sulawesi islands due to geographic interactions that favour the evolution of a better electricity network at Java-Bali and Sumatera islands. This is in line with PLN's roadmap to accelerate the electricity ratio throughout Indonesia – since 1985 PLN has established an interconnected system for Java-Bali islands which led to a fully integrated system by 1995, followed by Sumatera island in 2014, as well as Kalimantan and Sulawesi in 2018 (PLN 2017). When we control SDI for interactions with dummy islands (column 3), the negative effect of SDI on electricity adoption in Kalimantan and Sulawesi islands is amplified, while the opposite is true for Sumatera and Java-Bali – further confirming the impact of geographical distance dependent income levels (or for that matter development stages) on electricity adoption.

Next, we dig below the surface of SDT and SDI by presenting in Table 5 the regression results of equation (5), thus identifying which spatially specific variables that correlate with SDT and SDI help to explain the observed differences in the speed of electricity adoption across Indonesia's provinces. These variables essentially define the diffusion speed of electricity in the context of the S-curve, as described in equation (4). To smoothen out the short-term fluctuations in our dataset, we use five-year moving averages. The results in Table 5 show that an increasing per capita GDP, higher population density, less scattered population living across islands, larger share of households living in flat areas, higher firm density, and higher per capita capacity all positively impact the speed of electricity diffusion. These coefficients are statistically significant except for firm density (Table 5 column 1). The latter result might be because firms' location is concentrated only in a few

**Table 5**  
Relative contribution of determinants of the electrification ratio (dependent variable).

Variables (Expected Sign of $\beta$ )	Predicted $\beta$ (1)	Average Marginal Effect (2)	Marginal Effect at Means (3)
Logper capita GDP (+)	0.112*** (0.024)	0.0217*** (0.005)	0.0274*** (0.006)
Log population density (+)	0.180*** (0.017)	0.0349*** (0.003)	0.0441*** (0.004)
Log island distribution (-)	-0.159*** (0.011)	-0.0308*** (0.002)	-0.0390*** (0.003)
Share pop in flat area (+)	0.429*** (0.092)	0.0832*** (0.018)	0.1053*** (0.023)
Time (+)	0.046*** (0.002)	0.0089*** (0.001)	0.0112*** (0.001)
Firm density (+)	0.176 (0.604)	0.0341 (0.117)	0.0432 (0.148)
Logper capita capacity (+)	0.717*** (0.043)	0.1390*** (0.008)	0.1759*** (0.011)
Constant	-5.715*** (0.394)		
# of observations	1112	1112	1112
R <sup>2</sup>	0.967	0.964	0.970

Notes: Robust standard errors in parentheses. \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ .

areas within provinces; many big factories have their generators to ensure that they can operate uninterruptedly, so the concentration of firms is not statistically significant in the relationship with the electrification ratio. This implies that connecting people involves more pressure than providing electricity to firms.

Also in Table 5 we calculate the marginal effect at means to measure the magnitude of the respective variables' correlation with the electricity ratio as reported in the third column. As expected, the installed capacity of the power supply at an island is an important driver of the acceleration of electricity diffusion. If we increase the installed capacity per capita by 1 percent, we expect the share of electrified households to increase by 0.176 points. Since the electricity supply is an autonomous self-contained system on each island, and the timing of investments in

installed power supply capacity by PLN differs across islands, this suggests that the geographic island barrier is a main determinant of the (lack of) speed of electricity diffusion. Our analysis also shows that the geographic structure, as presented by the share of the population living in flat areas, contributes to speeding up the electricity diffusion process. We expect that the electrification ratio will increase by 0.1 as the share of flat areas increases by 1 point. Indonesia has a high variation in population density, ranging from 3.3 to 15,589 people per square kilometre (Table 2). Our results show that, if the population density increases by 1 percent, we expect the electrification ratio to rise by 0.044 points. Time also contributes to speeding up electrification. For every additional 10 years, we expect that the electrification ratio will increase by 1.1 points. This could explain why the provinces in Java and other islands that have already been connected since the early 1900s also experience a higher electrification ratio.

Finally, we translate the non-linear least square regression outcomes into the  $\beta$  parameter in the S-curve. By plugging the estimated  $\beta_i$  into our sample, we obtain the estimated electrification ratio to produce an S-curve over time for each province. The results, presented in Fig. 7, show that the predicted values reproduce actual trends very well, with a few exceptions. These exceptions are largely due to data inconsistencies, implied by the splitting of several provinces after decentralization as discussed in section 4.

### 6. Geography and diffusion patterns

Finally, we present the results of a simulation exercise in which we use the regression results of Section 5 to calculate how long it would have taken for a province  $i$  to reach a certain electrification ratio under the condition that a province would have had the same (combination of) features that helped driving the speed of electrification in the leading

province of Jakarta. These features include the power supply, per capita GDP, geographical landscape, and population density. We choose to take as relatively arbitrary thresholds 50 percent to reflect the mid-point of the S-curve and 25 percent threshold to mark the acceleration of electricity adoption above the take-off level of 10 percent. As noted we use Jakarta (excluding Seribu Island district) as a benchmark, because it is the economically most advanced and earliest fully electrified province – its electrification ratio reached 100 percent in 2008. We calculate the gap in years between the electrification rate of Jakarta and province  $i$  by comparing the predicted electrification rate of province  $i$  following the methodology developed in section 5, with the hypothetical rate in case that province would have had the power supply, per capita GDP, geographical landscape and population density of Jakarta. Finally, we decompose the total gap in years into the contribution of each of these features to the total gap.

The results of our simulation exercise at the Island level are presented in Table 6. Simulation 1 uses only the power supply of Jakarta; Simulation 2 adds this per capita GDP of Jakarta; Simulation 3 adds to this landscape of Jakarta; Simulation 4 includes all of these features. The results show that the Eastern Islands would have reached the threshold of a 50 % electrification ratio 26 years earlier if they would have had the same features as Jakarta. Of these features, the difference in power supply availability contributed 45 percent to the total gap in years, followed by differences in population density (34 %), per capita GDP (12 %), and landscape (9 %). A similar result is obtained when using the 25 percent electrification threshold. Also for the other islands, power supply availability and population density emerge as the most important drivers of the difference in time needed to reach a certain electrification rate at different islands. From Table 6 it can also be seen that population density plays a stronger role in reaching the first threshold of 25 percent electricity access than in reaching the 50 percent electrification ratio.

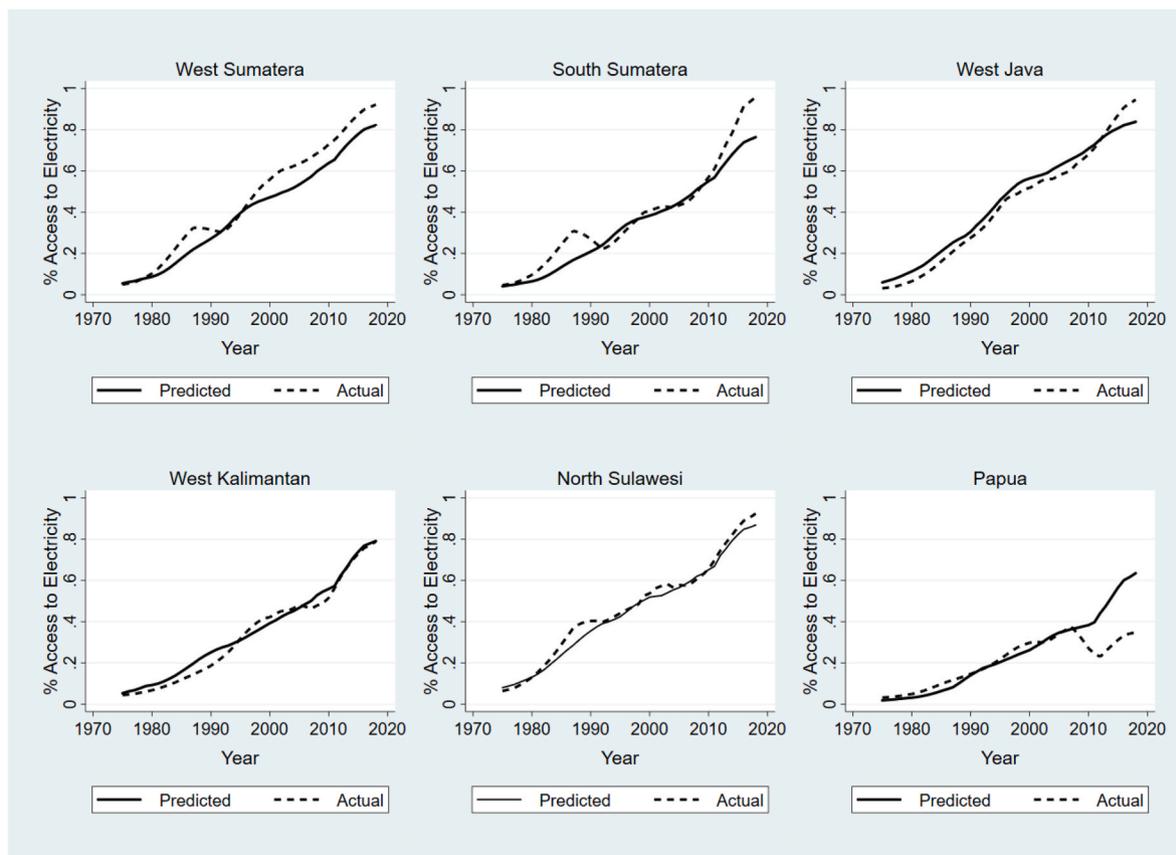


Fig. 7. Predicted and actual diffusion of electricity pattern in selected provinces, 1975–2021. Source: Authors' calculation and estimation.

**Table 6**

Average time required and its decomposition to accelerate 50 percent and 25 percent electricity access by islands.

