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Electricity and the Geography of Industrial Development in a Latecomer Country: Preliminary Evidence on Italy, 1901-1911

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Abstract

Italy, a latecomer country to industrialization, faced the hurdles of lacking coal in the age of steam. When the technology for long-distance electricity transmission became available, it invested heavily in hydropower. By 1911, 42.7% of Italy's installed industrial power came from hydroelectricity. Using methodologies rooted in New Economic Geography (NEG) and factor endowment theories, we analyze the location of industrial activity across Italian provinces during the census years 1901 and 1911. We evaluate the influence of electric power as a distinct factor alongside traditional determinants such as market potential, human capital, and energy intensity. Our approach incorporates new data on GDP, literacy, and energy stocks, enabling a fine-grained analysis at the NUTS-3 level. Dependent variables include provincial shares of industrial employment and GDP, regressed on interactions between industrial and provincial characteristics. Baseline OLS findings highlight the role of electricity in industrial location, with its influence growing markedly between 1901 and 1911. Alternative specifications and instrumental variable techniques confirm these results, underscoring electricity's transformative role in reducing Italy's dependence on water-powered manufacturing. These findings align with broader interpretations of electrification's role in enabling industrial diversification and regional economic development during the Second Industrial Revolution.

Keywords: Electrification, industry location, Italian manufacturing, market potential, factor endowments, Liberal Italy.

JEL codes: N73, N93, O18, R30

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1 Introduction

The received wisdom of the analysis of the Italian development can be summarized as follows. First, Italy was a latecomer to industrialization, experiencing it more than one hundred years after Britain. Second, when the country started the industrialization process around 1880, its backward productive structure led to low growth rates. Third, income was relatively similar across Italy at the time of Unification. In contrast, preconditions to economic growth (e.g., education) were not. When industrialization started, the combination of these preconditions with the manufacturing process led to economic divergence, particularly a North-South divide. Fourth, Italy approached the age of steam without coal. This was clearly a disadvantage that led to the exploitation of water (imaginatively called "white coal") as a substitute energy source.

This paper deals with the last point. Electricity is a General Purpose Technology, a particular type of radical innovation that fully shapes a technological era, such as the steam engine and superconductors. The economic history literature has been relatively shy in qualitatively addressing the role of electricity in the economic development of Italy, and even more so the quantitative literature. This paper attempts to evaluate the role of electricity in Italian economic development using provincial data from official statistics and historical sources. In particular, this work employs a novel dataset comprising information on electric and non-electric power stock, literacy, GDP, employment and market potential at the provincial (NUTS-3) level for Italy in the decade 1901-1911. We adopt an empirical methodology that allows us to consider both the impact of factor endowments (i.e. electric and non-electric energy, literacy) and geography (market potential) on the location of industrial activity in the final years of Liberal Italy, when the Second Industrial Revolution reached its climax.

The preliminary results we present suggest that electricity availability was, especially at the end of the decade, the single most important determinant of industrial location in the country, even more so than literacy and the size of domestic markets. However, studying the effects of electricity poses methodological challenges, given that its production and distribution remained entirely in private entrepreneurs' hands up until the sector's nationalization in 1962. This raises concerns about potential endogeneity in the relationship between electrification and industrial activity. Specifically, rather than electricity and its growing availability being the driving force behind the location, intensity, and outcome of industrial activity, it is plausible that the geographical diffusion of industries - already close to the water sources so relevant for hydroelectric power production - played a significant role in shaping the patterns of electrification across the country. To address this issue, we first employ an alternative specification for electricity availability, looking at the progressive construction of electricity distribution stations across Italian municipalities. Then, as this new measure of electricity access does not fully solve the aforementioned endogeneity

issue, we turn to an instrumental variable approach. As an instrument, we take the water streams per square kilometre, and to avoid collinearity issues, we used it to estimate a reduced form two-stage model. In both these approaches, results confirm the initial estimation of the impact of electricity and add nuance to it.
The paper is organized as follows: section 2 discusses the relevant strands of literature; section 3 presents the main methodology and its empirical applications; section 4 discusses the data we use and their sources. Section 5 describes the baseline results, while section 6 introduces an alternative measure of electricity availability based on the distance from electrified municipalities. Section 7 addresses the potential endogeneity bias of previous estimates via an IV approach. Finally, section 8 draws conclusions and traces directions for future research.

2 Relevant Literature

In this section, we consider two streams of literature: the assessment of the economic effects of electrification internationally and in Italy. The latter is closely related to its history of industrial development and the North/South divide.
Electricity has not been widely studied Compared to other industrial and service sectors. Besides a global overview (Brittain 1974), on the effects of electrification, a plurality of the studies unsurprisingly focus on the US. Du Boff (1967) described the advent of electrification in American manufacturing as a profound technological revolution.[1] Beginning in the late 1880s, advances in alternating current systems and electric motors enabled the widespread adoption of electricity across industries. The initial adoption was driven by cost savings, primarily in power transmission and operational efficiency, replacing steam engines. By 1920, manufacturing accounted for nearly half of the nation's electricity consumption. The shift from centralized steam engines to decentralized electric motors revolutionized factory design and operations, improving energy efficiency and enabling more flexible production layouts. This decentralization of power facilitated the growth of small and medium enterprises that the inefficiencies of steam power systems had previously constrained.
Resenberg (1998) situates electricity within the broader framework of General Purpose Technologies (GPTs), characterized by their widespread applicability and capacity to drive complementary innovations. He emphasizes that the versatility of electricity, which can be derived from various primary energy sources, has made it a pivotal force in industrialization. Electricity not only enhanced productivity but also liberated industries from locational constraints imposed by earlier energy sources such as coal and waterpower. The flexibility and scalability of electric motors allowed for decentralized industrial growth, empowering

[1] Devine (1983) maintains that the value of electricity was due to the precision in space, time, and scale with which energy in this particular form could be transferred.

regions previously disadvantaged by the lack of natural energy resources. Rosenberg also highlights electricity's transformative impact on firm size and organization. Unlike steam engines, which required significant economies of scale, electric power systems could efficiently cater to small and medium enterprises, contributing to the diversification of industrial activity and the proliferation of innovative business models. In a restatement of the Solow productivity paradox, Crafts (2004) found that the effect of electricity was smaller in terms of capital deepening and Total Factor Productivity than other GPTs, such as steam in Britain and ICT in the US, respectively. However, this seems to be a common feature of GPTs, which take a lot of time to affect the whole economy. For example, electrification drove structural change since it explains 50.5% of the total increase in operatives and 18.1% of the total decrease in farmers between 1910 and 1940 (Gaggl et al. 2021).[2] In Lewis and Severnini (2020), a distinction between short- and long-run effects of rural electrification is identified: the former increased agricultural employment, rural farm population, and rural property values, the latter characterized rural counties that gained early access to electricity, which experienced increased economic growth that persisted for decades after the country was fully electrified.

Severnini (2023) explores the role of hydroelectric dams in fostering local economic growth in the US. He identifies a "cheap-local-power advantage" associated with dams constructed before 1950, which catalyzed significant economic activity in their vicinity. This advantage was evident in the rapid industrialization and population density increases around dam sites, with some areas experiencing over 130% growth in density within six decades. However, the post-1950 period saw a decline in this advantage due to advancements in high-tension transmission lines and thermal power generation, which reduced the locational dependence of industries on hydroelectric sites.

Hydroelectric power is analyzed in other countries that strongly rely on it. Lipscomb et al. (2013) for Brazil find large effects of electrification on housing value and the Human Development Index, whereas Jayes et al. (2024) find positive effects in local labour markets where hydroelectric power was in place in Sweden during the first decades of the 20th century.

From a methodological point of view, uncovering the effects of electricity is plagued by an endogeneity problem. Electricity is brought where there is already some manufacturing activity, which is most likely to use it. For this reason, recent studies have applied techniques that account for this problem. For example, Lipscomb et al. (2013) develop a model to forecast hydropower dam placement and grid expansion to produce hypothetical maps that show how the electrical grid would have evolved based solely on geographic cost considerations, ignoring demand-side concerns. These values are used as an instrumental variable in the estimations. Lewis and Severnini (2020) use the synthetic control method

[2] A sizable structural change effect is also found by Brey (2023) for Switzerland.

(Abadie et al. 2010) to construct counterfactuals out of counties with hydropower potential but no dams and compare with those with dams, while Brey (2023) and Jayes et al. (2024) use a difference-in-difference design to compare areas treated with those not treated.
This concern for endogeneity is also carefully addressed in several studies analyzing electrification in developing countries, such as Dinkelman (2011), Rud (2012), Allcott et al. (2016), Abeberese (2017), Burlig and Preonas (2024).
Moving to Italy, although the literature generally acknowledges the role of electricity and water in shaping economic development in Italy, we share the claim by Toninelli (2010) that the topic has not been the object of a thorough analysis.[3] Already, Blanchard (1928) highlighted some issues in the role of electricity in Italian industrial development. Hydropower became a crucial element in Italy's energy strategy, addressing its lack of fossil fuel resources.[4] By the mid-1920s, Italy doubled its installed hydroelectric capacity within a decade. With its Alpine rivers and natural reservoirs, Northern Italy led the charge in hydroelectric development. Major projects utilized the steep slopes, glacier-fed streams, and moraine-dammed lakes of the Alps. However, the uneven seasonal flow of rivers posed challenges, prompting the construction of artificial reservoirs and interlinked transmission networks.[5] However, the increasing cost of exploiting less accessible hydropower sites hinted at the eventual limitations of this energy strategy.
Bardini (1997) emphasized the absence of domestic coal reserves and argued that Italy's industrial performance was hindered by its reliance on expensive imported coal and its limited ability to adopt steam power technologies, pivotal for advanced industrial production during the "age of steam". As high transport and handling costs resulted in coal prices that were two to four times higher than those in coal-rich countries like the United Kingdom, steam power, a coal-dependent technology crucial for industrialization, was prohibitively expensive.[6] Therefore, Italy substituted steam with electricity, often generated from hydroelectric power. While this strategy reduced dependency on coal, electricity in its early forms could not fully match the versatility and productivity-enhancing potential of steam power. Italy's industries primarily used electricity as a generic power input rather than as a driver of transformative industrial innovation. The high cost of coal led to a selective industrial structure. Steam-dependent, power-intensive sectors like heavy chemicals, textiles, and metallurgy, which thrived in coal-rich countries, remained underdeveloped in Italy. Instead, Italy specialized in labour-intensive and low-power-using

[3] A relatively large business history literature on electric companies exists, which is beyond the scope of this work (e.g., Pavese 1986; Segreto 1986; Caligaris 1993; Toninelli 1990).

