Was Brazilian Industrialisation Fuelled by Wood? Evaluating the Wood Hypothesis, 1900–1960*

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ABSTRACT

The ecological relationship between cities and resource hinterlands is a major theme in environmental history and historical geography. Most scholars described the twentieth-century industrialisation of São Paulo, Brazil, as reliant on hydroelectricity. Warren Dean's 'wood hypothesis', published posthumously in 1995, argued that industrialisation relied on wood fuel and charcoal during the first half of the twentieth century. However, Dean's wood hypothesis has not yet been tested or evaluated. Two substantive criticisms are offered here: the wood hypothesis is accurate in general but under-estimated the industrial consumption of fossil fuels, without conclusively reject the competing 'hydroelectricity' hypothesis; the method used for estimating potential energy supply from forest area was erroneous. The paper also makes several specific claims that advance the issues raised by the wood hypothesis: evidence of actual industrial demand for fuel, not potential supply, should advance the debate on São Paulo's energy use; wood fuel consumption required labourers, yet work and trade relations are still not well described; and specific moments in São Paulo's energy transition, such as the 1940s, require in-depth analysis. A revised wood hypothesis is that São Paulo's industrialisation depended on the interplay of three energy sources, led by biomass fuels, then fossil fuels and hydroelectricity, each of which was supplied by a distinct energy hinterland.

KEY WORDS

Energy; industrialisation; biomass; wood; Brazil

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INTRODUCTION

Resource hinterlands supply essential food, water, fuel and construction materials to cities through trading networks. For Lewis Mumford, trade encouraged ancient 'urban civilization … to throw off its original sense of limits' and break the 'symbiosis' with its hinterland. More recently, studies of material flows from hinterland to city illustrate human dependency on environmental resources and human-induced environmental changes in hinterlands.[1] Fuel is an essential resource supplied by hinterlands to cities. Numerous scholars have studied changes in fuel consumption, or energy transitions, by analysing datasets of annual energy consumption aggregated spatially to political territories. Energy data in litres, tonnes or kilowatt-hours (gasoline, coal and electricity, for example) are then converted to joules, the standard international unit for energy, or British Thermal Units (BTU), for comparison over time.[2]

In Brazil, resource hinterlands have played an increasingly recognised role in historical-geographical development. Coffee exports generated the necessary capital, market economy and demand for industrial goods that spurred industrialisation in São Paulo. The city's thriving hinterland also may have provided the decisive advantage over Rio de Janeiro in becoming Brazil's leading industrial centre during the early twentieth century.[3] An important river in São Paulo's hydrological hinterland, the Upper Tietê, is another case in point, as it was straightened to create land for urban expansion and its headwaters were redirected to run a hydroelectricity plant.[4]

However, the environmental history of Brazil's energy hinterlands is still not well understood. For several decades, scholars and observers argued that hydroelectricity was the predominant energy for the industrialisation of São Paulo, Brazil's main industrial centre. But ten years ago, Warren Dean argued that wood energy from the Atlantic Forest (Figure 1) powered São Paulo's economic growth during the first half of the twentieth century. This revisionist argument, which I shall henceforth call the 'wood hypothesis', was posthumously published in *With Broadax and Firebrand* (1995). Despite the high standing of the book in Latin American environmental history, the wood hypothesis has not yet been held up to critical review.[5]

The aim of this paper is a scholarly critique of the wood hypothesis. My objective is both to correct Dean's errors and bring light to new evidence that will advance the debate on São Paulo's environmental history. Several points sustain this critique. First, I review two datasets that Dean did not consult. These data confirm the general accuracy of the wood hypothesis – a strong reliance on biomass, rather than hydroelectricity – but they also show that Dean under-estimated the industrial importance of fossil fuels, such as imported and domestic coal. Second, I critique the way Dean framed the wood hypothesis as a question of gross energy that potentially was supplied by an estimated area

FIGURE 1. Brazilian Atlantic forest, *c* 1500–1990. After Warren Dean, *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest* (Berkeley: University of California Press, 1995), 349.

of the Brazilian Atlantic Forest. This argument relied on flawed methodology and unwarranted assumptions.

This paper also makes several specific claims intended to advance the important issues raised by the wood hypothesis. Analysis of São Paulo's energy sources should begin with actual industrial demand, not potential energy supply from standing forests. The wood hypothesis failed to mention how wood was supplied to industries. New evidence reveals the nature of contracting and flexible labour relations supporting the wood-fuel trade. Tighter periodisation should focus attention on specific moments in São Paulo's energy transition, such as the 1940s fossil fuel crisis. Finally, industrialisation in São Paulo relied less on one single energy source, as Dean suggested, and more on the inter-relations among three energy hinterlands (hydroelectricity, fossil fuels and biomass) that powered distinct industrial sectors.

This critical appraisal of the wood hypothesis raises two broad methodological issues. First, the study of energy consumed in industrialisation and urbanisation relies on assumptions that cannot always be met in contexts outside North America or Europe. These assumptions include statistical series on energy consumption, continuous territorial coverage and well-developed historiography on energy-intensive industrial sectors. Moreover, data on biomass are notoriously poor in comparison to fossil fuels and hydroelectricity, whilst the conversion of biomass volume into energy units necessarily generates wide error estimates.

Second, evaluation of the wood hypothesis exposes one of environmental history's many methodological and ideological fissures.[6] The wood hypothesis is powerful because it linked the rapid destruction of the Brazilian Atlantic Forest to rapid industrialisation within a single narrative. Yet Dean did not phrase his argument in terms that could be tested by social and natural scientists who seek to engage in the same academic conservation. Dean presented his argument as narrative, but other scholars would have demanded testable hypotheses based on transparent datasets.

THE WOOD HYPOTHESIS

Warren Dean's wood hypothesis proposed a major revision in understanding the ecological relationship between São Paulo and its hinterland. Contradicting the conventional wisdom that hydroelectricity powered São Paulo's industrial development, Dean argued that 'rather than electricity, the energy source more widely used in São Paulo's development was that supplied by a different product of its mild climate: the semitropical forests'. According to Dean, hydroelectricity

> was at the time [1900–1950] difficult to apply economically to many requirements that in other countries were satisfied by fossil fuels. Coffee exports did not earn enough to import great quantities of coal or oil, much of which was applied, in any case, to maritime transport. Brazilian industry therefore continued to depend for fuel primarily on its immense standing stocks of native wood resources.[7]

Dean estimated the 'immense standing stocks' in 1900 to be 187.2 billion gigajoules (GJ) (Figure 2), which, at the assumed annual consumption rate of

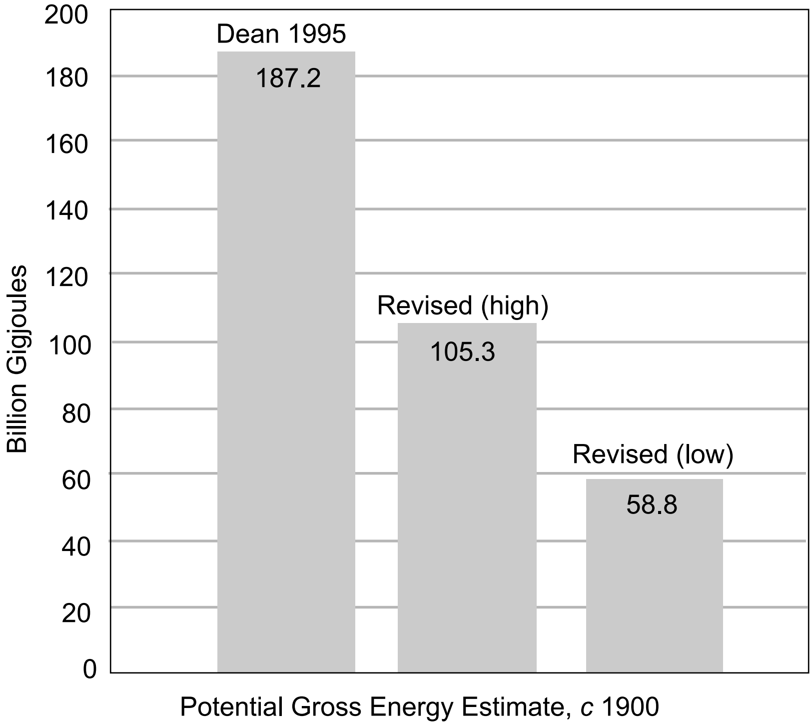

FIGURE 2. Comparison of potential gross energy estimates for Atlantic Forest, *c*. 1900. See text and note 16 for sources and explanation.

138 GJ per capita, potentially 'could have fuelled' the Brazilian economy for approximately 200 years. The fact that less than ten per cent of the 1.35 million square kilometre Atlantic Forest remained at the close of the twentieth century is testament to the 'avarice … ignorance, indifference, and alienation' responsible for forest destruction. In this way, São Paulo's 'modern and sophisticated' mid-twentieth-century economy 'was being built on the ruins of a predatory and exploitative economy'.[8]

Five major claims supported Dean's wood hypothesis: (1) rural and urban households relied on wood for cooking and fuelling small-scale agro-industries, such as processing manioc and manufacturing lard; (2) the construction of houses and buildings relied on wood fuel to fire bricks and prepare mortar, cement and lime; (3) pig iron and steel manufacture relied on charcoal for heat and as a reducing agent; (4) locomotives burned wood and its railways used wood crossties; (5) numerous industries, such as the manufacture of ceramics, beer and glass, relied on heat or power from wood fuel and charcoal.[9]

The wood hypothesis relied on two types of evidence. First, proxy data, in the form of twentieth-century Brazilian census data, aggregated to all of São Paulo state, indicate the number of households using wood ovens and the number of rural workers engaged in charcoal manufacture.[10] These data support estimates of total domestic wood fuel consumption and estimates of reliance on charcoal production. Reports of actual consumption of wood fuel comprise a second type of evidence used by Dean. Railroad reports often indicated the stacked volume of wood burned in locomotives or hauled from hinterland to São Paulo. For metallurgical consumption of wood, estimates of charcoal use begin with the fact that Brazil's coal production was limited to southern states, and the quality of coal was notoriously poor. Consequently, the pig-iron and steel sectors of Minas Gerais and São Paulo states relied on charcoal until the late 1940s, when the state-owned steel mill at Volta Redonda, near Rio de Janeiro, began using Brazilian coke.[11]

Dean also committed several methodological errors. First, he assumed that various industries used wood fuel intensively. He cited first-hand observations of wood fuel dependency for lime and brick-making in late-nineteenth-century Rio de Janeiro, but did not generate quantitative estimates of wood consumption from actual brick and tile production.[12] Dean further assumed that sectors such as cement, ceramics, beer and glass burned wood.

Second, Dean erred in the selection of empirical starting point for framing the wood hypothesis. Rather than estimate potential *demand* for wood energy by São Paulo's industries, Dean started with potential wood energy *supply* to industries, by converting estimated *c*. 1900 forest area into potential wood supply. This method relied on the dubious idea of estimating mean wood yield per area of Brazilian Atlantic Forest. Dean's estimate of 400 cubic metres of potential fuel wood per hectare of forested land is considerably larger than early-twentieth-century estimates. Most current scientific estimates for tropical forests report a wide range around a mean value that differs within a single ecoregion.[13] Moreover, Dean did not convert a stacked wood volume into solid wood. Most experts believe that this conversion rate should be between 0.65 and 0.80.[14] Dean also neglected to discuss the resulting energy estimate in terms of a range. Wood energy yield varies because specific gravity and humidity are variable. In addition, physiognomic differences among sub-types of Atlantic Forest, such as the interior Atlantic Forest and the forest–Cerrado (savanna) transition, must be considered in any estimate of potential wood fuel yield.[15]

My criticism is illustrated by a simple example. Altering Dean's unwarranted assumptions results in far lower estimates of potential gross energy from the Atlantic Forest. In Figure 2, I plot Dean's estimates against my revised high and low estimates. All three estimates begin with Dean's estimate of 39 million hectares of Atlantic Forest in 1900. Dean assumed an average of 400 cubic metres of fuel wood per hectare, at a mean density of 750 kilograms per cubic metre, with mean energy density of 16 MJ per kilogram. My estimates, which are informed by more accurate assumptions, are far lower. I use estimates of 300 and 290 cubic metres of fuel wood per hectare, in accordance with three independent early-twentieth-century observers. I then convert stacked wood volume to solid wood volume at rates of 0.75 and 0.65 for high and low estimates, respectively. Next, I use specific gravity estimates of 750 and 500 kilograms per cubic metre for high and low estimates, respectively. The resulting high estimate is 43.8 per cent lower than Dean's, whilst the low estimate is 68.6 per cent lower.[16] I must clarify that this exercise does not indicate my support for using estimated forest area to calculate gross energy yield from wood; rather, I want to emphasise that Dean's estimates were based on unwarranted assumptions that were not based on a scientific literature.[17]