	Average Time Acceleration (Years)				Decomposition of Average Time Acceleration			
	Sim4	Sim3	Sim2	Sim1	Pop. Density JKT	Landscape JKT	GDP/Cap. JKT	Supply JKT
<i>At Least 50 % Access</i>								
Sumatera	18	10	9	6	47 %	7 %	16 %	31 %
Java Bali	7	3	2	0	64 %	11 %	25 %	0 %
Kalimantan	19	8	6	5	54 %	12 %	7 %	26 %
Sulawesi	21	13	11	9	38 %	9 %	9 %	44 %
Eastern	26	17	15	12	34 %	9 %	12 %	45 %
<i>At Least 25 % Access</i>								
Sumatera	11	4	3	2	61 %	9 %	13 %	17 %
Java Bali	5	2	2	0	65 %	4 %	31 %	0 %
Kalimantan	13	4	3	2	71 %	4 %	8 %	18 %
Sulawesi	12	5	5	4	60 %	0 %	9 %	32 %
Eastern	18	11	10	8	42 %	5 %	8 %	44 %

Note: Authors' calculation from Tables 7 and 8.

Sim1 (with supply of Jakarta), Sim2 (with supply and per capita GDP of Jakarta), Sim3 (with supply, per capita GDP, and landscape of Jakarta), and Sim4 (with supply, per capita GDP, landscape and population density of Jakarta).

The relatively big gap in time for the Eastern Islands is in line with the findings of Comin et al. [2] that technology diffuses more slowly to locations that are farther away from the adoption leaders.

Tables 7 and 8 present the result of the same simulation exercise results as well as the factor decomposition contributing to the gap. The results show that Papua, located in the Eastern islands, features the largest gap with Jakarta in Simulation 4 (using all of Jakarta's characteristics) - it would have reached the 50 percent electricity access threshold 30 years faster if it have had all Jakarta's characteristics. If we simulate Papua using only the power supply of Jakarta (Simulation 1), the power supply and per capita GDP of Jakarta (Simulation 2), or the power supply, per capita GDP, and landscape of Jakarta (Simulation 3), then it would have taken Papua respectively 10, 13 and 17 years less to reach the threshold of having at least half of its households electrified (Table 7). In contrast, West Java, as part of Java Island, where the power supply system is the same as that of Jakarta and which has been electrified since 1900, features the smallest time gap with Jakarta in our simulation (see also Fig. 8). If West Java had Jakarta's features it would have reached the 50 percent electrification threshold only 2–7 years faster than it actually did.

From these simulations, it appears again that in most provinces population density (as an endogenous factor) and power supply availability (as an exogenous factor) are the main driving determinants of the observed time gap in reaching a certain electrification ratio. - Given the large fixed and sunk costs involved in electricity networks, higher population density increases demand concentration, lowers average connection costs, and improves the economic viability of both grid expansion and capacity upgrades, thereby accelerating electrification. In the Indonesian context, these effects are amplified by geographic fragmentation across islands. In densely populated regions – such as Java–Bali– electricity investments can exploit economies of scale and benefit from network externalities, resulting in earlier and faster diffusion. In contrast, in sparsely populated islands, the same investments must be spread over fewer users and longer distances, which delays electrification even when generation capacity becomes available. Especially in the provinces located in the Eastern islands, it is the availability of the power supply that is the main driving force. Table 7 shows that provinces in the eastern part of Indonesia, that is, Sulawesi (except North Sulawesi), Nusa Tenggara, Maluku, and Papua islands would have reached the 50 percent electrification threshold 10–14 years earlier if they would have had Jakarta's power supply capacity. Again, the dominance of power supply availability is less strong when we consider the time gap to reach the lower threshold of 25 % electrification (Table 8) – population density again plays a relatively strong role here. These results support the idea that the availability of power supply is more important at lower levels of population density when fewer people can potentially gain access to electricity.

## 7. Conclusions

This study set out to investigate the long-term spatial diffusion of electricity in a major Global South country—Indonesia—through the lens of regional variation in electrification outcomes over four decades. Building on newly developed, consistent historical time series data from 1975 to 2018, we provided new empirical evidence that electrification diffusion in Indonesia has been a protracted and uneven process, shaped by local geographic, economic, and demographic conditions. While national electrification rates have approached 100 percent in recent years, remote provinces—particularly in Eastern Indonesia—continue to lag behind. Our findings underthe importance of spatial heterogeneity for understanding the dynamics and drivers of electricity access in geographically fragmented countries.

To structure the analysis, we introduced a novel analytical framework combining a two-step regression model with a backcasting simulation exercise. The first step identified how distance from the national economic and technological core (Jakarta) mediates regional electrification trajectories. The second step employed a non-linear diffusion model to estimate the impact of key explanatory factors—namely, per capita GDP, population density, electricity supply, and landscape characteristics—on the speed of electrification. We then used these regression outcomes to simulate counterfactual adoption scenarios, quantifying how differences in structural characteristics translate into delays or accelerations in electrification progress. In particular, the simulations show that several Eastern provinces could have reached a 50 percent electrification threshold up to 26 years earlier under more favorable conditions.

Our analysis builds on a newly developed dataset, providing consistent time series on installed electricity generation capacity and household electrification ratios at the (sub-)regional level in Indonesia derived from previously unpublished energy statistics of Indonesia's national electricity utility company PLN, for the period 1975 to 2018. We complemented these data with information on per capita GDP, population density, firm density, landscape complexity (measured as the share of households living in flat areas), and per capita installed electricity generation capacity across provinces and islands.

Our contribution is threefold. First, we document long-term electrification patterns at the subnational level in a large, lower-middle-income country. Second, we extend spatial diffusion analysis to the subnational level, exploiting within-country heterogeneity in geography and economic structure. Third, we demonstrate how our framework can be used to evaluate disparities in electrification progress and to simulate the potential effects of structural convergence across regions.

We find that electrification adoption initially is slower in locations that are further away from the adoption leader (Jakarta), with the discrete diffusion of power supply across islands emerging as a key

**Table 7**  
Simulation Scenario 1: At least 50 Percent access to Electricity.

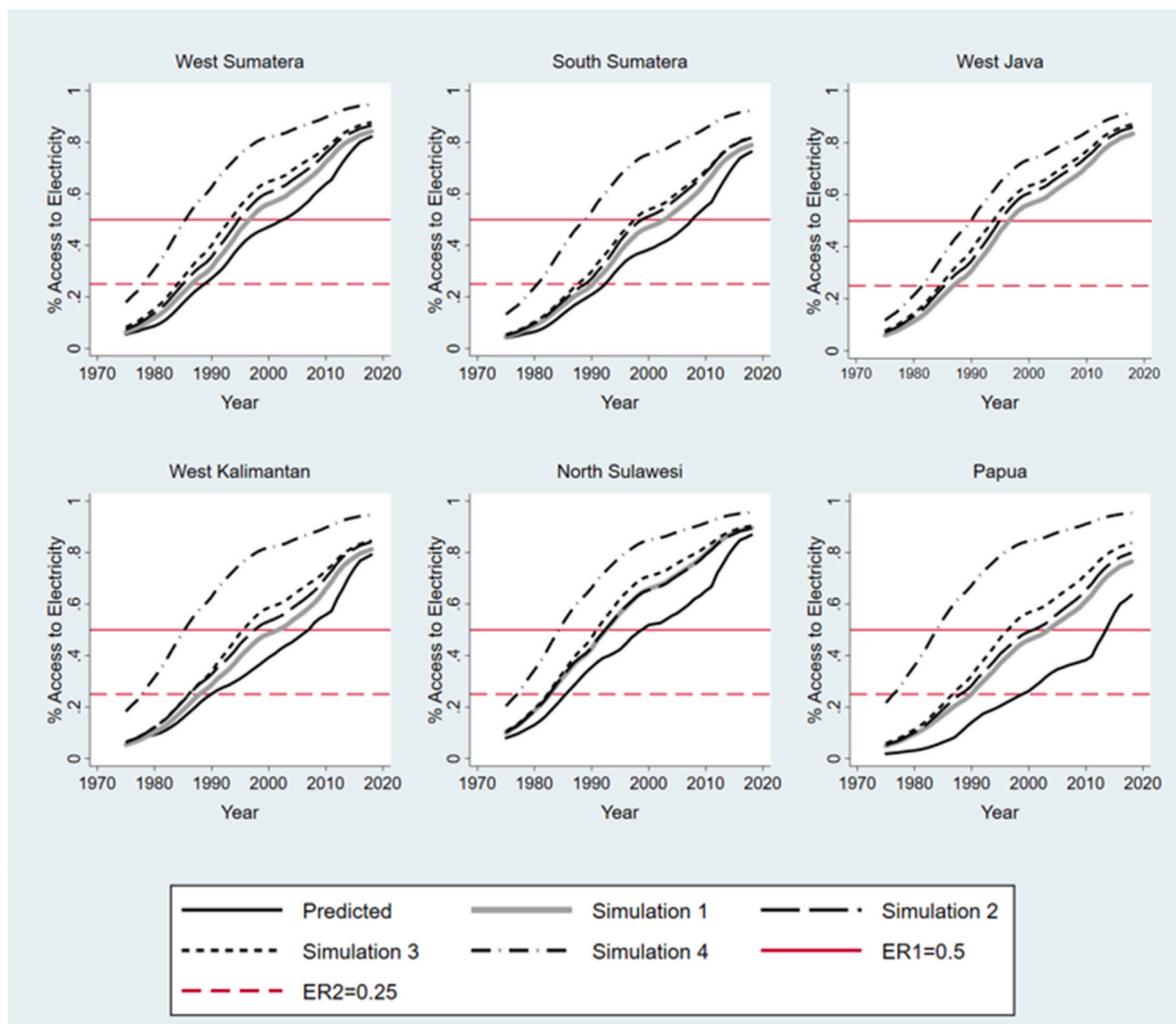
Province	Year when at least 50 % access to electricity					Changes (years)				Decomposition of % year changes				
	Predicted	Sim1	Sim2	Sim3	Sim4	Predicted - Sim4	Predicted - Sim3	Predicted - Sim2	Predicted - Sim1	All JKT	Population Density JKT	Landscape JKT	Per Capita GDP JKT	Supply JKT
<i>Sumatera Island</i>														
Aceh	1999	1995	1994	1994	1985	14	5	5	4	100 %	64 %	0 %	7 %	29 %
North Sumatera	2008	2001	1996	1994	1987	21	14	12	7	100 %	33 %	10 %	24 %	33 %
West Sumatera	2003	1997	1995	1994	1986	17	9	8	6	100 %	47 %	6 %	12 %	35 %
Riau	2006	1999	1998	1996	1987	19	10	8	7	100 %	47 %	11 %	5 %	37 %
Jambi	2010	2006	2002	1999	1989	21	11	8	4	100 %	48 %	14 %	19 %	19 %
South Sumatera	2008	2003	1999	1998	1989	19	10	9	5	100 %	47 %	5 %	21 %	26 %
Bengkulu	2007	2001	1997	1996	1987	20	11	10	6	100 %	45 %	5 %	20 %	30 %
Lampung	2003	1997	1995	1994	1987	16	9	8	6	100 %	44 %	6 %	13 %	38 %
<i>Java-Bali Island</i>														
West Java	1997	1997	1995	1994	1990	7	3	2	0	100 %	57 %	14 %	29 %	0 %
Central Java	1996	1996	1994	1993	1989	7	3	2	0	100 %	57 %	14 %	29 %	0 %
Yogyakarta	1996	1996	1994	1993	1989	7	3	2	0	100 %	57 %	14 %	29 %	0 %
East Java	1996	1996	1994	1994	1989	7	2	2	0	100 %	71 %	0 %	29 %	0 %
Bali	1995	1995	1994	1993	1987	8	2	1	0	100 %	75 %	13 %	13 %	0 %
<i>Kalimantan Island</i>														
West Kalimantan	2007	2002	1998	1996	1986	21	11	9	5	100 %	48 %	10 %	19 %	24 %
Central Kalimantan	2012	2008	2007	2002	1988	24	10	5	4	100 %	58 %	21 %	4 %	17 %
South Kalimantan	2001	1996	1995	1994	1986	15	7	6	5	100 %	53 %	7 %	7 %	33 %
East Kalimantan	2006	1999	1999	1997	1985	21	9	7	7	100 %	57 %	10 %	0 %	33 %
<i>Sulawesi Island</i>														
North Sulawesi	1999	1993	1993	1991	1985	14	8	6	6	100 %	43 %	14 %	0 %	43 %
Central Sulawesi	2009	1999	1996	1994	1984	25	15	13	10	100 %	40 %	8 %	12 %	40 %
South Sulawesi	2009	1998	1996	1994	1987	22	15	13	11	100 %	32 %	9 %	9 %	50 %
Southeast Sulawesi	2008	1998	1995	1993	1984	24	15	13	10	100 %	38 %	8 %	13 %	42 %
<i>Eastern Islands</i>														
West Nusatenggara	2005	1995	1993	1991	1985	20	14	12	10	100 %	30 %	10 %	10 %	50 %
East Nusatenggara	2012	1998	1995	1993	1984	28	19	17	14	100 %	32 %	7 %	11 %	50 %
Maluku	2011	1998	1993	1992	1984	27	19	18	13	100 %	30 %	4 %	19 %	48 %
Papua	2014	2004	2001	1997	1984	30	17	13	10	100 %	43 %	13 %	10 %	33 %

