

ON 'GREEN PREMATURE DEINDUSTRIALISATION'

Lessons on Green Industrial Contradictions
from Brazil's Wind Turbine Industry

Baptiste Albertone

Policy Lead of the Industrial Policy Programme,
TIDE Centre, University of Oxford

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ABSTRACT

Green industrialisation has emerged as a promising pathway for developing countries to reconcile growth imperatives with environmental sustainability. This article critically examines this proposition through an analysis of Brazil's wind turbine industry, which has often been celebrated as a successful case of green industrial development. The article demonstrates that Brazil's experience reveals fundamental vulnerabilities that are also a reproduction of past tendencies. While Brazil successfully established wind turbine manufacturing thanks to strategic development bank financing and local content requirements, this industrial achievement proved vulnerable. In recent years the sector has indeed been faced with what this article terms 'green premature deindustrialisation'- i.e., the contraction of nascent green manufacturing sectors within years of their establishment. This outcome reflects three critical factors: the heterogenous and potentially contradictory developmental logics of different renewable technologies; heterogenous 'easy' industrialisation potential between renewable energy technologies, and the persistence of 'minimalist' industrial policy approaches that prioritise employment over competitiveness. The article argues that an ambitious green developmentalist agenda for late developers requires moving toward comprehensive industrial policy strategies that foster competitive capabilities across productive sectors while taking a broader approach to the integration of development and sustainability objectives.



1. Introduction

Over the past decade, industrial policy has moved from the status of the ‘policy that shall not be named’ (Cherif & Hasanov, 2019), to that of the ‘policy that could do it all’. With regards to climate change and the energy transition, in particular, the idea that industrialisation and the environment could be reconciled has generated scholarly and policy enthusiasm.

For the developing world specifically, the sustainability agenda has been increasingly considered to offer a pathway to development and economic catch-up, and a means to reverse the dramatic tendency towards re-primarisation and de-industrialisation experienced by many developing economies (Altenburg et al., 2017; Lebdioui, 2024; Pegels, 2014; Rodrik, 2014). The concept of ‘green windows of opportunity’ (GWOs) most vividly captures this hopeful intuition (Lema et al., 2020, 2021; Lema & Perez, 2024; UNCTAD, 2023). As Lema et al. (2020, p. 1199) explain, ‘GWOs are defined as favourable, but time-bounded conditions for latecomer development, arising from changes in institutions, markets, or technologies, associated to the green transformation’.

Yet the empirical foundations of this optimism need to be interrogated. If GWOs and green industrial policy are to offer a meaningful analytical framework for understanding development prospects, such frameworks must be able to demonstrate that there exist real opportunities for green industrialisation beyond those demonstrated, most obviously by China and advanced nations, and that these opportunities can genuinely serve as a platform for economic catch-up, or at least to help reverse the premature deindustrialisation dynamic experienced by most of the developing world since the 1980s. Otherwise, such a concept might need to reconsider its scope as a general framework for sustainable economic development in the 21st century.

In discussing green industrialisation dynamics, moreover, insufficient attention has been given to the heterogeneous (and potentially contradictory) developmental potential of GWOs. Wind turbine production, for example, might present an accessible entry point for economies with inherited manufacturing capacity or large enough market, thereby facilitating

the use of local content requirements. Solar photovoltaic production, by contrast, is dominated by mass-manufacturing dynamics and extreme economies of scale that have enabled Chinese producers to achieve massive cost advantages. Similarly, it is important to recognise that while GWOs might prove complementary from the perspective of decarbonisation they are not necessarily so from an industrial policy perspective. When these technologies compete within a single national electricity system, the outcome is not neutral from a developmental standpoint.

This article presents a critical look at the GWO and green industrial policy approach. To do so, it draws on the experience of Brazil's wind turbine industry. This case study, I argue, while it has been celebrated as successful green industrialisation, is better described as a fragile and narrow experience that reproduces, rather than contradicts, the broader limits of Brazil's industrial policy, and that bears limited potential to substantially impact Brazil's broader development model. Moreover, Brazil's wind turbine industry has suffered from a phenomenon I describe as *green premature deindustrialisation*, a serious contraction of the sector only a few years after its establishment. This dynamic, I show, while it is partially attributable to conjunctural causes, also sheds light on more structural contradictions of the green industrial agenda.

The analysis draws on extensive fieldwork, more than 20 semi-structured interviews with key actors across the wind energy value chain, including industrial players (turbine manufacturers, component suppliers, project developers), policymakers and government representatives from ministries and agencies (e.g., the Brazilian Development Bank, Energy Research office, or the Ministry of Development, Industry, Trade and Services), and industry associations. In addition, these interviews were complemented by extensive analysis of newspaper articles, industry publications, and policy documents.

The rest of the article is organised as follows. Section 2 provides historical and analytical background to the concept of premature deindustrialisation. Section 3 examines the institutional and productive legacies that shaped Brazil's neo-developmental moment, with particular attention to the role of BNDES and analyses Brazil's green industrial policy in

the wind sector, demonstrating its character as a 'most likely' case of successful green industrialisation while identifying its structural limitations. Section 4 documents the emergence of green premature deindustrialisation, examining how solar expansion has undermined the wind industry's viability.

1. On Premature Deindustrialisation

In the immediate postwar period, the idea that industrialisation and industrial policy were important for development became widespread within the emerging field of development economics. Such a diagnosis was at the very heart of the development of development theory (Hirschman, 1958; Nurkse, 1952; Prebisch, 1950; Rosenstein-Rodan, 1943; Singer, 1949, 1978; Sunkel, 1977, 1991a). More than industrialisation *tout court*, however, most of the attention of development theorists initially focused on a particular type of industrialisation strategy, the so-called 'import-substituting industrialisation' (ISI).

Premature Deindustrialisation as Ideology Shifting

In the late 1950s, large corporations in advanced economies faced a dual crisis. On the one hand, technological innovation and productivity gains were slowing, fuelling inflation through wage pressures. On the other hand, many manufacturing goods' markets were reaching states of saturation, with market growth increasingly depending on planned obsolescence rather than new consumers (Perez, 2008). The inward-oriented industrialisation of the less-developed world, by providing generous state support and protection for the localisation of part of the production process closer to the consumer and thereby creating a virtuous cycle of employment creation and growth, helped mitigate some of these pressures at the same time as it served developmentalist ambitions. As Perez writes, 'market conditions were such that high productivity was not indispensable', the growth engine being primarily fuelled by the growth of consumption itself supported by the growth of formal employment. For a time, it appeared that these newly industrialising nations had finally managed to move from a development regime *externally* driven by commodity exports—often closely

associated with the *dependence* of the developing world on the developed world—to a self-sustaining accumulation dynamic.

By the late 1980s, industrialisation projects started to crumble one after the other (Hirschman, 2022). The oil crises, stagflation of the Western world, and the sharp rise in the US interest rate that was used in response provoked a balance of payments tension and the ballooning of external debts. Domestic industries in the developing world were increasingly costly to sustain, squeezed between the rising cost of external finance and the impossibility of competing in a global manufacturing landscape already saturated by successive waves of late developers producing the same goods more cheaply. In the face of these external and internal contradictions, developmentalist regimes were progressively replaced by (more or less authoritarian) governments closely aligned with a new developmental agenda characterised by a return to the principles of David Ricardo's doctrine of comparative advantages and to the policy prescription of the so-called Washington Consensus—i.e., the imperatives of liberalisation, privatisation, and deregulation.

By the early 2000s, industrial capacity across the developing world had shrunk dramatically. Across Latin America, manufacturing's share of GDP declined from around 28% in 1980 to 16.7% in 2003, while manufacturing employment—which had peaked at around 17% of total employment in the mid-1980s—fell to just 14.2% by 2003. This *premature deindustrialisation*, as it came to be termed, differed from dynamics of deindustrialisation in the developed world. Whereas deindustrialisation in the developed countries was primarily driven by endogenous factors such as faster growth of productivity in manufacturing, price changes, and demand shifts (Rowthorn & Ramaswamy, 1999), in the periphery it was described as a consequence of the dramatic shift in economic policy (Palma, 2005, 2008). Such a dynamic, Palma argued, could be described as a novel form of Dutch Disease. Whereas the classic concept referred to the deindustrialising effects of natural resource booms (as occurred in the Netherlands following the discovery of natural gas in the late 1950s), a similar dynamic can result from radical trade and financial liberalisation in middle-income countries. The effects, indeed, are similar. In both cases, what takes place is a transition 'from one group of reference to the other, that is, from the group of countries that

aim at generating a trade surplus in manufacturing to the group that can generate a trade surplus in primary commodities' (Palma, 2005, p. 85). '[T]hese new policies' he argued 'obstructed their transition toward a more mature—that is, self-sustaining (in a Kaldorian sense)—form of industrialisation' (Palma, 2005, p. 91).¹ This story, however, assumes that *ideological* factors were the principal factors behind the distinctively tragic fate of Latin America's developmentalist experiences. Yet this arguably is an incomplete picture.