Third, Dean neglected to characterise datasets on biomass energy. Scholars have long argued that a reporting bias exists against biomass and in favour of fossil fuels. In the mid 1930s the Brazilian scientist Sylvio Fróes Abreu argued that 'there are no data permitting the rigorous evaluation of the total consumption of fuel wood in Brazil'.[18] In the late 1950s, researchers attempting to compile data on wood fuel for all of Latin America confessed that data on biomass were often 'fragmentary, irregular and frequently contradictory'.[19] In addition, estimates of wood energy vary wildly depending on whether gross or net energy is measured. Gross energy estimates are much higher than estimates of net energy, because net energy excludes the latent heat of water that is lost in combustion. The main contents of wood, cellulose and hemicellulose, have less energy value than lignin, which usually is the third-leading component of wood. Although national energy balances frequently use estimates of net energy, gross energy estimates are more common in environmental studies of energy consumption, as they are considered superior for understanding society's overall consumption or 'metabolism' of resources.[20]

Fourth, Dean did not specify the actual territory to which the wood hypothesis applied. Dean initially considered the economic development of São Paulo city as a wood-fuelled phenomenon. In his 1995 book, Dean argued that the wood hypothesis covered the entire Atlantic Forest region (Figure 1). This would include not only São Paulo and Rio de Janeiro cities, but also Porto Alegre, Curitiba and Belo Horizonte, in addition to numerous other industrial cities in São Paulo and Rio de Janeiro states. However, most evidence Dean presented related to São Paulo city. Thus, it is possible that Dean's excessively general spatial resolution made the wood hypothesis accurate in general, but, at more detailed geographical scale, not a useful predictor of actual energy consumption.

Finally, the period covered by the wood hypothesis is excessively broad. Dean himself recognised the several periods of industrialisation and economic growth of São Paulo between the 1880s and 1960s.[21] Yet his focus on potential wood energy supply, stressing the rapid and simultaneous decline of São Paulo's forest cover, blurred transitions in the industrialisation process. Indeed, one receives the impression from *Broadax and Firebrand* that forest cover is more dynamic than industrial change in São Paulo. More fruitful would be to follow Martin Melosi's argument that the 'quantitative periodization' common in the energy transition literature is useful for its 'broad patterns of consumption', but 'does not sufficiently explain why and how energy choices are made'. This is because 'simply calculating the total consumption of an energy source gives little sense of the stages of transition, and creates artificial thresholds through which society apparently passes from one energy era to another'.[22] Toward this end, I now review the evidence in support of, and against, the wood hypothesis, beginning with datasets on gross energy consumption.

REVISING THE WOOD HYPOTHESIS

By nearly any measure São Paulo in 1920 had become 'Brazil's most important industrial center'. By 1940 São Paulo city 'undoubtedly possessed the largest agglomeration of manufacturing capacity in Latin America', when São Paulo state employed 36 per cent of Brazil's industrial workers, and the city's population, at 1.3 million, was rapidly approaching that of Rio de Janeiro.[23] What energy sources powered the city's prodigious industrialisation? I begin by considering datasets on gross energy consumption, then data and arguments for hydroelectricity, fossil fuels and biomass.

a. Gross energy estimates

Dean's wood hypothesis is correct in general terms. But Dean did not consult two datasets of São Paulo and Brazil's gross energy consumption.[24] One is a 1949 US government study of Brazil's coal industry reporting that firewood and charcoal met two-thirds of São Paulo state's energy needs in 1944 (Figure 3). These data, probably supplied by state or federal authorities in Brazil, excluded household energy consumption. The authors of the study commented that in 1943 and 1944 Brazil 'was suffering from an acute shortage of fuel of all kinds' and its industries were 'using almost anything that would burn'. Overall, the authors concluded,

> firewood has played an increasingly important role as a fuel in Brazil during recent years. Scarcity of coal and petroleum during the [Second World War] years and an increasing industrial tempo have combined to make wood one of the largest sources of energy in the country. Rapid depletion of forests near consuming centers and increasing cost of cutting and transporting the firewood will soon force consumers to convert to more-economical fuels, such as coal or oil, if they are available.[25]

Robert Gay, a sales engineer for Standard Oil in Brazil during the 1940s, corroborated these observations. With likely reference to gross energy, Gay

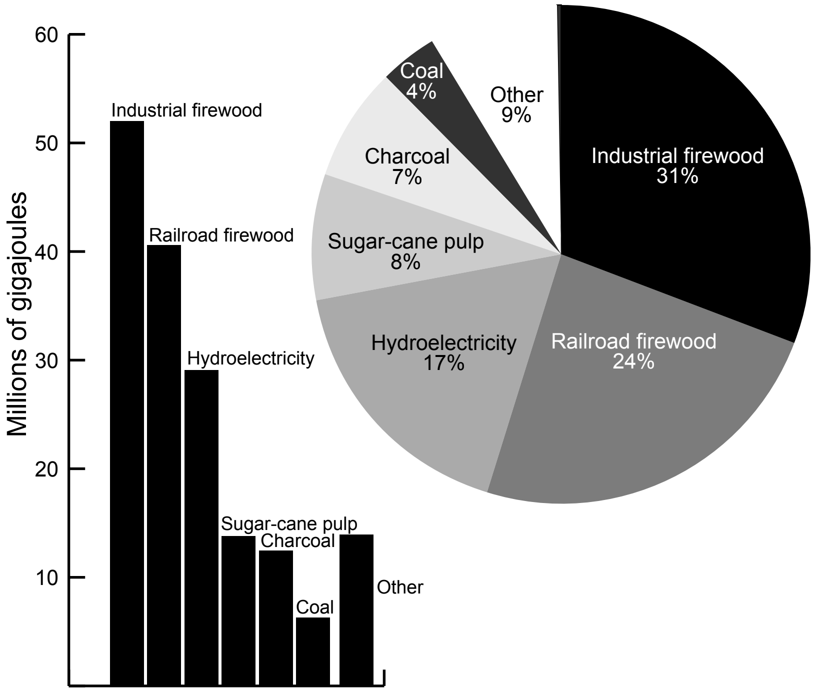

FIGURE 3. Gross energy consumption in São Paulo state in 1944. Source: John E. Good, Alvaro Abreu, and Thomas Fraser, *The Coal Industry of Brazil: Part I. General Economy, Production, and Marketing* (Washington, DC: GPO, 1949), 27.

estimated that biomass was 50 per cent of industrial fuels consumption in São Paulo city.[26]

A second data set is available from a 1950s United Nations study of Latin America's energy resources, which was confirmed a decade later by a French scholar of Brazilian industrialisation (Figure 4). These data, provided to UN researchers by the Brazilian government, were presented in volume or mass, then converted to energy units. Clearly, biomass – mainly wood, but also charcoal – was Brazil's main gross energy source during the first half of the twentieth century. Significantly, these data include estimates of household energy demand, which may have represented approximately 80 per cent of total gross energy consumed in Brazil between 1900 and 1939. However, the data are aggregated spatially for all of Brazil.[27]

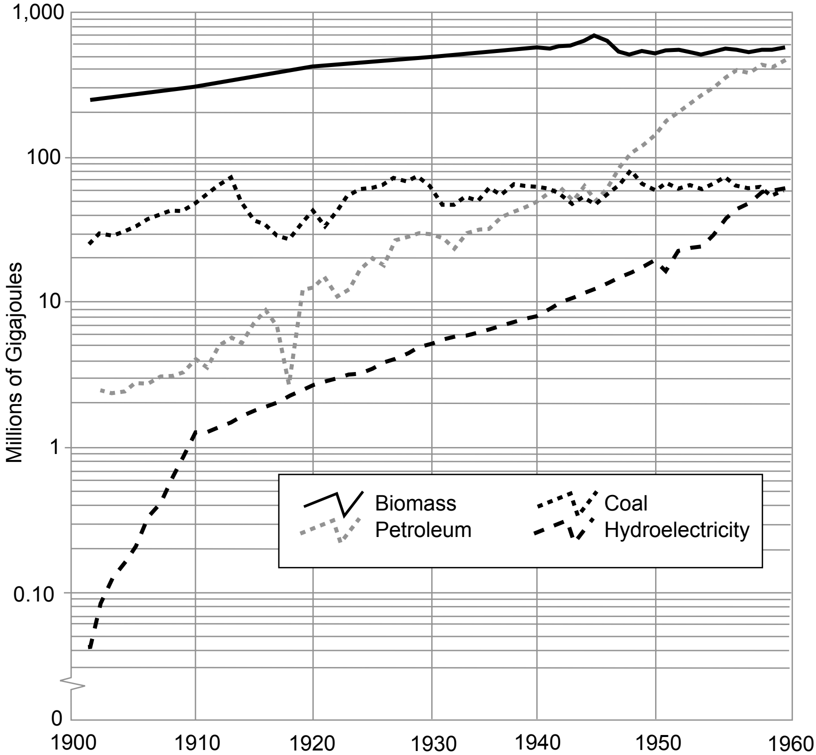

FIGURE 4. Gross energy consumption in Brazil, 1900–1960. Calculated from Jean-Marie Martin, *Processus d'Industrialisation et Développement Énergétique du Brésil* (Paris: Institut des Hautes Études de l'Amérique Latine, 1966), 347–48.

My estimates of gross energy consumption in São Paulo city compare four energy sources (Figure 5). First, the low estimate is shown for the supply of fuel wood energy to São Paulo city via the Sorocabana Railroad line. Second, the sale of electricity to industries and households by São Paulo city's Canadian-owned electricity firm, The Light, is represented in identical energy units. Third, coal imports to São Paulo's port city, Santos, are estimated. Fourth, petroleum sales (gasoline, diesel, fuel oil, etc.) in São Paulo state are shown in energy units.[28] This graph shows the unexpectedly high gross energy importance of imported coal, the prodigious contribution of railroads in hauling fuel wood and the relatively small gross energy sold by the Light.

Three conclusions arise from this review of gross energy datasets. First, Dean's wood hypothesis is correct in general terms. Gross energy datasets, which Dean did not consult, show the overwhelming role of biomass and the weak

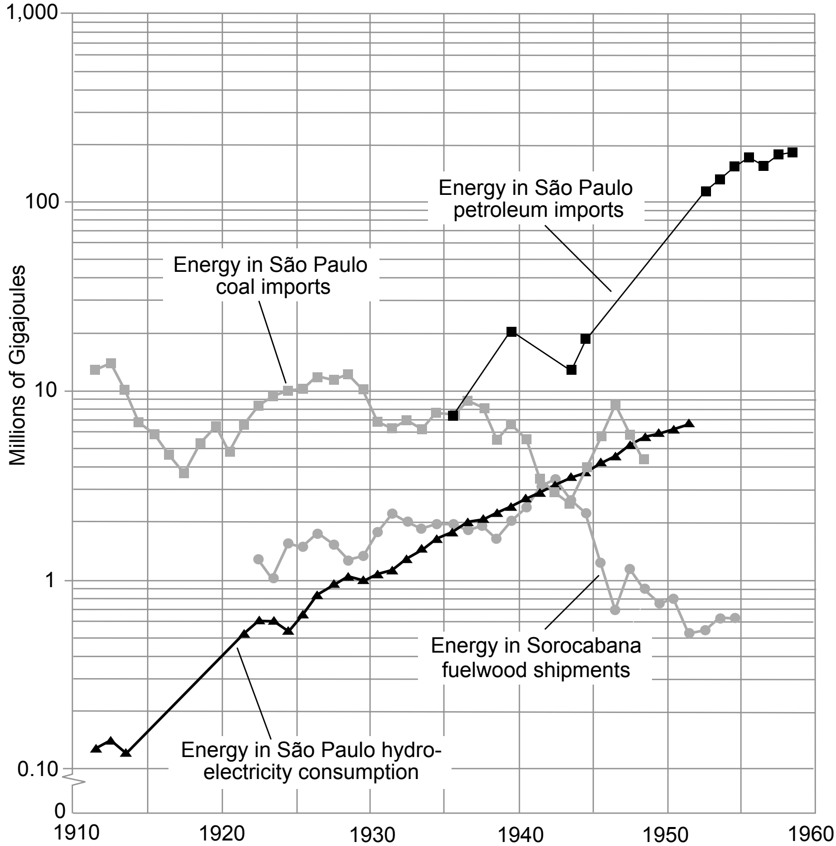

FIGURE 5. Comparison of gross energy sources in São Paulo's industrialisation, 1912–1960. See note 28 for explanation.

participation of hydroelectricity in Brazil's gross energy consumption. Second, railroads hauled large volumes of wood fuel over hundreds of kilometres. The gross wood-fuel energy hauled annually by only one railroad, the Sorocabana, for example, exceeded the gross energy of hydroelectricity sales until the late 1940s. The Sorocabana transported an estimated 2.7 million GJ in firewood into São Paulo in 1944, approximately five per cent of the 52.0 million GJ of industrial firewood consumed by the state in the same year. This estimate of wood fuel supply from São Paulo's energy hinterland obviously supports Dean's wood hypothesis whilst providing a transparent quantitative measure. Third, São Paulo state received a relatively small percentage of Brazil's coal imports, but the gross energy of imported coal was much greater than hydroelectricity sales statewide, and, indeed, the gross energy hauled by the Sorocabana (Figure 5). This finding does not support the wood hypothesis.