Note: Sim1 (with Supply Jakarta), Sim2 (with Supply and Per Capita GDP Jakarta), Sim3 (with Supply, Per Capita GDP, Landscape Jakarta), Sim4 (with Supply, Per Capita GDP, Landscape, Population Density Jakarta).

**Table 8**  
Simulation Scenario 2: At least 25 percent Access to Electricity.

Province	Year when at least 25 % access to electricity					Changes (years)				Decomposition of % year changes				
	Predicted	Sim1	Sim2	Sim3	Sim4	Predicted - Sim4	Predicted - Sim3	Predicted - Sim2	Predicted - Sim1	All JKT	Population Density JKT	Landscape JKT	Per Capita GDP JKT	Supply JKT
<i>Sumatera Island</i>														
Aceh	1986	1984	1984	1984	1978	8	2	2	2	100 %	75 %	0 %	0 %	25 %
North Sumatera	1992	1990	1986	1985	1979	13	7	6	2	100 %	46 %	8 %	31 %	15 %
West Sumatera	1989	1987	1986	1985	1978	11	4	3	2	100 %	64 %	9 %	9 %	18 %
Riau	1989	1987	1987	1987	1979	10	2	2	2	100 %	80 %	0 %	0 %	20 %
Jambi	1994	1993	1991	1989	1981	13	5	3	1	100 %	62 %	15 %	15 %	8 %
South Sumatera	1993	1991	1989	1988	1981	12	5	4	2	100 %	58 %	8 %	17 %	17 %
Bengkulu	1993	1991	1988	1986	1979	14	7	5	2	100 %	50 %	14 %	21 %	14 %
Lampung	1988	1986	1986	1985	1980	8	3	2	2	100 %	63 %	13 %	0 %	25 %
<i>Java-Bali Island</i>														
West Java	1987	1987	1986	1985	1982	5	2	1	0	100 %	60 %	20 %	20 %	0 %
Central Java	1986	1986	1984	1984	1981	5	2	2	0	100 %	60 %	0 %	40 %	0 %
Yogyakarta	1986	1986	1984	1984	1981	5	2	2	0	100 %	60 %	0 %	40 %	0 %
East Java	1986	1986	1985	1985	1981	5	1	1	0	100 %	80 %	0 %	20 %	0 %
Bali	1986	1986	1984	1984	1980	6	2	2	0	100 %	67 %	0 %	33 %	0 %
<i>Kalimantan Island</i>														
West Kalimantan	1990	1988	1987	1987	1978	12	3	3	2	100 %	75 %	0 %	8 %	17 %
Central Kalimantan	1996	1993	1991	1990	1980	16	6	5	3	100 %	63 %	6 %	13 %	19 %
South Kalimantan	1988	1986	1985	1985	1978	10	3	3	2	100 %	70 %	0 %	10 %	20 %
East Kalimantan	1990	1988	1988	1987	1977	13	3	2	2	100 %	77 %	8 %	0 %	15 %
<i>Sulawesi Island</i>														
North Sulawesi	1986	1983	1983	1983	1977	9	3	3	3	100 %	67 %	0 %	0 %	33 %
Central Sulawesi	1990	1986	1985	1985	1977	13	5	5	4	100 %	62 %	0 %	8 %	31 %
South Sulawesi	1991	1987	1985	1985	1979	12	6	6	4	100 %	50 %	0 %	17 %	33 %
Southeast Sulawesi	1989	1985	1984	1984	1976	13	5	5	4	100 %	62 %	0 %	8 %	31 %
<i>Eastern Islands</i>														
West Nusatenggara	1992	1985	1983	1983	1977	15	9	9	7	100 %	40 %	0 %	13 %	47 %
East Nusatenggara	1996	1987	1985	1984	1977	19	12	11	9	100 %	37 %	5 %	11 %	47 %
Maluku	1992	1985	1985	1984	1976	16	8	7	7	100 %	50 %	6 %	0 %	44 %
Papua	2000	1991	1989	1987	1977	23	13	11	9	100 %	43 %	9 %	9 %	39 %

Note: Sim1 (with Supply Jakarta), Sim2 (with Supply and Per Capita GDP Jakarta), Sim3 (with Supply, Per Capita GDP, Landscape Jakarta), Sim4 (with Supply, Per Capita GDP, Landscape, Population Density Jakarta).



**Fig. 8.** Simulation Scenarios to Reach Electrification Ratios of at Least 50 Percent and 25 Percent.  
 Note: Simulation 1 (with the supply of Jakarta), Simulation 2 (with the supply and per capita GDP of Jakarta), Simulation 3 (with the supply, per capita GDP, and landscape of Jakarta), and Simulation 4 (with the supply, per capita GDP, landscape and population density of Jakarta).

driver of the speed of electricity diffusion across space, followed by differences in population density, per capita GDP and landscape characteristics. A simulation exercise revealed that the Eastern Islands of Indonesia would have reached the threshold of a 50 % electrification ratio 26 years earlier if they would have had the same features as Jakarta. These results highlight the importance of within-country spatial interactions for understanding electrification dynamics in large, heterogeneous countries. Following the decentralization reforms initiated in 2000, Indonesia's electrification strategy increasingly relied on coordinated multi-level governance. This institutional arrangement reduced coordination failures and mistargeting that had constrained earlier electrification efforts. At the same time, the introduction of direct presidential elections in 2004 further elevated electrification as a national political priority, reflected in successive large-scale generation and grid expansion programs. These institutional changes provide a plausible explanation for the empirical patterns observed in our analysis, especially the marked acceleration of electrification after the early 2000s and the declining role of spatial distance over time. The increasing importance of installed capacity and population density in

explaining electrification outcomes is consistent with a setting in which national supply-side programs are increasingly complemented by locally informed planning and implementation.

While the empirical analysis is grounded in the Indonesian context, it is important to distinguish between country-specific outcomes and more generalizable mechanisms. The exact magnitudes and timing of electrification outcomes documented in this paper reflect Indonesia's particular institutional history, policy sequencing, and archipelagic geography. Indonesia's pronounced spatial heterogeneity allows us to isolate mechanisms that are difficult to observe in more geographically compact countries. Our analysis identifies a set of structural relationships that are not inherently Indonesia-specific and that are likely to generalize to other large, spatially fragmented, or archipelagic countries with incomplete electrification. In particular, our results highlight the importance of geography-mediated diffusion mechanisms that operate through distance, population dispersion, and infrastructure indivisibilities. The strong role of the island barrier – captured through the discrete availability of generation capacity and the lack of interconnection across islands – is especially salient for archipelagic states. This

mechanism is therefore most directly relevant for countries with island geographies or highly fragmented territories or island regions within larger states. Moreover, the estimated marginal effects provide testable, policy-relevant hypotheses that can be examined in other national contexts. For example, our finding that a one-percentage-point increase in the share of flat areas is associated with an increase of roughly 0.1 points in the electrification ratio, that a one-percent increase in population density raises the electrification ratio by about 0.044 points, may reflect structural regularities rather than Indonesia-specific institutions.

These findings illustrate how geography, demography, and time interact to shape diffusion dynamics. They offer benchmarks that can be empirically evaluated in other countries facing similar spatial challenges, and they carry clear policy relevance. Rural electrification remains a critical component of achieving Sustainable Development Goal 7 (SDG7), which calls for universal access to affordable, reliable, and modern energy services by 2030. Despite significant global progress, recent estimates by the International Energy Agency (IEA) and the World Bank indicate that about 675 million people—predominantly in Sub-Saharan Africa—still lack electricity access as of 2023 (2025). Accelerating electrification in rural and underserved areas is therefore not only essential for achieving SDG7, but also for supporting broader goals related to health, education, and economic inclusion. Our findings suggest that targeted strategies that address local barriers—such as geographic remoteness, limited supply capacity, or sparse population—can help reduce inequality in electricity access even within countries that are close to achieving universal coverage in aggregate terms. Also, the case of Indonesia suggests that coordinated multi-level governance – with provincial authorities identifying priority locations for rural electrification programs while financing is largely provided by the central government and technical implementation is carried out by the national utility – may be a very effective institutional arrangement to overcome coordination failures and mistargeting in electrification programs.