Premature Deindustrialisation as Market Disciplining

The literature on the East-Asian miracle (and on China) points to critical institutional factors behind the distinctive fate of latecomers to industrialisation: the capacity to exert market discipline and incentivise state-supported industries to compete on international markets (Cherif & Hasanov, 2024, 2025). As the seminal work of Alice Amsden (1992, 2001, 2009) demonstrated, successful late industrialisers deployed reciprocal control mechanisms in the form of performance requirements that 'disciplined capital'. Productive actors only received government support if they heeded certain performance requirements—typically export targets, technological upgrading benchmarks, or production and productivity standards. Firms that failed to meet their targets could expect to see their subsidies withdrawn, their access to credit curtailed, or even to be absorbed by more successful competitors. Global competitiveness of local industries was the ultimate *telos* of these developmentalist histories. Latin American ISI, by contrast, largely lacked such disciplinary mechanisms—although this does not mean that the imperative of external competitiveness was not recognised (Sunkel, 1967, 1991b).² As Sunkel (1967, p. 63) recognised, this form of industrialisation 'has created a productive manufacturing structure primarily aimed at producing for consumption and has allowed the traditional export sector to produce for

¹ This, indeed, is the true meaning of the 'premature' character of deindustrialisation as originally formulated by Palma. See Rowthorn, 2024.

² Latin American structuralist were well aware, against a common vulgar argument, of the limits of import substitution and of the necessity of export diversification. Already in the early 1960s Prebisch had recognised that ISI was facing a new critical situation. He wrote: in our countries, we developed an industrial structure that was almost isolated from the outside world. The selection criteria were not based on considerations of economic opportunity, but rather on immediate feasibility, regardless of the cost of production... tariffs have been increased to such an extent that they are undoubtedly the highest in the world, on average. It is not unusual to find tariffs above 500 per cent... As is well known, the proliferation of all kinds of industries in a closed market has deprived Latin American countries of the advantages of specialisation and economies of scale, and due to excessive tariffs and restrictions, and economies of scale, and due to excessive tariffs and restrictions, healthy internal competition has not developed, to the detriment of efficient production' (Prebisch, 1963, p. 71 cited in ; Hirschman, 1968a, p. 626).

investment'. While it created jobs and some productive and technological learning, it remained structurally dependent on protection, on access to capital goods and foreign technologies.

Beyond these internal determinants, however, there arguably were global factors that severely constrained the space for catching up. Already in the 1970s, the world was experiencing a situation of global overcapacity in several industrial segments (Benanav, 2020a; Brenner, 2003). The result was intensified competition, downward pressure on prices, and a secular decline in profitability. At the same time, a new technological paradigm was progressively opening. The Information and Communication Technology (ICT) revolution radically redefined the global conditions of economic development. 'The multinationals', Perez (2008, p. 7-8) writes, 'no longer had much interest in the assembly affiliates or the licensed producers; they were busy constructing global networks with Asian suppliers and exporting across the world at competitive prices'. From a neo-classical perspective, this dynamic was described as a return to the logic of comparative advantages. As Rodrik (2016, p. 4) argues, as developing countries opened up to trade, those without a strong comparative advantage in manufacturing (a group to which Latin America belongs) were not only exposed to global competitors but also "'imported" deindustrialisation from the advanced countries, because they became exposed to the relative price trends originating from advanced economies'—i.e., a consequence of the tendency for productivity in the manufacturing sector to grow more rapidly than in the service sector (Baumol, 2012; Rowthorn & Ramaswamy, 1999). In contrast, a few developing countries managed to pursue export-led industrialisation strategies and produce what is commonly described as the *Asian miracle*.

As various authors have noted, the recent rise of China represents a novel structural barrier to the industrialisation of the rest of the developing world (Benanav & Clegg, 2018; Nagaraj, 2025; Palley, 2011; Rodrik, 2024). As Benanav (2019, p. 30) argues, 'China has industrialised rapidly because its firms have been able to take market share away from other firms—not only in the US, but also in countries like Mexico and Brazil—which lost market share as Chinese firms expanded'. Indeed, it took place in a global landscape characterised by decelerating rates of productivity growth—a situation that has been described as one of

secular stagnation (Backhouse & Boianovsky, 2016; Benanav, 2020a; Moraitis, 2022; Summers, 2014, 2016). This industrialisation, moreover, has taken place at the cost of a dramatic expansion of the scale of overcapacity in various industrial segments (Alami et al., 2023; Benanav, 2020b).

As a result of this structural shift, some scholars have come to argue that ‘the main avenue of rapid economic convergence’ has now closed (Rodrik, 2016, p. 28). Against this background, developing countries would need to find alternative development strategies. For some, this would mean the promotion of tradable services (such as finance or tourism), or an extensive support to development and upgrading of Small and Medium Enterprises (SMEs) (Rodrik & Sandhu, 2025; Rodrik & Stiglitz, 2025). For others, the green windows of opportunity opened by the green transformation, as mentioned in the introduction, could represent another promising possibility. Before moving to the discussion of Brazil’s experience at ‘green’ industrialisation, it is important to first discuss another important reality: the persistence of some productive relics of the developmentalist period. These, indeed, offer an important context against which to critically assess, from a comparative perspective, the specific case of green industrialisation.

Tales of Industrial Survivors

As was briefly mentioned in the previous section, Latin America experienced, in the last 15 years of the 20th century, one of the most dramatic processes of deindustrialisation among developing regions. In Brazil the manufacturing sector share of GDP peaked at around 30% in 1985, before declining to approximately 17% by 2000. This aggregate picture, however, hides different deindustrialisation trends. As Dosi et al. (2021) argue, rather than discussing deindustrialisation as an aggregate tendency, we should think about ‘varieties of deindustrialisation’. The erosion of manufacturing’s weight in the Brazilian economy until the early 2000s was driven disproportionately by a specific set of industries: textiles; clothing, leather and footwear; furniture and wood; basic metals and metal products; chemicals and petrochemicals; and machinery and equipment (Morceiro & Guilhoto, 2019). Among the sectors that did not strictly follow the overall deindustrialisation trend, two sectors are worth

briefly discussing: the automotive industry, and the aerospace industry. Indeed, these two sectors provide contrasting stories about Brazil's contemporary industrial development, survival and success.

The automotive industry offers a revealing case of 'industrial survival'. The sector maintained a significant presence in the Brazilian economy—with most of the biggest car manufacturers operating in the country up to now. This was facilitated by the industry's natural tendency to localise production near major markets and the preservation of high tariff barriers (35% in 2000) and strict local content requirements (60%).

Yet this resilience came at a cost. As Humphrey (2003) shows, global assemblers imposed strategies of 'follow design' and 'follow sourcing', whereby design decisions remained centralised in headquarters and contracts were awarded to the same suppliers globally. As a result, transnational companies increased their share of component turnover from 48 per cent in 1994 to 59 per cent by 1997, and by 2001, eight of the twelve largest Brazilian-owned component manufacturers had been sold to foreign firms. The result was an industry that, while avoiding outright collapse, was progressively hollowed out. Moreover, the industry, and its associated jobs, were preserved at the cost of significant idle capacity, higher prices for Brazilian consumers, low overall productivity (Chagas, 2020; Laplane & Sarti, 2002). At the turn of the millennium, it was estimated that the labour productivity of the auto sector was about 1/3 that of the US, and 1/5 of Japan, while production overcapacity remained a common feature of the sector (McKinsey, 1998).³ Tariff barriers and local content requirements thus proved sufficient to retain multinational assembly operations, industrial employment, and some of the 'productive sublime' associated with the automobile industry—i.e., the idea that the capacity to produce cars, one of the most important symbols of modernity, is an essential feature of development (Wolfe, 2010).⁴ What they could not secure was productivity growth, technological upgrading or export diversification.

³ More recently, Sturgeon et al. (2019, p. 39) has estimated that 'the cost of a Toyota Corolla (a car that is produced and sold in many markets) to consumers in Brazil are the second highest of all counties where it is produced in significant volume'.

⁴ A capability that would occupy an important symbolic position in the developmental vision of the progressive governments that came to power in the 2000s.

The aerospace industry offers a contrasting trajectory. The sector is centred on one key industrial player: Embraer. Embraer was created as a state-owned enterprise in 1969. As Veiga & Rios (2019, p. 12) write, from early on, domestic market conditions precluded the possibility of inward-oriented development: the consolidation of airlines and shift to large aircraft in the 1960s left no market for Embraer's regional aircraft, forcing the company toward exports from its earliest years. When US airline deregulation in 1978 created new demand for regional aircraft, Embraer was positioned to capture it. By 1982, the company's main aircraft, the Bandeirante EMB 110 had captured one-third of the US market for 10-20 seat commuters (Goldstein, 2002). Yet the company struggled to prove sustainably profitable. After years of loss-making it was privatised in 1994. Profitability was restored while maintaining the productive performance of the company. As Goldstein (2002, p. 113) argues, 'the change of ownership forced it to adapt to the new scenario of rapid technological change, shorter product cycles, and shrinking public financial capabilities'. The state continued to provide export financing through the Brazilian Bank of National Economic and Social Development (BNDES) while the Brazilian Funding Authority for Studies and Projects (FINEP) supported R&D investments. Crucially, however, Embraer was granted a free trade regime for all its imported components and successive governments refrained from imposing local content requirements. By the early 2000s, Embraer was the world's third-largest aircraft manufacturer. Embraer thus represents a genuine, if singular, Brazilian industrial success story—one built on state capability-building, strategic adaptation and positioning, and export orientation.