Estimating gross energy consumption is only one way to critique and revise the wood hypothesis. At least as important is to review the arguments regarding the three energy sources that would have powered São Paulo's industrialisation: hydroelectricity, fossil fuels and wood. Indeed, Dean's wood hypothesis raised a question that had not been answered in the literature: what energy sources powered industrialisation? Several scholars have touched on this question, but none has made a definitive claim, not even Warren Dean. Wilson Cano, for example, reported that in 1920 approximately 43 per cent of São Paulo's electricity-using industrial firms generated their own power and 50 per cent of all industrial firms did not use electricity; however, he failed to mention what energy sources supplemented hydroelectrical power.[29] Other examples include a recent study of São Paulo's metalworking sector, which stated that the early twentieth century saw an 'important change' from steam power to electrical power, implying – without any evidence in support – that all metalworking was powered by electricity in 1920.[30] Finally, a recent synthesis of São Paulo's industrialisation includes photographs of factories with enormous stacks of wood and prominent smokestacks, yet the author discusses only hydroelectricity as source of industrial energy.[31] Clearly, the historiography of São Paulo's industrialisation overlooked a basic question that environmental historians are well placed to answer. Indeed, as Rolf Peter Sieferle argued, 'the history of energy is the secret history of industrialisation'.[32]

Although the target of Dean's wood hypothesis was the idea that hydroelectricity had powered industrialisation in São Paulo, Dean did not review the evidence or arguments in favour of the 'hydroelectricity hypothesis'. I now review this evidence in the interest of a more compelling rejection.

b. Hydroelectricity

Numerous scholars and contemporary observers assigned primary credit to hydroelectricity for São Paulo's industrialisation. The Canadian firm Brazilian Traction, Power and Light (known as 'The Light', later the transnational corporation Brascan), which developed much of south-eastern Brazil's water power, continues to receive accolades for having powered the industrial economy. Indeed, an historian of The Light concluded recently that its hydroelectrical power had 'crucial significance' for São Paulo's industrialisation. By any measure, the hydrological transformation of the Upper Tietê River Valley for hydroelectricity generation was spectacular. In the late 1920s, for example, a west-flowing tributary was impounded and water redirected to flow east toward the Atlantic Ocean to run a power plant.[33]

One important example in the creation of the hydroelectricity hypothesis is the opinion of Brazilian industrialist and economist Roberto Simonsen. Writing in the late 1930s, Simonsen argued that the Light's hydroelectricity 'delivered to São Paulo the possibility of obtaining enough energy to triple' industrial output. For urban historian Richard Morse, the Light's hydroelectricity could 'be isolated as precipitant, without which the heavy industrial development in the years and aftermaths of two World Wars would have been far milder'. Writing in the early 1940s, geographer Preston James claimed that 'the people of São Paulo owe a very considerable debt of gratitude' to the North American engineers who built the Light's hydroelectricity plants, '[making] possible the rise of their city to its present position'. Even Warren Dean's classic study of São Paulo's industrialisation, published in 1969, included a map of the state's hydroelectricity infrastructure in the inside cover to implicate The Light's crucial importance to industrialisation.[34]

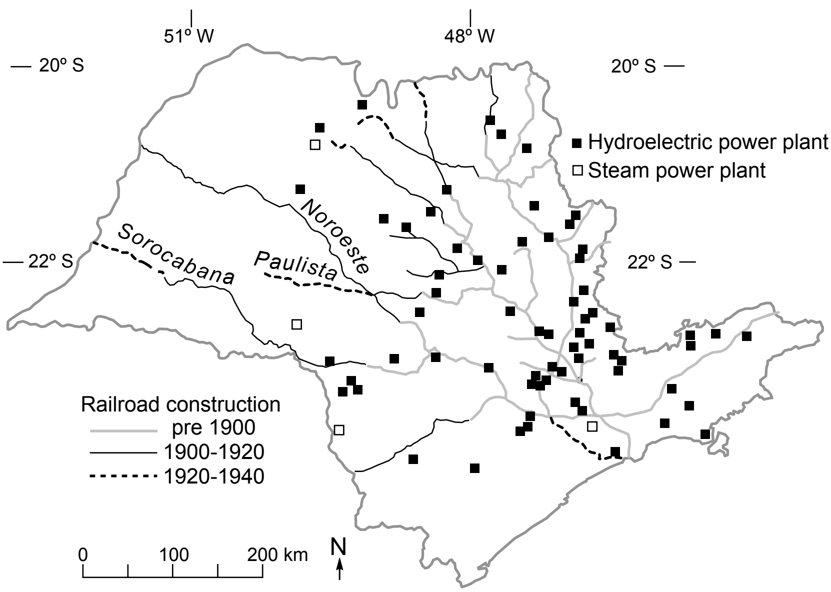

FIGURE 6. Railways and power generation in São Paulo state, 1929. Sources: for railways, Odilon Nogueira de Matos, *Café e Ferrovias: A Evolução Ferroviária de São Paulo e o Desenvolvimento da Cultura Cafeeira* (São Paulo: Alfa-Omega, 1974) and Flávio Azevedo Marques de Saes, *As Ferrovias de São Paulo, 1870–1940* (São Paulo: Hucitec, Instituto Nacional do Livro, 1981); for power generation, Preston E. James, 'Industrial Development in São Paulo State, Brazil', *Economic Geography* 11 (1935): 261.

Actual datasets developed from empirical study of industries that consumed hydroelectricity are not as dramatic, nor as abundant, as the qualitative claims for a hydro-powered industrial economy. My analysis of the Light's unpublished annual reports of the early 1900s indicates that textile mills, not a wide range of industries, were its main power consumers. The number of power customers increased from 245 in 1906 to 1,321 in 1914, with textile mills remaining the Light's main consumers of industrial power.[35]

Numerous small hydro- and thermoelectricity plants supplied energy elsewhere in the state, but actual output is unknown (Figure 6).[36] What is known is that by 1930 the Light had an installed capacity of 343,700 kilowatts, whilst the US-owned Electric Bond and Share, operating in Brazil as Empresas Elétricas Brasileiras, had approximately 87,000 kilowatts of installed capacity. By 1928 Electric Bond and Share had purchased 'all the most important [hydroelectric] plants in the state's interior' and the Light had purchased 'all the existing [electricity supplying] firms between Jundiaí and Rio de Janeiro'. Overall, 93 per cent of São Paulo state's installed electricity capacity in 1920 was hydroelectric.[37]

Yet at least one contemporary critic argued that high cost and low quality characterised São Paulo's hydroelectricity. In the late 1920s, Catullo Branco, a strongly nationalist Brazilian engineer, argued that electricity accounted for 'nearly half of total production costs' of industrial firms. Supply was plagued by 'constant interruption, variation of current frequency or strong drops in tension'. Electricity was available, but nonetheless 'innumerable firms' produced 'with small and antiquated steam engines that, in spite of everything, manage to compete with the electric motor'.[38] Complementing Branco's criticisms, Paul Singer argued in the 1960s that the Light's 'effective public relations' had made the idea of hydroelectricity-led industrialisation 'almost axiomatic'. For Singer, São Paulo's initial industrialisation occurred before the Light had significant capacity; thus, industrialisation spurred the increased supply of hydroelectric power.[39] Unfortunately, Singer did not specify which energy sources were mainly used before the Light's hydroelectricity supply increases, and his argument assumed a smooth energy transition.

What beliefs may have influenced the comments of observers who claimed that hydroelectricity had powered São Paulo's industrialisation? George Basalla defined 'energy myths' as the idea that 'any newly discovered source of energy is assumed to be without faults, infinitely abundant, and to have the potential to affect utopian changes in society'.[40] Observers of São Paulo's industrialisation were strong believers in the idea that hydroelectricity was a *houille blanche*, a mythic 'white' fuel, produced by the reorganisation of the Upper Tietê River, that would supply limitless power.[41] Other observers may have defined 'industry' as the 'modern' textile sector, which was in fact highly dependent both on hydroelectricity and a heat process, whilst ignoring wood-burning ceramics, bricks and other industries as 'traditional'. Perhaps observers had given into the 'temptation to treat the cotton industry as a microcosm' of industrialisation, as economic historian E. A. Wrigley noted for the British case.[42] Alternatively, electric tram cars and street lighting, supplied by the Light, may have been more visible to observers than heat-intensive commodities such as beer, bricks and lard. Were analysts biased against wood fuel because of its low energy density, its alleged role in 'creating deserts' and its supposed trade in 'anarchic' markets?[43]

Overall, hydroelectricity only ranked third, well behind coal and wood, amongst Brazil's gross energy sources during the first half of the 1900s. If São Paulo's industries were only partially powered by hydroelectricity, then only two options remain: fossil fuels and wood.

c. Fossil fuels

The wood hypothesis correctly placed biomass over hydroelectricity as the primary fuel and power source for São Paulo's industrialisation. But, according to my gross energy estimates (Figure 5), fossil fuels were far more important than Dean suggested. The high energy density of coal meant that a small mass of coal contained the same gross energy as a large mass of wood.[44] Brazil produced virtually no petroleum until the early 1950s.[45] Although the Brazilian government created many policies to encourage domestic coal consumption, its coal was of inferior quality (high ash and sulphur) and lower energy density than imported coal.[46] Thus, all petroleum was imported before 1950, and railways and industries preferred burning imported to domestic coal.

Numerous industries in São Paulo relied on boilers, furnaces and ovens for two essential aspects of industrial processes: heat to transform raw materials and steam for power generation. If São Paulo's industrialists were interested in burning coal, but were put off by the high price of imported coal, they may have turned to engineers such as Carlos Sonntag, the head of a Brazilian industrial firm. In the 1920s Sonntag reminded his industrial colleagues of an obvious and essential fact:

> Today in the centre of nearly all of our industrial establishments, whether specialised in mechanical or chemical transformation of raw material, whether for the production of energy, there is still fire, that is, the furnace or industrial oven, as the life-giving element, upon which technical and economic success often depends.

Sonntag went on to detail the latest technologies for adapting ovens and furnaces to burn domestic coal, rather unconcerned with how wood might be burned more efficiently.[47] The fact that Sonntag was interested in coal, not wood, suggested that his audience included coal-burning industries.

In fact, by the early twentieth century, several electricity plants and industries had already turned to domestic coal. In Porto Alegre, Brazil's major southern city (Figure 1), a Swiss firm built a power plant in the late 1920s that burned Brazilian coal. The power plant made necessary modifications that allowed it to burn low-quality domestic coal at 30 per cent cost savings compared to British coal.[48] During the early 1920s, several electricity plants elsewhere in Rio Grande do Sul had switched from burning expensive imported coal to locally supplied fuel wood or coal.[49] Porto Alegre had fewer natural conditions for hydroelectricity than São Paulo, and it was relatively close to coal mines. But if domestic coal was generating power there, it most certainly could have been burned in São Paulo's industries.