[4] Giannetti (1986, p. 289) reported data showing Italy in 1905 being the third producer in the World and the first in Europe.

[5] From 1885 to 1910, machines were installed to cover continuous flows, accounting for 23-25 per cent of hydroelectric capacity. After building adjustment tanks, 50 per cent of capacity was used, and in 1930-40 generators were installed to use up to 80 per cent of capacity (Giannetti 1986, p. 290).

[6] Bartoletto (2005) claims that the price of coal in the Italian ports was 5–6 times higher than in the British ports, and the price was even higher in the internal areas (10 times more). Licio (2023) provides estimates of coal prices for all Italian provinces between 1861 and 1911.

industries. Despite its relative advantage in electricity, Italy did not capitalize on emerging electricity-driven technologies as effectively as other nations. Besides the lack of flexibility, another factor that pushed back the competitiveness of this industry was the establishment of regional systems of production, which prevented the full exploitation of the economies of scale, causing higher prices (Giannetti 1985).

In the last decade, as soon as data became available, this literature met more quantitative analyses of Italian industrial development at the local level during the Liberal period (1861-1914). In these contributions, energy and electricity appear as localisation factors but are not typically the main focus of the analysis. Basile and Ciccarelli (2018) compared and tested factor endowment and domestic market potential as the main drivers of industrial location. They find that the location of capital intensive sectors (chemicals, cotton, metalmaking and paper) was driven by domestic market potential and literacy. Once market potential and literacy are accounted for, water endowment affects the industrial location of labour-intensive industries. Missiaia (2019) considers two competing theories on the determinants of the location of economic activity: the Heckscher–Ohlin theory on factor endowments and the new economic geography theory on access to markets. Endowments such as energy (water power) and human capital were the determinants of the geographical distribution of industrialization. Market access mattered only in its domestic formulation and through economies of scale. Clearly, northern provinces had a comparative advantage in terms of water energy endowment from the Alpine region.

Unsurprisingly, the different endowments in water between the North and the South are among the several explanations for the economic divide between these two areas. Water was first a determinant of the growth of agriculture and the silk industry and then a factor in electricity production, as we have seen above (Fenoaltea 2014, A'Hearn and Venables 2013), and in this way, affected economic growth.

3 Empirical Model

In this work, we are interested in studying the effect of electricity both as a relatively cheaper (for coal-fired steam engines) and more efficient (for water-powered engines) source of industrial power and as a driver of industrial location that – as its use spreads – reduces the relevance of easy access to natural resources. To do so, we turn to the seminal work of Midelfart-Knarvik et al. (2001), which provides a theoretical framework accounting for the role of both the traditional Heckscher-Ohlin (H-O) factor endowments and the New Economic Geography (NEG) market access in explaining the location of industry.

This approach has been extensively used in economic history, pioneered by Crafts and Mulatu (2005) to investigate geographic differences in industrialization in the United Kingdom during the First and Second Industrial Revolutions. Similar approaches have been applied to the study of the cases of Poland (Wolf 2007), the United States (Klein and Crafts 2012), Spain (Martinez-Galarraga 2012), Yugoslavia (Nikolić 2017) and Italy (Missiaia 2019). All these works adopt the stance that the interaction between the characteristics of potential locations (states, provinces, counties, etc.) and those of the economic sectors explains the location of industries. On the one hand, the H-O theory predicts that locations in which a factor of production is relatively abundant attract industries making intensive use of that very same factor. On the other hand, NEG's theoretical results dictate that a location's market potential should attract industries with larger economies of scale or greater dependence on upstream or downstream connections. Thus, the pattern of industrial location and its evolution can be explained by a set of H-O and NEG-type interactions between location and industry characteristics.

Missiaia (2019) is the work most closely related to our methodology. At the time, Italian economic history research had not yet produced estimates of provincial GDP via the more reliable Geary and Stark (2002) methodology (see Chiaiese 2024). She looked instead at the evolution of regional differences in employment shares between manufacturing sectors. Although our primary focus is electricity and its effects, we expand on her analysis in three dimensions. First, we look at the dynamics of both employment and GDP shares. Since the latter includes a productivity component, we better grasp the dynamics underlying changes in the production location. Second, we run our analysis at the provincial (NUTS-3) level, thus looking at a more refined representation of industrial activity distribution. Third, we study a sample of all industrial sectors, including mining, construction, and utilities. This allows for a better representation of the interdependencies between sectors and the country's industrial activity.

We adopt - just as Missiaia (2019) - the reduced-form specification of the model employed in Klein and Crafts (2012), reported in equation (1):

$$ln(s_{i,k}) = \sum_j \beta_j [I] + \sum_i \delta_i Province + \sum_k \gamma_k Industry \tag{1}$$

where $(s_{i,k})$ is, alternatively, the share of GDP or employment of industrial sector k in province i. $[I]$ is the vector of all H-O and NEG-type interactions, and $\sum_j \beta_j$ are the estimated coefficients of these terms. Province (δ_i) and industry (γ_k) fixed effects are included to control for unobserved characteristics and differences across provinces and industrial sectors.

As our primary focus is the role of electricity - interpreted as an H-O-like interaction - we will estimate the model on two census years, 1901 and 1911. Long-distance transport of electricity in Italy began in 1892, with a 28-kilometre line that connected the hydropower plant in Tivoli with Rome, but remained a fairly rare occurrence well into the 1900s. The industrial statistics of 1903 (MAIC 1905), for instance, report that at most 22% of all industrial horsepower at the provincial level came from electric engines, and many provinces had no electric power at all (see Figure 1a). Electricity spread rapidly in the 1901-1911 decade, and therefore, we estimate the model as both a repeated cross-section - to better identify the structural changes due to the growing electricity usage - and as a pooled sample.

The main equation of interest (Eq. 2) is the following:

$$\begin{aligned} ln(s_{i,k}) = &\beta_1(\text{Literacy Rate}_i \times \text{White-Collar}_k) \\ &+ \beta_2(\text{Electric Power}_i \times \text{Electric Intensity}_k) \\ &+ \beta_3(\text{Non-Electric Power}_i \times \text{Non-Electric Intensity}_k) \\ &+ \beta_4(\text{Market Potential}_i \times \text{Forward Linkages}_k) \\ &+ \beta_5(\text{Market Potential}_i \times \text{Backward Linkages}_k) \\ &+ \beta_6(\text{Market Potential}_i \times \text{Mean Plant Size}_k) \\ &+ \sum_i \delta_i Province + \sum_k \gamma_k Industry \end{aligned} \tag{2}$$

where the subscript i denotes one of the 69 Italian provinces that existed between 1871 and 1918, and k one of the 15 industrial sectors identified in statistical estimates since the seminal work sponsored by the Bank of Italy in the 1990s (Rey 1992). Table 1 presents the set of provincial and industry characteristics.

In our model, we include three H-O-type interactions. The first one captures the impact of skilled labour availability, measured by provincial literacy rates. The share of white-collar workers over the total number of employees in each industrial sector measures the intensity of skilled labour use in that sector. Higher literacy rates are expected to attract industries which more intensively use skilled labour, as is the case in Missiaia (2019), Wolf (2007), Nikolić (2017) and Crafts and Mulatu (2005). However, evidence favouring this hypothesis is unclear in the literature, with several studies finding zero or negative effects for this interaction (e.g. Klein and Crafts 2012, Martinez-Galarraga 2012). The two other H-O interactions included aim at disentangling the impact of electricity availability from the endowment of different forms of industrial power. Existing literature employs a variety of methods to measure energy endowment. Missiaia (2019) includes alternatively water power and hydroelectric power, keeping the two primary sources of energy for Italian industry separate. Crafts and Mulatu (2005), Wolf (2007), Klein and Crafts (2012) and Nikolić (2017) use coal abundance - at times proxied by local coal prices - but Italy produced little coal. Moreover, provincial coal prices reflected transport costs and distance from the port of import, as documented by Licio (2023). Here, we include energy endowment measured as the total horsepower of existing engines, distinguishing between electric motors and those using other sources (i.e. water, coal, wind, gas and oil). As there is a clear endogeneity problem, and the two variables can be correlated, we also estimate a reduced-form model