2. A Minimalist Green Industrial Policy

From the late 1980s onwards, the Brazilian economy has been shifting, towards a commodity- and fossil-centred development model. Both sectors expose Brazil to international scrutiny and are extremely vulnerable to both climate change and the consequence of its mitigation—i.e., as they could be the object of trade barriers or substitution risks from the transition. In the face of these development challenges, Brazil has, in recent years, showed a particular interest in the mobilisation of novel green sectors both as new development opportunities and diplomatic assets. The development of solar and wind

in Brazil has been spectacular. Between 2005 and 2025, the share of wind and solar in Brazil total electricity generation rose from 2% to about 30%.⁵

The Developmental Rationality of Sustainability

Several factors are behind this rapid and broad development. First, the very generous natural conditions on which the country could rely.⁶ Brazil possesses high capacity in the generation of both wind and solar power. As Cacciuttolo et al. (2025) note, 'Brazil's onshore wind farms average a capacity factor of 45–50%, surpassing the global average (~35%) and rivalling offshore wind hubs like the UK (40–50%). Regions like the Northeast boast peaks of 60%, among the highest onshore rates worldwide'. The capacity factor of solar generation, for its part, stands at a 25% rate, again above the global average which is closer to 17%.⁷ In the business of renewable energies investments characterised by relatively low rates of return, high-capacity factors represent an opportunity for project developers to (potentially) increase the profitability of their investment (Christophers, 2024; Werner & Lazaro, 2023). In addition to the intensity of its renewable resources, Brazil could also rely on the significant size of the territory on which new projects could be built, i.e., to the abundance of the land where renewable resources are themselves abundant.

Secondly, Brazil created the institutional conditions for the renewable boom. In 2009, Brazil, which had previously relied on feed-in tariffs—the PROINFA programme launched in 2002—for the development of wind and solar projects decided to implement an auction system (Hochstetler, 2020). Successful bidders were awarded 20-year Power Purchase Agreements (PPAs) with price subsidies. Moreover, BNDES provided access to subsidised and patient financing, with loans (in local currency) covering up to 70% of total investment (Ferraz et al., 2022; IRENA, 2024). In this first period, wind power projects disproportionately benefited from this support. In a country where interest rates are known to be particularly high, BNDES support helped dramatically reduce the cost of capital of renewable

⁵ Source: Ember. <https://ember-energy.org/countries-and-regions/brazil/>. Accessed January 1, 2026.

⁶ Interview 3, 7, 12, 15 and 17.

⁷ Source: IRENA. 2025. Average capacity factor for utility-scale solar PV systems worldwide from 2010 to 2024. <https://www.statista.com/statistics/799330/global-solar-pv-installation-cost-per-kilowatt/>. Accessed January 1, 2026.

investments. Between 2010 and 2016, wind power capacity was multiplied by a factor of 17.⁸ BNDES had helped to finance almost all the newly added wind power generation capacity, an expansion equivalent to 10,240 MW.⁹

BNDES's support for renewable projects, as had traditionally been the case with other investments and sectors (see below), was attached with a local content requirement.¹⁰ At first, the development of a local supply chain was limited to the production of only a few (the most sizable) parts (Ferreira, 2021; Hochstetler, 2020). The bank's sectoral approach was further radicalised in 2012 when the progressive accreditation model was introduced, that differentiated requirements based on technological sophistication demanding high localisation for simple components (e.g., steel towers), and encouraging gradual increases in domestic production of medium to high complexity parts (e.g., blades, some electronic components).¹¹ In the following years, the country saw the entry of many Original Equipment Manufacturers (OEMs) (i.e., Vestas, General Electric, Gamesa, Acciona) and the development of a broad set of national suppliers (Fabris, 2020; Ferreira, 2017, 2021; Hochstetler, 2020; Proença de Gouvea and Azzi da Silva, 2018). By 2022, it was estimated that 80% of the wind turbine supply chain was made of Brazilian providers.¹²

For many scholars and policy specialists, Brazil's experience in the wind turbine industry was perceived as a validation of the promising nature of industrial development based on green windows of opportunity.¹³ Yet such a narrative requires some qualification. Most notably, the development of green industries was, to a large extent, a consequence of

⁸ Source: . ABEEólica. 2016. 2016 Annual Wind Power Generation Report. https://abeeolica.org.br/wp-content/uploads/2022/03/424_Boletim_Anual_de_Geracao_Eolica_2016_Ingles_Final.pdf.

⁹ Source: BNDES. 2016. *Relatório Anual 2016: Nosso Desempenho - Destaques* (pp. 48–53). https://www.bndes.gov.br/SiteBNDES/bndes/bndes_pt/Hotsites/Relatorio_Anual_2016/assets/bndes_ra2016_web_08-2_nossodesempenhodestaques.pdf.

¹⁰ At first, the development bank applied its traditional 60% threshold to wind power investments, with no particular concern for the nature of the equipment or parts locally sourced (Ferraz et al., 2022). However, from 2009, it started to develop a new framework based on bilateral agreements with wind turbines manufacturers to progressively increase local production.

¹¹ More specifically, as Proença de Gouvea and Azzi da Silva (2018, p. 91) explain: 'BNDES determined that by January 2013, wind turbine manufacturers must meet at least three of four location criteria in Brazil: manufacture of towers, with at least 70% of steel plates made in the country or with reinforced concrete of national origin; manufacture of blades in their own or third-party units; assembly of the nacelle (main part of the wind turbine) in their own facilities; assembly of the hub (gearbox technology), with castings sourced domestically'.

¹² Source: Valor Econômico. 2022. "Índice de nacionalização é de 80% nos aerogeradores." May 30. <https://valor.globo.com/publicacoes/suplementos/noticia/2022/05/30/indice-de-nacionalizacao-e-de-80-nos-aerogeradores.gh.html>. Accessed October 2, 2025.

¹³ Interview 2, 3, 4, 11, 12, 13, 18.

the development of renewable energy in the country, rather than the reverse. Firstly, it was a response to the fragility of an electricity system highly dependent on hydropower (Hochstetler, 2020). At the turn of the century Brazil experienced a traumatic episode of energy rationing which led to a massive contraction of consumption and industrial production (Bardelin, 2004).¹⁴ Widely attributed to historically low rain levels this crisis prompted the adoption, in 2001, under the presidency of Fernando Henrique Cardoso, of the Emergency Wind Energy Programme (PROEÓLICA)—the predecessor of PROINFA (Amorim, 2021).¹⁵ Indeed, as Hochstetler (2020, p. 69) explains, '[w]ind power originally found a place in the grid plans as a comparatively cheap and quick way to diversify the matrix and provide energy security'. Energy diversification, moreover, became an even more strategic concern under neo-developmental governments. Between 2003 and 2014, the consumption of electricity increased by 57%, a rate higher than that of the growth of GDP over the same period.¹⁶ The expansion of energy supply was essential to that energy bills not weigh down on the consumption power of Brazilians—an essential aspect of both the political and economic strategy of neo-developmental governments (Loureiro, 2019).¹⁷

Secondly, it helped the neo-developmental governments of Lula da Silva and Dilma Rousseff to reduce the external political pressure resulting from the country's development regime's increasing dependence on two sectors widely considered of primary concern to the green agenda: the agro- and the oil industry. When looking at Brazil's *Production Development Policy* (2008-2010) most sectors identified as 'strategic' relied on the exploitation of natural resources and the consolidation of existing comparative advantages (Arbix, 2017; Loureiro, 2019). Among the six sectors requiring 'consolidating and expanding leadership', two related to extractive activities (i.e., oil and gas, mining), two to the

¹⁴ See, Folha de S.Paulo. 2001. "Racionalização de energia já preocupa setor de siderurgia". <https://www1.folha.uol.com.br/folha/dinheiro/ult91u18550.shtml>. Accessed October 2, 2025; Folha de S.Paulo. 2001. "Indústria deve reduzir consumo de energia em 10%". <https://www1.folha.uol.com.br/folha/dinheiro/ult91u18728.shtml>. Accessed October 2, 2025.

¹⁵ The PROEÓLICA programme was substituted, in 2002 and still under the presidency of Fernando Henrique Cardoso, by the Incentive Programme for Alternative Sources of Electricity (PROINFA), Law 10.438, a feed-in-tariff programme targeting the introduction to the National Interconnected System, small hydroelectric plants (SHPs), wind farms and biomass thermal power plants.

¹⁶ Author's calculations based on data from EPE National Energy Balance—Historical Series.

