Wind Energy Transition: Asymmetric Strategies between Brazil and China[1]

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Abstract: This article aims to assess the differences in the institutional trajectory of renewable transition policies, comparing its effects on the implementation of the wind power between Brazil and China. Additionally, it also intends to tangentially address whether the growth of new renewables in both countries opens up opportunities for them to play any significant role in the international trade of green hydrogen. The main focus will be on domestic institutional variables governing the challenges of renewable transition. In other words, socio-technical energy systems developed by both Brazil and China don't seem to fit into simplified analytical models. They demand multiple national explanatory variables such as economic growth, regime type, political institutions, and institutional capacity to address energy transition performance. Mainly, most of the asymmetries between the energy systems of Brazil and China is due to both the path dependence of its incumbent energy system and state capacities. Following approaches from previous scholarly work, this piece will emphasize the interactions between domestic institutions and legacy structures to explore asymmetries in the development of new renewables.

Keywords: Brazil, China, state capacity, path dependence, new renewables

1. Introduction

The sharp development of renewables in both Brazil and China has different points of departure and arrival. On the one hand, Brazil established the role of renewables in its energy matrix as the very basis for its astounding economic performance over the following three and a half decades after the World War II and, therefore, well before external constraints caused by oil price shocks in the 1970s. China, on the other hand, has introduced the need for renewables as a means of correcting the harmful effects of its energy-intensive and highly carbonized economy, which has been the foundation for unbridled economic growth over the past 35 years. In this sense, the structural incentives to move forward into the decarbonized economy are deeply asymmetric between the two countries.

Brazil is almost an energy self-sufficient country whereas China is heavily dependent on imported fossil fuels. Brazil bases already 45.3 percent of its total energy demand on renewables whereas China struggles to diminish its reliance on fossil. The share of coal in China's electricity matrix is falling (from 80 to 60 percent between 2007 and 2023) but installed coal capacity continues to grow in absolute terms: it increased more than five times, rising from 222 to 1140 GW between 2002 and 2023 (Figure 2). China is the world's largest energy consumer and greenhouse gas emitter (Liu and Wei, 2020) whereas Brazil ranks as the seventh largest GHG global emitter, with 46 percent of 2015 emissions

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coming from land use sector while energy sector accounted for 23.6 percent (Azevedo et al., 2018).

Comparing the way how Brazil and China have implemented its energy efficiency and environmental conservation policies it seems that China has shown a better institutional capacity to tackle those issues. According to International Energy Agency, China was able to reduce the carbon intensity in both economy and energy supply by 31.8 and 36.2 percent, respectively, between 2003-2016 whereas Brazil increased those rates by 2.8 and 3.4 percent during the same period. The updated data reinforces the above figures. On the one hand, shows that China overcame in 2021 its carbon intensity target with an 18.8 percent decrease from 2015 levels. Although the China's energy intensity fell slightly short the original target, it also decreased an approximately 13.7 percent from 2016 through 2020 (Lewis & Edwards, 2021). On the other hand, despite the carbon intensity of the Brazilian economy and carbon emissions from the country's power generation still being ones of the world's smallest, the evolution of total CO2 emissions associated with energy matrix jumped from 288.4 to 445.4 MtCO2eq between 2000 and 2021, according to data from Brazil's Energy Research Office (EPE, 2022). Despite the Amazon preservation policy having managed to reduce the area deforested by almost five times between 2004 and 2012 (Ribeiro et al., 2023) - contributing to the drop-in emissions - Amazon deforestation has resumed growth since 2012 and currently reaches an area nearly three times larger, according to Brazil's National Institute for Space Research (INPE), undermining the rainforest's role as an important carbon sink.

This article will narrow down the topic and aims to assess the differences in the institutional trajectory of renewable transition policies, comparing its effects on the implementation of the wind power between Brazil and China. Additionally, it also intends to tangentially address whether the growth of new renewables in both countries opens up opportunities for them to play any significant role in the international trade of green hydrogen. The main focus will be on domestic institutional variables governing the challenges of renewable transition. In other words, socio-technical energy systems developed by both Brazil and China don't seem to fit into simplified analytical models. They demand multiple national explanatory variables such as economic growth, regime type, political institutions, and institutional capacity to address energy transition performance (Fiorino, 2011). Mainly, most of the asymmetries between the energy systems of Brazil and China is due to both the path dependence of its incumbent energy system and state capacities.

According to comparative analyses, most energy transitions have been path dependent rather than revolutionary, that is, in order to tackle incumbent energy systems is mandatory a comprehensive and lasting approach that jointly modify technological, regulatory, economic and social dimensions (Sovacool, 2017). For instance, the differences between state capacities and political regime types in both Brazil and China and their institutional intertwining result in decision-making processes with asymmetric effects for renewable transition (Hochstetler and Tranjan, 2016; Kostka, 2016). In other words, regardless the relatively well-succeeded renewable transition agendas of both countries in comparative terms, its bureaucratic capacities have different scope, that is, they are embedded in regimes and political institutions with very unlike legacies.

This means the institutional change aimed at new renewables in Brazil and China is still embedded in disputes between proponents of the new and incumbent technological systems. In other words, such disputes are constrained by the effects of path dependence whereby the preceding institutional stages reinforces processes of increasing returns, as the relative benefits of maintaining the previous course increase in relation to any possible change in path (Pierson, 2000). This piece will emphasize the interactions between domestic institutions and legacy structures to explore asymmetries in the development of new renewables, particularly wind sources in Brazil and China.

Main Achievements of China's and Brazil's Renewable Transition

According to the data from the International Renewable Energy Agency (IRENA), in absolute terms China has become the leader when it comes to renewables. In 2021, China already accounted for more than 70 percent of the world's solar modules and was home to nearly half of global wind turbine manufacturing capacity (Meidan, 2021). The country's efforts to increase energy efficiency have made it the largest market for smart meters. Besides, in order to meet a growing demand resulting from increased sales of subsidized electric vehicles China's investments have catapulted the country's lithium-ion battery capacity, which accounted for 77 percent of global volume in 2020 (Yu and Sumangil, 2021).

According to the latest report from the European Patent Office and the International Energy Agency (IEA), China has showed a steady increase in the number of international patent families (IPF) being filled for low carbon energy (LCE) technologies from 2000 to 2019 (Ménière et al., 2021). Although China is still behind leading countries in LCE technologies, like Japan, Germany and U.S., this lag shouldn't last for long considering the country's leadership as the largest manufacturer, exporter and installer of solar panels, wind turbines, batteries and electric vehicles. In that sense, the China's big push to renewables shouldn't be seen just as an environmental strategy but also as developmental and business ones. The aforementioned renewables industries have become pillars and export platforms for the country's economy, able to create a domestic industry that provides future-oriented jobs, mitigate pollution and enhance energy supply security as well as reduce the costs of its domestic industry's supply chains (Korsnes, 2020; Mathews and Tan, 2015).