Consumption of imported and domestic coal in São Paulo is known only in general terms. For example, in the mid 1920s an observer of Brazil's fuel consumption indicated that nearly one-third of coal imports were burned by a single railway, and most of the rest was devoted to maritime shipping, which left 'very little' for industries.[50] In 1945, at the height of fossil fuel shortages caused by the Second World War, the Brazilian government allocated its domestic coal to electric power plants, gas producers, navigation companies, meatpacking firms and breweries; some of these firms were located in São Paulo.[51] In the late 1940s observers of the coal industry in Brazil reported that imported coal in São Paulo, approximately 20 per cent of Brazil's overall imports, was destined mainly to railroads, steamers and gasworks. Main consumers of domestic coal in São Paulo were railroad locomotives (70,000 tonnes out of nearly 80,000 tonnes in 1945), leaving only a modest amount for a glassworks, a brewery and a producer of refractory bricks.[52]

Some of São Paulo's industries had adopted imported fuel oil by the 1920s. In the mid 1920s, a US trade official concluded that Brazil's petroleum market showed signs of rapid growth in demand, especially for fuel oil in industries and maritime transport. A key factor was the fact that suppliers of fuel oil provided 'technical advice and fuel burners at cost' to interested customers. The main industries burning fuel oil were 'open-hearth furnaces' and 'forging, heat treating, and glass making'. However, industries producing bread, bricks and sugar had 'other sources of energy', probably wood or charcoal.[53]

The fact that a fossil fuel crisis engulfed São Paulo's industries during the Second World War is further testament to industrial reliance on imported coal and petroleum. According to a US government report, São Paulo's industries were burning imported fossil fuels before the Second World War began: 'many industries which previously had employed only imported fuels adapted their equipment to utilise domestic fuels – low-grade coal, charcoal, and wood'.[54]

Fuel oil and imported coal were crucial to the development of at least one key industry: cement. In Dean's wood hypothesis, cement manufacture is assumed to have relied on wood fuel. Brazil produced virtually no cement until the mid 1920s. When domestic industry developed, fuel oil and coal – not wood – were the main sources of heat for the kiln, whilst electricity powered mixing and grinding phases. In the mid 1930s, an engineer noted that the cement mixture had to be in contact with temperatures of 1,500 degrees Celsius. To create this heat, Brazil's first cement factory burned fuel oil, following the example of other cement factories. Another study of Brazil's cement industry saw nothing exceptional in the fact that firms kept separate budget lines for heating fuel – coal or fuel oil – and electricity needed for crushing. The use of fossil fuels in the cement industry is further corroborated by US officials who reported in the 1920s that Brazil's cement industry faced a major obstacle in that it '[lacked] the proper sort of [domestic] coal for making cement'. In the late 1940s other US officials reported that Brazil's cement manufacture was 'dependent upon imported fuel oil'.[55]

By the 1960s, as Brazil developed its nationalised refining capacity for petroleum, the growing consumption of fossil fuels was understood by some enthusiasts as the victory of petroleum over 'desert-creating' dependency on fuel wood. Products such as diesel, liquefied petroleum gas and synthetic nitrogen fertiliser – all produced in Brazil from imported petroleum – would 'sweep aside the dangers of deforestation' caused by wood-fuel demand.[56] However, less ebullient observers of Brazil's increasing fossil-fuel dependency during the early 1960s were more cautious: 'fuel wood, a symbol of the sixteenth century, competes side-by-side with modern petroleum refineries, and soon with ultra-modern atomic reactors'.[57]

d. Wood fuel

Warren Dean's wood hypothesis is accurate in general, but incorrect in some specific issues. Hinterland forests and Cerrado supplied wood fuel, providing greater gross energy supply than fossil fuels or hydroelectricity to São Paulo's industries until sometime in the 1950s. But Dean underestimated fossil fuel consumption and erroneously assumed that cement manufacture, a key industry, relied on wood fuel. And, as I argue in this section, the wood hypothesis neglected important technical writing on wood fuel and the labour relations supporting the fuel wood trade.

The writings of scientists and technicians who studied Brazil's fuel issues during the first half of the twentieth century illuminate some issues of the wood hypothesis. One important starting point is the 1921 establishment of the Brazilian government's Experimental Station for Fuels and Minerals, the Estação Experimental de Combustíveis e Minérios (EECM) in Rio de Janeiro. Under the direction of Ernesto Lopes da Fonseca Costa, the EECM became Brazil's national technology institute in 1933 and carried out numerous studies on the industrial suitability of southern Brazil's coal. Fonseca Costa also convened a national conference on fuels in 1922 and directed several studies leading to a conference on burning sugar-cane ethanol in motor vehicle engines. This research influenced federal policy mandating the addition of ethanol to gasoline sold in Brazil, long before the 1970s ethanol subsidies.[58]

The work of Fonseca Costa also was influential in the contemporary debate on whether Brazil's iron and steel industry should depend on domestic coal or charcoal. Fonseca Costa promoted southern Brazilian coal over charcoal;

indeed, his predecessor in the chair of metallurgy at the Escola Politécnica in Rio de Janeiro, Fernando Laboriau, had developed a cogent position against charcoal use.[59] Fonseca Costa would also provide a notable example in the creation of Brazil's myth of hydroelectrical power supremacy when he argued that the country's potential hydroelectricity – *houille blanche* – would permit the country to fully develop all of its abundant mineral resources.[60]

The charcoal-versus-coal debate must have encouraged scientists during the 1920s and 1930s to develop proposals for a modernised charcoal industry. As they criticised the rudimentary – and inefficient – existing technologies, these scientists spoke not only to the needs of metallurgy, but also to requirements of Brazil's locomotives and heat-dependent industries. Frederich Freise, a scientist not associated with Fonseca Costa's experimental laboratory, was probably the most prominent. Unlike Fonseca Costa, Freise was committed to the idea that Brazilian iron and steel should rely on charcoal.[61] Freise also believed that Brazil could modernise its charcoal sector into an efficient fuel source for locomotives, metallurgy and other industries. His 1926 papers, published in Brazil's leading engineering journal, began by estimating Brazil's 1920 fuel wood consumption at 16.3 million cubic metres, of which 8.2 million were consumed by non-metallurgical industries and 7.8 million by locomotives. He cited three examples of changes in the fuel market between 1915 and 1925, and indicated that fuel wood and charcoal had become several times more expensive as supply regions became more distant from places of consumption whilst the quality of wood fuel and charcoal had decreased. Freise then outlined the necessary steps for modernising the charcoal industry as a means to create a high-quality domestic fuel.[62]

Brazil's national technology institute was not opposed to research on wood fuels. In the 1930s, a scientist with the institute, Sylvio Fróes Abreu, published important studies on wood fuel. Fróes Abreu stated that Brazil should be characterised as '*a fuelwood civilisation*' on account of its heavy reliance on wood. Prodigious amounts of wood were consumed in Brazil's interior regions because wood fuel was 'found everywhere and at a reasonable price'. Particularly heavy consumers of fuel wood were riverboats, railroads, sugarcane mills, textile mills and cotton and grain processors. Wood fuel provided energy at relatively low cost compared to expensive fossil fuels.

Fróes Abreu did not see the wood fuel market as chaotic. He outlined three factors determining price formation of wood fuel: availability of biomass, competition among consumers (mainly locomotives and industries) and the opportunity cost of labour required to extract and haul wood. But Fróes Abreu was not ideologically favourable to wood fuel as an industrial energy source. He argued that '*a large industrial leap forward cannot be based on wood fuel*' because of the 'increasing difficulty of supplying population centres and because it [wood] is a poorly concentrated source of energy' that could only attend to relatively small areas.[63]

Outside of Rio de Janeiro, other scientists also were interested in wood fuel, although their writings were less numerous and their motivations were different. In the 1920s technicians at São Paulo's Escola Politécnica carried out some of the first experiments to measure the energy densities of Brazil's timber. These data later appeared in the Brazilian government's promotional literature aimed at encouraging timber exports.[64] Scientists admitted that 'burning wood certainly is not the most noble use, but Brazil, a country poor in [fossil fuels] … is obliged, by the force of circumstance, to rely on this source of heat by setting fire to its forests'.[65] Another scientist at the Escola Politécnica decried the tragic possibility that Brazil's insatiable demand for wood fuel would condemn tree species to destruction, even those with 'special characteristics' potentially useful in some industrial products.[66]

Among the more prominent scientists and observers lamenting the huge appetite of São Paulo's economy for wood fuel were those knowledgeable about locomotive fuel. Indeed, these writers are important sources of evidence supporting the wood hypothesis.[67] For example, Albert Löfgren, the Swedish head of São Paulo's forest and botanical service in the early 1900s, argued that the 'extraordinary forest devastation' in the state 'increased annually because of

FIGURE 7. Fuel wood for Noroeste railroad locomotives, *c* 1940, Tres Lagoas, Mato Grosso state (presently Mato Grosso do Sul). Source: Hélder Barros, 'Noroeste' (1989), Centro de Memória Regional, UNESP-RFFSA, Bauru.

the enormous quantities of fuel wood consumed daily by railroads, without any reforestation'. Löfgren's successor, Navarro de Andrade, who had established *Eucalyptus* plantations for the Paulista railway, summarised São Paulo's wood consumption as simply 'shocking'. His more famous contemporary, Euclides da Cunha, described railroads as 'desert makers' or *fazedores de desertos*, arguing that Brazil's economy skirted 'the financial crisis and high price of coal by a frontal attack on the land economy and, every day, diluting several hectares of flora into the smoke of steam engines'.[68]

Indeed, massive stores of wood fuel near railways are a testament to the inexorable demand of fuel-hungry locomotives before they switched to diesel or electricity in the late 1950s (Figure 7). The annual reports of railways often provided data on locomotive consumption of wood fuel.[69] In 1944, locomotive fuel wood represented approximately one-fourth of total gross energy in São Paulo state (Figure 3). Wood from *Eucalyptus* plantations, which were established in São Paulo after 1900, covered approximately 25,000 hectares in 1940,[70] but they were 'extremely limited' in comparison to forest and Cerrado areas.[71] Imported coal was less commonly used than wood, and some railways burned both fuels.[72] Nonetheless, coal shortages during the First and Second World Wars forced heavy reliance on wood. For example, the Douradense railroad, a privately owned stretch of 273 kilometres in São Paulo, reported in 1922 that imported coal had 'disappeared' and its locomotives had to burn wood exclusively throughout the line.[73]

Plumes of black wood smoke pouring from locomotives and ubiquitous railway woodlots were so visible to observers that they overshadowed other, less obvious sites of wood burning. The authors of a landmark survey of world forests in the early 1920s wrote that wood in Brazil was 'practically the only fuel used in the homes and the smaller shops and factories and by railroads and river steamers, so that the consumption is enormous'.[74] The head of a US technical mission to Brazil in 1942 commented that wood occupied 'the overwhelming place of wood in the fuel economy of Brazil' and accounted for more than 71 per cent of Brazil's gross energy consumption.[75]

If certain sectors of São Paulo's industrial economy relied on wood fuel, then how was such massive volume supplied? Railroads hauled massive amounts of wood fuel from São Paulo's western interior hinterland to its industrial core. For example, the Sorocabana railroad (see Figure 6) hauled an average of nearly 100,000 tonnes of fuel wood annually between 1923 and 1955, reaching nearly 200,000 tonnes annually during the fossil fuel crisis brought on by the Second World War.[76] This mass of wood fuel is represented as gross energy in Figure 5. The Paulista railroad hauled an average of 30,000 tonnes of fuel wood between 1916 and 1920.[77] Even the Douradense railroad regularly hauled more than 1,000 tonnes of fuel wood annually (19,000 GJ) in the 1920s, 1930s and 1940s.[78]

Thus far, I have reviewed the evidence for gross energy obtained from biomass and quantitative estimates of railroad transport of wood fuel from hinterland to centre. However, the only accounts of industrial burning of wood fuel are qualitative. Clearly, industrial consumption of fuel needs closer attention; the cement industry, which Dean had assumed to be wood burning, was in fact reliant on fossil fuels. Typical of qualitative accounts is the 1930 report of US officials on São Paulo's chemical industry, which made 'considerable' use of charcoal. Some 'larger chemical firms' even produced their own charcoal.[79] These industries, and numerous others, may have been using four-stroke engines such as the Deutz AG product, which was capable of burning produced gas from coal, charcoal or wood (Figure 8). But, the criteria that guided the choices of industrialists in fuel selection are still unknown.