Finally, our results suggest that accelerating electrification in geographically fragmented countries such as Indonesia requires a sequenced and spatially differentiated planning strategy. In frontier, outermost, and least developed regions—characterized by low population density, difficult terrain, and limited installed capacity—early electrification is most effectively achieved through decentralized and off-grid solutions. In Indonesia, this approach is reflected in the rural electrification program, which initially prioritizes solar photovoltaic (PV) systems and energy-saving solar home systems (Lampu Tenaga Surya Hemat Energi, LTSHE) to provide basic electricity services for approximately 6–8 h per day in non-electrified settlements. This first phase enables rapid access in areas where our analysis shows that grid-based diffusion would otherwise be slow and costly. Subsequent phases of electrification focus on extending service availability to 24 h and improving reliability, typically through integration with utility-operated mini-grids or extensions of the main grid. Our findings indicate that such grid-based investments should be prioritized in regions where structural conditions are more favorable—specifically, where population density is higher, terrain is relatively flat, and demand potential is sufficient to exploit economies of scale. Our empirical results thus underline the importance of aligning technology choice and investment sequencing with local geographic and demographic conditions.

At the same time, our approach has limitations. While we are able to capture structural drivers of regional electrification with high spatial

and temporal resolution, our dataset does not include information on the type, duration, or quality of electricity access. As a result, our measure of electrification primarily reflects connection rates rather than effective energy use or service quality. This distinction matters, as recent studies have shown that nominal grid connection often coexists with unreliable supply or unaffordable tariffs, particularly in rural or peripheral provinces (e.g., Ref. [43,44]). Moreover, the provincial level of aggregation used in this study, while necessary for data consistency over a long historical period, inevitably masks significant intra-provincial heterogeneity in electrification trajectories. Differences between coastal and inland districts, or between urban centres and remote islands, may therefore be understated. Future research could address this by using district- or village-level microdata or by integrating night-time light intensity as a proxy for electricity use.

A further limitation concerns the historical data harmonization and interpolation procedures applied to ensure temporal consistency. While these were carefully designed and tested, they may smooth short-term fluctuations or local discontinuities—for example, those caused by infrastructure damage or policy shifts. Similarly, our spatial diffusion indicators (SDT and SDI) capture geographic and economic proximity in a static way; they do not account for changes in transport networks or institutional coordination over time, which likely affected the pace of technology diffusion. Finally, our analysis focuses on structural determinants of electrification but abstracts from political economy dynamics, such as regional governance capacity, fiscal decentralization, or the strategic priorities of state-owned utilities. Future research could therefore combine our quantitative diffusion model with qualitative or mixed-methods approaches to better understand how institutional, political, and socio-cultural contexts mediate spatial inequality in electricity access. This could, for example, be done by applying complementary tools such as a PESTLE analysis (Political, Economic, Sociological, Technological, Legal, and Environmental) to assess how context-specific institutional and policy conditions interact with structural factors to shape electrification trajectories.

In conclusion, understanding the spatial dynamics of electricity diffusion is crucial for designing effective and equitable electrification strategies. Our analytical framework offers a replicable tool for other middle- and low-income countries aiming to address subnational disparities in access to modern energy services. Bridging these gaps is not only a technical and economic challenge, but also a matter of energy justice and inclusive development.

#### Credit author statement

Isfandiarni S. Rosidin: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Henri L.F. de Groot: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration, Funding acquisition, Peter Mulder, Conceptualization, Methodology, Investigation, Writing - Original Draft, Writing - Review & Editing, Supervision.

#### 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.

Appendix A. Additional results

**Table A**  
Correlation Matrix: Key Variables.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Electrification Ratio	1.000								
2. Per Capita GDP (in Million Rupiah)	0.303*	1.000							
3. Spatial Distance from Technology (SDT) in 000 km	0.424*	0.103*	1.000						
4. Spatial Distance from Income (SDI) in 000 rupiah	-0.077*	-0.016	0.782*	1.000					
5. Population Density	0.283*	0.412*	-0.107*	-0.150*	1.000				
6. People Distribution per Island (in Thousands)	0.129*	-0.112*	-0.211*	-0.317*	0.090*	1.000			
7. Share of Households Living in Flat Areas	0.206*	0.112*	-0.308*	-0.350*	0.295*	0.191*	1.000		
8. Firm Density	0.345*	0.294*	-0.163*	-0.297*	0.610*	0.378*	0.270*	1.000	
9. Per Capita Installed Capacity (in Watts)	0.715*	0.157*	0.168*	-0.191*	0.149*	0.266*	0.251*	0.353*	1.000

Note: \* $p < 0.01$ .

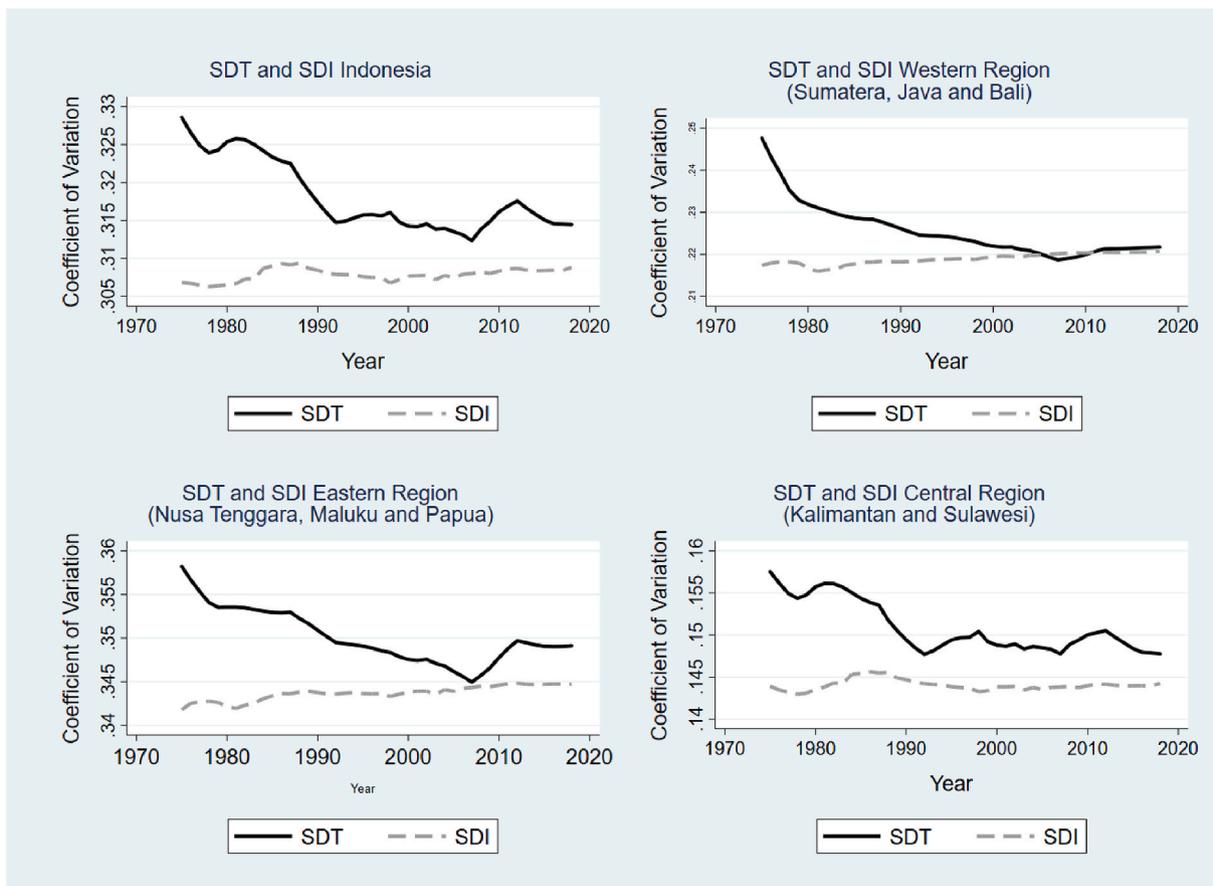


Fig. A.1. Variance SDT and SDI in Indonesia and across Provinces in 3 Main Regions of Indonesia.



Fig. A.2. Variance SDT and SDI across Provinces in 7 Main Islands of Indonesia.