Table 1. Provincial and Industry Characteristics

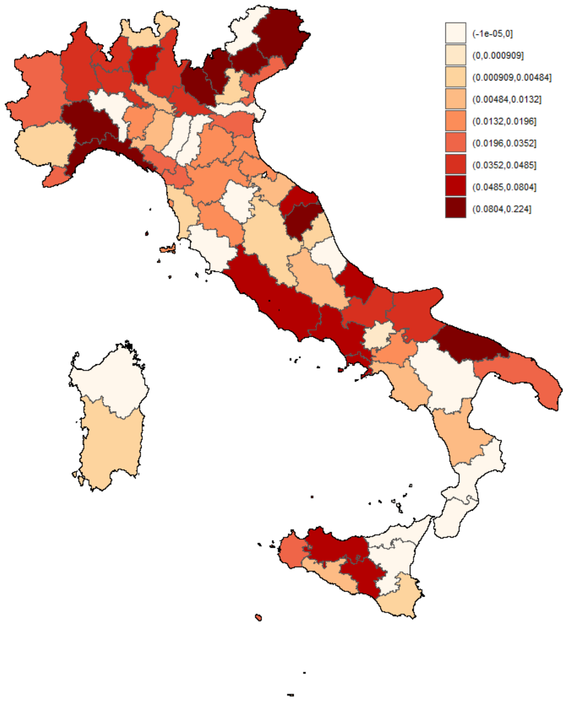
Variable	Description
Provincial characteristics:	
Literacy Rate	Share of the school-age population (>6 years of age) able to read and write
Non-Electric Power	Total industrial horsepower from non-electric sources (steam, water, wind, gas, oil, etc.)
Electric Power	Industrial horsepower from electric engines
Market Potential	Domestic market potential following Harris (1954)
Industry characteristics:	
White-Collar	Share of white-collar workers on total employment
Non-Electric Intensity	Non-electric horsepower per employee
Electric Intensity	Electric horsepower per employee
Backward Linkages	Share of intermediates from other industries on total VA
Forward Linkages	Share of sales to other industries on total VA
Mean Plant Size	Average number of employees per plant

Notes: The provinces are the sixty-nine existing historically in Italy between 1871 and 1918. We consider 15 two-digit industries in manufacturing following the classification of industrial activities established in Rey (1992): mining, tobacco, foodstuff, textiles, clothing, leather, wood, metalmaking, engineering, non-metal minerals, chemicals, paper, sundry manufacturing, construction, and utilities.
Sources: see text.

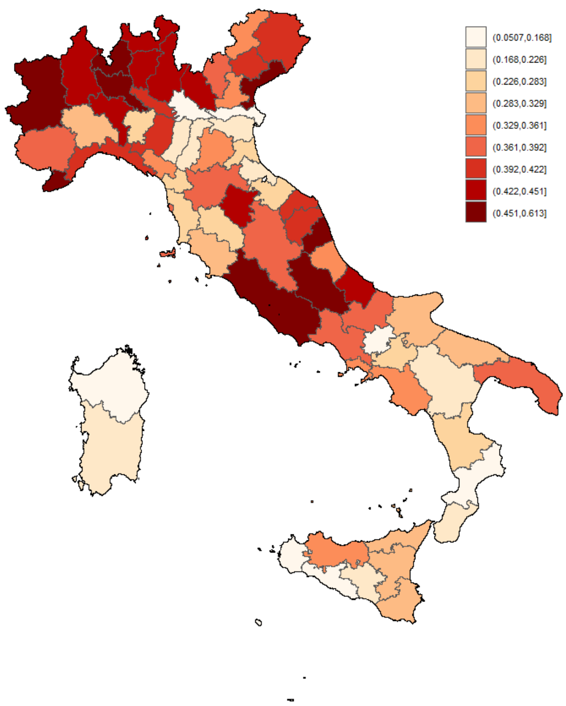
that contains only the electricity interaction, further instrumented using water availability (Tables 6 and 7). For the intensity of energy use in production, we use the horsepower per worker, again distinguishing between electric and non-electric power. Overall, the literature unanimously establishes a positive and robust effect on industrial location for energy endowment.

The NEG-type interactions we consider in equation (2) are based on a novel calculation of market potential at the provincial level. We adopt the formulation introduced by Harris (1954), which defines market potential in province i as the sum of the GDP of all provinces, weighted by the distance to province i. In this work, we employ the new estimates of province-level GDP produced by Chiaiese (2024) and, following Basile and Ciccarelli (2018), approximate province-to-province distance with the great circle distance in kilometres between provincial capitals. Other works use effective distances, considering transport costs and trade barriers in the calculation of market potential, as in Missiaia (2016), Crafts (2005), Schulze (2007) and Martinez-Galarraga (2012). Still, the intuition on the effect of market potential remains the same: for province i, the larger the GDP of other provinces, the larger the market to which firms located in i would have access. The greater the distance, however, the harder it would be to reach that market, and

Figure 1. Share of Electric power, Italian Provinces, 1903-1911



(a) 1903



(b) 1911

Share of electric engines horsepower over total industrial horsepower at historical provincial borders. *Sources:* Authors' elaborations on data from MAIC (1905, 1914).

thus, the lower relevance of the GDP of that province in province i's market potential. Following existing literature, we consider the market potential interactions with forward and backward linkages and with the average plant size. Forward linkages are computed as the share of sales to other industries over total value added. Backward linkages are the share of intermediates from other sectors over total value added. These two interactions measure firms' tendencies to locate themselves close to the sectors they supply or their own suppliers. Average plant size, measured as the mean number of employees per establishment, should capture the effect of market size tied to economies of scale. We expect all three interactions to have positive effects. The literature's estimates confirm the positive effect expectations, differing primarily in the coefficients' significance: Missiaia (2019) finds to be relevant only the interactions of domestic market potential with forward linkages and average plant size, as do Klein and Crafts (2012). Both Martinez-Galarraga (2012) and Crafts and Mulatu (2005) find significance only in the average size interaction.

4 Data and Sources

This section discusses the dataset we assembled to estimate our baseline regression (Eq. 2) and the sources for the dependent variables, and the provincial and industry characteristics.

4.1 Dependent variables

In our model, we take as dependent variables the logarithm of the share of - alternatively - constant-price GDP and sectoral employment at the provincial level. First, we consider the share of GDP for a given industrial sector over the total value added of a province. The GDP figures at constant 1911 prices come from Chiaiese (2024), which provides the most recent estimates of Italian GDP at the provincial (NUTS-3) level adopting the Geary and Stark (2002) methodology. Looking at GDP shares allows us to consider the spatial distribution of industrial production, which also captures the different performance of industries in different locations.
Second, we look at the share of sector-specific employment over the total employment of a province. Employment figures at the provincial level come from the labour force estimates by Ciccarelli and Missiaia (2013). They employ population censuses taken in 1871, 1881, 1901 and 1911, discussing the related shortcomings. In particular, southern regions misreport an implausibly high number of women employed in the textile sector. This issue, however, is only present in the 1871 and 1881 censuses and does not affect our sample. By studying employment at the province-industry level, we make our analysis comparable with Missiaia (2019). Furthermore, we look directly at the pure location pattern of industrial activity, removing from the picture the differences in performance that affect GDP figures.

Figures 2 and 3 show, respectively, the distribution by province of total industrial employment and total GDP at 1911 prices.

4.2 Provincial Characteristics

This section reports the source of the provincial characteristics listed in Table 1. The literacy rate for the population above six years of age across Italian provinces comes from Cappelli and Quiroga Valle (2021). They provide harmonized figures for Italy in 1861, 1870, 1877, 1887, 1901, 1907, and 1921, for which official statistics on schooling are available. As we lack information on 1911, we estimate the literacy level in that year by linear interpolation.

Information on the available industrial power comes from two official statistics. The first industrial census in Italy dates back to 1911 (MAIC 1914). Despite its well-known underreporting of industrial activities (Fenoaltea 2015), it remains the best source for detail and coverage over the 1871-1911 period. Therefore, we use it as the source of our 1911 figures. For 1901, the official statistics with nationwide coverage closest in time refer to 1903 (MAIC 1905). As this is the most accurate data point available, we take it as the source for our 1901 power stock.

In both years, we consider the total reported horsepower. The sources we use allow us to distinguish between the power available from electric engines and that from engines using all other forms of energy (steam, wind, water, gas and oil). This distinction is crucial, as it allows us to identify the effect of the electric power stock on industrial location, which is our main regressor of interest[7]. The resulting variables - electric and non-electric power - for 1901 and 1911 are reported in the appendix in Table A1.

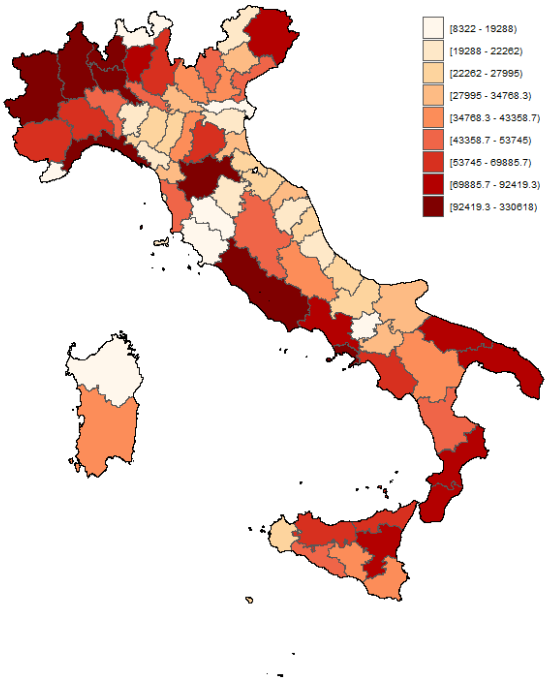
Following well-established practice (see, for instance, Crafts 2005 and Schulze 2007), we adopt Harris (1954) methodology to compute market potential. This method has seen extensive use in historical analysis and has been adopted for Italy in the 1871-1911 period by Missiaia (2016, 2019) and Basile and Ciccarelli (2018). Then, market potential is determined by the following equation (3):

$$Mktpot_{it} = \Sigma_{j=1}^{N} GDP_{jt} \times d_{ij}^{-1} \tag{3}$$

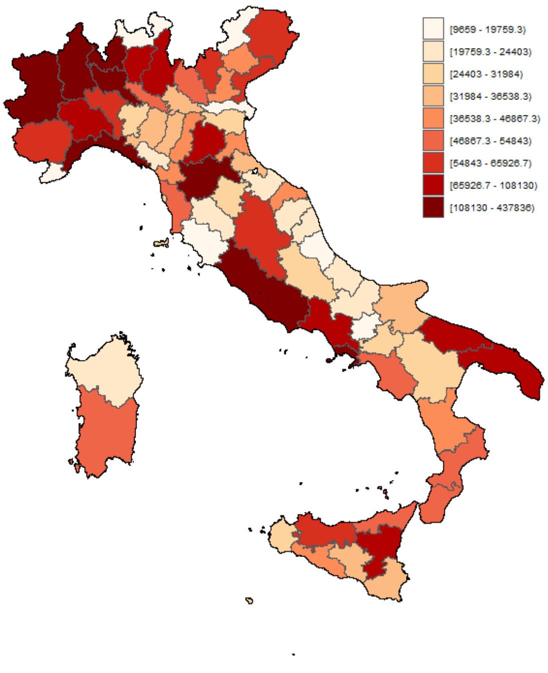
where i, j denotes provinces, d_{ij} is the distance between province i and j, and GDP_{jt} the GDP of province j in year t. Following Basile and Ciccarelli (2018) we compute d_{ij} as the great circle distance in kilometres between the main nodes of province i and j, irrespective of the actual transport infrastructure and costs. As provincial capitals are usually the

[7]The 1911 census allows for the distinction between engines only producing electricity, those producing and consuming it, and those only consuming electricity. To avoid double counting, we consider only the power of engines consuming electricity. Our results are robust to alternative specifications, considering only the power in engines producing electricity and the total power of all three categories.