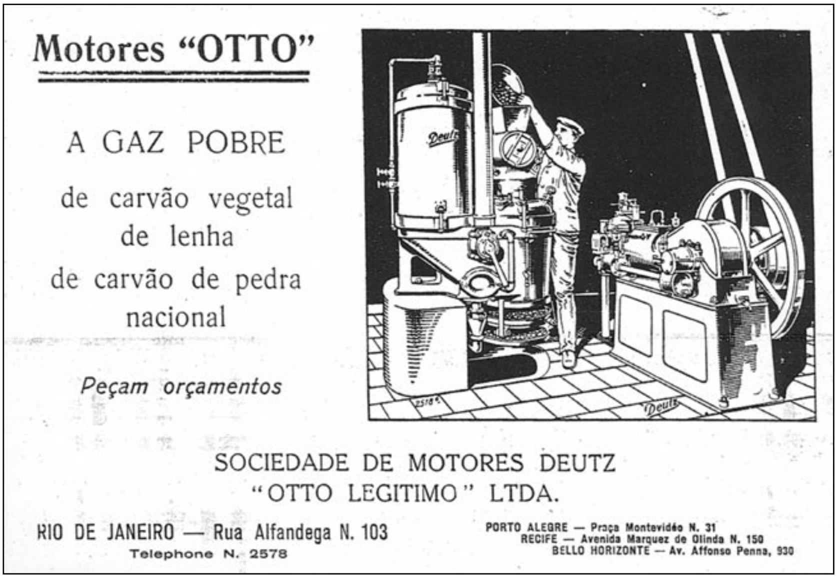

FIGURE 8. Advertisement for Deutz AG gasifier engine burning charcoal, fuelwood or Brazilian coal, in *Revista Brasileira de Engenharia* 4, no. 6 (1922): 16.

Beyond the city of São Paulo, the state's many medium-sized cities (population *ca* 25,000 in 1920) in the hinterland typically had a half-dozen brick works, one or two coffee roasters, a few drinks manufacturers and several bakeries. All of these small industries relied on wood for most, if not all, energy consumed, even though hydroelectric power was available for street lighting and limited domestic use. For example, Presidente Prudente, a city with 19,000 inhabitants and one electricity plant, had two breweries, one coffee roaster, 12 sawmills and six bakeries. Bauru (20,400 inhabitants) had one lard factory, nine sausage factories, eight bakeries, three breweries, five brick works and two coffee mills; most certainly, its one hydroelectricity plant did not power these and other industries. Araçatuba (population 12,000) also had one electricity plant, but its five bakeries, one brewery, 14 brick works and three coffee roasters probably burned wood and charcoal.[80] Any one of these industries may have been similar to the case of the Assis municipal slaughterhouse, which in the 1940s produced tallow for export to São Paulo. The necessary fuel was wood, cut from nearby Cerrado by contractors hired by large landowners.[81]

I have been suggesting in this and the previous section that future research should seek datasets on the actual industrial consumption of wood and fossil fuels. Data for wood probably would appear as stacked volumes, which must be converted to a solid and then gross energy. For example, Table 1 shows the conversion of data on stacked wood that fuelled São Paulo's locomotives in 1902. Wood fuel, stacked in cubic metres, must be converted to a solid by a factor between 0.65 and 0.80. Then, assumptions must be made about mean specific gravity and energy density of wood. The mean estimate is 3.7 million GJ, but the range is 2.3 to 5.1 million GJ.[82]

TABLE. 1. Estimated gross energy yield from volume of stacked wood fuel consumed by railroad locomotives in São Paulo state, 1902. See note 82 for sources.

Stacked wood (1,000 m^3)	Solid wood (1,000 m^3)		Wood mass (kg)		Wood energy density (million GJ)		Gross energy yield (million GJ)	
	High	Low	High	Low	High	Low	Mean	Range
445.1	356.1	289.4	267,079	144,668	5.07	2.31	3.695	±1.380

Analysis of specific moments, such as the fuel crisis that hit São Paulo's industries and transport during the Second World War, provides additional insight on the use of biomass and fossil fuels. Severe cutbacks in fossil fuel imports led to rationing, whilst the São Paulo state government created a commission charged with stimulating the production of gasifiers. Gasifiers, commonly used during the early twentieth century in Europe, produce gas from wood, charcoal, coal or peat. The produced gas is then burned in traditional engines, but often at a higher compression ratio than for gasoline or diesel.[83] São Paulo's industrial organisation supported legislation that forced consumers of wood fuel to reforest corresponding supply areas, recognising that 'nearly all' of the city's 'small-scale heavy industries use charcoal as fuel'.[84] The increased demand created by gasifiers and other wood-burning engines may have doubled fuel wood consumption and caused price increases as large as 600 per cent.[85] Fuelwood consumption rose as quickly as the burning of fuel oil and gasoline declined. Between mid 1941 and May 1942, the monthly demand for wood fuel in São Paulo city increased from 150,000 to 220,000 cubic metres.[86]

The rapid adoption of wood- and charcoal-burning gasifiers, as a response to the fossil fuel crisis, is a fascinating phenomenon. In the early 1940s 'hundreds of individual pieces of equipment, made in many machine shops' in Brazil were installed in cars and trucks, inspiring state-funded experiments comparing the efficiency and power obtained from wood and charcoal. By 1942 approximately 22,000 automobiles, out of a total of 245,000, were equipped with biomass-burning gasifiers. The Brazilian government issued provisions limiting the prices charged for gasifier-quality charcoal. Wood distillation plants were dedicated to supplying the rapidly growing market. Numerous firms probably coped with gasoline rationing in similar fashion as a sawmill near Londrina, northern Paraná state. The sawmill fitted its trucks with gasifiers and thus continued to haul wood from forest clearings. Unfortunately, gasifiers produced less power than gasoline or diesel fuel and remained 'a temporary expedient' in the face of severe shortages of liquid fuel.[87]

São Paulo's response to the fossil fuel crisis of the Second World War indeed merits further study. One may envision at least two scenarios. First, a large portion of São Paulo's metallurgy, chemical and textile industries relied exclusively on fossil fuels, especially imported coal and fuel oil, before 1939. As fossil fuel shortages hit, these industries switched to the biomass fuels they had abandoned only a few years earlier, and continued production. Breweries, brickworks, glassworks and others continued to use wood fuels. A second scenario is that only a small fraction of São Paulo's metallurgy, chemical and textile industries had switched from biomass to fossil fuels by 1939. Most industries did not have to abandon fossil fuels because they had yet to switch; under this scenario, most industries would adopt fossil fuels after the end of the Second World War.

One further issue, overlooked by Dean's wood hypothesis, is fundamental to understanding both the burning of wood by São Paulo's industries and the transport of woodfuel by railroads: the contracts and labour practices that governed the removal of wood fuel from forest and Cerrado. Generalisations about this essential aspect of wood fuel consumption are supported by documents preserved in two judicial archives located in São Paulo's hinterland. I created a database of judicial proceedings relating to wood, from 1920 to the late 1950s, in Assis (western São Paulo) and Londrina (northern Paraná) (Figure 1). The judicial proceedings contain valuable information on various stages of the wood trades, such as labour relations, death and accident investigations, forest fires and polemic business deals.[88]

Demand for wood fuel supported activities and relationships that are poorly understood. Among the many instruments used in the wood trade were contracts that reduced the liability that merchants would face in the event of death or injury to workers whilst cutting wood.[89] A survey of contracts for wood fuel extraction in Londrina and Assis reveals wide variation in terms between landowners and wood merchants. Contracts intended for fuel wood excluded timber species and prohibited felling large trees, often providing a fixed period of forest or Cerrado access.[90] For example, a December 1920 contract for 260 hectares near Assis excluded Peroba, 'oleo' trees (probably *Copaifera langsdorfii*), and all trees larger than 120 centimetres in circumference. Larger trees would satisfy timber demands, while smaller trees would enter the wood fuel trade.[91]

At the base of the wood trades, thousands of labourers chopped pieces of fuel wood. The actual work of felling trees for fuel was often performed in subcontracting schemes that eliminated or reduced the potential liability of wood merchants. Subcontracting probably was itself reshaped from earlier 'flexible' forms of labour mobilisation in the coffee economy.[92] To shield themselves from legal responsibility, merchants paid workers per stacked volume of wood, and in this way, wood cutters were not 'workers' but rather belonged to a vague category of 'self-employed' *empreiteiros* (contractors). These empreiteiros were not considered to be formal employees of fuel merchants, who developed legal arguments to enforce subcontracting. Judges and state attorneys often accepted these arguments, but in some cases merchants were not successful in separating their enterprises from labour relations, even while paying per cubic metre delivered.[93]

Capital accumulation strategies in the fuel wood trade may be appreciated by considering selected dealings of Antônio da Silva, who became mayor of Assis in the 1950s. In 1940, the 36-year-old Silva directly controlled more than 2,500 hectares of forest and Cerrado used for fuel woodcutting and gravel mining supplying the Sorocabana railroad. Silva required substantial numbers of wood cutters; in one court case, testimony revealed that he supplied medical care to one of these, an illiterate 27-year old male who lost an eye whilst cutting wood. Another of the many wood cutters had been authorised by Silva to cut wood and deliver it to the slaughterhouse that produced tallow for export to São Paulo. One woodcutter had been contracted by simple letter in the 1940s to supply 6,000 cubic metres of stacked wood fuel for supplying Sorocabana locomotives. The letter emphasised that Silva would have nothing to do with the woodcutter's accounts, nor his hiring of subcontractors or suppliers to deliver the wood fuel. Other court documents showed Silva's advances of cash and supplies to 'contractors'. Another labour conflict shows how Silva relied on field managers to oversee the delivery of cut wood from many woodcutters, creating at least two or three layers of subcontractors between Silva, administrators and the workers who cut wood.[94]

Finally, a survey of court records reveals the terminology used in the wood fuel trade. Areas of forest and Cerrado that supplied wood fuel were known as *lenheiros* and the fuelwood depot was the *lenhadora* that belonged to a *com-*

erciante de lenha (fuelwood merchant) who supplied urban consumers. Brick manufacturers employed their own *lenheiro*, *picador de lenha* or *cortador de lenha* (fuelwood cutter) to *puxar lenha* (haul fuelwood). Fuel wood could be rejected by merchants for being of improper thickness or displaying signs of rot; some labourers took a 25 per cent discount on inferior types of wood fuel.[95]

Who were the woodcutters supplying such prodigious amounts of fuel to locomotives, industries and households? Court documents reveal little about the thousands of men who cut wood from forest and Cerrado. Only fragmentary information is provided on birthplaces, families and salaries. Although many woodcutters probably were amongst the lowest-paid labourers dedicated to the fuel industry, others may have been smallholders, tenant farmers or sharecroppers. These men, and their families, may have cut fuel in the agricultural off-season or other slack period.[96]

Overall, wood fuel consumption in São Paulo's industrialisation presents a paradox. Railroads hauled wood fuel over long distances to supply households and industries. Labour relations and contracts were specific to woodcutting. However, no datasets on wood burning by specific industries, outside of locomotives, were identified for this paper, nor were they located by Warren Dean in support of the wood hypothesis. Locomotives obviously were not the only wood-burning activity in São Paulo state. This paradox is not unique. Arthur Cole, writing about wood fuel marketing in the early US economy, argued that the documentary paper trail created by the wood trade was extremely light. With feigned disbelief, Cole wrote that 'monies paid for the millions of cords of wood passed, it seems, from consumer to producer with little mediation'.[97]

CONCLUSION

In this paper I have confirmed some aspects of the wood hypothesis proposed by Warren Dean for explaining the energy sources of São Paulo's industrial growth during the first half of the twentieth century.[98] This exercise is important because it reconsiders the energy sources that fuelled São Paulo's industrialisation during the first half of the twentieth century and raises issues regarding the methodology of environmental history.

I presented two substantive revisions to the wood hypothesis. Datasets not consulted by Warren Dean indicate that the wood hypothesis is accurate in general terms: wood was the main gross energy source for São Paulo state from 1900 until the mid 1950s. But comparison of datasets also showed that Dean under-estimated fossil fuel demand, especially for imported coal and fuel oil. Second, the wood hypothesis was based on flawed methodology that should be abandoned. Framing the fuel-for-industrialisation issue in terms of potential gross energy supplied by estimated forest area is plagued with suspect assumptions and unacknowledged error. My revised high estimate is still nearly 44 per cent lower than Dean's. This exercise revealed Dean's unwarranted assumptions, but should not overshadow my criticism of the overall idea of estimating potential wood fuel supply. Indeed, I offer three claims well beyond this narrow focus on gross energy that advance the important issues raised by the wood hypothesis.

First, analysis of São Paulo's energy sources should begin with industrial demand, not potential biomass supply. The challenge for future research is to find data on industrial fuel consumption, or to estimate fuel consumption from records of commodity production. This task is not without its own methodological problems, but transparent methods were outlined in this paper (Table 1). Second, the contracting and flexible labour relations that sustained the wood-fuel trade should attract greater attention. Labour relations, adapted from agriculture, were deployed to secure an essential fuel that was marketed through poorly known networks. Further research on this issue will reveal the intensity and territorial extent of the wood fuel supply chain. Third, tighter periodisation should focus attention on specific moments in São Paulo's energy transition, such as the 1940s fossil fuel crisis, to discern industrial fuel consumption. By studying how industries adapted to fuel shortages, we may begin to understand what fuels they actually burned and what criteria guided selection of fuel.