China's renewables industry has been beaconed by three central government industrial-policy documents: the strategic emerging industries catalogue, the 'Made in China 2025', and the 13th Five-Year Plan (Kenderdine, 2017). Lately such goals have been increased by measures introduced by the dual carbon targets, also known as *Shuangtan* (Crowther, 2023). When setting national specific targets for energy transition to renewables, China stipulated in its 12th Five-Year Plan for Energy Development a target of 100 GW of installed wind power capacity by 2015, but surpassed the original target by reaching 131 GW that year. In the following Five-Year Plan, the China's government was expecting to reach 210 GW of installed wind capacity by 2020 but, according to National Energy Administration (NEA), the country reached the astounding mark of 281.5 GW that year, leaving far behind all competing countries in the renewable transition. European Union and United States, for instance, have amassed 220 GW and 122.48 GW till the same year, respectively, according to WindEurope and American Clean Power Association. To summarize this unprecedented transformation in a nutshell, while the China's coal installed capacity has multiplied by 1.75 times between 2011-2020, the country's renewable sources have multiplied by 3.68 times in the same period, which allowed some analysts to predict that China's electric power system should be greener than brown by 2026 (Mathews and Huang, 2021). However, the most recent data indicates that this forecast has already been exceeded (Figure 2). According to U.S. Energy Information Administration, non-fossil fuels already accounted for 49 percent of China's total installed electricity generation capacity in 2022 (EIA, 2023); a year later, this share jumped to 50.9 percent, according to China's National Reform and Development Commission. In this context the share of wind already accounted for 15.1 percent. That explains why Chinese manufacturers were able to capture almost half of the global wind market since 2018 (Lacal-Arántegui, 2019).

Despite the asymmetries of structural incentives vis-a-vis China, the overall picture of Brazil's energy transition is no less striking. In the last ten years, the country's electric power system has reduced the hydropower share, increased the dependence on gas-fired power plants, and stepped up energy transition based on wind, solar and biomass sources (Table 1). In addition to the country having the world's second largest volume of jobs coming from the renewable energy industry, behind only China, the share of renewable sources in the Brazil's total energy demand still holds the unmatched 45.3 percent (IRENA, 2020). When observing only the electricity supply, renewable sources reached 85.4 percent in 2023, with the hydropower accounting for 50.2 percent, bioenergy 7.6 percent (mostly from sugarcane biomass), wind 12.3 percent, and solar 15.3 percent, according to Brazil's National Agency of Electric Energy (ANEEL). Considering those figures, it is still surprising to come across scholarly works making bold claims that European Union has become the world's greenest electric power system since 2009 (Mathews and Huang, 2021).

	2013	2014	2016	2018	2020	2022	2024*	% of Installed Capacity in 2024*	% of Installed Capacity in 2018
Hydro	85,557	87,970	95,819	102,300	109,277	109,844	109,928	47.2	63.8
Biomass	11,111	12,210	13,845	14,729	15,187	15,539	16,948	7.2	9.0
Wind	2,109	3,840	9,507	13,381	16,317	24,637	30,977	13.25	8.8
Solar	3	15	23	1,750	6,906	24,740	44,322	18.96	1.4
Natural Gas	13,620	12,581	13,018	13,003	14,953	17,456	17,910	7.7	8.0
Oil	7,459	9,093	10,205	9,965	9,147	8,445	7,900	3.4	5.7
Coal	3,024	3,593	3,613	3,718	3,583	3,465	3,461	1.5	2.0
Nuclear	1,990	1,990	1,990	1,990	1,990	1,990	1,990	0.9	1.2

Table 1. Brazil's Installed Generation Capacity by Energy Source (MW)
Source: Table elaborated by the Author based on data from "Boletim Mensal de Monitoramento do Sistema Elétrico" published by the Brazil's Ministry of Mines and Energy (*Ministério das Minas e Energia* - MNE) *Data until June 2024

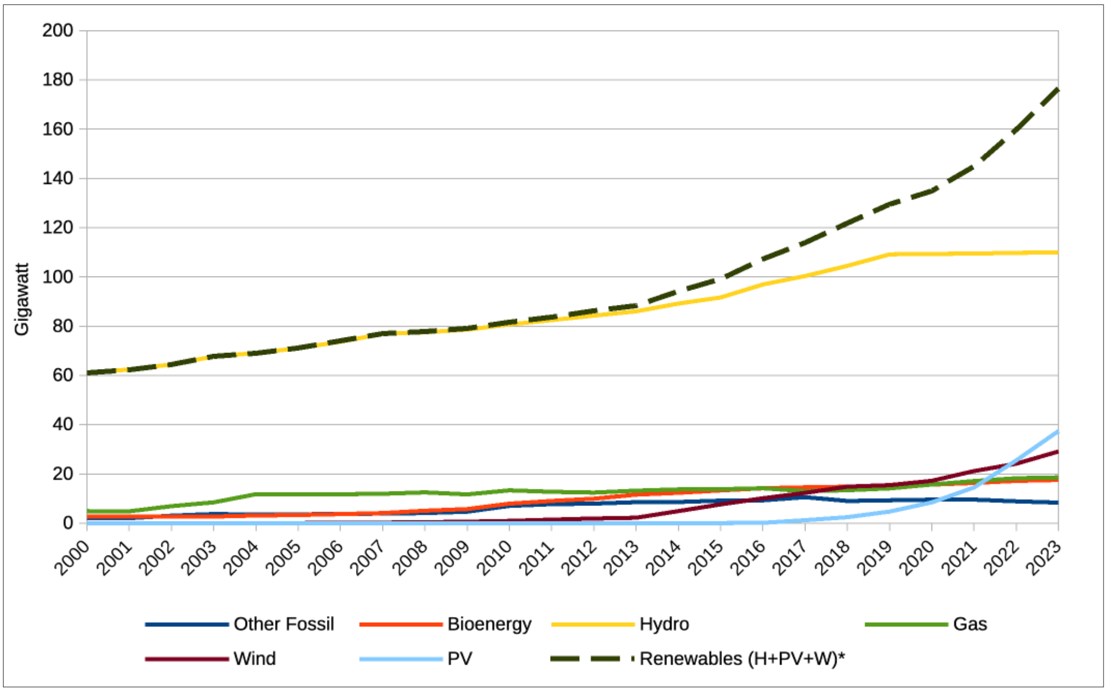

Figure 1. Brazil's Power Installed Capacity (GW)
* Hydro, Photovoltaic and Wind
Source: Elaborated by the Author based on "Ember Electricity Data Explore"