Figure 2. Total industrial employment by province, 1901-1911



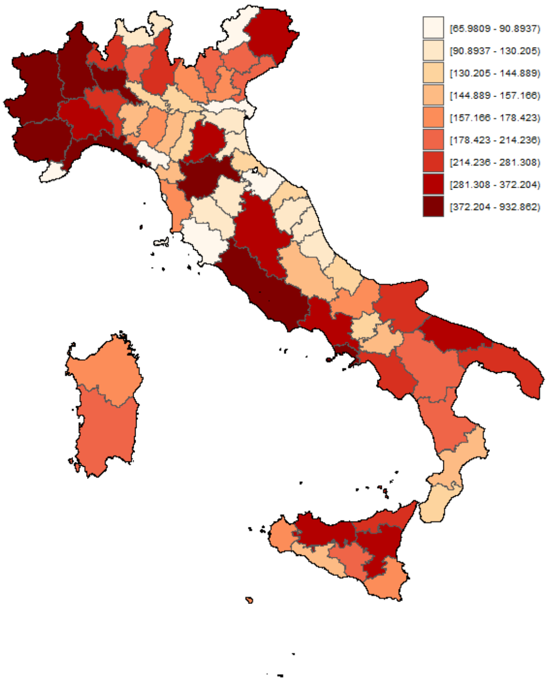
(a) 1901



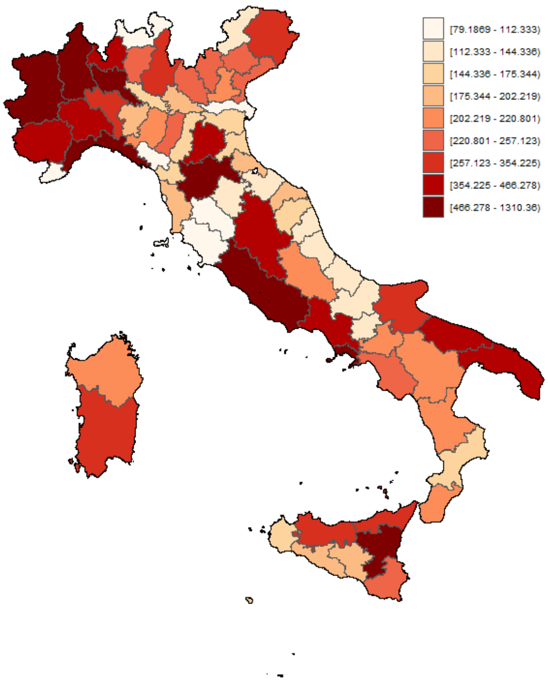
(b) 1911

Total industrial employment at historical provincial borders. *Source:* Authors' elaborations on data from Ciccarelli and Missiaia (2013).

FIGURE 3. TOTAL GDP BY PROVINCE, 1901-1911



(A) 1903



(B) 1911

Total GDP at 1911 prices at historical provincial borders. *Source:* Authors' elaborations on data from Chiaiese (2024).

largest and most economically active centres in their province, we take them as our main nodes.
This formulation also considers the GDP of the province i itself in year t and its distance from itself (d_{ii}). Rather than setting this distance to zero, we consider how spread could GDP_{it} be given the province's size. To do so, we compute the distance factor d_{ii} as proposed by Keeble et al. (1982) using the equation that follows:

$$d_{ii} = 0.333 \times \sqrt{\frac{Area_i}{\pi}} \tag{4}$$

where $Area_i$ is the area of province i in square kilometres.
In the Italian case, existing research (Missiaia 2016, 2019, Basile and Ciccarelli 2018) finds local market access - as opposed to access to the international market - to be particularly relevant in the country's industrialization. Therefore, we limit our analysis to domestic market potential without considering access to the markets of Italy's international trading partners. Our estimations of domestic market potential for all Italian provinces in 1901 and 1911 are reported in the appendix in Table A2.
A more accurate way to compute market potential would be to consider actual transport costs and trade barriers, as Missiaia (2016) does for Italian regions. At the provincial level, however, this approach would require data not readily available on the infrastructural network and mode of transportation (i.e. roads, railways, canals and shipping lanes). Moreover, existing approximations do not significantly outperform our methodology of choice (see the appendix analysis in Missiaia 2019).

4.3 Industrial Characteristics

This section describes the sources of the industry-level characteristics reported in Table 1. These variables come from the official industrial census of 1911 (MAIC 1914) or the input-output table for the Italian economy in 1911 reported in Vitali (2003).
Both these sources report industry-level data for 1911. Following Missiaia (2019), we use the information on 1911 for 1901 interactions as well. In so doing, we are implicitly assuming the technology of production in 1911 - the factor usage, return to scale and dependence on other sectors - closely resembles the one available in 1901. Most of the literature adopting this empirical methodology does the same, primarily due to the scarcity of historical data. In our case, only a decade has passed between our two years of analysis, and this is likely to reduce distortions and concerns about radical changes in production technology. The resulting set of industry-level variables is presented in the appendix in Table A3.
The white-collar share is computed from the number of total white-collar workers - excluding owners and family members - over total employment by sector. The data on white-collar

workers is only available from the industrial census of 1911, so we follow Missiaia (2019) and use the same number for the 1901 interactions as well.

As a measure of power intensity in production, we take the amount of horsepower per employee in the industry from the 1911 industrial census. As with the power availability, we distinguish between electric and non-electric power. To avoid double counting, the total stock of electric power is computed by considering only those engines that consume electricity[8].

Backwards and forward linkages are computed, respectively, as the share of inputs coming from and the share of output going to other industries over the total value added of the industry considered. Data on the value of intermediate inputs and outputs come from the input-output tables by Vitali (2003). Vitali presented consistent tables for the Italian economy in 1891, 1911, 1938 and 1951. Considering the time frame of our analysis, and for consistency with other industry-level variables, we follow Missiaia (2019) and use only the information for 1911. For the total sectoral value added, we take the reconstruction of Fenoaltea (2020), which underlies the reconstruction at the province-level GDP of Chiaiese (2024).

The average plant size is the mean number of employees per plant. Information on total employment by industry and the number of plants come from the 1911 industrial census, and for consistency, is employed in both 1911 and 1901.

5 Baseline Results

The results of the ordinary least squares (OLS) estimation of equation 2 are presented in tables 2 and 3, using as dependent variable the logarithm of GDP and industrial employment shares, respectively. Both specifications were estimated using first cross-sections for 1901 and 1911 and then the two years together in a pooled sample). All variables have been standardized, and heteroscedastic-robust standard errors are clustered at the provincial level. As the dependent variable is the standardized logarithmic transformation of a share and our regressors of choice are the interaction between provincial and sectoral characteristics, a direct interpretation of the estimated coefficients is not straightforward. Instead, we will primarily comment on those effects' magnitude, statistical significance, and direction.

Estimates are broadly comparable between the two dependent variables. Among the H-O-type interactions, two appear to have significantly impacted industry location in the years we consider. Human capital - the literacy-white collar interaction - is strongly significant in 1901. Still, its magnitude and significance shrink in 1911, although the pooled sample's results suggest this force mattered throughout the decade. More importantly,

[8]As for the electric power stock, our results are robust to measuring electricity intensity using the total horsepower of all the electric engines, as well as only those producing electric power.