Overall, São Paulo's industrialisation during the first half of the twentieth century relied on the unequal interplay of three energy hinterlands. A biomass hinterland amidst the forest, secondary growth and Cerrado in the Atlantic Forest mosaic was the main gross energy source for industrialisation. A fossil fuel hinterland, mainly in British coal mines and Venezuelan oilfields, connected by maritime freight to São Paulo's industries, complemented biomass fuels. A hydrological hinterland, mainly controlled by foreign investors and managers, supplied hydroelectricity to many industries that also burned wood or fossil fuels for their heat processes; nevertheless, hydroelectricity lagged behind biomass and fossil fuels as a gross energy source. Explaining more precisely how these energy sources supplied the industries that created South America's leading industrial centre is a task that begins with the insights of Dean's wood hypothesis, but only advances by evaluating Dean's method and sources and by bringing new evidence to the discussion.

NOTES

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[1] Lewis Mumford, 'The Natural History of Urbanization', in *Man's Role in Changing the Face of the Earth*, vol. 1, ed. W. L. J. Thomas (Chicago: University of Chicago Press), 385. See also William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W.W. Norton and Co., 1991); Matthew Gandy, *Concrete and Clay: Reworking Nature in New York City* (Cambridge: MIT Press, 2002), 22; Gray Brechin, *Imperial San Francisco: Urban Power, Earthly Ruin* (Berkeley: University of California Press, 1999), xxiii.

[2] See Sam H. Schurr and Bruce C. Netschert, *Energy in the American Economy, 1850–1975: An Economic Study of its History and Prospects* (Baltimore: Johns Hopkins Press, 1960); Jean-Claude Debeir, Jean-Paul Deléage and Daniel Hémery, *In the Servitude of Power: Energy and Civilisation through the Ages* (London: Zed Books, 1991); Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution* (Cambridge: White Horse Press, 2001); A. Kander, *Economic Growth, Energy Consumption and* CO_2 *Emissions in Sweden, 1800–2000* (Lund: Lund University, 2002); Fridolin Krausmann and Helmut Haberl, 'The Process of Industrialization from the Perspective of Energetic Metabolism: Socioeconomic Energy Flows in Austria 1830–1995', *Ecological Economics* 41 (2002): 177–201; Heinz Schandl and Niels Schulz, 'Changes in the United Kingdom's Natural Relations in Terms of Society's Metabolism and Land-use from 1850 to the Present Day', *Ecological Economics* 41 (2002): 203–21.

[3] Warren Dean, *The Industrialization of São Paulo 1880–1945* (Austin: University of Texas Press, 1969), 3–13; Mauricio A. Font, 'City and Countryside in the Onset of Brazilian Industrialization', *Studies in Comparative International Development* 27 (1992): 29; Martin T. Katzman, *Cities and Frontiers in Brazil: Regional Dimensions of Economic Development* (Cambridge: Harvard University Press, 1977), 129.

[4] Christopher Armstrong and H. V. Nelles, *Southern Exposure: Canadian Promoters in Latin America and the Caribbean 1896–1930* (Toronto: University of Toronto Press, 1988), 43–84; Duncan McDowall, *The Light: Brazilian Traction, Light and Power Company Limited, 1899–1945* (Toronto: University of Toronto Press, 1988), 242–62.

[5] Warren Dean, *With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest* (Berkeley: University of California Press, 1995). Dean was 'arguably the region's [Latin America] most accomplished environmental historian' according to J. R. McNeill, 'Observations on the Nature and Culture of Environmental History', *History and Theory* 42 (2003): 24. For a critique of Dean's interpretation of colonial forest policy in Brazil, see Shawn William Miller, *Fruitless Trees: Portuguese Conservation and Brazil's Timber* (Stanford: Stanford University Press, 2000), 5–12.

[6] For J. R. McNeill, the field is divided amongst material, cultural-intellectual and political varieties; see 'Observations', 6–9. Other fissures include the ecocentric-anthropcentric divide and the polemic over the 'usefulness' of environmental history to public policies; see Christian Brannstrom and Stefania Gallini, 'An Introduction to Environmental History', in *Territories, Commodities and Knowledges: Latin American Environmental History in the Nineteenth and Twentieth Centuries*, ed. C. Brannstrom (London: Institute for the Study of the Americas, 2004).

[7] Dean, *With Broadax and Firebrand*, 251–2. Dean first outlined his wood hypothesis in a 1986 conference paper published as 'A Floresta como Fonte de Energia na Urbanização e na Industrialização de São Paulo: 1900–1950', in *Anais do 1o. Seminário Nacional de História e Energia* (São Paulo: Eletropaulo, Departamento de Patrimônio Histórico, 1987), 41.

[8] Dean, *With Broadax and Firebrand*, 364; Dean, 'Floresta como Fonte de Energia', 51.

[9] Dean, *With Broadax and Firebrand*, 252, 254, 364; Dean, 'Floresta como Fonte de Energia', 41.

[10] Dean, *With Broadax and Firebrand*, 254.

[11] Werner Baer, *The Development of the Brazilian Steel Industry* (Nashville: Vanderbilt University Press, 1969); Francisco de A. Magalhães Gomes, *História da Siderugia Brasileira* (Belo Horizonte; São Paulo: Editoria Itatiaia; Editora da Universidade de São Paulo, 1983).

[12] Dean, *With Broadax and Firebrand*, 196–7.

[13] Aboveground biomass is usually expressed as mass per area, and it is calculated by measuring the diameter and specific gravity of trees greater than ten centimetres, at 1.3 metre height. However, sources of error in obtaining this estimate include error in tree measurement, error in modelling, uncertainty in sampling and representativeness of small plots. For discussion, see J. Chave, et al., 'Error Propagation and Scaling for Tropical Forest Biomass Estimates', *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 359, n. 1443 (2004): 409–12. For studies showing a wide range in Amazonian aboveground biomass and wood density, see T. R. Baker, et al., 'Variation in Wood Density Determines Spatial Patterns in Amazonian Forest Biomass', *Global Change Biology* 10, n. 5 (2004): 545–62; R. A. Houghton, et al., 'The Spatial Distribution of Forest Biomass in the Brazilian Amazon: A Comparison of Estimates', *Global Change Biology* 7 (2001): 731–46. In addition, estimates of aboveground biomass for Cerrado formations are far lower than Amazon forests; see R. I. Barbosa and P. M. Fearnside, 'Wood Density of Trees in Open Savannas of the Brazilian Amazon', *Forest Ecology and Management* 199, no. 1 (2004): 115–23.

[14] Vaclav Smil, *Biomass Energies: Resources, Links, Constraints* (New York: Plenum Press, 1983), 82.

[15] For wood fuel energy yield, see Smil, *Biomass*, 76–7. On differences between interior and coastal Atlantic Forest, see Christian Brannstrom, 'Rethinking the "Atlantic Forest" of Brazil: New Evidence for Land Cover and Land Value in Western São Paulo, 1900–1930', *Journal of Historical Geography* 28 (2002): 420–21, 431–33. In fact, one scholar admitted that 'Atlantic Forest is a popular term with no real scientific basis'; see Ibsen de Gusmão Câmara, 'Brief History of Conservation in the Atlantic Forest', in *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook*, ed. C. Galindo-Leal and I. G. Câmara (Washington, D.C.: Island Press, 2003), 31.

[16] For Dean's calculations, see *Broadax*, 252. For early-twentieth-century estimates of stacked wood yield per area, see Edmundo Navarro de Andrade, *A Cultura do Eucalyptus* (São Paulo: Typographia Brazil de Rothschild & Cia., 1909); F. W. Freise, 'Notas sobre Carbonisação de Madeira e Briquettagem de Carvão Vegetal', *Revista Brasileira de Engenharia* 12, n. 2 (1926): 48–58; Alberto Löfgren, 'Serviço Florestal no Estado de S. Paulo', *Boletim da Agricultura* 3 (1902): 593. For conversion factors of stacked wood to solid wood volumes, see Smil, *Biomass*, 82. Wood energy density estimates are provided in Vaclav Smil, *Energy in World History* (Boulder: Westview, 1994), 12 and Smil, *Biomass*, 76–7.

[17] I was unable to locate any published study that measured mean biomass or mean specific gravity per area of Atlantic Forest. Recent studies in the Brazilian scientific literature

analyse forest structure, not biomass per hectare of Atlantic Forest; for a review, see Giselda Durigan, et al., 'Estrutura e Diversidade do Componente Arbóreo da Floresta na Estação Ecológica dos Caetetus, Gália, SP', *Revista Brasileira de Botânica* 23 (2000): 372. The most comprehensive recent publication on the Atlantic Forest also lacks mention of mean biomass or specific gravity; see Carlos Galindo-Leal and Ibsen de Gusmão Câmara, ed., *The Atlantic Forest of South America: Biodiversity Status, Threats, and Outlook* (Washington, DC: Island Press, 2003).

[18] S. Fróes Abreu, 'Lenha', *Revista Brasileira de Engenharia* 31, n. 5 (1936): 97.

[19] The idea of bias against wood fuel is developed by Geoffrey W. Barnard, 'Woodfuel in Developing Countries', in *Biomass: Regenerable Energy*, ed. D. O. Hall and R. P. Overend (Chichester: John Wiley & Sons, 1987), 349; David O. Hall, Jo I. House and Ivan Scrase, 'Overview of Biomass Energy', in *Industrial Uses of Biomass Energy: The Example of Brazil*, ed. F. Rosillo-Calle, S. V. Bajay and H. Rothman (London: Taylor & Francis, 2000), 2. The characteristics of data on wood fuel were described in the 1950s by a survey of Latin America's energy situation; see United Nations (Economic Commission for Latin America), *Energy in Latin America* (Geneva: United Nations, 1957), 30, 181.

[20] Smil, *Biomass*, 76–7; Helmut Haberl, 'The Energetic Metabolism of Societies: Part I: Accounting Concepts', *Journal of Industrial Ecology* 5 (2001): 17–22.

[21] Dean, *Industrialization of São Paulo*.

[22] Martin V. Melosi, 'Energy Transitions in the Nineteenth-century Economy', in *Energy and Transport: Historical Perspectives on Policy Issues*, ed. G. H. Daniels and M. H. Rose (Beverly Hills, CA: Sage Publications, 1982), 58.

[23] Dean, *Industrialization of São Paulo*, 13, 83; Font, 'City and Countryside', 33–4.

[24] The closest Dean came to estimating gross energy consumption was his claim that in 1950 'wood and charcoal burning was certainly not less than 50% of fuel consumption, despite a significant amount of hydroelectric generation and the region's improved capacity to import fossil fuels' (Dean, *With Broadax and Firebrand*, 254). Earlier, Dean argued that hydroelectricity represented less than 25% of São Paulo's energy needs (Dean, 'Floresta como Fonte de Energia', 41). However, he neglected to specify if the estimates were for gross or net energy, or whether domestic consumption was included.

[25] John E. Good, Alvaro Abreu, and Thomas Fraser, *The Coal Industry of Brazil: Part I. General Economy, Production, and Marketing* (Washington, DC: GPO, 1949), 27, 26, 23–4. This study is not cited in the end notes of Dean, *With Broadax and Firebrand*.

[26] Robert Neill Gay, Jr., 'The Fuel and Power Resources of Brazil and their Development' (Master's thesis, University of Texas [Austin]), 5.

[27] United Nations, *Energy in Latin America*, 49, 141; Jean-Marie Martin, *Processus d'Industrialisation et Développement Énergétique du Brésil* (Paris: Institut des Hautes Études de l'Amérique Latine, 1966), 342. *With Broadax and Firebrand* does not cite Martin's study.

[28] Low energy estimates are shown in Fig. 5. For Sorocabana fuel wood shipments, I used Estrada de Ferro Sorocabana, *Relatório* (São Paulo: various publishers, 1924–1955). The Light's electricity sales (kilowatt hours) in São Paulo city were obtained from McDowall, *Light*, 406; Maria de Lourdes P. Souza Radesca, 'O Problema da Energia Elétrica', in Aroldo de Azevedo, ed., *A Cidade de São Paulo: Estudos de Geografia Urbana: Aspectos da Metrópole Paulista* (São Paulo: Companhia Editoria Nacional, 1958), 104; and

The São Paulo Tramway, Light and Power Company, Limited, 'Annual Report 1914' (unpublished document), Fundação Patrimônio Histórico da Energia de São Paulo. Coal imports to Santos, São Paulo, between 1938–1949 averaged to 17% of Brazil's total coal imports, but here I use 20% as an estimate for years in which São Paulo's share was not reported; data were obtained from Brasil (Ministério da Fazenda), *Importação de Carvão de Pedra, Coque e Briquette* (Rio de Janeiro: Imprensa Nacional, 1941, 1947, 1949, 1951). Consumption of petroleum fuels in São Paulo was obtained from Brasil, *Anuário Estatístico* (Rio de Janeiro, various years).