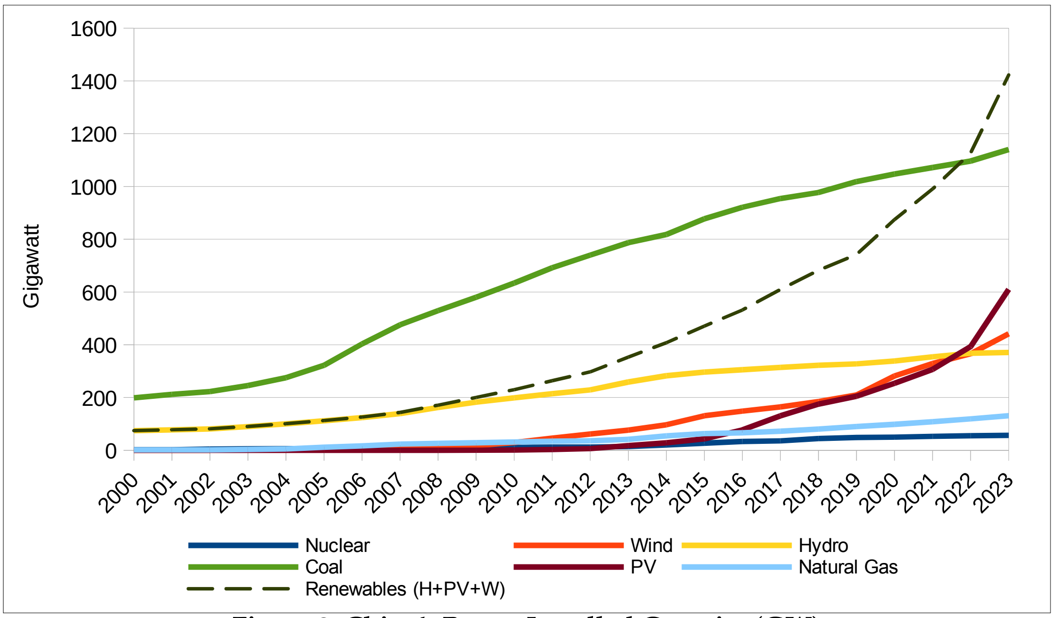

Figure 2. China's Power Installed Capacity (GW)
Source: Elaborated by the Author based on "Ember Electricity Data Explore"

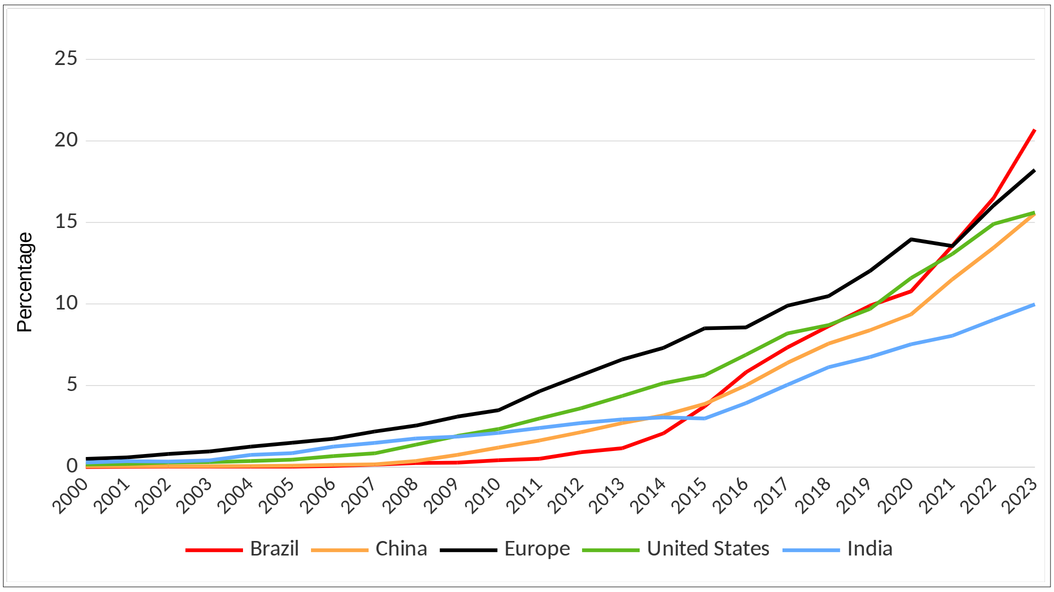

Figure 3. Wind and Solar Electricity Generation (% Share)
Source: Elaborated by the Author based on "Ember Electricity Data Explore"

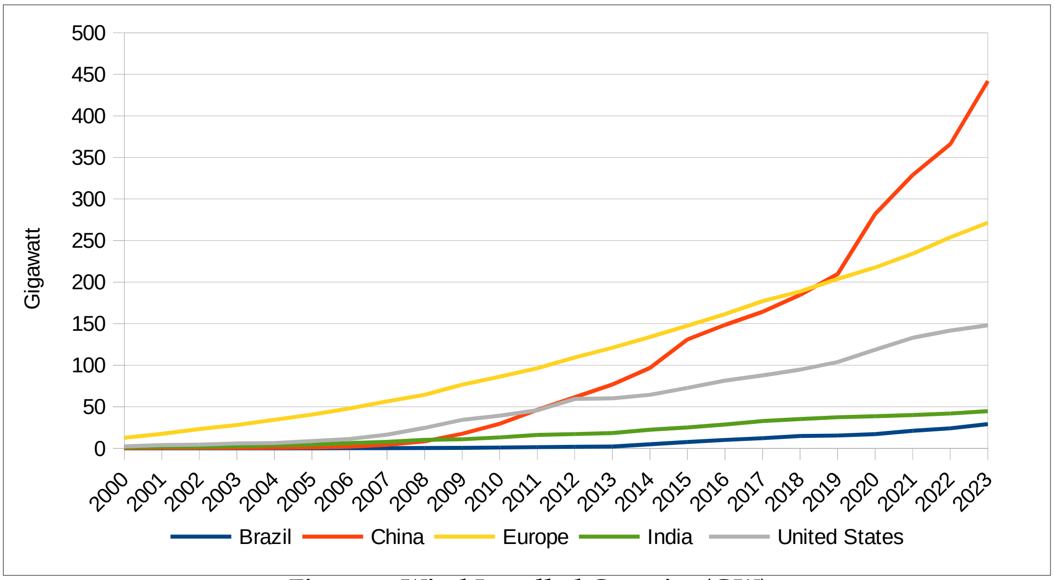

Figure 4. Wind Installed Capacity (GW)
Source: Elaborated by the Author based on "Ember Electricity Data Explore"

Additionally, Brazil was the country that received the most international investments in renewable energy projects between 2015 and 2022. In total, USD $114.8 billion was poured into the country, which represented 11 percent of foreign investments in economies classified as "emerging"(UNCTAD, 2023). Such investments helped to catapult the country's wind capacity from 1.7 to 31 GW between 2010 and 2024, increasing its share on the Brazil's installed capacity to 13.3 percent (Table 1). Although natural gas and biomass have also gained ground in Brazil, it was the new renewables (solar and wind) that have obtained a greater enlargement in the country's electricity generation share (Figure 1 and 3).