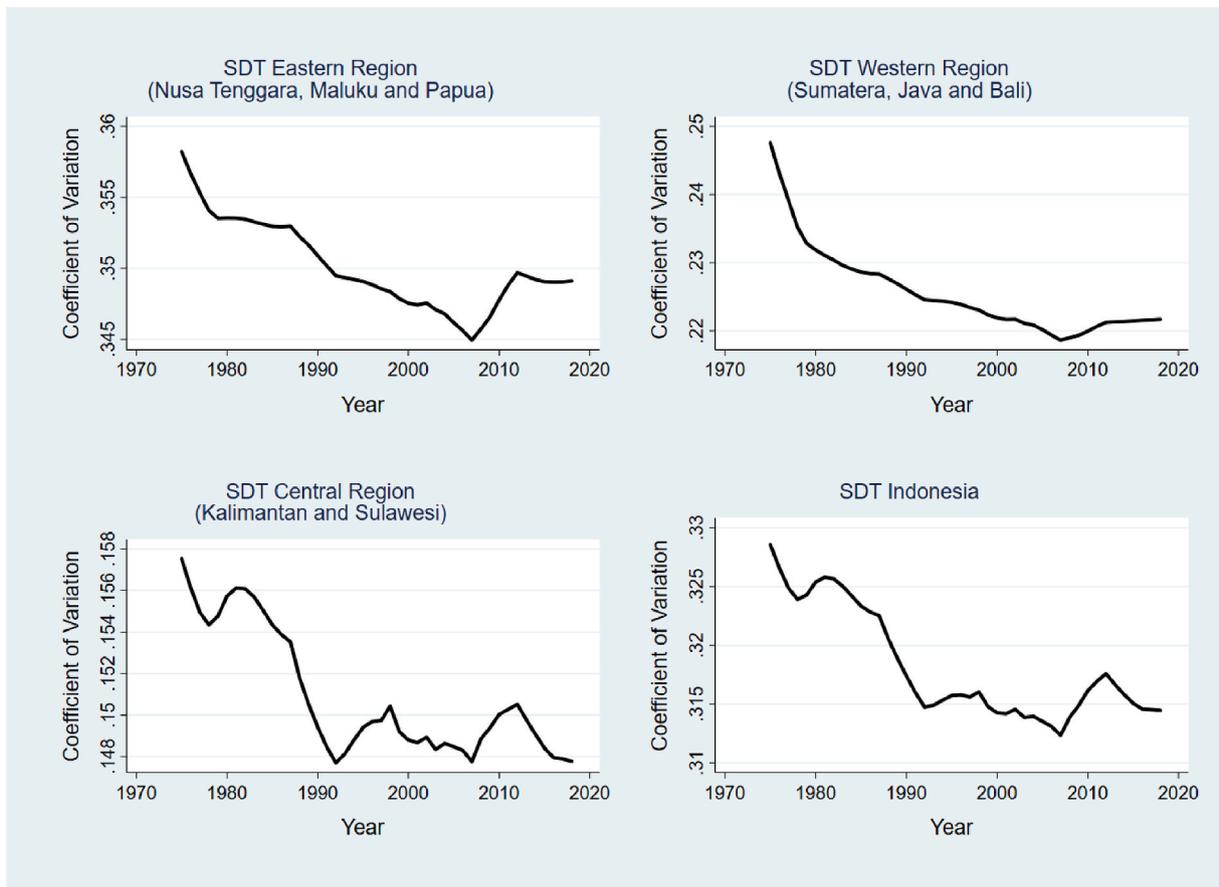


Fig. A.3. Variance SDT across Provinces within 3 Main Regions in Indonesia, 1975–2018.



Fig. A.4. Variance SDT across Provinces within 7 Main Islands in Indonesia, 1975–2018.

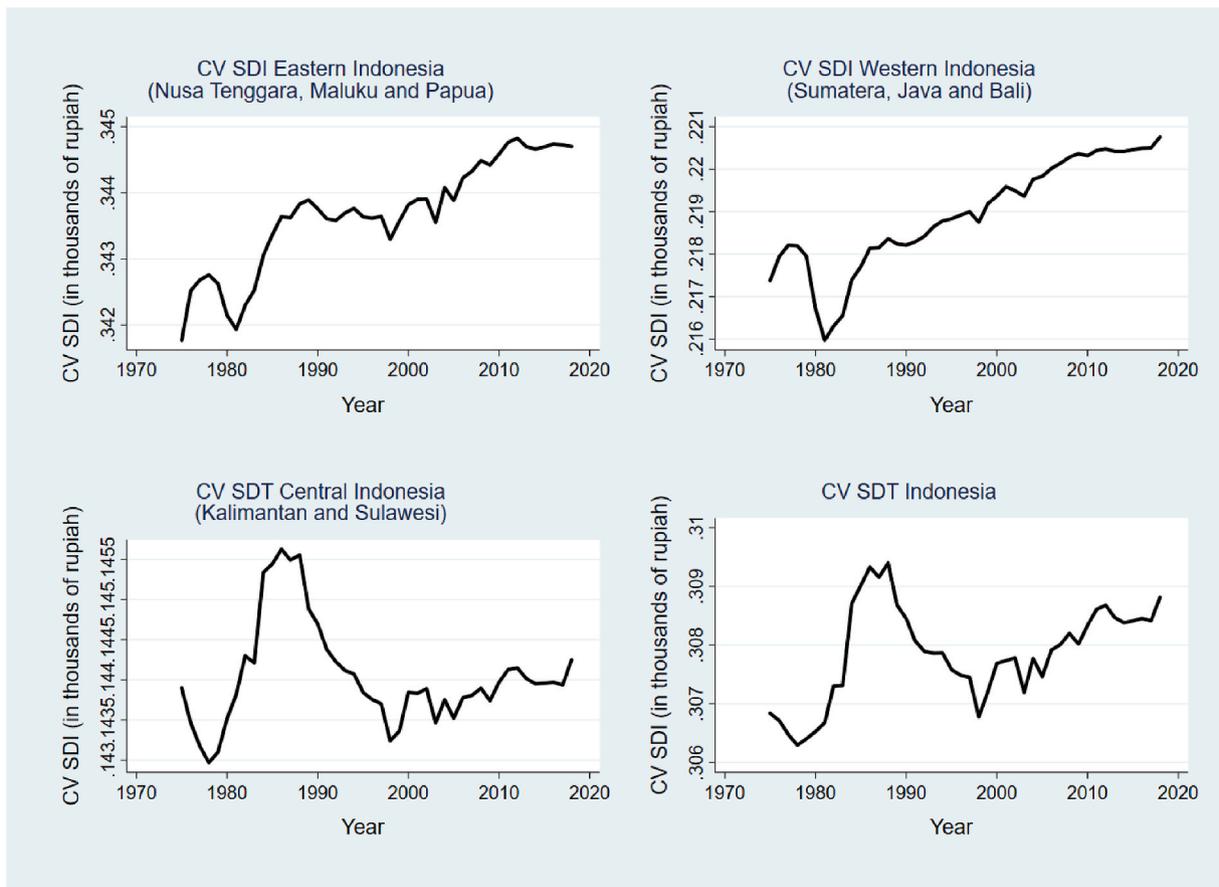


Fig. A.5. Variance SDI across Provinces within 3 Main Regions of Indonesia.



Fig. A.6. Variance SDI across Provinces within 7 Main Islands in Indonesia, 1975–2018.

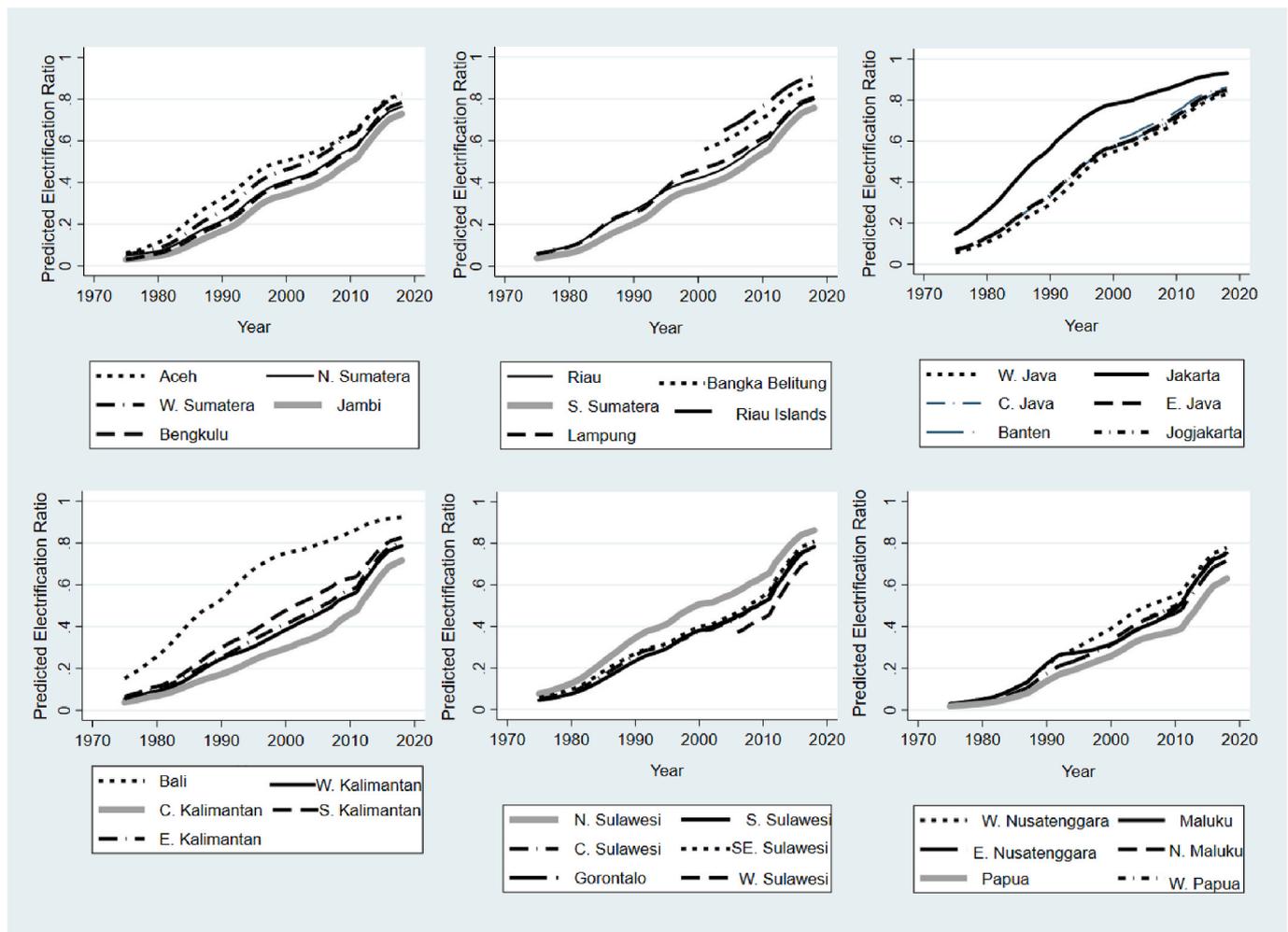


Fig. A.7. Predicted Electrification Ratio All Provinces, 1975–2018. Source: Authors' estimation

### Appendix B. Constructing a Long-term Electricity Dataset

Below we present the unique electricity dataset that we have constructed for the research presented in this paper. The dataset is constructed on the basis of unpublished statistics kept by PLN, Indonesia's main electricity provider. We also directly consult a resource person from PLN<sup>4</sup> to understand the technical aspects and the context behind the statistics. Below we explain the main features of our dataset and the methodological choices involved in processing the raw data.