Table 2. GDP Shares - OLS Regressions

Dependent Variable:	Log GDP Share		
	1901	1911	Pooled
Lit. Rate × White-Collar	0.0577***	0.0068	0.0337**
	(0.0177)	(0.0156)	(0.0155)
Electric Power × El. Intensity	0.0456***	0.1146***	0.0547***
	(0.0141)	(0.0405)	(0.0108)
Non-Electric Power × Non-El. Intensity	0.0164	-0.0777***	-0.0091
	(0.0111)	(0.0261)	(0.0081)
MP × Forward Links	-0.0126	-0.0029	-0.0027
	(0.0190)	(0.0183)	(0.0161)
MP × Backward Links	0.0357***	0.0198**	0.0286***
	(0.0086)	(0.0076)	(0.0076)
MP × Avg. Plant Size	0.0232	0.0273	0.0249
	(0.0287)	(0.0396)	(0.0317)
Literacy Rate			0.1956
			(0.1287)
Electric Power			0.0044
			(0.0104)
Non-Electric Power			-0.0206
			(0.0137)
Market Potential			0.1164
			(0.1552)
Fixed-effects			
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year			Yes
Observations	993	1,007	2,000
Adjusted R^2	0.73691	0.71061	0.72789
F-test	10.781	9.4749	6.2879

Note: All variables have been standardized. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

Table 3. Employment Shares - OLS Regressions

Dependent Variable:	Log Employment Share		
	1901	1911	Pooled
Lit. Rate × White-Collar	0.0555***	0.0102	0.0346**
	(0.0154)	(0.0135)	(0.0135)
Electric Power × El. Intensity	0.0381***	0.1087***	0.0496***
	(0.0117)	(0.0370)	(0.0099)
Non-Electric Power × Non-El. Intensity	0.0121	-0.0745***	-0.0108
	(0.0086)	(0.0235)	(0.0073)
MP × Forward Links	-0.0168	0.0052	-0.0013
	(0.0159)	(0.0178)	(0.0145)
MP × Backward Links	0.0245***	0.0142**	0.0202***
	(0.0080)	(0.0065)	(0.0068)
MP × Avg. Plant Size	0.0133	0.0352	0.0223
	(0.0209)	(0.0336)	(0.0245)
Literacy Rate			0.0865
			(0.1397)
Electric Power			0.0007
			(0.0111)
Non-Electric Power			-0.0238*
			(0.0134)
Market Potential			0.1887
			(0.1580)
Fixed-effects			
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year			Yes
Observations	994	1,015	2,009
Adjusted R^2	0.808	0.758	0.785
F-test	16.075	11.979	8.5483

Note: All variables have been standardized. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

the other significant H-O interaction is the one that captures electricity availability. The estimated effect increases over time for GDP and employment shares, from around 0.04 to 0.1 standard deviations, remaining strongly significant. Moreover, for 1901, this effect is about the same magnitude as the one of human capital. More interestingly, the interaction that captures non-electric power availability is nonsignificant at first, then turns significant but with an estimated negative effect on industrial location. This could imply that older forms of power production became progressively less relevant in explaining the location of industry. Furthermore, the expansion of industrial electricity seems to have taken over the role of other power sources by 1911. It might also have been the case that these other sources expanded in those provinces that lagged in production and industrial activities. In contrast, richer areas invested more in the new electrical technology.

Of the three NEG-type interactions, only one is statistically significant, the one considering backward linkages. At least at the 5% level, it remains significant in the cross-sections and pooled sample estimates for both GDP and employment shares. The magnitude of the effects shrinks significantly over time, with the coefficients for 1911 being about half those of 1901. The coefficients are positive, suggesting that access to intermediate inputs was driving the location of Italian industries in the decade under scrutiny. Contrary to most of the literature, our analysis finds no significance in the market potential interaction with forward linkages and average plant size. This suggests that access to sectors buying their intermediate output and economies of scale played little part in industrial location, at least at the provincial level. We should note that this differentiates our results also from the tentative provincial estimates put forward by Missiaia (2019), which found a relevant positive effect for the economies of scale interaction in 1901.

To summarize, we find evidence that both factor endowments and - albeit to a lesser extent - market potential mattered in the location of Italian industry. Specifically, we find that electricity availability has a growing and highly significant effect on industrial agglomeration. This effect is the most relevant - looking at its magnitude - determinant of the industrial location at the end of the decade when the electrification of the Italian economy was much more advanced than in 1901. Moreover, the pooled sample estimates suggest this was the case throughout the decade, as the magnitude of the electricity endowment's coefficient is comparable but larger than the one for human capital interaction. Nonetheless, as the literature discussed in section 2 highlighted, the availability of electric power was arguably endogenous to the presence of electricity-intensive industries. Endogeneity is even more likely in the case of Italy, where the production and distribution of electricity were left entirely to private entrepreneurs until the early 1960s. To address this concern, we will discuss an alternative measure of electricity availability in the following section 6. Then, in section 7, we will introduce an instrumental variable approach to address potential endogeneity-related bias directly.

6 Measuring Electricity Access

In the previous section, we measured the availability of electricity through the stock of available power coming from electric engines. However, an alternative way to measure it is to look at the extent of electricity distribution lines instead. Rather than measuring available power, this approach would capture access to electric energy by looking at how widespread the electric infrastructure was in a particular territory.

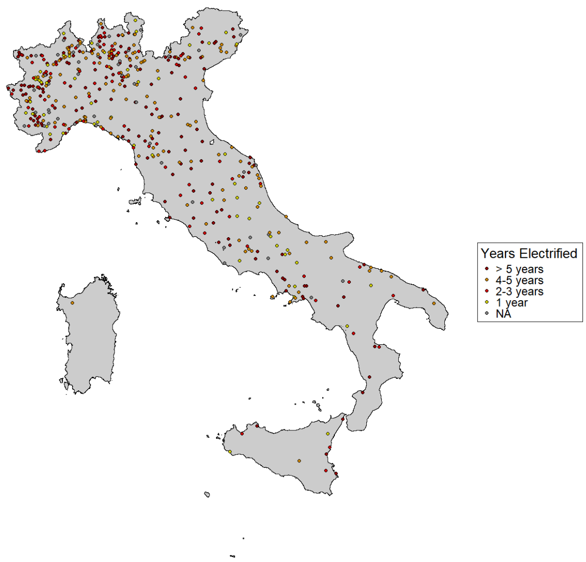
Historical sources allow us to know how much the Italian territory had access to electricity with a reasonable degree of accuracy. In 1895, the government introduced an excise tax on electricity consumption and established a process of decentralized checks on the existing electric plants.[9] Building on these data, in 1898, the MAIC statistical office ran a survey across all Italian municipalities, collecting information on the areas of electricity production and distribution the fiscal sources did not cover. The resulting publication (MAIC 1901) offers a detailed picture of the diffusion and use of electricity all over Italy. Crucially, it also provides extensive information on the location, construction date, installed power, type of current (direct or alternate) and primary energy source (e.g., steam, hydro, gas, oil) of all the electricity distribution stations built in the country between 1892 and 1898 (see figure A1 in the appendix). This first publication was compounded in 1911 by a second statistic, compiled by the same office (MAIC 1911). This source extended the data presented in the 1901 statistic to the decade that followed, from 1898 to 1908. It contained comparable, if less detailed, information on the distribution stations for electric energy that were either built or expanded in 1898-1908. It also reported some distribution stations were still under construction when the survey was conducted. The main data reported concern, again, location, primary energy source, type of current, installed power and construction date (see figure A2 in the appendix).[10]

These two sources allow us to accurately identify which Italian municipalities had a local electricity distribution station built between 1892 and 1908. In particular, we put together the information in the two statistics to recover the situation of electrified municipalities in Italy during 1901. By that year, the records contain 490 municipalities where an electricity distribution station was available. This situation is reported in figure 4a. However, the official statistics extend only up to 1908, which leaves a 3 years gap before our next reference year, 1911. To bridge this gap, we refer to two other historical sources. The first is a publication by the Associazione Esercenti Imprese Elettriche in Italia (AEIE, the Italian Association of Electricity Producers), containing information on the most relevant electric plants active in the country by 1911 (AEIE 1911). The second is a specialized

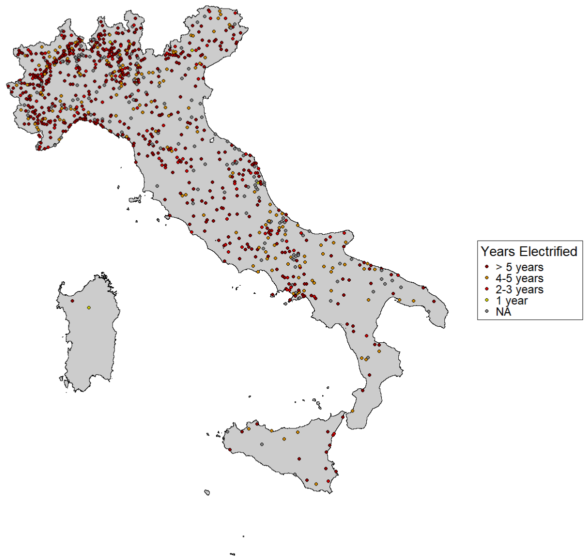
[9]Law 8 August 1895, n. 486, annex F. The tax was levied on private electric energy consumption for lighting or heating and amounted to 0.6 lira cents per 100 W/h. There was an exemption for public lighting and industrial consumption.

[10]These sources are used to study the effects of early electrification on population growth and density at the municipal level in Weisdorf et al. (2024).

Figure 4. Municipalities with Electricity, 1901-1911



(a) 1901



(b) 1911

Municipalities with an electricity distribution station and years since its construction. *Sources:* Authors' elaborations on data primarily from MAIC (1901, 1911). See also section 6.

periodical, *L'Elettricista*, that regularly reported in its 'News' section the opening of new electric plants and distribution stations (*L'Elettricista*, 1908-1911). Integrating the information from the MAIC electricity statistics of 1908 with these two sources, we can paint a more complete picture of the electrified municipalities in 1911 (see figure 4b).
To use access to electricity - that is, how easy it is to access electricity given the spread of distribution stations across municipalities - we need to produce a provincial-level indicator

of access to electricity from the municipal-level data we collected. We elect to use the inverse of the average distance of all municipalities within a province from their closest electricity distribution station. First, we use Dijkstra's algorithm to compute the least-cost paths between each municipality and the municipalities with a distribution station. To consider the presence of regional rather than provincial networks of electricity distribution (see Giannetti 1985) and the possibility that distribution stations right outside the provincial borders were the closest ones, we consider all distribution stations in each province and its neighbouring provinces. The transition cost matrix for this distance measure is computed exclusively from elevation differences, assuming that the most significant cost in building an electricity transmission line came from the material itself, the copper used in electric cables. We select the closest distribution station from the resulting distance matrix. Then, for each municipality-distribution station pair, we take the length in kilometres of the path that connects the two, minimizing the total absolute changes in elevation. Finally, we compute the average of these distances across all province municipalities and take its inverse. This way, we produce a measure of electricity access that grows larger as the average distance is lower (i.e. when more municipalities have direct access to electricity). Furthermore, this index does not depend on municipalities' size, arguably the primary determinant of potential demand for electricity. Therefore, it is less exposed to the endogeneity problem we have previously highlighted.