Against this backdrop, it is understandable that reports from the International Energy Agency (IEA) sought to associate cooperation and investment agreements between Brazil and China for renewable energy with the surge in Chinese investments in the Brazilian energy sector and that such capital would not have been guided merely to gain control of resources (IEA, 2015). Considering the unprecedented volume of resources that Chinese power companies poured into Brazil - USD $33 billion between 2007 and 2023, according to Brazil-China Business Council (Cariello, 2024) - the IEA hypothesis seemed plausible. Nevertheless, such investments were oriented not to greenfield projects but rather towards brownfield assets. According to the China Global Power Database, from Boston University's Center for Global Development Policy, between 2009 and 2024 Chinese investments in Brazilian energy infrastructure assets, through mergers and acquisitions, accumulated 19,654 MW in installed capacity, while greenfield projects totaled 2,151 MW. Furthermore, 67.8 percent of these investments were in the acquisition of amortized hydropower plants. In other words, Chinese capital went shopping in Brazil, eagerly participating in the asset auctions of power utility companies. But, as will be detailed later, this did not translate into technology transfer and development of an indigenous wind turbine industry in Brazil as occurred in China.

2. Path Dependence and State Capacities: Institutions Matter in Wind Transition

Both the path dependence of bureaucratic governance and decision-making deadlocks resulted from multi-level coordination may explain differences and communalities on energy transition figures between Brazil and China. Besides, *transformative policy experimentation* approach has the potential to address the main implementation hindrances presented to new renewables. According to scholars, the concept of *transformative experimentation* bypasses the spontaneous and random diffusion approach to *policy* and is associated with coordinated initiatives aimed at generating policy options that are adopted by official policymakers and eventually converted into strategies with a broader reach (Heilmann, 2008).

2.1. Brazil

Brazil has a long and early history of investment in renewable sources that is intertwined with the forging of the developmental State itself. The country is ranked among the top ten in the world that have built the largest number of big dams. At its peak in the 1950s-60s, the country built 100 big dams every decade (Khagram, 2004). Obviously, this remarkable achievement of a hydropower infrastructure had more social and economic reasons - oriented towards energy security - than just environmental ones (Schaeffer et al., 2015; Vieira and Dalgaard, 2013; Szklo et al, 2005). Besides, as the market-oriented reforms of the 1990s forged a new regulatory regime for the power sector, the legacy of *esprit de corps* of the electricity bureaucracy that built the socio-technical system was incorporated into its institutional design, ensuring path dependence from the incumbent power system which mitigated the reach but not the disruptive effects of privatizations (Prado, 2012; Tankha, 2009; Oliveira, 2007). In view of that, Brazil's energy transition policy has a pronounced path-dependence in its multi-level coordination mechanisms based on a divided competence to legislate energy transition: municipalities are in charge of building codes; sales taxes are in the states' jurisdiction; the Brazilian electricity grid is national (Basso, 2019).

Such path dependence driven by a centralized hydropower system led to a situation of "lock-in". Added to the poorly coordinated market-oriented reforms of the 1990s that resulted in a lack of planning for investment in generation, the then incumbent power system while resisting against alternative energy technologies and creating constraints to achieve emerging policy goals such as energy supply security (Bradshaw, 2018). Pushed by an unprecedented electricity shortage crisis in 2001, the Brazilian government launched one year later a feed-in tariff program called Incentive Program for Alternative Energy Sources (PROINFA) aimed at increasing the share of small hydro, wind, and biomass thermoelectric in the energy supply (Cavaliero and Silva, 2005). Throughout this first and incipient phase of implementation, PROINFA faced bottlenecks such as the financial shortages of program eligible candidates, that is, Autonomous Independent Power Producers - which could not be under total or partial control of any power utility; besides the candidates' failure to meet the 60 percent local content requirements (Dutra and Szklo, 2008).

Till 2011, the wind energy development in Brazil was primarily driven by PROINFA but later on tenders have established as the major driver (Bayer, 2018). In this context, Brazilian Development Bank (BNDES) has stood out as the main provider of subsidized loans, whether based on the feed-in tariff system or project finance models in which BNDES took equity participation up to 80 percent. Although some scholars claim that the wind farms mushrooming in Brazil was mostly a market response to the institutional changes promoted in the sector, focused on boosting private investment (Diniz, 2018), it is not possible to underestimate the role played by BNDES which has taken part in financing roughly 76 percent of the accumulated wind installed capacity between 2008 and 2016 (Esposito, 2018).

With this in mind, BNDES and Brazilian Electricity Regulatory Agency (ANEEL) have become notable as institutional drivers behind new renewables in Brazil. Those institutions were able to forge a regulatory space through which a network of interactions between stakeholders took place collaboratively, updating the country's state capacity (Bradshaw, 2017). Despite this, the wind transition has been supported by political implementation mediated by restricted representation among stakeholders - with economic interests prevailing to the detriment of other forms of participation (Soares; Gava; and Puppim de Oliveira, 2021).

In addition to the constraints of this new regulatory environment, renewable transition initiatives have a subnational driver that plays a niche-forming role, an aspect that receives less attention at the national policy level (Bradshaw and Jannuzzi, 2019). Indeed, those local initiatives have also redistributive effects as more than 85 percent of the Brazil's wind capacity is hosted at cities with the lowest human development indexes (Yanaguizawa Lucena & Lucena, 2019). However, those subnational initiatives still facing regulatory challenges at national level to move forward renewable transition such as those relating to the adoption of centralized wind-PV hybrid power plants in Northeastern Brazil (Santos et al., 2020). Besides, as regional actors opt for renewable sources, aiming primarily to develop economic opportunities and their own power supply, the environmental and social issues have just benefitted as a subsidiary effect of economic viability of wind farms. In other words, path dependence of incumbent socio-technical power system is still sidelining environmental issues in Brazil's energy transition agenda.

In order to scaling up new renewables socio-technical systems both political coalitions and multi-level dynamic will be required (Geels, 2019; Breetz; Mildenberger; and Stokes, 2018). Whether the path dependence of Brazil's incumbent power system was able to constrain the scope for both the system marketization and the renewable transition itself, its bureaucracy does not seem to have been able to mobilize both organizational reputation and networks (Carpenter, 2001) to prevent disruptive privatizations of remaining instruments of state capacity over power system. The privatization of the main state-owned power company, Eletrobras, sealed by an Act of Congress signed into law by President Bolsonaro in 2021, promises to further deteriorate the state capacity to coordinate energy transition policies in Brazil.