[29] Wilson Cano, *Raízes da Concentração Industrial em São Paulo* (Rio de Janeiro: Difel, 1977), 204, 212. Dean reported that wood-burning steam engines represented approximately 30% of the city of São Paulo's stationary engines in 1920, and in 1950 still represented 11%; see Dean, *Broadax*, 253–54.

[30] Maria Luiza R. Souza and Hélio Júlio Gordon, 'Indústria e Tecnologia Metal-mecânica no Estado de São Paulo 1880–1980: Um Estudo Exploratório', in *Tecnologia e industrialização no Brasil: Uma perspectiva histórica*, ed. S. Motoyama (São Paulo: Editora UNESP; CEETEPS, 1994), 216.

[31] Edgard Carone, *A Evolução Industrial de São Paulo, 1889–1930* (São Paulo: Editora Senac, 2001).

[32] Sieferle, *Subterranean Forest*, 137.

[33] McDowall, *The Light*, 101.

[34] Roberto C. Simonsen, *Evolução Industrial do Brasil e Outros Ensaios* (São Paulo: Editora Nacional; Editora da USP, 1973 [1939]), 31; Richard M. Morse, *From Community to Metropolis: A Biography of São Paulo, Brazil* (Gainesville: University of Florida Press, 1958), 227; Preston E. James, *Latin America* (New York: Lothrop, Lee and Shepard Co., 1942), 495; Dean, *Industrialization of São Paulo*. Several other observers noted the dependency of industrialisation on hydroelectricity; see R. H. Whitbeck, *Economic Geography of South America*, 2nd ed. (New York: McGraw-Hill Book Company, 1931), 371, 373; Henri van Deursen, 'L'Emancipation Industrielle du Bresil: Caracteres et Developpement de l'Industrie dans l'Etat de Sao Paulo', *Revue Economique Internationale* 26 (1934), 277; Philip S. Smith, *Electrical Goods in Argentina, Uruguay, and Brazil* (Washington, DC: GPO, 1919), 95–6, 114; US Department of Commerce, *Electrical Development and Guide to Marketing of Electrical Equipment in Brazil* (Washington, DC: GPO, 1927), 10–15.

[35] The São Paulo Tramway, Light and Power Company, Limited, 'Annual Report 1914', 94 (unpublished document) Fundação Patrimônio Histórico da Energia de São Paulo.

[36] José Luiz Lima, *Estado e Energia no Brasil* (São Paulo: Instituto de Pesquisas Econômicas/USP, 1984).

[37] A. W. K. Billings, 'Water Power in Brazil', *The Engineering Journal* (Montreal) 13 (1930): 493–503; Catulo Branco, *Energia Elétrica e Capital Estrangeiro no Brasil* (São Paulo: Alfa-Omega, 1975), 66; Centro de Memória da Eletricidade do Brasil, *Panorama do Setor de Energia Elétrica no Brasil* (Rio de Janeiro: Centro de Memória da Eletricidade no Brasil, 1988), 54; Deursen, 'L'Emancipation Industrielle', 290.

[38] Catullo Branco, 'Fornecimento de Energia Eletrica ao Estado de São Paulo', *Boletim do Instituto de Engenharia* 16, n. 82 (1932): 182.

[39] Paul Israel Singer, *Desenvolvimento Econômico e Evolução Urbana: Análise da Evolução Econômica de São Paulo, Blumenau, Pôrto Alegre, Belo Horizonte e Recife* (São Paulo: Editôra Nacional; Editôra da USP, 1968), 56–7.

[40] George Bassalla, 'Some Persistent Energy Myths', in *Energy and Transport: Historical Perspectives on Policy Issues*, ed. George H. Daniels and Mark H. Rose (Beverly Hills, CA: Sage Publications, 1982), 27.

[41] See, for example, E. L. da Fonseca Costa, 'Richesses Minérales et Houille Blanche au Brésil', *Annales de Géographie* 41 (1932): 618–30.

[42] E. A. Wrigley, 'The Supply of Raw Materials in the Industrial Revolution', *Economic History Review* 15, n. 1 (1962): 14.

[43] Arthur Levy, *Energia Não se Importa … (Estudo da Melhor Estrutura Energética para o Brasil)* (Rio de Janeiro: Editôra Biblioteca do Exército, 1962), 150–51, 348; Paulo Oliveira, 'Petróleo contra os "Fazedores de Desertos"', *Petrobrás* 11 (1965): 6–13.

[44] The energy density of wood, between 16 and 19 MJ per kilogram, is far less than bituminous coal (29 MJ per kilogram) and crude oil (43 MJ per kilogram); see Smil, *Biomass*, 76–7. In Porto Alegre, one tonne of British coal was the energy equivalent of two tonnes of Brazilian coal, which in turn was the energy equivalent of 7.6 cubic metres of locally procured fuel wood; see Roberto Marinho, 'Alguns Dados sobre as Usinas Electricas do Estado de Rio Grande do Sul', *Revista Brasileira de Engenharia* 1, n. 9 (1921): 308–9. Other observers estimated that between eight and ten cubic metres of Brazilian wood fuel were required to create the same energy as one tonne of imported British coal; see Plinio de Queiroz, *Os Meios de Transporte e a Obtenção de Energia* (São Paulo: Empreza Graphica Industrial, 1927), 29; Löfgren, 'Serviço Florestal', 593. Gay ('Fuel and Power Resources', 19) reported that in during the late 1940s, imported coal was more expensive than domestic coal; but the higher energy density of imported coal made it 25% cheaper on a tonne-for-tonne basis.

[45] Laura Randall, *The Political Economy of Brazilian Oil* (Westport, CT: Praeger, 1993).

[46] Baer, *Development of Brazilian Steel*; Magalhães Gomes, *História da Siderugia Brasileira*; Donald Edmund Rady, *Volta Redonda: A Steel Mill Comes to a Brazilian Coffee Plantation* (Albuquerque: Rio Grande Publishing Company, 1973); see also Gay ('Fuel and Power Resources', 23–4) on the many subsidies created between 1915 and the late 1940s.

[47] Carlos Sonntag, 'Fornalhas, Fornos Industriaes e Enxugadores de Madeiras', *Revista Brasileira de Engenharia* 8, n. 4 (1924): 167–72.

[48] 'The Sulzer Boiler Plant with Pulverised Coal Firing in the New Power Plant of the Cia. Energia Electrica Rio Grandense at Porto Alegre (Rio Grande do Sul), Brazil', *Sulzer Technical Review* 2 (1930): 15–22; C. H. S. Tupholme, 'New Brazil Plant Burns Low-grade Coal at High Efficiency', *Combustion* [New York] 3, n. 6 (1931): 23–5, 33, 36.

[49] Marinho, 'Alguns Dados', 308–9.

[50] M. A. Cremer, *Coal Market of Brazil* (Washington, D.C.: GPO, 1924), 1, 3.

[51] 'Carvão Mineral', *O Observador Econômico e Financeiro* 10, n. 111 (1945): 194.

[52] Good, Abreu and Fraser, *The Coal Industry of Brazil*.

[53] M. A. Cremer, *Petroleum in Brazil* (Washington, DC: GPO, 1925), 23, 27.

[54] US Tariff Commission, *Mining and Manufacturing Industries in Brazil* (Washington, DC: GPO, 1949), 30.

[55] Coal is the favoured fuel to produce clinker in the high-temperature kiln necessary for cement production, whilst electricity is usually used for grinding clinker and gypsum into cement; see Hendrik G. van Oss and Amy C. Padovani, 'Cement Manufacture and the Environment: Part I: Chemistry and Technology', *Journal of Industrial Ecology* 6, n. 1 (2002): 94–104. For the history of Brazil's cement industry, see 'A Fabricação de Cimento no Brasil', *Revista Brasileira de Engenharia* 10, n. 4 (1930): 145–7; 'O Progresso da Fabricação de Cimento no Brasil', *Revista Brasileira de Engenharia* 30, n. 6 (1935): 195–8; 'A Indústria de Cimento no Brasil', *Revista Brasileira de Engenharia* 38, n. 5 (1941): 113–18, 159–63; Raul de Senna Caldas, 'Producção e Consumo de Cimento no Brasil', *Revista Brasileira de Engenharia* 29, n. 3 (1935): 80–2; Felix Hegg, 'Algunas Consideraçoes sobre o Futuro da Industria do Cimento no Brasil', *Revista Brasileira de Engenharia* 4, n. 4 (1922): 143–51; M. A. Cremer, *Market for Construction Materials in Brazil* (Washington, DC: GPO, 1923), 7; US Tariff Commission, *Mining and Manufacturing*, 30, 77.

[56] Oliveira, 'Petróleo contra os "Fazedores de Desertos"', 6–13.

[57] Levy, *Energia Não se Importa*, 158.

[58] Maria Helena Magalhães Castro and Simon Schwartzman, *Tecnologia para a Indústria: A História do Instituto Nacional de Tecnologia* (1981), available at www.schwartzman.org.br/simon/int/int.htm, accessed January 2004. During the mid 1920s, Fonseca Costa advised the group that built Brazil's first steel mill powered by electricity, in Ribeirão Preto.

[59] Proponents of charcoal touted the relatively low cost of charcoal and the poor characteristics of Brazil's coal; see Magalhães Gomes, *História da Siderugia Brasileira*, 182–4.

[60] Fonseca Costa, 'Richesses Minérales', 622.

[61] Frederico W. Freise, 'Estudo Comparativo do Preço do Ferro Obtido no Forno Alto com Diversos Combustiveis', *Revista Brasileira de Engenharia* 11, n. 5 (1926): 180–2.

[62] F. W. Freise, 'Subsidios para o Conhocimento do Carvão de Madeira Nacional', *Revista Brasileira de Engenharia* 11, n. 1 (1926): 18–25; Freise, 'Notas sobre Carbonisação', 48–58. A few years later, another scientist also published extensive details on modernising charcoal manufacture to supply locomotives and industries; see Thomas Le Gall, 'A Fabricação de Carvão Vegetal', *Revista Brasileira de Engenharia* 33, n. 6 (1937): 197–204; Thomas Le Gall, 'A Fabricação de Carvão Vegetal', *Revista Brasileira de Engenharia* 34, n. 1 (1938): 1–6.

[63] Sylvio Fróes Abreu, *Carvão, Petróleo, Sal-Gema e Enxofre* (Rio de Janeiro: Instituto Nacional de Tecnologia, 1944), 31–5 (italics in original); Fróes Abreu, 'Lenha', 95–98; Rubem Roquette and S. Fróes Abreu, *Composição Elementar e Immediata de Alguns Combustiveis Nacionaes* (Rio de Janeiro: Instituto Nacional de Technologia, 1936), 7–8. Evidence for long-distance rail transport of wood fuel undermines Fróes Abreu's claim that wood fuel markets had limited territorial scope. Fróes Abreu's arguments against wood as an industrial fuel also appeared in the writings of an early twentieth-century expert who argued that 'wood is seldom employed as a fuel on an industrial scale, and then only in such localities were coal is scarce' (F. J. Brislee, *An Introduction to the Study of Fuel: A Text Book for Those Entering the Engineering, Chemical and Technical Industries* [New York: D. Van Nostrand Company, 1912], 138). Another expert claimed that 'wood is basically a local fuel' and 'wood has never sustained a broad national in-

dustrialized economy' in the long term (David A. Tilman, *Wood as an Energy Resource* [New York: Academic Press, 1978], 26).

[64] Ministry of Agriculture, Industrie and Commerce [sic], *Brazilian Timber* (Rio de Janeiro: publisher unknown, 1928), 8; Ministry of Foreign Affairs, *Forest Industries of Brazil* (Rio de Janeiro: Gráfica Vitória, 1949), 48.

[65] L. A. Wanderley, 'A Madeira Como Combustivel', *Revista Brasileira de Engenharia* 15, n. 5 (1928): 174. Wanderley did not estimate a mean density per area, however.

[66] Frederico A. Brotero, *Sugestões para o Melhor Conhecimento de Nossas Madeiras* (São Paulo: Escolas Profissionaes do Lyceu Coração de Jesus, 1931), 11.