Tables 4 and 5 report the OLS estimations of our main regression model (eq. 2), substituting the electric power stock with the new indicator for electricity access. As in our baseline analysis, the estimated coefficients' magnitude, direction, and significance are comparable and similar for both the dependent variables. However, the picture is more nuanced than before among the three H-O-type interactions that remain the core of our investigation of electricity effects. On the one hand, the human capital interaction is significant and, with an estimated effect of about 0.05 standard deviations, the primary determinant of industrial location in 1901. However, its impact is no longer significant in 1911 and the pooled sample. Similarly, the non-electric power interaction is strongly significant and positive in 1901, and even if it remains so in the pooled sample, it greatly shrinks in size, losing all significance in 1911. On the other hand, the interaction between our measure of electricity access and electricity intensity in production appears, for 1901, insignificant. In contrast, it turns significant in 1911 and becomes the primary determinant of industrial location, with an estimated positive effect of about 0.035 standard deviations. The same is true when looking at the pooled sample results, which further support its relevance throughout the decade we study.

The emerging picture is remarkably close to our baseline in the NEG-type interactions. For both GDP and employment shares, only the interaction between domestic market potential and backward linkages is significant, and strongly so, across all specifications. The effects are positive and shrink over time in a fashion broadly comparable to what

Table 4. GDP Shares - OLS Regressions with Electricity Access

Dependent Variable:	Log GDP Share		
	1901	1911	Pooled
Lit. Rate × White-Collar	0.0478*	0.0007	0.0228
	(0.0241)	(0.0192)	(0.0199)
Electricity Access × El. Intensity	0.0256	0.0374**	0.0333*
	(0.0200)	(0.0186)	(0.0173)
Non-Electric Power × Non-El. Intensity	0.0355***	0.0082	0.0210***
	(0.0091)	(0.0105)	(0.0078)
MP × Forward Links	-0.0095	0.0148	0.0028
	(0.0199)	(0.0174)	(0.0167)
MP × Backward Links	0.0363***	0.0229***	0.0296***
	(0.0085)	(0.0077)	(0.0075)
MP × Avg. Plant Size	0.0239	0.0277	0.0260
	(0.0285)	(0.0394)	(0.0314)
Literacy Rate			0.1849
			(0.1235)
Electricity Access			0.0014
			(0.0222)
Non-Electric Power			-0.0201
			(0.0123)
Market Potential			0.1116
			(0.1574)
Fixed-effects			
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year			Yes
Observations	993	1,007	2,000
Adjusted R^2	0.736	0.708	0.727
F-test	10.720	9.3698	6.2642

Note: All variables have been standardized. Electricity access is measured as the inverse of the average least cost path distance of all the municipalities in the province from their closest electricity distributing station. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

Table 5. Employment Shares - OLS Regressions with Electricity Access

Dependent Variable:	Log Employment Share		
	1901	1911	Pooled
Lit. Rate × White-Collar	0.0503**	0.0050	0.0263
	(0.0205)	(0.0170)	(0.0174)
Electricity Access × El. Intensity	0.0160	0.0344*	0.0269*
	(0.0163)	(0.0180)	(0.0156)
Non-Electric Power × Non-El. Intensity	0.0288***	0.0071	0.0171**
	(0.0071)	(0.0093)	(0.0071)
MP × Forward Links	-0.0139	0.0219	0.0038
	(0.0167)	(0.0168)	(0.0150)
MP × Backward Links	0.0251***	0.0171***	0.0211***
	(0.0079)	(0.0064)	(0.0067)
MP × Avg. Plant Size	0.0135	0.0356	0.0231
	(0.0208)	(0.0334)	(0.0243)
Literacy Rate			0.0728
			(0.1357)
Electricity Access			0.0118
			(0.0243)
Non-Electric Power			-0.0229*
			(0.0131)
Market Potential			0.1958
			(0.1578)
Fixed-effects			
Province	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Year			Yes
Observations	994	1,015	2,009
Adjusted R^2	0.807	0.756	0.784
F-test	15.983	11.840	8.5114

Note: All variables have been standardized. Electricity access is measured as the inverse of the average least cost path distance of all the municipalities in the province from their closest electricity distributing station. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

the previous section already highlighted. Again, neither economies of scale nor access to downstream buyers along the production value chain appear to play any role in driving industrial location across Italian provinces in this period.

To summarize our findings, the overall impact of access to electricity changed significantly between 1901 and 1911. In 1901, when little more than 5% of municipalities had direct access to electric energy, access to non-electric power and available human capital played the primary role in driving the location of industrial production. However, between 1901 and 1911, electricity became more and more widespread. Not only, as the 1911 industrial census highlights, by the end of the decade about 43% of all industrial power came from electric engines. Also, the new energy was significantly more accessible, with distribution stations present in more than 1,000 municipalities. As we mentioned, it is likely that the diffusion of electricity in the Italian case was highly endogenous to the potential local demand. These municipalities probably represented the best markets for electricity, the places in which the new technology was ready to be adopted. Thus, in 1911, access to electricity was much more relevant in explaining industrial location, as we find. Part of this effect is, of course, due to the lingering and still unresolved effect of endogeneity: the electricity was brought where a potential market for it existed. To solve this issue, in the next section we turn to an instrumental variable approach.

7 Instrumental Variable Approach

To further assess the robustness of our results, we present in Tables 6 and 7 an instrumental variable strategy that addresses the potential endogeneity bias related to electric power diffusion. This bias stems from the plausible relation between existing industrial activity, the demand for electricity, and the electric power available for industrial use. In principle, places with a higher concentration of industrial activities that more intensively used electricity in production would demand - and, in the medium-long run, attract more - electric power. Therefore, this reverse causality might bias our previous estimate: while we find a significant effect of electricity availability on industrial activity, it might be industrial activity that, over time, influenced the spread of electricity. As an instrument, we use the total stream of rivers per square kilometre in each province. This measure is intended to capture the potential for producing energy - particularly electricity - from water and is therefore exogenous with respect to both the employment structure and economic production.

As the instrument is plausibly related to both electric and - through hydropower - non-electric power, we estimate a reduced-form model, dropping the non-electric power interaction from the baseline specification of equation 2. To provide a proper comparison point, then, the two tables report both OLS and IV estimations of this reduced-form model. The instrument is significant at the 1% level in the first step in all the specifications. The coefficients are comparable in magnitude, and our previous results are confirmed in terms of significance, suggesting that at least for 1901 and in the pooled sample, electric energy was a major determinant in the location of Italian industries across provinces. We should note that, in 1911, the instrumented model coefficient for the electricity interaction is not significant for both dependent variables. This is arguably due to the fact that, while quite widespread, electricity production is not as tied to water availability as it was in the very early adoption years and as it would become after the construction of the large hydroelectric dams in the Alps during the 1920s.

Table 6. GDP Shares - OLS and IV Regressions on Reduced Model

Dependent Variable:	Log GDP Share					
	1901		1911		Pooled	
	OLS	IV	OLS	IV	OLS	IV
Lit. Rate × White-Collar	0.0616***	0.0274	0.0013	0.0147	0.0321**	0.0324**
	(0.0179)	(0.0272)	(0.0143)	(0.0152)	(0.0150)	(0.0162)
Electric Power × El. Intensity	0.0532***	0.1773**	0.0494***	0.0186	0.0489***	0.0481**
	(0.0163)	(0.0735)	(0.0130)	(0.0164)	(0.0092)	(0.0217)
MP × Forward Links	-0.0143	-0.0230	0.0105	0.0137	-0.0016	-0.0015
	(0.0189)	(0.0186)	(0.0174)	(0.0175)	(0.0159)	(0.0158)
MP × Backward Links	0.0346***	0.0364***	0.0237***	0.0230***	0.0292***	0.0292***
	(0.0087)	(0.0089)	(0.0076)	(0.0076)	(0.0076)	(0.0075)
MP × Avg. Plant Size	0.0223	0.0301	0.0286	0.0256	0.0252	0.0251
	(0.0286)	(0.0304)	(0.0396)	(0.0406)	(0.0316)	(0.0324)
Literacy Rate					0.2011	0.1966
					(0.1293)	(0.1367)
Electric Power					0.0047	0.0023
					(0.0109)	(0.0161)
Market Potential					0.1303	0.1275
					(0.1522)	(0.1470)
Fixed-effects						
Province	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year					Yes	Yes
Observations	993	993	1,007	1,007	2,000	2,000
Adjusted R^2	0.737	0.737	0.709	0.708	0.728	0.728
F-test	11.338	11.216	9.8972	9.8087	6.9377	6.8766

Note: All variables have been standardized. IV columns report two-stage least square estimates; instrument for the first stage is water streams per square kilometre. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

Table 7. Employment Shares - OLS and IV Regressions on Reduced Model

Dependent Variable:	Log Employment Share					
	1901		1911		Pooled	
	OLS	IV	OLS	IV	OLS	IV
Lit. Rate × White-Collar	0.0584***	0.0220	0.0050	0.0171	0.0327**	0.0311**
	(0.0152)	(0.0229)	(0.0124)	(0.0140)	(0.0130)	(0.0145)
Electric Power × El. Intensity	0.0438***	0.1767***	0.0462***	0.0184	0.0427***	0.0472**
	(0.0134)	(0.0595)	(0.0110)	(0.0163)	(0.0079)	(0.0195)
MP × Forward Links	-0.0180	-0.0273*	0.0181	0.0210	0.0001	-0.0003
	(0.0158)	(0.0156)	(0.0171)	(0.0173)	(0.0144)	(0.0143)
MP × Backward Links	0.0237***	0.0256***	0.0178***	0.0172***	0.0208***	0.0209***
	(0.0080)	(0.0082)	(0.0064)	(0.0063)	(0.0068)	(0.0067)
MP × Avg. Plant Size	0.0128	0.0202	0.0366	0.0337	0.0226	0.0229
	(0.0208)	(0.0223)	(0.0336)	(0.0345)	(0.0244)	(0.0251)
Literacy Rate					0.0939	0.0881
					(0.1418)	(0.1469)
Electric Power					0.0009	-0.0019
					(0.0120)	(0.0140)
Market Potential					0.2040	0.2004
					(0.1552)	(0.1503)
Fixed-effects						
Province	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes
Year					Yes	Yes
Observations	994	994	1,015	1,015	2,009	2,009
Adjusted R^2	0.808	0.809	0.757	0.756	0.785	0.785
F-test	16.910	16.778	12.509	12.400	9.4387	9.3683

Note: All variables have been standardized. IV columns report two-stage least square estimates; instrument for the first stage is water streams per square kilometre. Heteroscedastic-robust standard errors clustered at the provincial level in parentheses. Significance codes: *p<0.1; **p<0.05; ***p<0.01.