¹⁷ See, Reuters. 2013. "Rousseff Slashes Brazil Power Rates to Attack Inflation." <https://www.reuters.com/article/business/rousseff-slashes-brazil-power-rates-to-attack-inflation-idUSBRE90M1MK/>. Accessed October 2, 2025.

agricultural sector (i.e., meat and bioethanol), and two to commodity-based industries (i.e., cellulose and paper, and steel) (Andrade, 2022). Similarly, among the twelve sectors requiring ‘fortifying competitiveness’—and apart from those relating to existing but relatively uncompetitive manufacturing base (automotive, capital goods, textiles)—it was possible to find the agro-industrial activities, wood and furniture products, biodiesel, and plastics. In other words, if ‘fossil’ and ‘agro-developmentalism’ were certainly key features of Brazil’s neo-developmental years (Massi & Singh, 2019; Nem Singh, 2014)—Brazil’s green developmentalism, for its part, was rather marginal to the governments’ political economy.

Most fundamentally, it has followed what can be described as a *minimal developmentalism*. Indeed, the capacity of a national developmental bank to serve as an instrument of industrial transformation, is ultimately dependent on it being part of a broader industrial policy institutionality. In the history of economic development, development banks have often been necessary but certainly not sufficient elements of successful developmentalist state capacity. Moreover, if BNDES has played a unique role in Brazil developmental history, it possesses some institutional features that limit its developmental power. From 1972, BNDES has indeed been defined as a State-Owned Enterprise under private law. This status has contributed to insulating BNDES from some of the corporatist pressures it had suffered and facilitated the bank’s ‘technocratisation’, a feature that became instrumental to its capacity to survive the neoliberal turn towards a neoliberal agenda (Gambacurta-Scopello, 2017; Krahé, 2021). In the 1990s, the Bank was tasked with the governance of the Brazilian Privatisation Program (Lazzarini et al., 2015). As a result, it acquired a very special position as being, at the same time, one of the most important relics of developmentalism’s golden age and a key actor of Brazil’s transition away from it.

Notably, the Bank preserved its use of local-content requirements (LCRs) as conditions to the qualification of investments to its financial support. BNDES’s history with local content requirements dates back to the 1970s, when the Bank first introduced a Nationalisation Index to its methodology of loans disbursement. Initially the index was set at a 67% threshold, before increasing it to 85%. In the 1990s, the target was brought down to an overall level of

60%¹⁸ and remained at this level across the following decades. By and large, the capacity for the BNDES to influence demand for local industrial inputs—an important source of employment management—remained intact. From 2002 to 2014 BNDES financing was vastly expanded—in particular between 2008 and 2014 (Ferraz et al., 2015; Ferraz & Coutinho, 2019; Lazzarini et al., 2015). In this period, the assets managed by the bank grew by close to 500%.¹⁹ This growth, while partly supported by the capacity of the bank to generate important returns from its investments, was also greatly facilitated by the generous injection of resources from the federal government—itself greatly facilitated by the commodity super cycle (Hochstetler & Montero, 2013; Loureiro, 2019).

Under the neo-developmental governments of Lula da Silva and Dilma Rousseff, the BNDES actively expanded its involvement in the productive development of the country—through the creation of new targeted programmes (e.g., Proplástico, Proaeronautics, Prosoft)²⁰ which have helped increase the local benefits of foreign direct investments (FDIs). Yet it remains the case that its developmental power has mostly been limited by the very form of its privileged instruments. While it has helped to safeguard existing industrial capacity, and support, to a limited extent, the development of novel capacity—in the old ISI way—, it has however failed to have a structural effect on both the deindustrialisation trend, and even more so, on the emergence of new competitive industries (Lazzarini et al., 2015; Loureiro, 2019; Palma, 2012). This does not diminish BNDES's achievements. BNDES's capacity to preserve its strategic autonomy, develop strong bureaucratic and technical capacity, and maintain a deep involvement with the private sector has certainly been instrumental in supporting Brazil's economic development (Ferraz et al., 2026). This limitation is not to be attributed to an incapacity for BNDES to fulfil its developmental role, but to the broader and more profound, incapacity of the Brazilian state to build a broader effective industrial policy (Guimarães & Guimarães, 2021; Loureiro, 2019). In many ways, BNDES's presence and unique status, have helped the government follow a passive approach to industrial policy since, in a context of high FDI interest in the country,

¹⁸ Although certain sectors were subject to specific conditions, i.e., different levels.

¹⁹ Source: BNDES. 2016. *Relatório Anual 2016: Nosso Desempenho - Destaques* (pp. 48–53).

²⁰ See Ferraz & Coutinho, 2019.

the bank offered a quasi-automatic guarantee of job creation and demand creation for local industrial firms. In that sense, the reality of green industrialisation is, by and large, an illustration of a broader pattern.

A 'Most Likely' Case of Green Industrialisation

The extent to which the neo-developmental governments recognised a developmental potential in wind and solar was limited. Thus, if renewable energy technologies were listed in both Brazil's first and second industrial policy documents—i.e., the Industrial, Technological and Foreign Trade Policy (PITCE) published in 2003, and the Production Development Policy (PDP) published in 2008—it is only in the country's third iteration, published in 2011, that they became the object of a more detailed sectoral focus. Yet, *de facto* green industrial policy in Brazil, remained more than limited (Guimarães & Guimarães, 2021; Podcameni, 2014; Suzigan et al., 2020; Telésforo, 2025). Access to subsidised loans, even when they include local content requirements, is, as we have seen, the most minimal form of industrial policy. BNDES's mandate was not to support 'national champions' in the sector but rather to increase the developmental potential of investments in renewable energies.²¹ Renewable investments offered an accessible opportunity to create jobs and economic activity aligning with the primary attention devoted by the neo-developmental governments to infrastructure development rather than industrial or technological development.²²

While there were market pulls, technology push was virtually absent (Nahm, 2017). Beyond BNDES, the efforts aimed at fostering innovative capabilities, whether through R&D financing, fostering joint ventures with foreign companies, or facilitating technology transfers, have been extremely limited—in contrast to China's or India's experiences, for example (Lacal-Arántegui, 2019). As a result, the sector remains dominated by foreign firms. These, for their part, were particularly interested in the possibility of penetrating the Brazilian market.

²¹ Interview 2, 3, 4, 6, 11.

²² See, Financial Times. 2024. "Lula's playbook: Brazil bets on a return to state capitalism". <https://www.ft.com/content/5c9d5735-639e-47c0-9eb6-a1fae26096e8>. Accessed October 2, 2025

Since the 2008 financial crisis, profit margins in the sector had declined and the sector was facing a situation of oversupply and consolidation.²³ Their expansion in emerging markets, however, principally involved the deployment of depreciated technology allowing for high returns.²⁴ In a sector where profitability, as we have seen, is often brought down by the price of auctions, the globalisation of European wind turbine manufacturers proved instrumental to the development of Brazil's wind sector; a dynamic that is currently reproduced by Chinese manufacturers' global expansion after having initially almost entirely focused on the Chinese domestic market.²⁵

Overall, state interventionism in the wind industry, by contrast, has been limited. As such, it constitutes something of an example of 'import substitution with limited nationalisation'—a case of what Evans's (1979) classically described as 'dependent development', only that it does not even involve the active participation of state-owned enterprises. In contrast, the state actively used Petrobras as an instrument to foster industrial development across various industrial segments in the oil sector—through local content requirements but also by investing in adjacent activities such as fertilizers or shipbuilding (Alves, 2024; DuBois & Primo, 2016; Lima-de-Oliveira, 2020). One bright spot has come from the emergence of a Brazilian wind-turbine manufacturer domestically competing with international manufacturers. Since the early 2000s, WEG, a multinational Brazilian company founded in the 1960s and specialised in electric motors, started to produce its own turbines—after having first licensed and then acquired the wind turbine technology developed by the US firm Northern Power Systems²⁶—and has come to occupy close to 10% of the Brazilian market for wind turbines.²⁷ If the company did receive some support from the Brazilian state²⁸, its success can primarily be linked to both its capacity to repurpose existing productive capabilities and its own entrepreneurial initiative.²⁹ Similarly, Aeris, the leading Brazilian

²³ See, Wind Systems Magazine. 2015. "Report: Wind Turbines Are in Oversupply Globally."

<https://www.windsystemsmag.com/report-wind-turbines-are-in-oversupply-globally/>. Accessed October 2, 2025.

²⁴ Interview 1.

²⁵ Source: FDI Intelligence. <https://www.fdiintelligence.com/content/78ad7148-d7a4-4e1c-8e6e-023131cafaa2>. Accessed January 1, 2026.

²⁶ Interview 14, 15, 16.

²⁷ Estimates based on data from The Wind Power (https://www.thewindpower.net/country_windfarms_en_26_brazil.php).

²⁸ See Fabris, 2020; Podcameni, 2014; Telésforo, 2025.