This new round of state divestment should repeat the results of the privatization of power distributors in 1990s when the financial indicators of sold companies improved, benefiting their shareholders, but the quality of service provided to consumers did not (Silvestre et al., 2010). Responsible for most electrical power interconnection and controlling approximately 45 percent of the transmission lines, the Eletrobras holding company also accounts for 30 percent of the country's electricity generation. One of the most insidious effects of this privatization Act is the elimination of the quota system. A significant part of the power currently sold by Eletrobras is cheaper due to the fact that it is produced by old hydropower plants, whose debt for its construction is already amortized. For this reason, Eletrobras dams sell power at half the price charged by private producers on the 'free energy market'. As part of the prize to attract private investors, the privatization eliminates the quota system, that is, the end of the cheaper sale of power from Eletrobras and its alignment with 'free market prices'. Experts have pointed out that this will have a cascading effect, increasing the costs of production chains and depressing the income of consumers mostly wage earners. By the way, Brazil is already a country whose residential electricity bill absorbs the largest share of households' annual income, considering a comparative survey with OECD countries carried out by Abrace[2] (Salomão, 2023).

In addition to the regressive effects on disposable income resulting from the end of the quota system, the loss of state control over Eletrobras will also have environmental consequences. This new privatization law makes it mandatory to contract 8 GW from new gas-fired thermoelectric plants between 2026 and 2030. These power plants must operate full-time at 70 percent of their capacity for at least 15 years. Consequently, it is estimated that annual emissions of greenhouse gases would increase 60 percent compared to the volume already emitted by current gas-fired thermoelectric plants in operation. Forecasts of greenhouse gas emissions resulting from the entry into operation of new thermoelectric plants determined by the Eletrobras privatization should add another 260.3 $MtCO_2e$ or more than was emitted by the transport sector in 2019 (Iema, 2021).

2.2. China

Renewables transition in China is also embedded in path dependence driven by a multi-level governance of networked actors. The legacy of fiscal reforms adopted in the 1980s also paved the way for the emergence of a local state corporatism which increased authority of regional governments (Qian and Xu, 1993; Oi, 1992). Often named by neo-institutionalist scholars as a "regionally decentralized authoritarian system" (Xu, 2011), such institutional architecture has delimited the scope of China's transition policies. Between 2003 and 2011, for instance, over 90 percent of wind farms were implemented by local governments driven by inter-provincial competition (Kirkegaard, 2018).

Indeed, the leading role of local governments in forging a renewable transition market was made possible as the main criterion for the rise of

2 ABRACE: Brazilian Association of Large Industrial Energy Consumers and Free Consumers

bureaucratic cadres in the administrative and party hierarchy in China was the performance of local economies (McNally, 2006). In other words, China still holds a central agency and a powerful bureaucracy in charge of binding targets for renewable energy policies, underpinned by a cadre management system which has persuasive schemes of incentives to assure the performance of its officials (Kostka, 2016). As it enables both the diffusion of national models to subnational spheres and the adoption of successful local experiments in national policymaking (Lo and Broto, 2019). Policy stakeholders adapt the goals of renewable policies in response to experiences and new information, forging a dynamic of policy learning (Mah and Hills, 2014).

Such policy learning in China has been underpinned by an institutional pendulum movement in which the country's energy bureaucracy oscillates between cycles of fragmentation and centralization, combining hierarchical and heterarchical features (Cai and Aoyama, 2018). The wind policy was an example of this: in the initial phase of experimentation it was relatively open, but the decision-making system later closed in the final stages, as the tendering policy began to be adopted for national implementation (Mah and Hills, 2014). Alongside innovation based on local experimentation, the central government paves the way to generalize such local initiatives, ensuring coordination. (Heilmann, 2008).

Although China has been able to reduce greenhouse gas emissions across its energy system, policies aimed at new renewables also have to deal with diminishing returns. As it is driven by regionally decentralized authoritarian system, the local adoption of new renewables is underpinned by uncoordinated governance, permeated by bargains, entrenched interests, state and party players. (Kirkegaard & Caliskan, 2019; Korsnes 2014). Although it has the largest wind generation capacity in the world, China has been challenged by forced spillage - most of that is due to the high fragmentation of both the regulation of the electricity sector and the energy bureaucracy itself (Davidson; Kahrl; and Karplus, 2017). While worldwide wind curtailment[3] rate ranges from 1 to 3 percent (Bird et al., 2016), in China as much as 15 percent was curtailed from 2009 to 2017 (Xia; Lu; and Song, 2020).

This is the context that explains the energy system's inertia that has constrained China's electricity market reform, announced in 2015 - another example of sociotechnical lock-in.

This market-oriented reform sought to make room for competition between generation, distribution and retail companies, that is, was designed to address the malfunctioning of both the price mechanism and power planning and the use of renewables (Zeng et al., 2016). However, China's state-owned power companies, whether local or national, are still instruments of the state's public policy, as 90 percent of the country's generation capacity still lies in their hands. In other words, even with the marketization driven by both 'corporativization' of state-owned enterprises and regulatory liberalization, the incumbent energy system beaconed by political regime and bureaucratic capacity still call the shots. Independently or in collusion with local governments, those companies are able to counter the implementation of central government policies such as market-oriented reforms in the power sector (Zhang and Andrews-Speed, 2020).

The continued wind power investment by China's central state-owned enterprises (CSOEs), even under wind curtailment, does not means whatsoever to attribute to its economic behavior an absence of market rationality due to political/policy burdens (Zhu et al., 2019). Indeed, scholars have claimed state control and marketization should be seen as complementary rather than contradictory as it has resulted not only in extraordinary increase of wind capacity but has been also able to address both market fragmentation and renewables curtailment (Yu, 2020). Notwithstanding the above, although the lack of coordination among energy stakeholders has not implied a weakening of the China's state capacity to move forward the wind infrastructure, it has resulted in hardships in adjust energy demand and its efficiency (Hove; Meidan; and Andrews-Speed, 2021).

3. Renewable Transition, State-Owned Banks, and Development Strategy

Unlike the undermining measures lately adopted by the Brazilian government against its development bank, the official development finance

[3] Curtailment occurs when the power grid interrupts the connection of wind capacity, partially abandoning its power generated

undertaken by China's state-owned banks has maintained and deepened low-interest loans, preferential export credit, and equity investments for the development of energy projects domestically and abroad. With a difference in size, BNDES played basically the same role as the China Development Bank (the largest Chinese policy bank). BNDES was acknowledged as the world's third largest national development bank (after its Chinese and German counterparts) until the middle of the last decade, not just for the country's domestic market but also to international project finance in support for infrastructure (Sierra and Hochstetler, 2017).