[67] Dean, *Broadax*, 230–35.

[68] Löfgren, 'Serviço Florestal', 537; Navarro de Andrade, *Eucalyptus*, 124; Euclides da Cunha, *Contrastes e Confrontos*, 8th ed. (Porto: Livraria Lello & Irmão, 1941 [1907]), 206; see also Dean, *Broadax*, 233–35; Susanna B. Hecht, 'The Last Unfinished Page of Gensis: Euclides da Cunha and the Amazon', *Historical Geography* 32 (2004): 43–69.

[69] Dean used annual reports to conclude, for example, that the Paulista railroad consumed 540,000 cubic metres in 1935; see Dean, *Broadax*, 255. I consulted the annual reports of the Sorocabana railway to estimate energy supply to São Paulo city. In 1931, for example, the Sorocabana railroad reported consumption of 962,100 cubic metres of fuel wood; see Estrada de Ferro Sorocabana, *Relatório…1931* (São Paulo: Tip. Brasil de Rothschild & Cia., 1932), 214–15.

[70] Robin W. Doughty, *The Eucalyptus: A Natural and Commercial History of the Gum Tree* (Baltimore: The Johns Hopkins University Press, 2000), 96–100.

[71] Dean, *Broadax*, 254.

[72] Löfgren, 'Serviço Florestal'; Hunnicutt, *Brazil*, 190.

[73] Companhia Estrada de Ferro do Dourado, *Relatório No. 6* (São Paulo: Typ. da EFD, 1922), 5–6.

[74] Raphael Zon and William N. Sparhawk, *Forest Resources of the World*, vol. 2 (New York: McGraw-Hill Book Company, 1923), 703, 707.

[75] Morris Llewellyn Cooke, *Brazil on the March--A Study in International Cooperation: Reflections on the Report of the American Technical Mission to Brazil* (New York: McGraw-Hill Book Co., 1944), 178, 160–61.

[76] Data compiled from Estrada de Ferro Sorocabana, *Relatório* (São Paulo: various publishers, 1924–1958).

[77] Dean, *Broadax*, 252.

[78] Data compiled from Companhia Estrada de Ferro do Dourado, *Relatório* (São Paulo: various publishers, 1923–1946). Unfortunately, a survey of all of São Paulo's railroad lines is not yet available. The Noroeste railway (Fig. 7) must have reported annual fuel consumption, but I was unable to locate these data among reports filed at the Centro de Memória Regional (UNESP/RFFSA) in Bauru.

[79] US Department of Commerce, *The Chemical Industry and Trade of Brazil* (Washington, DC: GPO, 1932), 15.

[80] Marcello Piza, *Os Municipios do Estado de S. Paulo: Informações Interessantes* (São Paulo: Secretaria da Agricultura, Commercio e Obras Publicas do Estado de São Paulo, 1924), 17–8, 36–8, 199–200.

[81] Slaughterhouse information from Prefeitura Municipal de Assis v. C. Bonfante, *Processo-crime* (1944), Caixa 161, Centro de Documentação e Apoio à Pesquisa, Arquivo do Fórum da Comarca de Assis, Cartório do Primeiro Ofício (hereafter CEDAP, AFCA, CPO). Industries such as wood-burning brickworks did not operate continuously, according to testimony in Rómulo Massi v. Teofilo Pereira de Castro, *Queixa Crime* (1939), Caixa 158, CPO, AFCA, CEDAP.

[82] Source of original data is Löfgren, 'Serviço Florestal', 593. Specific gravity is estimated between 500 and 750 kilograms per cubic metre; energy density is estimated between 16 and 19 MJ per kilogram.

[83] J. J. Hos and M. J. Groeneveld, 'Biomass Gasification', in *Biomass: Regenerable Energy*, ed. D. O. Hall and R. P. Overend (Chichester: John Wiley & Sons, 1987), 237–8.

[84] Humberto Dantas, 'Indústrias Paulistas', *O Observador Econômico e Financeiro* 8, n. 96 (1944): 40.

[85] Dean, 'Floresta como Fonte de Energia', 48.

[86] Dantas, 'Indústrias Paulistas', 34.

[87] Quotes from Cooke, *Brazil on the March*, 177. Contemporary estimates, study and regulations on gasifiers were obtained from: 'Preço e Quota de Produção de Carvão para Gasogênio', *O Observador Econômico e Financeiro* 8, n. 90 (1942): 139; 'Gasogenes', *Newsweek*, 26 July 1943: 57–61; 'Carvão para Gasogênio e Sub-produtos de Madeira', *O Observador Econômico e Financeiro* 9, n. 105 (1943): 133; C. A. Barton, *Instalação de Gasogênios em Caminhões de Transporte* (Rio de Janeiro: Ministério da Agricultura, 1940); Gustav Egloff and Prudence Van Arsdell, 'Motor Vehicles Propelled by Producer Gas', *The Petroleum Engineer* 15, n. 3 (1943): 65–73. Sawmill use of gasifiers is from Nadir Aparecida Cancian, 'Conjuntura Econômica da Madeira no Norte do Paraná' (Master's diss., Universidade Federal do Paraná, 1974), 135.

[88] Documents from AFCA, CEDAP are held at the campus of the Universidade Estadual Paulista-Assis; these documents were supplemented by materials from the Arquivo do Fórum da Comarca de Londrina held by the Centro de Documentação e Pesquisas Históricas of the Universidade Estadual de Londrina (UEL) (hereafter AFCL, CDPH). Both of these archives presently have some form of searchable database that assisted the research, but at CEDAP nearly all documents consulted were found in 1996–97 by searching individually through dozens of boxes of civil and criminal cases before a database was available in 2001. The CDPH database, opened in 2002, was limited to criminal cases. Publications relying on this database include: C. Brannstrom, 'The Timber Trade in South-eastern Brazil, 1920–1960', *Bulletin of Latin American Research*, 4, n. 3 (2005): 288–310; Brannstrom, 'Coffee Labor Regimes and Deforestation on a Brazilian frontier, 1915–1965', *Economic Geography* 76, n. 4 (2000): 326–46; Brannstrom, 'Rethinking the "Atlantic Forest"'.

[89] However, timber and wood fuel contracts were often made without official notary (*Cartório*) registration. In the words of a witness in a mid 1930s trial in Assis, logging and fuel contracts were made 'sometimes in utmost confidence, without documents' (A. Villalva v. E. E. Conceição and J. Coelho, *Força Nova Turbativa* [1934], Cartório do Segundo Ofício [hereafter CSO], AFCA, CEDAP, Caixa 140ci, f. 46v-47, 48).

[90] F. Jurban v. L. S. Paiva, *Ação de Manutenção de Posse* (1924), f. 5–10, Caixa 78ci, CSO, AFCA, CEDAP; O. D. Oliveira v. F. A. Silva, *Ação Força Nova* (1922), f. 5–7, Caixa 98, CPO, AFCA, CEDAP; A. Villalva v. E. E. Conceição and J. Coelho, *Força*

Nova Turbativa (1934), f. 4–6, Caixa 140ci, CSO, AFCA, CEDAP; T. Figueiredo v. Claúdio & Rito, *Ação Possessória* (1932), f. 8, Caixa 113ci, CSO, AFCA, CEDAP; M. J. Barone, *Inventário* (1932) (Inventariado: M. Japolucci), f. 87, Caixa 66, CPO, AFCA, CEDAP; W. Murad v. M. M. Correia, *Ação Ordinária* (1936), f. 5–6, Caixa 120, CPO, AFCA, CEDAP; R. Messias v. T. Matsumoto, *Ação Ordinária* (1937), f 4, Caixa 122, CPO, AFCA, CEDAP; AJP v. B. Haddad, *Processo Crime* (1944), f. 36, Caixa 191, CPO, AFCA, CEDAP.

91 M. V. Silva, *Inventário* (1921) (Inventariado: F. G. Silva), f. 17–19, Caixa 52, CPO, AFCA, CEDAP.

92 Brannstrom, 'Coffee Labor Regimes'; Thomas H. Holloway, *Immigrants on the Land: Coffee and Society in São Paulo, 1886–1934* (Chapel Hill: University of North Carolina Press, 1980); Verena Stolcke, *Coffee Planters, Workers and Wives: Class Conflict and Gender Relations on São Paulo Plantations, 1850–1980* (New York: St. Martin's Press, 1988).

93 Curador de Acidentes v. Machado Bastos e Companhia, *Acidente de Trabalho* (1951) (Vítima: A. Travagli), f. 9–10, 42–3, Caixa 238, CPO, AFCA, CEDAP; A Justíca Pública, *Acidente* (1927) (Vítima: J. C. Bastos), f. 3v-9v, 11–11v, Caixa 103, CPO, AFCA, CEDAP; Curador de Acidentes no Trabalho, *Acidente de Trabalho* (Vítima: Luis Albino) (1933), Caixa 117, CPO, AFCA, CEDAP; Curador de Acidentes no Trabalho v. Adriano Costa, *Acidente no Trabalho* (Vítima: José Antonio Cardoso) (1940), Caixa 127, CPO, AFCA, CEDAP; Curador de Acidentes no Trabalho v. Luiz Kobal, *Acidente no Trabalho* (Vítima: Diamantino Gonçalves) (April 1942), Caixa 146, CPO, AFCA, CEDAP.

94 Prefeitura Municipal de Assis v. A. Silva and C. D. Cerqueira, *Ação Ordinária de Desapropriação* (1942), 144–5, Caixa 182, CPO, AFCA, CEDAP; Curador de Acidentes, *Acidente no Trabalho* (Vítima: João Klück) (1939), 4–5, Caixa 125, CPO, AFCA, CEDAP; Prefeitura Municipal de Assis v. C. Bonfante, *Processo-crime* (1944), Caixa 161, CPO, AFCA, CEDAP; S. F. Godoy v. A. Silva, *Ação Ordinária de Cobrança* (1943), Caixa 163, CPO, AFCA, CEDAP; A Justiça Pública v. M. Ribeiro and P. B. Santos, Processo Crime (1938), Caixa 151, CPO, AFCA, CEDAP.

95 A Justiça Pública, *Inquérito Policial* (1943) (Vítima: Auriel de Arruda), Caixa 152, CPO, AFCA, CEDAP; *Processo-Crime* (1959) (Denunciado: Paulo Balieiro et al.), AC 8778/59, 2a Vara, Pacote 67, CDPH, AFCL; *Inquérito Policial* (1953) (Vítima: José Francelino Filho), AC 194/53, 2a Vara, Pacote 26-B, CDPH, AFCL; Rómulo Massi v. Teofilo Pereira de Castro, *Queixa Crime* (1939), Caixa 158, CPO, AFCA, CEDAP; Saturnino Franco de Godoy v. Antonio Silva, *Ação Ordinária de Cobrança* (1943), f. 39–44, Caixa 163, CPO, AFCA, CEDAP; Curador de Acidentes v. Adriano Costa, *Acidente no Trabalho* (1940) (Vítima: José Antonio Cardoso), Caixa 127, CPO, AFCA, CEDAP; Curador de Acidentes no Trabalho, *Acidente no Trabalho* (1942) (Vítima: Diamantino Gonçalves), Caixa 146, CPO, AFCA, CEDAP; Curador de Acidentes, *Acidente de Trabalho* (1933) (Vítima: Luis Albino), Caixa 117, CPO, AFCA, CEDAP.

96 Personal interview, J. Rosa (Assis, April-August 1997). Dean (*Broadax and Firebrand*, 254) reported that in 1950 7.5% of São Paulo's rural labour force was employed in wood cutting and charcoal production.

97 Arthur H. Cole, 'The Mystery of Fuel Wood Marketing in the United States', *Business History Review* 44, n. 3 (1970): 359.

[98] At present biomass fuels account for approximately 21% of Brazil's gross total energy. Charcoal is an important input in pig-iron and speciality steel industries, whilst ethanol distilled from sugarcane powers millions of automobiles – including new 'flex-fuel' cars that burn both ethanol and gasoline – and sugar mills sell excess electricity obtained from burning sugarcane bagasse; see F. Rosillo-Calle, 'Brazil: A Biomass Society', in *Biomass: Regenerable Energy*, ed. D. O. Hall and R. P. Overend (Chichester: John Wiley & Sons, 1987), 329–48; José Otávio Brito, 'Fuelwood Utilization in Brazil', *Biomass and Bioenergy* 12 (1997): 69; Todd Benson, 'More Brazilian Drivers Turn to Ethanol', *The New York Times*, 20 October 2004.