²⁹ Interview 9, 10, 14, 15, 16.

company producing blades for wind turbines (and the biggest in Latin America), which was created in 2010, almost entirely developed as a private initiative.³⁰

In more general terms, the development of the wind turbine industry was largely made possible by idiosyncratic factors. Beyond the influence of Brazil's market size, the wind turbine sector has an 'industrialising bias' favouring local production.³¹ As Hirschman (1968b) observed, certain industries emerge not primarily because of policy intervention but because the expansion of domestic demand dynamics. He termed this process 'import-swallowing' industrialisation. It proved particularly applicable to heavy industries, involving large and heavy parts and for which transportation and logistical costs created a natural incentive for localisation. Wind turbines fit into this pattern. Indeed, it is an industry that involves assembling large and heavy components (e.g., blades, towers, nacelle).

This demand-driven logic of import-swallowing operates independently of policy mandates, though it can be reinforced by local content requirements. Moreover, as Nahm (2017, p. 76) remarks, 'although some turbine components require the use of advanced materials and complex manufacturing processes, others, such as wind turbine towers, rely on more traditional metalworking capabilities'. This has been described by Huenteler et al (2016, p. 106) as "'simple industrial craftsmanship" i.e., standard industrial processes that require skilled manual labour and are performed on multi-purpose machinery, such as welding, milling, and drilling machines'. Such capacity was present in Brazil. The persistence of some productive capabilities inherited from the ISI period—the suppliers to the aerospace industry (Hochstetler, 2020)—provided OEMs with a network of SMEs with which they could partner to substitute imports.³² For these reasons, it can be described as a 'most likely' case of green industrialisation.³³

³⁰ Interview 7.

³¹ Which does not mean, however, that the development of a local supply chain *must* happen in every large market. As Matsuo & Schmidt (2019) show, Mexico is an illustrative example of a case where, despite a large domestic market, very limited local industrial development took place. Argentina is another one. Thus, if pure competition is maximised in the auction system, as in the case of Mexico, or if the cost of capital is extremely high, as in the case of Argentina, this will evidently disincentivise local industrial development.

³² Some of the most complex components have remained imported (e.g., gearboxes, advanced electronics, control panels). Moreover, as significant even when domestic industries in more technologically intensive exist in the country, they tend to rely on significant share of imports of complex inputs. This is the case of Aeris, for example.

³³ Interview 24.

One way to think about Brazil's green industrialisation is, therefore, as a dynamic partially based on what could be described as *reactive linkages*. Albert Hirschman famously coined the concepts of *backward* and *forward* linkages (Hirschman, 2013, 2016). Backward linkages occur when the establishment of an industry creates demand for domestic production of some of its inputs. Forward linkages move in the opposite direction—when a product or intermediate good stimulates new industries that can utilise it as an input. The wind turbine industry clearly describes a case of backward linkages. Yet, in Hirschman's original model, linkages were principally discussed in the context of the development of new productive capacity. In that sense they can be said to follow an active dynamic. In the case of the wind turbine, however, many of the suppliers are not new but already operating and therefore diversifying their clients for a product they already produced, or adapting their production capacity to produce inputs tailored for this new demand. In that sense, they are following a *reactive* logic, one that allows for the preservation of industrial capacity rather than pure 'industrialisation'. This is important because, when contemplating the developmental potential of green industrialisation, and GWOs more generally, one is forced to look at its capacity to create the kind of cumulative causation dynamic that was at the centre of classical development theory's approach to economic catch-up and productive transformation.

In many ways, the case of the wind turbine industry closely parallels that of the automotive industry. As we have seen, the automotive sector has itself primarily been used as a source of jobs creation and import substitution rather than a vector of global competitiveness for the Brazilian economy. As in the case of the automotive sector, most of the key wind turbine producers entered the Brazilian market as Brazil provided a vast potential of accumulation. Moreover, as Larsen & Hansen (2022, p. 193) write, '[t]he global wind-turbine value chain resembles a so-called producer-driven chain, in which lead firms coordinate the production networks of component suppliers, and where competition is mainly based on technological progress through continued R&D'. In that sense, it also fits within the old ISI pattern, since the process of industrialisation in Latin America almost entirely took place around producer-driven supply chains (Gereffi, 2001). Even protectionist support, initially absent, was recently added. Indeed, since 2022, in the face of rising costs, slowing

demand, and fiercer global competition (see below), Brazil has decided to introduce tariff barriers to the imports of wind turbines (starting at 11% from 2022 and planned to culminate at 25% from 2026).³⁴ Finally, both sectors are principally inward-oriented with limited (in the case of the automotive sector) or virtually no (in the case of wind turbines) exports.

One important distinction, however, does separate the wind sector from the automotive parallel: the existence of a local OEM. If, as we have discussed above, WEG's entry into the wind turbine business is principally the result of internal business decisions rather than the consequence of strategic industrial policy, it might be the case that it could have the capacity to achieve global competitiveness. In that direction, WEG announced, in 2023, a strategic partnership with Petrobras to develop a 7 MW turbine—with the potential of becoming the largest model in operation in the country. The partnership was framed as an opportunity to expand WEG's market share and competitiveness while offering Petrobras a pathway for the Brazil's NOC to diversify in green sectors. This partnership represented a more serious commitment of the Brazilian state to green industrial policy. As mentioned above, Petrobras has been the main instrument of the neo-developmental government's industrial policy.

Yet some contradictions have already emerged. Indeed, this novel ambition has taken place in parallel to the recent entry of Chinese manufacturers to the Brazilian market—e.g., Goldwind, the world's largest wind turbine producer decided to establish its first overseas production facility in Brazil. These players, however, are entering the Brazilian market with turbines that already surpass WEG's development targets in both size and technical sophistication. Goldwind is producing models ranging from 6.2 to 8.3 MW for onshore wind projects, and up to 20MW in the case of offshore projects. In this context, WEG's position—and Petrobras' diversification desires—are seriously at risk (Lee, 2019, 2024). In the absence of an effort to pursue a more strategic, coherent and articulated green industrial policy, the

³⁴ See, Forbes. 2024. "Taxa de importação fortalece setor de turbinas eólicas do Brasil, geradores reclamam". <https://forbes.com.br/forbes-money/2024/01/taxa-de-importacao-fortalece-setor-de-turbinas-eolicas-do-brasil-geradores-reclamam/>. (Accessed 3 October 2025).

entry of these Chinese players might prove difficult to reconcile with the development of a national champion, and to the expansion of local ownership more generally.³⁵

3. 'Green Premature Deindustrialisation'

It is common to talk about wind and solar power as complementary forces driving a unitary process, that of the decarbonisation of our energy systems. While this is true from the perspective of the energy transition, from a developmental point of view, the reality is very different. In the case of Brazil, as we will now see, the emergence and rapid penetration of the solar PV technology have had seriously negative consequences on the green industrial development of Brazil.

Renewable Competition

As Hochstetler (2020, p. 93) writes, in the initial years of Brazil's interest in renewable technologies, '[s]olar was considered too expensive and too challenging for local manufacturers for inclusion in PROINFA'. As a result, until 2017, the development of solar power was rather limited—in 2017 the total installed capacity of wind power was more than six times greater than that of solar power.³⁶ Since 2017, however, it has seen an exponential growth. From 2017 to 2023, installed capacity increased by about 3,700%. This trend has been driven by two main dynamics. On the one hand, the Brazilian government introduced technology-specific solar power auctions from 2014 onward, and access to BNDES subsidised financing—with loans covering up to 70% of investment at favourable rates. Solar power auctions, however, proved far less consequential than wind power, with only 5.6 GW of solar capacity contracted through this mechanism by 2024. On the other hand, the introduction of net metering regulations alongside falling global solar panel costs and sharply rising domestic electricity tariffs (increases of ~50% for residential and commercial consumers in the mid-2010s) created the conditions for the exponential development of distributed generation

³⁵ For a similar critique, in the context of Indonesia, see Lee & Kamiya, 2025.

³⁶ Source: ABEEólica. 2017. 2017 Annual Wind Energy Report. <https://abeeolica.org.br/wp-content/uploads/2022/03/Boletim.pdf>. Accessed October 2, 2025.

(Costa et al., 2023).³⁷ This expansion was facilitated by access to BNDES subsidised financing for installers, through its FINAME programme. Thus, by 2024, distributed solar generation accounted for approximately 71% of Brazil's total installed capacity of solar PV, representing about 15% of the country's total electricity generation.

The explosive development of solar power in Brazil, however, has led to the saturation of Brazil's electricity grid.³⁸ This has resulted in a sharp decline in the number of new auction openings for the development of new renewable projects as well as the multiplication of curtailment, with heavy financial consequences for wind park developers. Moreover, this has, in turn, prompted wind-turbine manufacturers to freeze their operations and, in certain cases, even exit the country.³⁹ Thus, the country began to suffer from a phenomenon that could be described as a 'green premature deindustrialisation'.⁴⁰ Indeed, only a few years after having emerged, the supply chain of the wind sector in Brazil started to retract significantly. In 2022, General Electric stopped its local production. In 2023, Siemens Gamesa announced the hibernation of its productive capacity.⁴¹ In 2024, WEG announced that it would suspend its production and Nordex-Acciona that it would reduce its operations in Brazil.⁴² These decisions also impacted suppliers. Thus, LM Wind Power (subsidiary of GE producing blades) and Aeris, respectively announced the elimination of thousands of jobs due to order cancellations from the OEMs.⁴³ As a result of this dynamic, from 2018 to 2025, more than 10,000 jobs have been lost.⁴⁴

³⁷ Interview 19, 20.