However, the political events which led to former President Dilma Rousseff's ousting in 2016 and the election of a crypto-fascist as president in 2018 have deeply affected the role of BNDES. The institutional advantage measured by subsidized interest rates which guide development banks worldwide has been suppressed in the case of BNDES as one of the first institutional measures took by the new ruling coalition which overthrew President Rousseff in 2016 (Santana, 2018; Martins and Torres Filho, 2020). BNDES' annual disbursement capacity has plummeted from BRL $263.8 billion to BRL $66.9 billion between 2014-2020 (Figure 5). Chinese policy banks, in turn, have surpassed the leading development finance institutions (DFIs) to become the world's largest providers of funding for energy infrastructural projects. In the last two decades, China's development banks have poured worldwide a total of USD $117 billion for power projects (Kong and Gallagher, 2021).

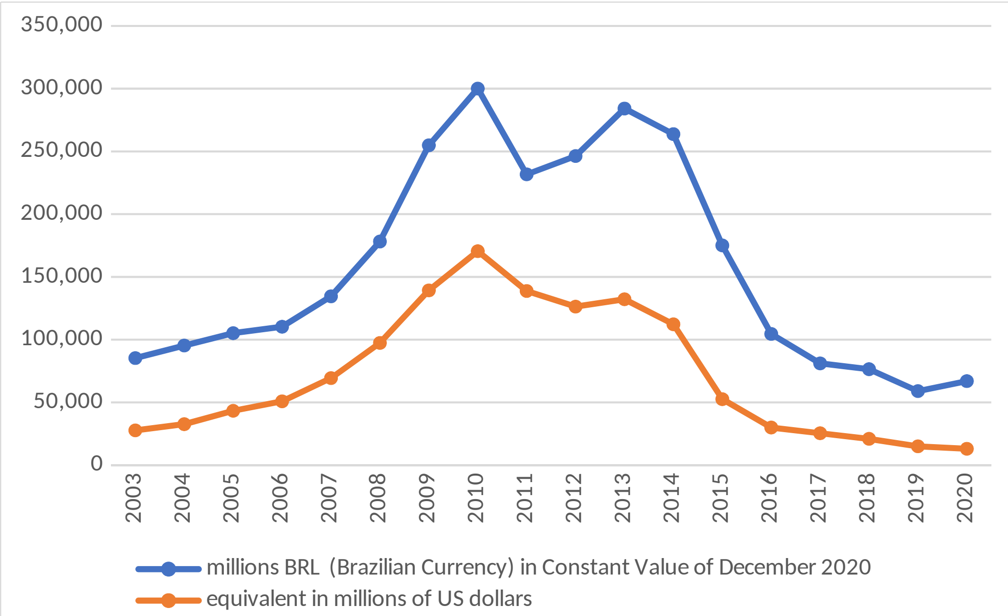

Figure 5. Total BNDES Disbursements
Source: Elaborated by the Author from BNDES database: *Desembolsos do Sistema BNDES*

The institutional bifurcation of the financial engines of the renewable transition in Brazil and China has already resulted in different effects on the deployment and diffusion of renewable technological spillover. This resonates with studies which claim the 'direction' of innovation depends on the type of financial actor, that is, public financial actors take greater risks in portfolios with new technologies besides they also increased their share in total investment dramatically over time (Mazzucato and Semieniuk, 2018). Whereas China has used its state-owned banks and industrial policies to drive its domestic companies to capture the value of developing renewable technologies as well as replacing imports by developing a domestic supply chain, Brazil has let such spillover slip despite the significant increase of new renewables share in the country's installed capacity. Local content requirements (LCR) were also the central industrial policy for the development of China's wind industry. But, unlike Brazil, China has made access to public development and research funds conditional on technology transfer through joint ventures and Chinese patent applications (Hayashi, 2020).

3.1. BNDES and New Renewables: from Backbone to an Elusive Institution

BNDES's total accumulated loans to power infrastructure projects have declined by half between the first and second half of the past decade, being only partially offset by other sources of funding (Figure 6). Besides those constrains over its financing capacity, the major turn over in BNDES policy was the alignment of its interest rates with those from open credit market and the decreasing the institution's equity participation in wind farm development costs from 80 percent to not more than 50 percent. It made Bank's competitive loan interest rates no longer available. Based on domestic content requirements of 60 percent, BNDES's subsidized credit policy was being responsible for driving import-substitution moves on wind supply chains, drawing wind turbine manufacturers and assemblers to Brazil from 2009 onwards (Adami; Verschoore; and Sellitto, 2021). It is not possible to be surprised, therefore, when stakeholders' perception regarding to wind implementation barriers in Brazil attributes to the high cost of capital its main cause, driven both by the increase in financing interest rates and the decrease in equity participation from BNDES (Diógenes; Claro; and Rodrigues, 2019).

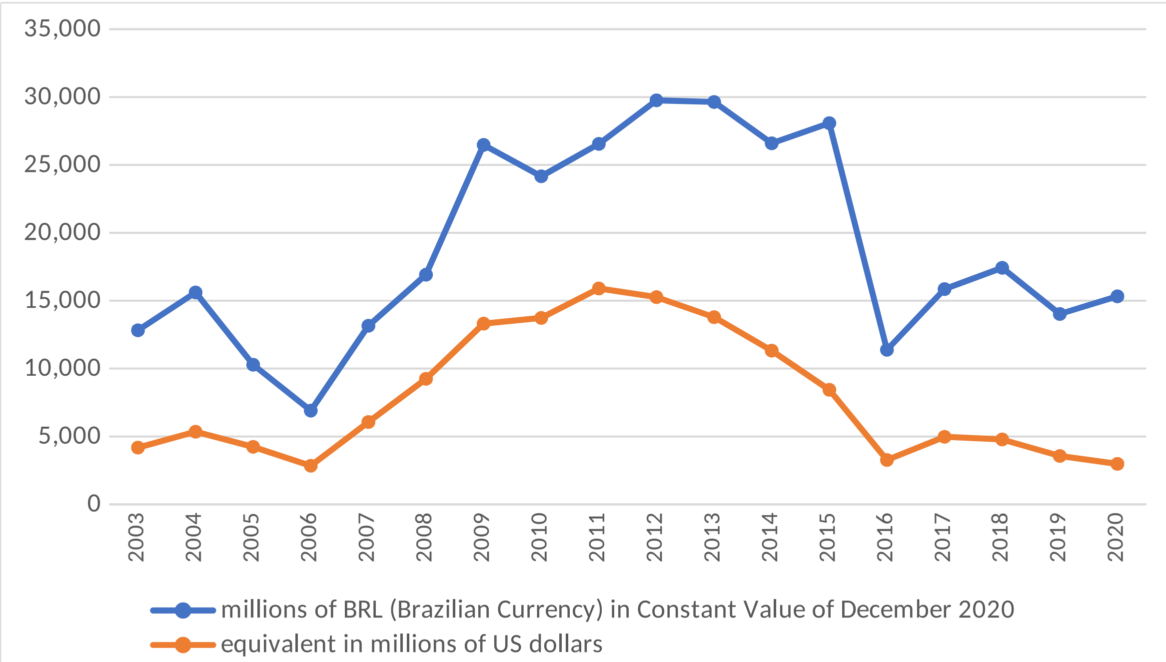

Figure 6. BNDES Disbursements for Electricity Infrastructure
Source: Elaborated by the Author from BNDES database: *Desembolsos do Sistema BNDES*