#### B.1 Nomenclature and Dynamics of PLN Business Units

To serve customers throughout Indonesia, PLN established two main business units, *Kantor Wilayah* (the regional office) and *Kantor Distribusi* (the distribution office). *Kantor Wilayah* is responsible for managing not only the customer but also the production side, while *Kantor Distribusi* is mainly in charge of the customer side. In particular regions, such as Maluku and Papua, *Kantor Wilayah* performs three main functions, that is, production, transmission and distribution. Meanwhile, in Java–Bali, where all the systems are already interconnected, each function is carried out by an independent entity; that is, the production is under subsidiary companies, the transmission is carried out by the Transmission Load and Dispatch Centre (*Pusat Pengatur dan Penyaluran Beban –P3B*) and the distribution is performed by *Kantor Distribusi*. These task divisions are carried out for efficiency and reliability purposes. Due to this nature, PLN frequently changes its business units to accommodate the electricity development. This company's transformation affects our data collection process. For instance, PLN business units in 1975 comprised 1 generating unit, 2 *Kantor Distribusi* and 13 *Kantor Wilayah*, and since 2018 number of business units have become 15 *Kantor Wilayah*, 7 *Kantor Distribusi* and 10 related generating units. As a consequence, customer and installed capacity data are recorded and stored in different PLN's business units following the new organization. Therefore, the consistency in the annual PLN statistics needs to be taken into consideration.

In this section, we will discuss the historical dynamics of PLN business units, its practicalities and problems encountered in constructing electricity dataset from PLN statistics. As a state company and main electricity provider served customers throughout Indonesia, the structure of PLN's

<sup>4</sup> We are grateful to Amir Rosidin for his expert judgement in preparing the electricity dataset.

organization is determined by the Ministry of State-Owned Enterprises (MSOE), and the business units are established accordingly. Prior to 2008, PLN did not have any regional directors, only a functional management. As a consequence, all the strategic decisions concerning the regions should be taken at the PLN headquarters in Jakarta. This of course affected the decision-making process. From 2008 onwards, the ministry added regional directors so that regional problems could be settled faster by the regional directors without waiting too long for decisions to be made at the headquarters in Jakarta.<sup>5</sup> Given changing in organization structure and the needs to accommodate the electricity development, PLN frequently changes its business units that affect our data collection processes.

Prior to 1981/1982, PLN had one *Pembangkit* (generation unit), two *Kantor Distribusi* (the distribution offices) in Jakarta and West Java and thirteen *Kantor Wilayah* (the regional offices), namely (1) Aceh, (2) North Sumatera, (3) West Sumatera, Riau and Riau Island, (4) South Sumatera, Jambi, Lampung, Bengkulu and Bangka Belitung, (5) West Kalimantan, (6) Central Kalimantan, South Kalimantan and East Kalimantan, (7) North Sulawesi, Central Sulawesi and Gorontalo, (8) South Sulawesi, Southeast Sulawesi and West Sulawesi, (9) Maluku and North Maluku, (10) Papua and West Papua, (11) Bali, West Nusatenggara and East Nusatenggara, (12) East Java and (13) Central Java. The last two regional offices have been altered to the distribution offices of East Java and Central Java since 1982/1983, so the number of PLN business units became 11 *Kantor Wilayah* and 4 *Kantor Distribusi* until 2001.

In addition, since 1982/1983, two generation units in Eastern and Western Java have been established, and since 1985 they have been integrated with their transmission units as *Pembangkitan dan Penyaluran (Kitlur)*: generation and transmission in Eastern and Western Java. Moreover, PLN established two subsidiary companies, *PT Pembangkit Jawa Bali (PT PJBI and PT PJB II)*, focusing on power generation in Java and Bali, in 1995. Since then, those generation units have been handed over as part of subsidiary companies while the transmission lines have been managed separately by *Pusat Pengatur dan Penyaluran Beban (P3B)* or the Transmission Load and Dispatch Centre Java Bali. Following Java–Bali interconnected system, PLN has operated this system in Sumatera since 2014 and built this system in Sulawesi and Kalimantan since 2018.

PLN split its regional offices by establishing six new *Kantor Wilayah* and one *Kantor Distribusi* in 2002, namely the *Kantor Wilayah* Riau, Bangka Belitung, Lampung, East Kalimantan, East Nusatenggara and West Nusatenggara and the new *Kantor Distribusi* Bali. Furthermore, since 2012, *Kantor Wilayah* Lampung has been altered to *Kantor Distribusi*, and, since 2016, the Banten branch has split from the *Kantor Distribusi* West Java and established an independent *Kantor Distribusi* Banten; thus PLN currently has 15 *Kantor Wilayah* and 7 *Kantor Distribusi*.

**Table B.1** describes the dynamics of PLN's business units, which have been split into specialized and independent distribution, transmission and production units. The latter refers to the installed capacity that we use in this paper. We apply the same names of *Kantor Wilayah* and *Kantor Distribusi* in both the connection and the installed capacity dataset. This table also shows how the electricity data was recorded and stored in several PLN units. Therefore, the consistency in the annual PLN statistics needs to be taken into consideration.

Further, PLN has established several new development units (IUPs) to respond to President Jokowi's programme of 35,000 MW, which was launched in 2015. After the recovery from the Asian Financial Crisis, the former president of Indonesia Susilo Bambang Yudhoyono (SBY) initiated two fast-track programmes (FTPs) aiming to accelerate the development of electricity; specifically, FTP I 10,000 MW commenced in 2006 to substitute diesel or fuel power plants for coal-fired power plants and FTP II 17,400 MW was launched in 2010 to increase the use of renewable power plants. Almost 100 per cent of FTP I was completed, but only 28 percent of FTP II materialized, which was then carried over to the 35,000 MW programme. To operate and manage the new completed power plants resulting from the FTPs, PLN formed *Unit Pembangkitan Jawa Bali (UPJB)* or generation unit Java–Bali in 2012 (**Table B.1**). This unit was also responsible for handing over these power plants to PLN subsidiary companies (PT PJB and PT IP) in 2016, and it was dissolved afterward.

**Table B.1**  
Summary of Business Units Related to Customers and Production, 1975–2018.<sup>a</sup>

Period	Number of Business Units Related to Customers (Connection)	Number of Business Units Related to Production (Installed Capacity)
1975/ 1976–1981/ 1982	13 regions 2 distributions	13 regions, 2 distributions, 1 generation (K)
1982/1983	11 regions 4 distributions	11 regions, 4 distributions, 2 generations (K <sub>I</sub> and K <sub>II</sub> )
1989/ 1990–1990/ 1991	11 regions 4 distributions	11 regions, 4 distributions New units: generation of Eastern and Western Java
1992–2001	11 regions 4 distributions Batam (as a special region in 1993 and as a subsidiary company, PT PLN Batam, in 2000)	11 regions, 4 distributions, generation of Eastern and Western Java New units: <ul style="list-style-type: none"> <li>• Batam (as a special region in 1993 and as a subsidiary company, PT PLN Batam, in 2000)</li> <li>• Transmission Load and Dispatch Centre Java Bali or <i>Pusat Pengatur dan Penyaluran Beban (P3B)</i> to expand the former load dispatch centre (P2B)</li> <li>• Subsidiary generation company:  <ul style="list-style-type: none"> <li>• <i>PT Pembangkit Jawa Bali I</i> in 1995, which then changed to <i>PT Indonesia Power (PT IP)</i> in 2000</li> <li>• <i>PT Pembangkit Jawa Bali II</i> in 1995, which then changed to <i>PT Pembangkit Jawa Bali (PT PJB)</i> in 2000</li> </ul> </li> <li>• Generation of Northern and Southern Sumatera (1997)</li> </ul>
2002–2011	16 regions 5 distributions PT PLN Batam	16 regions, 5 distributions, PT PLN Batam, PT IP, PT PJB, generation of Northern and Southern Sumatera New units: <ul style="list-style-type: none"> <li>• Subsidiary company PT PLN Tarakan (2004)</li> <li>• Power plants (Muara Tawar in 2005, Tanjung in Jati B 2006, Lontar Unit 1 in 2010, Indramayu Unit 1 in 2011)</li> </ul>

(continued on next page)

<sup>5</sup> The number of regional directors was amended based on PLN's needs. For example, two regions distinguished from 2008 until 2015 expanded into seven regions from 2016 to 2019 and were then merged back into the current four regions.

**Table B.1** (continued)

Period	Number of Business Units Related to Customers (Connection)	Number of Business Units Related to Production (Installed Capacity)
2012–2013	15 regions 6 distributions PT PLN Batam PT PLN Tarakan	15 regions, 6 distributions, PT PLN Batam, PT IP, PT PJB, generation of Northern and Southern Sumatera, PT PLN Tarakan, Muara Tawar, Tanjung Jati B, Indramayu Unit 1, Lontar Unit 1 New units: <ul style="list-style-type: none"> <li>• <i>Unit Pembangkitan Jawa Bali</i> (UPJB) or the generation unit of Jawa–Bali focused on managing and operating power plants under Fast Track Program (FTP) I, namely Indramayu Unit 2 and Unit 3 (2012) and Lontar Unit 2 (2013)</li> </ul>
2014–2015	15 regions 6 distributions PT PLN Batam PT PLN Tarakan	15 regions, 6 distributions, PT PLN Batam, PT IP, PT PJB, generation Northern and Southern Sumatera, PT PLN Tarakan, Tanjung Jati B, UPJB (Indramayu and Lontar) New units: <ul style="list-style-type: none"> <li>• <i>Pusat Pengatur dan Penyaluran Beban (P3B)</i> or Transmission Load Dispatch Centre Sumatera</li> <li>• Development Units (UIP) Eastern Kalimantan, Nusatenggara, Eastern Java and Bali (2014), Sumatera and Centre of Kalimantan (2015)</li> </ul>
2016–2018	15 regions 7 distributions PT PLN Batam	15 regions, 7 distributions, PT PLN Batam, PT IP, PT PJB, generation in Northern and Southern Sumatera, Tanjung Jati B, P3B Sumatera, P2B Jawa–Bali, IUP (Eastern Java–Bali, Sumatera, Centre of Kalimantan, Eastern Kalimantan). PT PLN Tarakan was closed and merged back with Region East Kalimantan in 2017 New units: <ul style="list-style-type: none"> <li>• Generation of Western Java, Centre of Java, Eastern Java and Bali (2016) and Nusatenggara (2018)</li> <li>• Development Unit (IUP) Southern Sulawesi (2017), Western Kalimantan, and Papua and West Papua (2018)</li> <li>• <i>Unit Induk Pembangkitan dan Penyaluran</i> (UIKL) or Unit of Generation and Transmission Kalimantan and Sulawesi (2018)</li> </ul>

Notes.