³⁸ See, Bloomberg Línea. 2025. "Por que a indústria eólica no Brasil enfrenta uma crise dentro da crise." (June 2025) <https://www.bloomberglinea.com.br/negocios/por-que-a-industria-eolica-no-brasil-enfrenta-uma-crise-dentro-da-crise/>. Accessed October 2, 2025.

³⁹ These decisions must also be viewed in the context of the overall unfavourable situation facing wind turbine manufacturers worldwide (increased costs, declining productivity, etc.).

⁴⁰ See, Folha de S.Paulo. 2024. "Setor eólico fecha as portas no Brasil, demite milhares e não vê retomada imediata." <https://www1.folha.uol.com.br/mercado/2024/05/setor-eolico-fecha-as-portas-no-brasil-demite-milhares-e-nao-ve-retomada-imediata.shtml>. Accessed October 2, 2025.

⁴¹ See, FLJ. 2023. "Siemens Gamesa decide suspender temporariamente produção de turbinas eólicas na Bahia, dizem fontes." <https://flj.com.br/empresas/siemens-gamesa-decide-suspender-temporariamente-producao-de-turbinas-eolicas-na-bahia-dizem-fontes/>. Accessed October 2, 2025.

⁴² See, Valor Econômico. 2024. "Exclusivo: Nordex reduz produção de turbinas eólicas no Brasil devido à baixa demanda." April 15. <https://valor.globo.com/empresas/noticia/2024/04/15/exclusivo-nordex-reduz-producao-de-turbinas-eolicas-no-brasil-devido-a-baixa-demanda.ghtml>. Accessed October 2, 2025.

⁴³ See, Valor Econômico. 2024. "Desindustrialização do setor eólico acende alerta." April 16. <https://valor.globo.com/empresas/noticia/2024/04/16/desindustrializacao-do-setor-eolico-acende-alerta.ghtml>. Accessed October 2, 2025.

⁴⁴ See, Valor Econômico. 2025. "Renováveis têm demissões e buscam ressarcimento." May 27. <https://valor.globo.com/empresas/noticia/2025/05/27/renovaveis-tem-demissoes-e-buscam-ressarcimento.ghtml>. Accessed October 2, 2025.

Unlike the irregular and slow character of demand for centralised forms of electricity generation (i.e., solar farms, wind farms, power stations, or dams), decentralised systems of solar generation allow solar panels to benefit from a demand structure fitting the model of some durable consumer goods or capital goods. Individual consumers can acquire solar PV as a novel kind of domestic appliance. Such a 'demand regime' gives the solar PV industry a distinctive advantage over wind turbine manufacturers when competing for a place in the grid—even accounting for the possibility for firms to privately build wind farms through corporate PPAs⁴⁵ (Haverkamp & Andreoni, 2026). Yet domestic green industrialisation in the solar industry has been very limited. Access to FINAME financing was initially conditioned on compliance with local-content criteria. This partly explains the delayed take off of solar power in Brazil. Yet, since 2018, BNDES shifted from strict percentage-style local-content thresholds to a scoring/accreditation system (and, more generally, has demonstrated a retreat from certain of its developmentalist commitments) (Montalvão, 2026).⁴⁶ In practice, while BNDES measures have tended to facilitate downstream assembly and the accreditation of suppliers, much of the upstream value chain (cells, wafers and many key inputs) remains imported.⁴⁷ As a result, in 2024, Brazil was the second biggest importer of Chinese solar panels at the global level.⁴⁸ In response to mounting concerns over the impact of cheap imports on nascent domestic manufacturing attempts, the Brazilian government introduced tariffs on imported solar panels in 2023. Initially set around 10%, these tariffs increased to 25% by 2025, above an import quota (US\$ 1,014,790,000).⁴⁹

Such a failure, however, fundamentally reflects the much more difficult task of solar-led industrialisation. Contrary to wind turbines, solar panels' production involves smaller, lighter, and more complex parts. Solar cells are manufactured in vast quantities on complex production lines. As Nahm (2017, p. 76) notes, 'the production of solar panels (...) comprises

⁴⁵ This, indeed, is possible under Brazil's Free Contracting Environment (ACL).

⁴⁶ See, Agência Senado. 2025. Aumento da tributação sobre painéis solares será tema de debate na CI. <https://www12.senado.leg.br/noticias/materias/2025/06/10/aumento-da-tributacao-sobre-paineis-solares-sera-tema-de-debate-na-ci>. Accessed January 1, 2026.

⁴⁷ Interview 3 and 18.

⁴⁸ Source: Portal Solar. 2025. Brasil foi o país que mais importou placas solares chinesas no mundo em 2024. <https://www.portalsolar.com.br/noticias/mercado/internacional/brasil-foi-o-pais-que-mais-importou-placas-solares-chinesas-no-mundo-em-2024>. Accessed January 1, 2026.

⁴⁹Source: Secretaria de Comunicação Social. 2024. Mudança de imposto de importação só afeta painéis solares montados. <https://www.gov.br/secom/pt-br/fatos/brasil-contra-fake/noticias/2024/11/mudanca-de-imposto-de-importacao-so-afeta-paineis-solares-montados>. Accessed January 1, 2026.

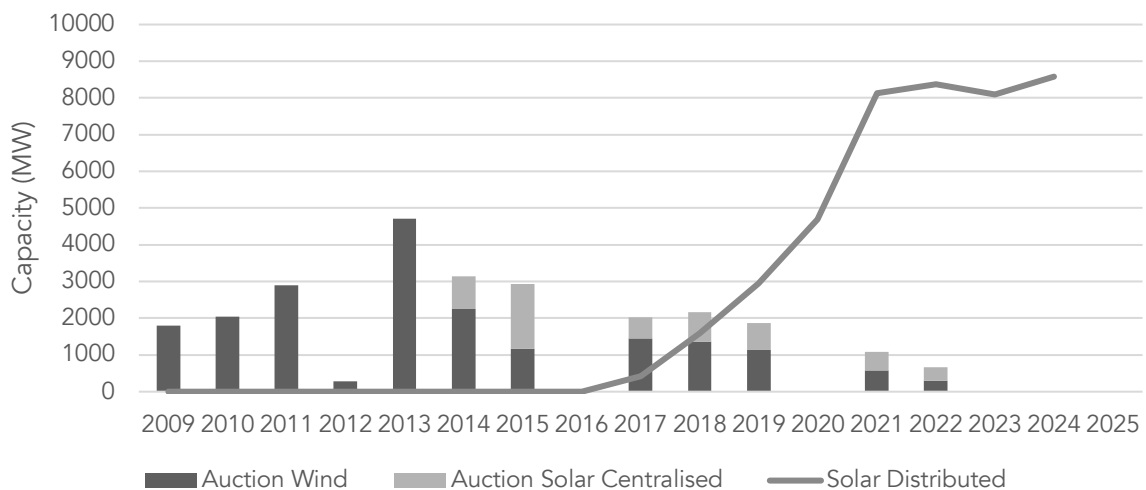
far fewer actors and a much shorter supply chain that bears resemblance to the chemical manufacturing processes of the semiconductor industry'. It is both made of more complex inputs and processes and more easily transportable. More fundamentally, as Huenteler et al. (2016, p. 105) note, 'the market for solar modules exhibits many features of mass-manufactured commodities'. As a result, firms rely on massive economies of scale, and high capital expenditures, to achieve competitive costs. Thus, to a much larger extent than for wind turbines, the production of solar inputs, from solar cells, wafers and ingots, polysilicon or solar inverters⁵⁰ is dominated by Chinese producers and has been characterised by extensive overproduction (Alami et al., 2023; Hart, 2020).⁵¹ In Brazil, as a local project developer explains, local firms 'produce less than 5 per cent of what the market needs, with prices that are up to 50 per cent more expensive than international products'.⁵² In this context, the use of tariff barriers, in the absence of complementary ambitious efforts to incentivise technology transfer or credibly support domestic firms with clear criteria for success, is unlikely to foster broad industrial development and support the structural transformation and green industrialisation the country hopes to realise (Fu, 2008; Fu et al., 2011; Nahm & Steinfeld, 2014).

⁵⁰ Source: Bloomberg (Newsletter). 2024. "China Extends Clean-Tech Dominance over U.S." <https://www.bloomberg.com/news/newsletters/2024-04-16/china-extends-clean-tech-dominance-over-us-despite-biden-s-ira-blueprint>. Accessed October 2, 2025.