8 Conclusions

We have shown how, in the first decade of the 20th century, electricity played a significant role in shaping the location of industrial activity in Italy. The importance of electric energy grew over time, as did its geographical spread over the country and its overall availability. Comparably, the relevance it had in driving industrial location grew as well. When the distinction between electricity and other industrial power sources is explicitly accounted for, as in our baseline model, other factors traditionally associated with the unequal distribution of Italian economic development - the North-South divide - such as literacy and access to domestic demand, appear less relevant. Whether electricity eased the constraints of geography remains to be seen. It indeed was the case for the "water shackles", the need of most industries to locate close to abundant and regular water streams, that undeniably held Italy's south back with respect to its Northern Alpine regions. However, the extent to which this shift impacted the entire country or only its more advanced areas, where existing industries had the most to gain from relocating away from water and closer to communication hubs, remains an open question.

While this study provides important insights, its scope is limited in several respects. First, focusing on the first decade of Italy's electrification leaves open the opportunity to extend the analysis into the 1920s and 1930s, which would capture long-term dynamics and the sustained effects of early electrification. Second, our measure of market potential is constrained to provincial markets within Italy and could be expanded to include foreign trading partners and incorporate actual transportation costs. Lastly, the electricity access indicator, while innovative, could benefit from alternative approaches to the same data to address potential endogeneity more effectively.

Nonetheless, this work is the first to quantitatively assess the role of electricity adoption in Italy's economic development, particularly at the provincial level. It underscores the significant impact of "white coal" in coal-scarce contexts like Italy during the Second Industrial Revolution, highlighting a critical aspect of energy transitions. Furthermore, this research opens promising avenues for further investigation into the spatial distribution of industrial activity and the local availability of emerging energy sources, providing a framework for comparative studies in other nations facing similar constraints during their industrialization processes.

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Appendix

Table A1. Electric and Non-electric power by Province, 1901-1911

Province	Electric		Non-electric		Province	Electric		Non-electric	
	1901	1911	1901	1911		1901	1911	1901	1911
Alessandria	1.37	10.10	11.65	22.37	Massa e Carrara	0.17	4.34	5.34	7.68
Ancona	0.51	11.44	6.82	16.35	Messina	0.00	2.58	3.09	6.44
Aquila degli Abruzzi	0.12	13.91	9.30	12.59	Milano	4.01	181.43	83.45	114.33
Arezzo	0.00	10.53	5.56	13.05	Modena	0.00	2.10	4.61	8.47
Ascoli Piceno	0.02	9.69	4.20	11.24	Naples	2.49	42.91	33.30	83.71
Avellino	0.05	1.71	3.42	4.46	Novara	1.83	76.65	39.26	93.84
Bari	0.58	6.38	6.07	14.18	Padua	0.01	6.68	4.12	11.92
Belluno	0.00	3.83	5.67	7.49	Palermo	0.66	7.67	8.83	14.71
Benevento	0.00	0.61	3.58	3.11	Parma	0.03	15.52	3.85	23.44
Bergamo	1.73	49.69	29.97	62.04	Pavia	0.00	13.03	10.59	17.15
Bologna	0.13	14.78	7.81	26.71	Perugia	0.28	37.43	58.01	65.97
Brescia	0.83	99.16	17.33	122.63	Pesaro e Urbino	0.04	1.53	3.75	5.00
Cagliari	0.01	2.19	4.65	9.57	Piacenza	0.09	2.74	5.22	6.93
Caltanissetta	0.29	1.98	3.83	6.91	Pisa	0.02	7.32	7.90	24.24
Campobasso	0.14	3.76	3.20	5.84	Porto Maurizio	0.09	14.34	2.87	14.92
Caserta	0.73	14.96	14.20	25.82	Potenza	0.00	1.48	3.83	5.14
Catania	0.00	5.40	5.68	13.26	Ravenna	0.07	3.58	3.94	9.53
Catanzaro	0.00	0.73	2.20	6.18	Reggio di Calabria	0.00	1.83	3.46	6.55
Chieti	0.25	12.64	3.05	17.27	Reggio nell'Emilia	0.00	1.93	2.11	7.44
Como	1.08	45.53	21.68	49.39	Roma	1.02	43.83	19.45	46.60
Cosenza	0.02	1.33	3.46	4.36	Rovigo	0.00	0.45	1.90	8.38
Cremona	0.03	3.58	3.96	5.24	Salerno	0.09	12.92	10.77	25.00
Cuneo	0.04	14.21	9.52	24.66	Sassari	0.00	0.51	2.09	3.49
Ferrara	0.19	2.49	5.20	12.21	Siena	0.09	1.58	6.71	5.17
Florence	0.21	17.57	12.04	30.58	Syracuse	0.00	2.39	1.86	5.51
Foggia	0.12	2.78	2.75	6.91	Sondrio	0.01	17.89	3.29	23.21
Forlì	0.05	2.75	3.60	9.57	Teramo	0.00	2.67	2.79	4.94
Genoa	13.77	79.32	47.61	109.73	Turin	1.45	102.31	59.65	123.71
Girgenti	0.02	0.46	2.28	4.61	Trapani	0.07	0.69	2.61	3.80
Grosseto	0.00	2.07	3.25	4.66	Treviso	0.58	10.54	5.74	16.18
Lecce	0.10	10.60	4.44	18.36	Udine	1.46	28.98	11.84	43.63
Leghorn	0.12	15.21	8.04	23.57	Venice	0.24	13.20	7.03	10.20
Lucca	0.26	4.74	7.22	12.85	Verona	0.70	11.66	7.15	15.44
Macerata	0.36	5.34	2.19	7.75	Vicenza	2.95	14.40	15.55	23.20
Mantua	0.13	0.98	3.56	8.97					

Thousands of horsepower. For further details, see section 4.2. *Sources:* Authors' elaborations on MAIC (1905, 1914).

Table A2. Domestic Market Potential by Province, 1901-1911

Province	Market Potential 1901	Market Potential 1911	Province	Market Potential 1901	Market Potential 1911
Alessandria	110.57	139.83	Massa e Carrara	87.95	111.16
Ancona	72.60	92.10	Messina	64.64	85.32
Aquila degli Abruzzi	68.99	87.23	Milan	173.47	229.93
Arezzo	78.12	100.06	Modena	102.54	131.72
Ascoli Piceno	72.03	89.11	Naples	152.90	201.21
Avellino	86.80	107.40	Novara	116.82	145.09
Bari	60.36	78.80	Padua	96.62	121.64
Belluno	64.15	81.43	Palermo	55.30	68.09
Benevento	86.03	104.55	Parma	103.56	132.89
Bergamo	111.76	142.88	Pavia	129.61	167.18
Bologna	102.73	132.09	Perugia	75.31	94.39
Brescia	103.49	131.37	Pesaro e Urbino	69.23	87.44
Cagliari	36.71	45.95	Piacenza	111.65	141.69
Caltanissetta	53.84	64.36	Pisa	94.15	118.09
Campobasso	70.86	83.58	Porto Maurizio	72.26	88.35
Caserta	97.02	122.03	Potenza	56.43	68.73
Catania	59.94	79.93	Ravenna	85.49	109.32
Catanzaro	44.99	56.03	Reggio di Calabria	62.95	83.86
Chieti	67.21	80.94	Reggio nell'Emilia	106.30	138.67
Como	118.22	151.78	Rome	80.94	104.43
Cosenza	48.19	59.77	Rovigo	89.14	111.42
Cremona	111.29	141.88	Salerno	78.84	95.45
Cuneo	79.89	97.36	Sassari	39.68	50.77
Ferrara	91.67	118.22	Siena	77.73	97.32
Florence	100.44	126.07	Syracuse	48.97	62.78
Foggia	62.82	77.95	Sondrio	75.87	94.17
Forlì	88.62	114.15	Teramo	73.09	87.98
Genova	115.23	153.16	Turin	91.00	116.74
Girgenti	48.42	61.17	Trapani	49.77	57.43
Grosseto	62.91	79.20	Treviso	88.49	111.38
Lecce	44.38	60.31	Udine	65.94	78.73
Leghorn	94.79	124.43	Venice	89.82	113.37
Lucca	102.10	126.24	Verona	96.05	123.49
Macerata	70.49	89.03	Vicenza	93.64	119.36
Mantua	101.54	129.57			

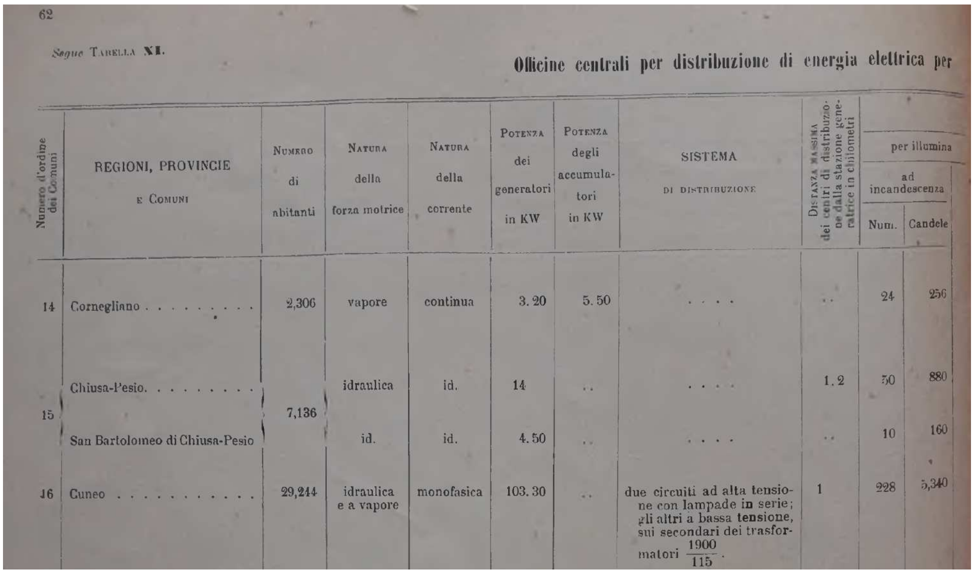
Sources: Authors' calculation following Harris (1954) methodology. Provincial GDP at 1911 prices from Chiaiese (2024). Weights are great circle distances (in kilometres) between provincial capitals. See section 4.2 for further details.