In line with those findings, scholarly works have underlined that delays in grid connection, local content requirements, the red tape associated with environmental feasibility studies, late delivery of wind turbines, supply bottlenecks, poor project management, and relatively short deadlines for implementation are some of reasons for 30 percent of wind and 50 percent of biomass power plants are with the contract timetable behind schedule (Tolmasquim et al., 2021). As it is possible to see in the chart below (Figure 7), BNDES lending towards wind infrastructure showed a steady growth until 2015 but it became erratic and declining after that year.

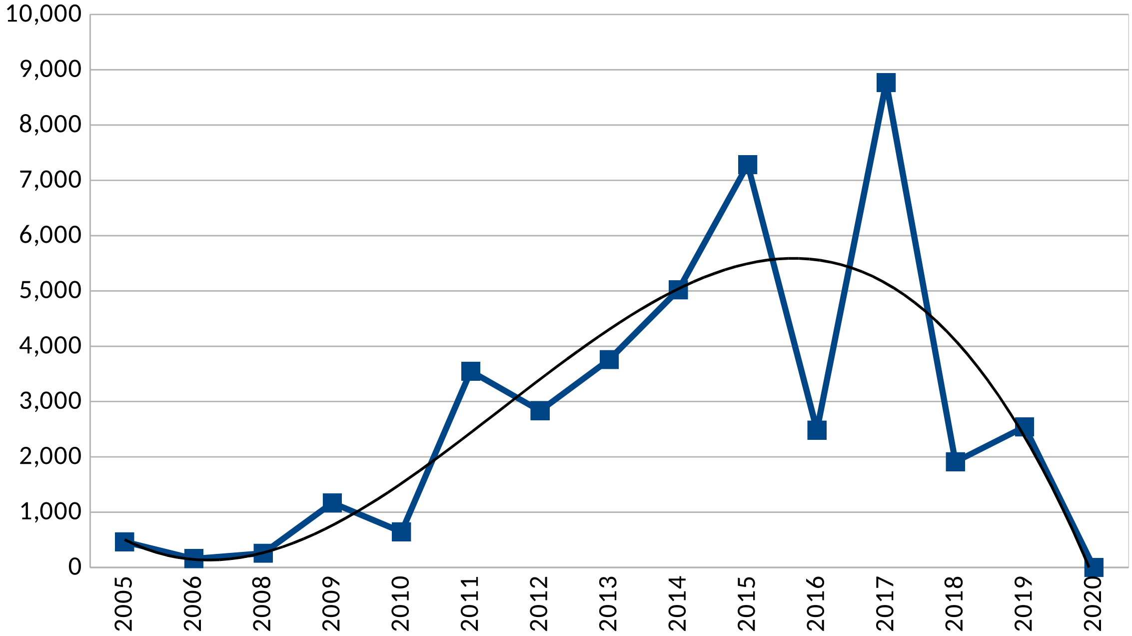

Figure 7. BNDES Disbursements for Wind Farms (BRL million)
Source: Elaborated by the Author from BNDES database: *Desembolsos do Sistema BNDES*

Till the mid-2010s, BNDES was the largest provider of long-term loans for power infrastructure – particularly toward wind (Esposito, 2018) - but the Brazilian state's support for new renewables ended up leaning towards competitive auctions, public–private partnerships, and stricter financing rules (Hochstetler and Kostka, 2015). In order to overcome capital shortage and prevent a disruptive power rationing, like the one that hit the country in 2001, the Brazil's government passed a power reform Act in 2004 that adopted energy auctions as the main tool to procure electricity. This allowed Brazil to contract 9571 TWh of power in 82 auction rounds between 2004 and 2019, adding 105 GW of installed capacity, of which 77 GW were from renewable sources (Tolmasquim et al., 2021). According to the Monthly Monitoring Bulletin of the Brazilian Electric System, the country had 1,051 wind farms in operation able to deliver 26.9 GW of installed capacity by August of 2023.

As aftermath of the energy procurement model and capital shortages, both driven by *ad hoc* constrains, the erratic effects on Brazil's innovation policies on renewables became palpable. While technological spillover effects from Chinese industrial policy on new renewables have upgraded the country's value chain - mostly driven under the rubric of the Innovation-Driven Development Strategy (Naughton, 2021) - Brazil remains dependent on foreign technology and most wind research, development and innovation is not carried out domestically (Melo et al., 2020). China's developmental paradigm led new renewables in the country to be stimulated by a cultivated interaction between the state, the academic-scientific field and industry through corporatist networks (Chen and Lees, 2016); in Brazil, even with government programs to support research and development, none of the seven foreign subsidiaries installed in the country sought out Brazilian research institutes or universities to develop a specific wind turbine for the country (Adami; Antunes; Dawson, 2022). In other words, government policies aimed at wind development in Brazil have adopted a cost-efficient approach in relation to other energy sources in addition to being dependent on the import of technology (Gandenberger and Strauch, 2018). Indeed, Brazil's wind industry has specialized in the less sophisticated components and still accounts for a very small share of the nacelle manufacturing - the component of the windmill that concentrates the technological state of the art (Bazilian; Cuming; Kenyon, 2020).

New renewable policies driven primarily by cost efficiency measures can be observed in tariff and tax regimes for the industry. Till 2023, Brazil's central government still maintained tariff exemptions for the import of photovoltaic modules and wind turbines, which contributed to market capture by foreign suppliers - particularly from China, Germany, Denmark and the U.S. - hindering the development of a local industry. Besides, fossil fuels have been granted USD $72.23 billion in tax subsidies between 2018-2022 while renewables only received USD $13.39 billion during the same time span (INESC, 2023) – showing that incumbent socio-technical energy system is still very well entrenched. Although there are multiple mechanisms and sectoral policies to tackle renewable transition, updated works have claimed that Brazil lacks a long-term strategy for low-carbon energy innovation, which also explains the sharp decline in public investment on research and development for renewable sources (ECLAC/CGEE, 2020). That means while China's economy has overcome the bottlenecks typical of latecomers and kept the advantage in high technology-intensive sectors, Brazil has deepened the participation of sectors with less technological content (Araújo and Diegues, 2022).