⁵¹ Themselves deflated by the massive overcapacity that characterises the sector. It is estimated that China's solar panels manufacturing capacity is about twice as large as global demand. See, Reuters. 2025. "China Says Solar Sector Needs to Curb Overcapacity." August 19. <https://www.reuters.com/sustainability/climate-energy/china-says-solar-sector-needs-curb-overcapacity-2025-08-19/>. Accessed October 2, 2025.

⁵² Source: CNN Brasil. 2024. "Tarifa de importação sobre painéis solares pode afetar mais de 85% dos projetos, diz associação." <https://www.cnnbrasil.com.br/economia/macroeconomia/tarifa-de-importacao-sobre-paineis-solares-pode-afetar-mais-de-85-dos-projetos-diz-associacao/>. Accessed October 2, 2025.

Figure 1: The Distributed Solar Energy Boom



Source: Author's calculation using data from ANEEL, ABEEOLICA, and ABSOLAR.

Towards Green Reindustrialisation

In response to green premature deindustrialisation, some pathways for a green reindustrialisation have already been contemplated. Firstly, through the development of green hydrogen. Green hydrogen, besides having the potential to become a new export product of its own, could help release the limits of the domestic market (Hunt and Tilsted, 2024).⁵³ By rendering renewable electricity tradable, wind and solar radiation exportable, green hydrogen appears to suspend the limits of domestic demand for electricity.⁵⁴ Secondly, through the development of offshore wind. This second option is particularly attractive in that it could help to merge Brazil's onshore wind and offshore oil and gas knowledge and industrial capacity. At the same time, it would facilitate the participation and support the diversification process of Petrobras.

While the success of these pathways cannot yet be fully assessed, there are reasons to be cautious about their capacity to resolve the fundamental contradictions evident in Brazil's green industrialisation trajectory. Both sectors are characterized by significant technological barriers. On the one hand, green hydrogen remains characterised by significant

⁵³ Interview 16.

⁵⁴ Another solution to this problem is offered by the development of data centres, a possibility in which Brazil has shown great interest.

uncertainty from both supply and demand sides (UNDP & TIDE, 2025). On the other hand, offshore wind turbine industry involves dramatically different scales and complexity compared to onshore wind operations. As one Vestas executive explained, ‘onshore is like the Brazilian championship, offshore is the Champions League. This is the magnitude we are talking about in terms of the difference in competitiveness, in terms of the difference in level and size of investment’.⁵⁵ Thus, if the size factor could continue to play a role in fostering some local industrial development, it could also be a factor constraining its expansion. On the whole, as Utkin et al. (2023) explain, ‘[t]he expectations around the jump-start of a comprehensive supply chain for offshore wind, including offshore foundations and installation, remain challenging to reconcile with the onshore wind experience’.

In addition, both sectors face structural demand constraints that limit their developmental potential. Offshore wind power continues to depend on domestic electricity demand growth and the capacity to compete effectively with other renewable technologies. Green hydrogen, despite President Lula da Silva’s ambition to transform Brazil into the ‘Saudi Arabia of renewable energy’⁵⁶, even if it does take off, is likely to prove considerably more competitive and less lucrative than fossil fuel extraction (IRENA, 2021). It does not offer to producers the same capacity to ‘enforce scarcity’ as conventional fossil fuels (Huber, 2011; Le Billon and Cervantes, 2009). While significant variation exists in capacity factors and other cost determinants across countries (e.g., population density, land availability), renewable energy resources remain fundamentally more abundant and geographically dispersed than fossil fuel deposits.

Beyond the question of the likelihood of these potential fixes to re-dynamize Brazil’s wind turbine supply chain, the approaches, like additional tariff protection, fail to address the structural limitations underlying Brazil’s green industrial policy. The structural limits to Brazil’s productive diversification, industrialisation and technological complexification, do not come

⁵⁵See, Eixos. 2023. “Eólica offshore é desafio muito maior que onshore para fornecedores, diz Vestas.” <https://eixos.com.br/videos-e-podcasts/ao-vivo/eolica-offshore-e-desafio-muito-maior-que-onshore-para-fornecedores-diz-vestas/>. Accessed October 2, 2025.

⁵⁶See, Government of Brazil. 2023. “Brazil Will Be the Saudi Arabia of Renewable Energy in 10 Years, Says Lula.” November. <https://www.gov.br/planalto/en/latest-news/2023/11/brazil-will-be-the-saudi-arabia-of-renewable-energy-in-10-years-says-lula>. Accessed October 2, 2025.

(and never have) from the demand side *per se*. Rather, the fundamental problem lies in the exclusive reliance on demand-side fluctuations. While demand management unquestionably constitutes an essential component of the industrial policy toolkit (Chang & Andreoni, 2020; Haverkamp & Andreoni, 2026), successful late industrialisation fundamentally requires, as Cherif & Hasanov, (2025, p. 103) argue ‘a proactive and continuous state action to steer resources into the development of sophisticated industries, with the goal that domestic firms participate fully in technology creation and innovation’. Without such reorientation—from ‘import-swallowing’ industrialisation and a ‘low intensity’ industrial policy to an approach predicated on technological development and competitive discipline—green industrialisation will likely reproduce the contradictions of past experiences. The sectoral novelty of renewable energy technologies does not exempt them from the determinative influence of inadequate industrial policy commitment and coherence.

Taking Green Industrial Policy Seriously

We can now return to the concept of Green Industrial Policy. The study of the Brazilian wind turbine sector carries lessons that extend beyond Brazil’s policy making. In fact, it tells us something about both industrialisation in general, and green industries in particular.

First, let’s start with the contradictions inherent to the idea of green industrial policy itself. Increasingly, it seems like the term serves as an ‘everything bagel policy’, i.e., a solution to all kinds of problems, to all kinds of people, or what Loïc Wacquant (2023) has termed, in a different context, a ‘conceptual speculative bubble’. Though it was born as a demonstration of the possibility of reconciliation between developmental and ecological objectives, it now seems to be facing serious conceptual limits and a clear tendency towards diminishing usefulness as its use spreads across academic and policy circles. As it has been extensively recognised, the unity of the concept hides serious internal trade-offs and structural contradictions. Most commonly, the term is used to describe state-led efforts to steer investment and divestment across the energy system. This, however, says little about the real capacity of states to ensure that such a transition supports the development of new competitive green productive capabilities (Allan et al., 2021; Doshi & Spencer, 2025; Matsuo

& Schmidt, 2019; Radosevic, 2025). Moreover, the latter objective is often contradicted by other concerns such as energy security and affordability objectives (Möhle et al., 2026). The difficulties faced by the European Union in living up to its green industrial ambitions are maybe one of the most illustrative examples of these tensions and trade-offs (Polyák, 2026). And Brazil, as we have seen, is not exempted from such a conflicting reality.

The reality of the concept's increasingly confusing meaning is itself intimately tied to its incapacity to contemplate some structural features of green industries. To begin with, it is worth remembering that although a certain selection of sector is always required for any successful industrial policy, no experiences of economic catch-up have ever taken place based on such narrow set of sectors. There are various theories of sector selection. Lin & Chang (2009) famously debated whether countries should focus on 'comparative-advantage-conforming' industries or if they can engage in 'comparative-advantage-defying' industrialisation paths. The experiences of many countries from South Korea's shipbuilding experience to Taiwan's semiconductor industry, or Brazil's aerospace success are examples of the capacity of countries to build competitive industries well beyond their narrow comparative advantages. Others like Lee & Lim (2001) have emphasised the importance of 'technological regimes' and have identified characteristics such as low innovation cumulativeness, higher predictability, low frequency and explicit knowledge as factors facilitating the capacity for countries to catch up.

Against this background, there are at least two obvious problems with the current approach to green industrial policy. Firstly, there is a problem of scope. Most discussions are still concentrated in a very narrow set of sectors that include wind turbines, batteries, electric vehicles, solar panels, electrolyzers. The problem with that list is that: (i) it is a narrow subset even within the clean technologies, (ii) it is an even narrower subset of green technology if we consider that green can mean sustainability more broadly (Albertone et al., 2025; Lebdioui, 2024). Moreover, contrary to the experience of late industrialisers in the 20th century, most of these technologies are not mature industries. If they might have been genuine windows of opportunity a few years back, the most common green sectors are commonly characterised by a rather constrained and unfavourable technological regime for

economic catch-up as well as a clear ‘fallacy of composition’ as they are the same sectors targeted by most countries in the world (see Table 1).

Table 1: Green Technological Regime Characteristics and Current Market Dynamics

Technology	Cumulativeness	Predictability	Knowledge base	Overcapacity
Wind turbines	Moderate	High	Mixed	Moderate
Solar PV	High	Low	Mixed	Severe
Batteries	High	Moderate	Tacit	Severe
EVs	Low-moderate	Low-moderate	Explicit	Severe
Electrolysers	High	Low-moderate	Mixed	Moderate

Finally, we should return to the connection between premature deindustrialisation and green industrial policy. We should try to avoid thinking about technological revolutions in a cyclical fashion. One step in that direction is to recognise with Lema & Perez (2024), that the green transformation is a *direction-driven* technological revolution—in contrast to a *technology-driven* technological revolution. This implies recognising that it is ‘the social construction of direction, rather than the inherent nature of “green technologies” themselves which may create windows of opportunity for latecomer development’ (Lema & Perez, 2024). This is certainly important as it recognises that green industrial policies’ successes depend on the capacity to take advantage of, adapt to, or align with demand-pull policies at both the domestic and international level. At the same time, as they also note, it means that green technologies are less capable of generating the cumulative dynamics that the original concept of premature deindustrialisation problematised.