<sup>a</sup> We use the terms generation, region and distribution to refer to PLN's business unit names in Bahasa, that is, *Pembangkit*, *Kantor Wilayah* and *Kantor Distribusi*, respectively.

After reclassifying PLN business units to obtain customers and production data, we recode the PLN's area into BPS province as described in Table B.2. In response to PLN's needs and electricity development, PLN established new business units in some provinces. In those cases, we reclassify new PLN business units back to the parent regions or provinces, as we did for PLN Batam and PT PLN Tarakan, to make our dataset consistent at the province level overtime. PLN Batam was established in 1993, when Batam was treated as a special economic zone and turned into a subsidiary company, PT PLN Batam, in 2000. On the other hand, Riau Island province, where PLN Batam is located, was established in 2002 after splitting from Riau province. Thus, we add PLN Batam to Riau province from 1993 to 2001, then, after 2002, we add PLN Batam to Riau Island province.

**Table B.2**

Coverage Area of PLN Business Units, BPS Provinces and Islands

PLN Business Unit	BPS Province	Island
Region I (Banda Aceh)	Nanggroe Aceh Darussalam	Sumatera
Region II (Medan)	North Sumatera	Sumatera
Region III (Padang) <sup>a</sup>	West Sumatera, Riau, Riau Island	Sumatera
Region IV (Palembang) <sup>a</sup>	South Sumatera, Bangka Belitung, Jambi, Lampung, Bengkulu	Sumatera
Region V (Pontianak)	West Kalimantan	Kalimantan
Region VI (Bnjarmasin) <sup>a</sup>	Central Kalimantan, South Kalimantan, East Kalimantan	Kalimantan
Region VII (Manado)	North Sulawesi, Central Sulawesi, Gorontalo	Sulawesi
Region VIII (Makassar)	South Sulawesi, Southeast Sulawesi, West Sulawesi	Sulawesi
Region IX (Ambon)	Maluku, North Maluku	Eastern
Region X (Jayapura)	Papua, West Papua	Eastern
Region XI (Denpasar) <sup>a</sup>	Bali and West Nusa Tenggara, East Nusatenggara	Java-Bali, Eastern
PT PLN Batam	Riau island	Sumatera
Dist. East Java (Surabaya)	East Java	Java-Bali
Dist. Central Java (Semarang)	Central Java, Jogjakarta	Java-Bali
Dist. W. Java and Banten (Bandung) <sup>a</sup>	West Java, Banten	Java-Bali
Dist. Jaya and Tangerang (Jakarta)	Jakarta, Banten ( <i>Kota Tangerang, Kabupaten Tangerang, Kota South Tangerang</i> )	Java-Bali

Parentheses refer to the capital city where the region or distribution office is located.

<sup>a</sup> Riau, Bangka Belitung, Lampung, East Kalimantan, West Nusatenggara, and East Nusatenggara have been established as independent regional office (*Kantor Wilayah*) and Bali as a distribution office (*Kantor Distribusi*) since 2002. Lampung's regional office was changed to Lampung's distribution office in 2012, while Banten's branch was established as an independent distribution office in 2016.

Moreover, East Kalimantan's region was established in 2002 after splitting from Region VI while PT PLN Tarakan, as a subsidiary company located in East Kalimantan province, was established in 2004. Therefore, we combine PT PLN Tarakan with East Kalimantan province from 2004 to 2016, then we add the new province North Kalimantan back to its parent province East Kalimantan after 2014. Other regional offices or distribution offices are coded as they are as long as they represent the province where these business units are located. For example, Lampung's regional unit, which changed into a distribution unit in 2012, is still coded as Lampung province in our dataset. Through this procedure, our dataset becomes more consistent with the BPS's classification at the province level overtime.

## B.2 Area Coverage

PLN distinguishes the areas for customers and production where the boundaries differ from those of the BPS's provinces. One PLN area can consist of more than one BPS province. To compile all the electricity data from the annual PLN statistics, we first match the PLN area coverage within the PLN statistics over time to obtain a coherent dataset at the province level and then we reclassify the matched PLN provinces into the BPS's provinces. For the period from 1990 onwards, the PLN statistics are available at the regional level with a provincial breakdown, so we can easily match them with the

BPS province data. However, the name of PLN regions might not reflect the true coverage area, so we need to reconfirm this with PLN during this reclassification process.

Some PLN regions cover several provinces. For the purpose of coding thirty-three provinces, we recode these regions and distributions as follows. Prior to 1990, for some regions with more than one province, their data are recoded to the province where the regional office was located. This pragmatic strategy is chosen because, according to PLN, the location of the regional office was selected based on the number of PLN customers. In other words, the capital province of a region represents more electrified households than other provinces within the region. For example, Region III consists of West Sumatera, Riau and Riau Island, so data were recorded as West Sumatera province because the office of Region III is located in Padang, the capital city of West Sumatera province. Thus, seven regional provinces were considered as one province according to this pragmatic strategy, namely West Sumatera (Region III), South Sumatera (Region IV), South Kalimantan (Region VI), North Sulawesi (Region VII), South Sulawesi (Region VIII), Bali (Region XI) and Central Java (Distribution Central Java and Yogyakarta). However, it should be noted that there is a potential jump in the number of customers due to discontinuity in the definition of the regions. Detailed coverage area PLN business units and BPS can be found in Table B.2. For new business units that are established as a response to electricity development in some provinces, we reclassify these new business units back to the parent regions or provinces to make our dataset consistent with the BPS's classification at the province level.

**B.2.1. Area Coverage in Kantor Distribusi Jakarta, West Java and Banten**

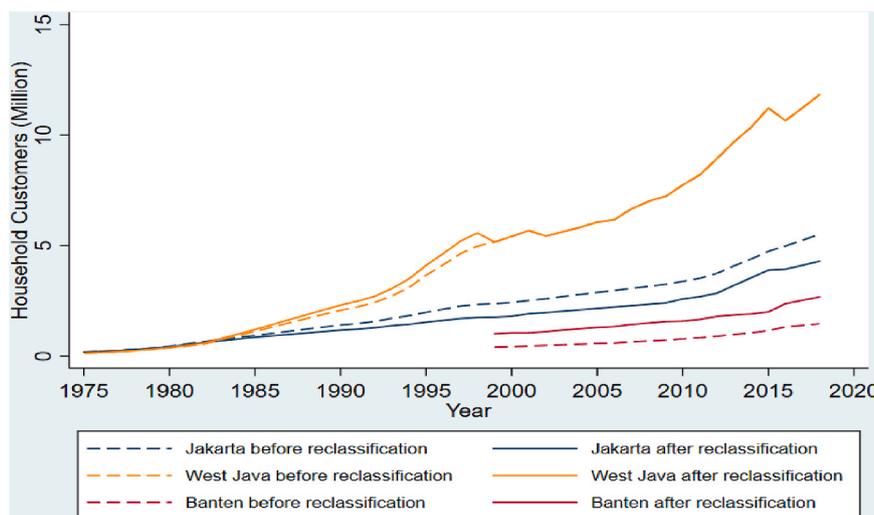
Prior to 2015, the Banten's branch was part of *Kantor Distribusi Jawa Barat dan Banten* or the distribution office of DJBB. Due to increasing demand for electricity, especially from large-scale industrial customers, and the growing development of Banten province, PLN separated the Banten's branch from DJBB in 2015 and the Banten's branch became an independent distribution office (*Kantor Distribusi Banten*). As a consequence, the Tangerang's branch, which was originally part of *Kantor Distribusi Jakarta Raya dan Tangerang* or the distribution office of Disjaya, should be recorded not as Disjaya but as *Kantor Distribusi Banten* by reclassifying it at the branch level and recalculating the number of connections and the capacity of these three distribution offices of Jakarta, West Java and Banten.

Without this procedure, our data would be misleading. For instance, when we calculate access to electricity as a percentage of electrified households in the total households, the figure is much higher for Jakarta province and much lower for Banten province due to different definitions of Tangerang's coverage between BPS and PLN. The total number of households as the denominator is calculated by the BPS according to the administrative definition of the Ministry of Home Affairs; on the other hand, the number of electrified households as the nominator is recorded by PLN based on the technical area of PLN, and the discrepancy due to this area definition is significant. Below is a detailed description of the coverage area of the BPS and PLN.

**Administrative area of the BPS.** Our dataset at the province level following the BPS coding is in line with the definition of the Ministry of Home Affairs: Jakarta province, West Java province and Banten province. The latter was established in 1999 after splitting from West Java province. Hence, prior to 1999, Banten was part of West Java province. Banten province comprises four cities (*kota*) and four districts (*kabupaten*), and three out of those eight autonomous regions are neighbours of Jakarta province, namely *Kota Tangerang*, *Kabupaten Tangerang* and *Kota South Tangerang*.

**Technical area of PLN.** The lowest level in the distribution office is the branch, which is formed on the base of technical aspects and is likely to cross the administrative area of the BPS. Tangerang branch was part of *Kantor Distribusi Jakarta Raya dan Tangerang*, while Tangerang branch itself covered four administrative areas of the BPS, namely (i) *Kota Tangerang* (sub-branch Cikokol), (ii) *Kota South Tangerang* (sub-branch Serpong), (iii) *Kabupaten Tangerang* (sub-branch Sepatan, Teluk Naga, Curug, Cisoka and Cikupa) and (iv) *Kota West Jakarta* (sub-branch Cengkareng and Kalideres). It is obvious that Tangerang branch crossed two provinces i.e. Banten and Jakarta.

The main implication of those different area definitions is that the electrification ratio could be overestimated for Jakarta province but underestimated for West Java province for the period 1975–1998 and for Banten province for the period 1999–2018. Due to this problem, we reclassify our household customer dataset at the branch level. We unbundle the Tangerang branch from Jakarta province and then tally it up with West Java province for the period 1975–1998 and with Banten province for the period 1999–2018. For incomplete years, we interpolate using the moving average. Hence, our new dataset for Jakarta, West Java and Banten provinces is now more sensible.