Table A3. Industrial Characteristics by sector, 1911

Industry	White Collars	Power Usage		Linkages		Size
		Electric	Non-Electric	Forward	Backward	
Mining	3.58	0.13	0.26	3.01	0.16	17.43
Tobacco	5.69	0.07	0.05	0.00	1.57	391.08
Foodstuff	2.36	0.19	0.88	0.48	4.45	4.84
Textile	2.58	0.25	0.29	1.28	1.76	64.06
Clothing	2.81	0.02	0.02	0.20	2.06	6.01
Leather	1.28	0.05	0.05	0.10	0.56	4.12
Wood	1.16	0.12	0.13	1.23	0.45	4.29
Metalmaking	3.64	0.81	2.29	4.15	1.46	37.89
Engineering	4.01	0.28	0.18	0.46	0.71	7.83
Non-metal minerals	2.58	0.15	0.25	1.49	0.48	15.25
Chemicals	6.70	0.98	1.07	3.95	2.04	18.58
Paper	4.71	0.36	0.48	1.42	0.43	17.04
Sundry manuf.	3.57	0.16	0.07	0.43	0.93	15.38
Construction	2.76	0.04	0.07	0.46	1.08	21.55
Utilities	11.02	2.27	24.36	0.88	0.26	16.31

White Collars is the share of white-collar workers per 100 workers. Power usage is the HP per worker, distinguishing between electric and non-electric power. Linkages are computed as intermediate inputs and output shares on sectoral value added. Size is the average number of employees per plant. *Sources:* See section 4.3.

Figure A1. Data on Electricity Distribution Stations, 1898



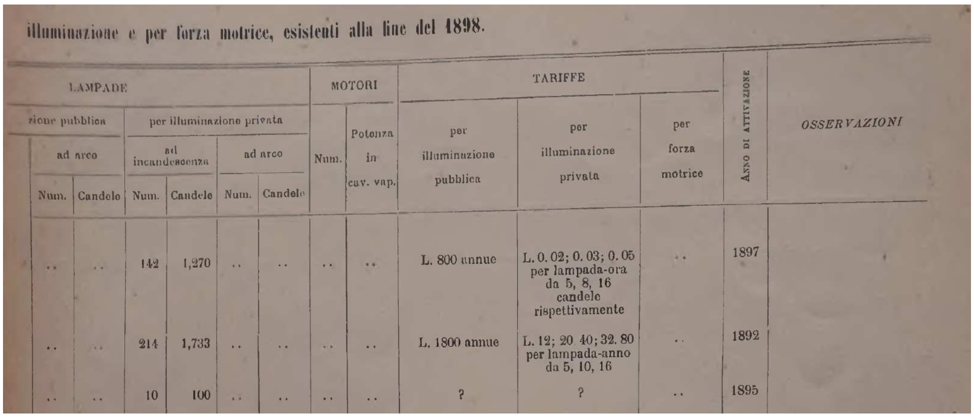
62

Segue Tabella XI.

Officine centrali per distribuzione di energia elettrica per

Numero d'ordine dei Comuni	Regioni, provincie e Comuni	Numero di abitanti	Natura della forza motrice	Natura della corrente	Potenza dei generatori in KW	Potenza degli accumulatori in KW	Sistema di distribuzione	Distanza massima dei centri di distribuzione dalla stazione generatrice in chilometri	per illumina[zione] ad incandescenza Num.	per illumina[zione] ad incandescenza Candele
14	Cornegliano	2,306	vapore	continua	3. 20	5. 50	. . . .	. .	24	256
15	Chiusa-Pesio.	7,136	idraulica	id.	14	. .	. . . .	1. 2	50	880
	San Bartolomeo di Chiusa-Pesio		id.	id.	4. 50	. .	. . . .	. .	10	160
16	Cuneo	29,244	idraulica e a vapore	monofasica	103. 30	. .	due circuiti ad alta tensione con lampade in serie; gli altri a bassa tensione, sui secondari dei trasformatori $\frac{1900}{115}$.	1	228	5,340

(a) Left-hand side



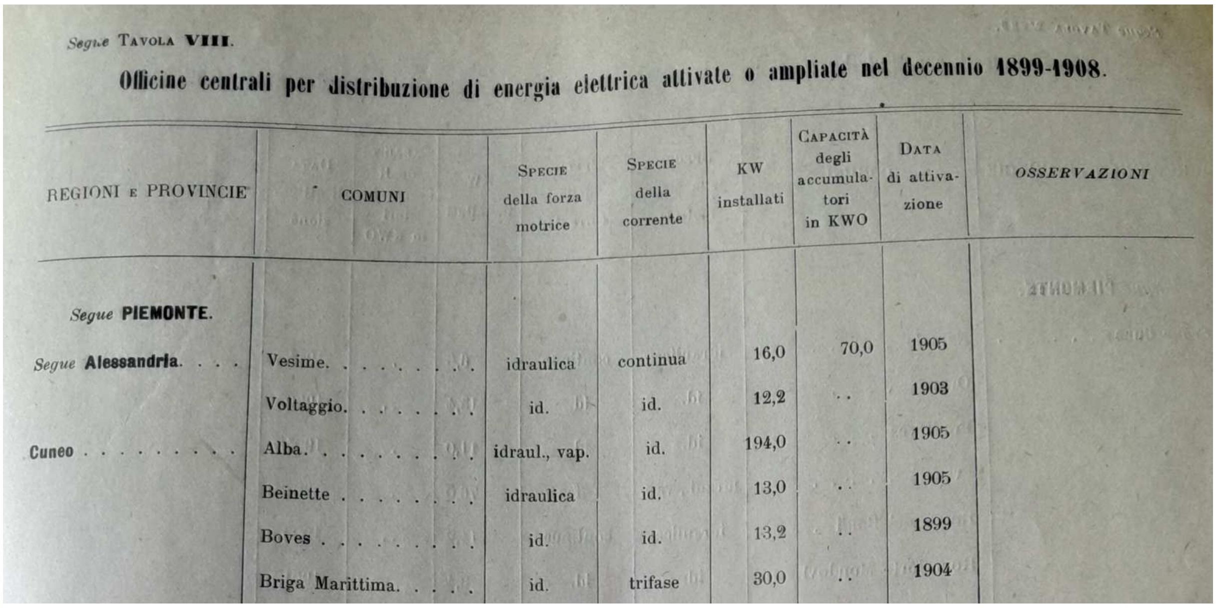
illuminazione e per forza motrice, esistenti alla fine del 1898.

Lampade – [illumina]zione pubblica – ad arco Num.	Candele	per illuminazione privata – ad incandescenza Num.	Candele	ad arco Num.	Candele	Motori Num.	Potenza in cav. vap.	Tariffe per illuminazione pubblica	Tariffe per illuminazione privata	Tariffe per forza motrice	Anno di attivazione	Osservazioni
. .	. .	142	1,270	. .	. .	. .	. .	L. 800 annue	L. 0. 02; 0. 03; 0. 05 per lampada-ora da 5, 8, 16 candele rispettivamente	. .	1897	
. .	. .	214	1,733	. .	. .	. .	. .	L. 1800 annue	L. 12; 20 40; 32. 80 per lampada-anno da 5, 10, 16	. .	1892	
. .	. .	10	100	. .	. .	. .	. .	?	?	. .	1895	

(b) Right-hand side

Headers of the table reporting information on the electricity distribution stations existing in Italy in 1898 at the municipal level. *Source:*MAIC (1901, p. 62–63).

Figure A2. Data on Electricity Distribution Stations, 1908



Segue Tavola **VIII**.

Officine centrali per distribuzione di energia elettrica attivate o ampliate nel decennio 1899-1908.

Regioni e provincie	Comuni	Specie della forza motrice	Specie della corrente	KW installati	Capacità degli accumulatori in KWO	Data di attivazione	Osservazioni
Segue **PIEMONTE.**							
Segue **Alessandria** . . .	Vesime.	idraulica	continua	16,0	70,0	1905	
	Voltaggio.	id.	id.	12,2	. .	1903	
Cuneo	Alba.	idraul., vap.	id.	194,0	. .	1905	
	Beinette	idraulica	id.	13,0	. .	1905	
	Boves	id.	id.	13,2	. .	1899	
	Briga Marittima.	id.	trifase	30,0	. .	1904	

Headers of the table reporting information on the electricity distribution stations existing in Italy in 1908 at the municipal level. *Source:*MAIC (1911, p. 113).