Another, however, is to recognise the global context in which this broad process is taking place. That context is defined by intensifying mercantilist behaviours between advanced economies and China as well as the deepening of the ICT revolution. These create various pressures. First, a pressure towards localisation. Such an effort could both align with a green agenda by promoting recycling and remanufacturing activities and be facilitated by advances in automation. The consequences of this new reality, however, are that the capacity for

advanced nations to absorb industrial imports, while it will never disappear is likely to be severely constrained, in particular in sophisticated industrial segments.

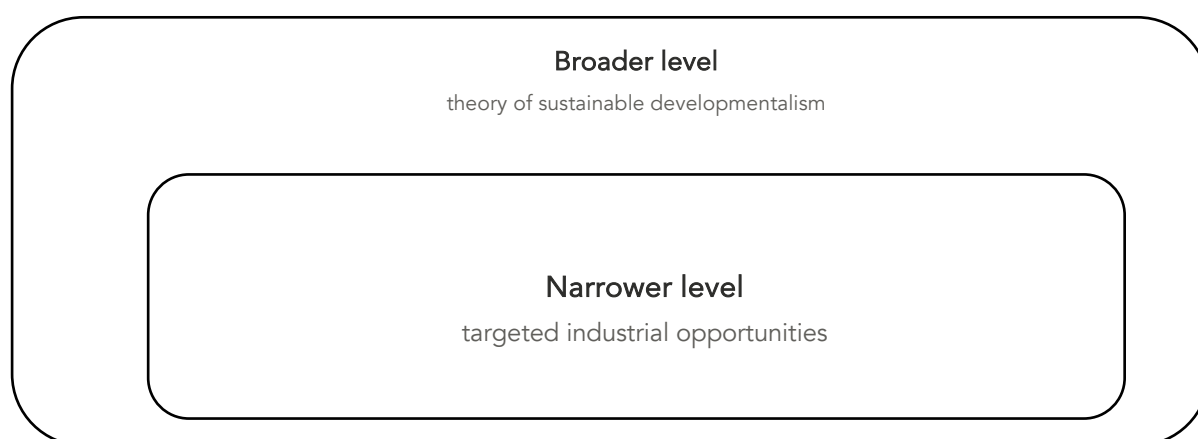
Second, a pressure towards exports. During the Biden administration, this vision was most explicitly articulated by Brian Deese in an essay published in 2024 in *Foreign Affairs* titled 'The Case for a Clean Energy Marshall Plan'. The text envisioned an era of American leadership in clean technologies that would be supported by the acceleration of the transition in partner countries as a source of demand for green imports. Similarly, China has been increasingly relying on clean technology exports as a source of growth. In 2025, more than a third of China's growth was supported by these exports.⁵⁷ More than green windows of opportunity, the future of development is likely to be shaped by the capacity for developing countries to efficiently learn from and leverage technology transfers. In doing so, countries should be careful not to reproduce some of the errors of the past. Indeed, the early post-WWII period, was also characterised by sustained US FDI flows that served to expand external demand for producers that must find new sources of final demand. Yet in the absence of the right institutions, incentives, and discipline, such dynamics might prove insufficient to foster real convergence.

Overall, the concept of green industrial policy would benefit from redefining its scope and ambitions. This calls for a dual approach, inspired by the one developed by Perez (2010). On one level, the term needs a narrower and more granular understanding of the term as the task of identifying targeted industrial opportunities offered by the imperative of sustainability. Such a definition would neither expect such a policy to be responsible for driving countries' green transition in a broad sense, nor would it encompass the full spectrum of a country's industrial policy from which it would only be a subpart. It calls instead for the design of supply chains and technological regimes, and the definition of discrete industrial policy tools, tailored financing schemes, and strategic partnerships. At the same time, the concept should help shape a theory of sustainable developmentalism, where the objective is to think much

⁵⁷ Source: Myllyvirta, L., & Schaepe, B. (2026, February 5). 'Analysis: Clean energy drove more than a third of China's GDP growth in 2025'. *Carbon Brief*. <https://www.carbonbrief.org/analysis-clean-energy-drove-more-than-a-third-of-chinas-gdp-growth-in-2025>.

more broadly about defining new development styles. This means interrogating the production sphere from a much deeper and broader perspective, thinking about consumption patterns, technological choices, or even the structure of income distribution. As I have shown elsewhere, this was indeed the direction taken by developmentalist thinkers in the 1970s.

Figure 2: A two levels approach to Green Industrial Policy



4. Concluding Remarks

This article has provided a critical examination of Brazil's green industrialisation experience in the wind turbine sector. Although Brazil's experience has been described as an example of successful latecomer development in renewable energy, as this article has shown, this enthusiasm should however be tempered. Green industrialisation, indeed, has not only tended to demonstrate similar characteristics to the country's more general industrialisation difficulties, but it has also displayed some structural barriers of its own. This article has put emphasis on a novel phenomenon, that of a 'green premature deindustrialisation', a dynamic of industrial recession taking place rapidly after such a green industrialisation started. Beyond contributing to debates about Brazil's neo-developmentalism, this discussion invites a broader recalibration of the limits of green industrialisation, the scope of ambitions for green windows of opportunity, and the broader critical reflection on the nature of green developmentalism for the developing world.

Firstly, Brazil's experience sheds light on some important tensions that lie within the idea of green industrialisation. It suggests that green windows, rather than providing broad catch-up opportunities, may be highly contingent, technology-specific, and, ultimately, fragile. Of course, as we have seen, part of the reason Brazil did not manage to take advantage of wind power to achieve industrial upgrading, and the development of domestic champions is primarily the consequence of the absence of a coherent industrial policy. Yet, as we have also shown, the very nature of the market for green technologies as well as the competing character of certain green technologies, might make it insufficient for developing countries to rely solely on green windows when contemplating a broader strategy of economic development.

Secondly, the sectoral focus displayed by the broader green industrial policy literature presents deeper problems. As argued above, *premature deindustrialisation* is fundamentally about the failure to achieve a self-sustaining form of industrialisation. More generally, as classical development theorists recognised, industrialisation and structural transformation are inherently a broad, interconnected process of cumulative causation. From this premise, strategies centred on capturing positions in specific green technologies, even if successful, may not generate the transformative effects attributed to them. In this sense, the focus on specific green sectors may fail to create the conditions for a sustainable structural transformation that the green industrialisation approach ultimately hopes to realise. This suggests the need to adopt a broader approach to what a new green developmentalism should look like (Albertone, 2025).

Finally, in a neo-mercantilist world marked by intense global competition and resurgent protectionism, a green developmentalism needs to rely on the identification of complementarities and coordination with neighbours and strategic economic partners (Albertone & Lebdioui, 2026). In that direction, the offshore wind sector, because of its scale, complexity, and capital-intensiveness, might serve as a productive platform to envision a coordinated industrial policy.

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List of Interviews

No	Name/Function/ Employer	Date	Location
1	Vestas Latam	17/04/2023	Online
2	Secretariat for Industrial Development, Innovation, Trade and Services	16/05/2023	Brasilia
3	Secretariat for Industrial Development, Innovation, Trade and Services	16/05/2023	Brasilia
4	Secretariat for Industrial Development, Innovation, Trade and Services	16/05/2023	Brasilia
5	Absolar	23/05/2023	Online
6	Abimaq	26/05/2023	Online
7	Aeris	12/06/2023	Online
8	BNDES	13/06/2023	Rio de Janeiro
9	ABEEOLICA	19/06/2023	Online
10	ABEEOLICA	19/06/2023	Online
11	National Council for Industrial Development of Brazil	28/06/2023	Online
12	Secretariat for Strategic Policies and Programmes of Brazil	30/06/2023	Online
13	Secretariat for Technological Development and Innovation of Brazil	03/07/2023	Online
14	WEG	04/07/2023	Jaragua do Sul
15	WEG	04/07/2023	Jaragua do Sul
16	WEG	04/07/2023	Jaragua do Sul
17	Secretariat for Green Economy, Decarbonisation and Bioindustry of Brazil	31/07/2023	Online
18	Business Mobilisation for Innovation Steering Committee - National	01/08/2023	Online

	Confederation of Industry		
19	Energy Research Company (EPE)	03/08/2023	Online
20	Energy Research Company (EPE)	03/08/2023	Online
21	Pecém Port Authorities	01/07/2024	Online
22	ENEL	20/08/2024	Online
23	Absolar	17/12/2024	Online
24	Energy Scholar	27/05/2025	Online