**Fig. B.1.** Number of Electrified Households in Jakarta, West Java and Banten before and after Reclassification, 1975–2018  
Source: Calculated by the authors.

Figure B.1 presents the number of PLN household customers before and after reclassification, as we discussed. The new Jakarta blue line after

excluding the Tangerang branch is lower than the old Jakarta blue dashed line, while the new Banten maroon line after including the Tangerang branch is higher than the old Banten maroon dashed line; the new West Java orange line is slightly higher than the old West Java orange dashed line before 1999 or when Banten was still part of West Java, then, after 1999, the two lines of West Java appear to overlap. Spikes are shown in two transition periods: (i) around 1999, when Banten administration split from West Java province and was established as a new province, and (ii) around 2015, when Banten area split from the distribution office of West Java and Banten (DJBB) and became a new independent distribution office.

In addition, high spikes in the number of customers Jakarta in 2011 was partly due to the programme *Gerakan Sehari Sejuta Sambungan* (GRASS), or 1 million customers per day, launched in 2011, in which 1 house was allowed to have more than 1 m at that time. As a result, there are 4,040,310 household customers in Jakarta [45] while the number of households issued by the BPS is 3,393,014; hence, if we calculate the electrification ratio for Jakarta, the figure is 119 per cent. This measurement error leads to an incorrect picture of the electrification programme. To overcome this problem, we recalculate the denominator in 2011 by dividing the total population of Jakarta by 3, the average number of household members in Jakarta so the electrification ratio is corrected accordingly.

### B.3 Installed Capacity and Power Plants

In this paper, we use installed capacity (megawatt) as a proxy of power supply, which is to be understood as the arrival of power supply in that area (island). According to PLN, the installed capacity is the capacity of one generating unit as written on the generator's name plate. In other words, the installed capacity is the maximum output of electricity that a generator can produce under ideal conditions. PLN records this information based on the location of the power plants, including the ones owned by private companies, and the interconnection system in which the capacity of the entire area should be managed (Appendix B). As a consequence, the division of regions for installed capacity becomes more complicated because it should be managed as one system and in line with its transmission. For instance, the generator system of Northern Sumatera covers Aceh, North Sumatera, West Sumatera, Riau and Riau Island, while the generator system of Southern Sumatera comprises South Sumatera, Bangka Belitung, Jambi, Bengkulu and Lampung. As a result, electricity can be transmitted across provinces throughout Sumatera Island. This interconnected system is also known as autonomous self-contained electricity system in which the capacity could be supplied, transmitted and distributed within one island via this system.

Having this complexity and as suggested by PLN, we prepare the capacity dataset at the island level, and then we use the weighted population to obtain the installed capacity per province. We categorize islands into five groups as follows: (i) Sumatera, (ii) Java–Bali, (iii) Kalimantan, (iv) Sulawesi and (v) Eastern. Unlike the first three main islands, the latter consists of one big island (Papua) and many small islands (Maluku and Nusatenggara). The weighted population ( $wpop_{ij}$ ) for each province is calculated as the share of the population of province  $i$  on island  $j$  ( $pop_{ij}$ ) in the total population of island  $j$  ( $pop_j$ ), where  $i$  is an index for provinces ( $i = 1, \dots, 33$ ) and  $j$  is an index for islands ( $j = 1, \dots, 5$ ):

$$wpop_{ij} = \frac{pop_{ij}}{pop_j}$$

The calculation of the installed capacity also includes the amount of installed capacity from the private sector or the independent power producer (IPP) as part of the power supply since 2014. In sum, the quite frequent changes in PLN's organization structure require us not only to consult PLN directly but also to prepare our electricity dataset carefully, especially due to the fact that the power plants belong to different units in different regions.

### B.4 Tariff Classification and Transformation

As discussed, PLN issued annual statistics in different formats, including a tariff classification. We reclassify tariffs to calculate the number of customers as follows: (i) prior to 1980, tariffs A, B and C are classified as residential, industry and business, respectively, and tariffs D, E and F and *Khusus* are classified as "other"; (ii) in the period from 1980/1981 onwards, tariff R is classified as residential, I as industry, U and H as "business" and S, G, J and M as "other". We then translate customers who held a residential tariff as household customers. Thus, in general, we have four types of customers: households, industry, business and other (Table B.3). From 1989 onwards, PLN issued not only the number of customers based on tariffs but also the number of customers based on types, namely residential, industry, business, social, government office and public street lighting. To make our classification consistent with previous classifications, we categorize the last three types as "other". In this paper, we only use household customers to determine the number of connections.

PLN has recorded number of customers based on tariff classification and changed this classification regularly as electricity develops. Table B.3 describes the transformation of electricity tariff. We encountered some problems in calculating number of household customers as follows. The very poor households without a meter were sometimes categorized as  $S_1$  (social users) in PLN statistics, so we reclassify them as households after consulting PLN. This specific problem was relevant to the Tangerang branch. Therefore, we sum up the number of customers under tariffs  $S_1, R_1, R_2, R_3$  and  $R_4$  to arrive at the total number of household connections in Tangerang in 1992, 1993 and 1997.

**Table B.3**  
Tariff Classification 1975–2018

Period	Tariff Classification/Customer Type			
	Household	Industry	Business	Other
Before 1980/1981	A <sub>1</sub> and A <sub>2</sub>	B <sub>1</sub> and B <sub>2</sub>	C <sub>1</sub> and C <sub>2</sub>	D: gov. office E: social F: street lighting <i>Khusus</i> : special tariff
1980/1981 –1998	R <sub>1</sub> : simple house R <sub>2</sub> : small house R <sub>3</sub> : medium house R <sub>4</sub> : large house	I <sub>1</sub> : micro industry I <sub>2</sub> : small industry I <sub>3</sub> : medium industry I <sub>4</sub> : large industry	U <sub>1</sub> : small enterprise U <sub>2</sub> : medium enterprise U <sub>3</sub> : large enterprise H <sub>1</sub> : simple and small accommodation H <sub>2</sub> : hotel industry	S <sub>1</sub> : very small user S <sub>2</sub> : social foundation G <sub>1</sub> : medium gov. office G <sub>2</sub> : large gov. office J: street lighting M: multipurpose (special tariff)

(continued on next page)

Table B.3 (continued)

Period	Tariff Classification/Customer Type			
	Household	Industry	Business	Other
1999–onwards	R <sub>1</sub> : simple house R <sub>2</sub> : small house R <sub>3</sub> : medium/large house	I <sub>1</sub> : micro industry I <sub>2</sub> : small industry I <sub>3</sub> : medium/large industry	B <sub>1</sub> : small business B <sub>2</sub> : medium business B <sub>3</sub> : large business	S <sub>1</sub> : very small user S <sub>2</sub> : small social foundation S <sub>3</sub> : medium social foundation P <sub>1</sub> : medium gov. office P <sub>2</sub> : large gov. office P <sub>3</sub> : street lighting T: <i>traksi</i> (train, MRT) C: <i>curah</i> (special tariff) M: multipurpose

Source: PLN statistics

Regarding the payment method, PLN initially applied a post-paid method, but, since 2007, it has introduced a prepaid method to reduce the cost of collection.<sup>6</sup> A mistake occurred in PT PLN Batam that required reclassification before calculating the electrification ratio. PT PLN Batam recorded prepaid household customers as business type customers due to the multipurpose (*Multiguna*) tariffs from 2011 to 2016, but in fact those customers were household customers who merely changed their payment method. Therefore, we subtract prepaid customers from “business” and add them to “household” for the period 2011–2016. In some cases, we also find two different numbers of customers, by tariff as well as by type, in the PLN statistics. If this is the case, we choose the number of customers by type rather than by tariff, which involves more technical aspects.

### B.5 Electrification Ratio

The main variable in this paper is the electrification ratio, which we use as the dependent variable in our diffusion model. According to the Asia Development Bank (ADB 2016), the *electrification ratio* is defined as the ratio of the number of households with access to electricity relative to the total number of households. This ratio is important for measuring the extent to which people have benefited from the development, that is, electricity. As discussed previously, PLN only issues annual statistics without the total number of households. Therefore, the electrification ratio is calculated based on two different sources: (i) the number of households with access to electricity as the nominator is recorded by PLN as its customers and the Ministry of Energy and Mineral Resources (MEMR) for non-PLN customers<sup>7</sup>; and (ii) the total number of households as the denominator is recorded by the BPS based on the family card. In this paper, we only focus on electrified households based on PLN data because the share of non-PLN electrified households is less than 5 per cent of the total number of electrified households.

Electrified households are recorded by PLN based on the number of meters installed at the customer's house – 1 m is counted as one household customer. There are two potential measurement issues. First, in rural areas where several families live in one house, the electrification ratio measured could be lower than the effective ratio. For instance, the electrification ratio calculated by PLN is 56.3 per cent while the author's calculation using the BPS data results in a ratio of 58.5 per cent.<sup>8</sup>

Second, in the big cities like Jakarta, where housing is also available in the form of apartments or flats, pavilions (part of a main house that can be rented) and rental rooms inside a house (*kos-kosan*), the name of the owner of those properties could be the same as the name of the PLN customer who lives in the rental property where the individual meter is installed. Thus, the effective number of PLN household customers will be larger than the number of actual households because an owner's name could be registered for several meters.

During our data collection, we could not find the PLN statistics from 1984 to 1988, even when we searched the archives at the PLN headquarters in Jakarta. To fill in the missing values, we interpolate two groups: (i) 1984 to 1985, using data from 1979 to 1983, and (ii) 1986 to 1988, using data from 1989 to 1999. After interpolating them, we consult PLN to check that the figures are reasonable.

### Data availability

Data will be made available on request.

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<sup>6</sup> The number of prepaid customers is continuing to increase and was almost half of the total number of PLN household customers in 2019. However, this prepaid method will no longer be implemented in the future. According to PLN, it is now preparing to replace the existing meter with a smart meter that could reduce the collection fee and implement the post-paid method much more easily.

<sup>7</sup> These electrified households are part of rural electrification program under Ministry of Energy and Mineral Resources.

<sup>8</sup> In several PLN statistics, we also find that the denominator for calculating the electrification ratio was three years behind while the nominator was calculated from the actual or current data, so the ratio might be too high compared with the effective one.

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