3.2. China and Wind: Capturing Global Value Chains

Along with the role played by the flexibility of Chinese decision makers entangled by robust state capacities, the development of the country's wind industry has depended on subnational, private and international initiatives (Binz et al., 2017; Nahm, 2017). Hence, many studies have attempted to identify the explanatory variables for the extraordinary growth in both installed and manufacturing capacity that has placed China as a global technological leader in the wind industry (Xu; Yang; and Zhao, 2021; Liu et al., 2018; Groba and Cao, 2015).

In 2006, the Chinese government passed a law aimed at promoting the renewable technologies based on financing models through feed-in mechanisms - which sought to underpin the price of its tariffs and thus develop the renewables market. Additionally, other financial support arrangements were adopted such as: cost-sharing measures, grants and subsidies for manufacturers and research institutions focused on renewable sources (Andrews-Speed and Zhang, 2015). The sunk costs in the early stages of renewables development have compelled the successful performance of the industry to rely on governmental policy support - at least until it has been able to compete economically with incumbent systems (Yang; Cheng; and Yao, 2019). In other words, by combining public R&D funding with regulatory policies to increase market demand, China was able to establish a domestic renewable industry (Nahm, 2017).

The sources of financing for the development of new renewables in China have been both local governments and the country's state-owned banks. Until 2011, the loans share from state-owned banks over the total invested in wind and PV power accounted for approximately 80 percent. Since then, China has emerged as the wind industry's largest global market, with regional capacity soaring 22.4-fold between 2006 and 2011 (Ming et al., 2014).

Such trajectory gained new impetus when China Banking Regulatory Commission (CBRC) launched the green credit system in 2013 and three years later the Green Financial System, when green bond and credit policies emerged as the most robust sources of financing for renewable energy. Such measures have laid ground across regulators and executive bodies, providing financial incentives through monetary policies and macroprudential assessments. They have been driven by both the removal of loan-to-deposit ratio (LDR) requirements by the People's Bank of China and the decreasing size of customer deposits, making room for banks raise capital in international and Chinese interbank markets (Choi; Escalante; and Larsen, 2020).

In this context, China's domestic bank system has kept a significant role to develop renewables throughout the 2010s. While the 21 largest banks reached USD $1.5 trillion in green loans by the end of 2019, more than twice the amount of 2013, China's green bond market became the world's largest with USD $140 billion by 2019 (Choi and Li, 2021). In other words, the role of the China's state-owned banks in supporting renewables projects have raised in a context in which instead of the government incurring direct expenses for such projects it enhanced its creditworthiness in order to make them viable to the market or as it has been called: "state-supported, market based" means of development finance (Chen, 2020).

Some scholarly works have still claimed the China's wind turbine industry has been driven by protectionist measures favoring local firms which would have remained both dominated by state-owned companies and uncompetitive internationally (Brandt and Wang, 2019). However, following the development of financing policies toward renewables China has established comparative advantages on wind technology components, and managed to mitigate carbon emissions domestically (Zheng; Song; and Shen, 2021; Yu et al., 2020). As the costs of new renewables have fallen alongside technological, scale, and grid enhancements, this allowed China to diversify its domestic supply chain and expand its exports. Throughout 2010s Chinese wind turbine manufacturers have virtually captured the largest share of global market as the number of Chinese companies among the top ten global wind turbine manufacturers jumped from 4 to 7 between 2011 and 2020.

3.3. New Renewables and the Drivers for International Green Hydrogen Trade

According to data gathered until mid-2024, the combined share of wind and photovoltaic sources in China's overall installed capacity currently accounts for 38.4 percent while these new renewables share already represents 32.21 percent of Brazil's installed capacity. At first sight, socio-technical energy systems of both countries could potentially to emerge as candidates to become relevant contributors to the international green hydrogen trade. However, forging a competitive international market for this green energy carrier vis-à-vis other incumbent energy markets represents a challenge still full of barriers even for large producers of new renewables. Generate a surplus of green hydrogen capable of exceeding producers' domestic needs, in addition to circumventing logistical, technological and regulatory path dependencies of established energy markets make the outlook of green hydrogen still uncertain. To overcome these challenges, it is necessary to forge a network of interactions along the supply chains and industrial use of hydrogen (Griffiths et al., 2021).

Although still in its infancy, the latest works on green hydrogen in China and Brazil has highlighted the challenges for its development. As far as it was possible to verify, there are virtually no scholarly works that indicate an assertive role for both countries as green hydrogen suppliers to international trade. A recently published comparative analysis, for instance, has identified the main clean hydrogen trade routes linking North Africa to Europe, the Middle East to India, Australia to China, and North America to Japan and Korea (Shirizadeh et al., 2023), which reinforces analyzes on the emergence of new geoeconomic dependencies between states arising from the hydrogen trade (Van de Graaf et al., 2020). In other words, taking advantage of this new renewable economy in a sustainable way depends on the ability of hydrogen producing countries to avoid the commodity export trap as occurred in the past with oil producers, but rather to use the resource to attract downstream industries and promote import substitution policies. Considering its consolidation as the largest importer of raw material in the world - particularly energy carriers - it is very unlikely that the Chinese economy could become an exporter of green hydrogen. On the other hand, considering the recent undermining of the Brazilian state's capacities, reflected in both the deverticalization of the power sector and the dwarfing of country's development finance institutions, the likelihood of Brazil being dragged by the flow of hard currency resulting from the hydrogen export trap is higher - effect of a poorly coordinated industrial and technological policy for hydrogen that could subordinate the country again to a relationship of commodity supplier.

According to the China Hydrogen Alliance, hydrogen will account for about 10 percent of country's total final energy demand by 2050. Estimates are that the country will be able to supply 133 Mtoe of green hydrogen by 2030 from curtailed renewables (Zhao; Kamp; Lukszo, 2022). However, China will remain an importer of green hydrogen for many decades to come, despite reducing its level of dependence which will still be observed at increasing levels among other major importers such as Europe, India, Japan, and Korea (Shirizadeh et al., 2023). In fact, expert opinion surveys have indicated that the cost of green hydrogen produced in China is neither clean nor yet competitive, and will not be for at least another five years (Li; Shi; Phoumin, 2022).

Brazil, in turn, has been considered as the emerging economy with the largest number of international partnerships for the development of green hydrogen – all of them with European countries, by the way. Such an advantage has been considered by scholarly works largely the effect of path dependence arising from either comparatively developed infrastructure or regulatory frameworks driven by strong political support at local and national level (Lindner, 2023). According to IRENA report, Brazil has been ranked at 3rd when it comes to the country with the highest economic potential for both clean hydrogen below USD 4/kgH2 in 2030 and an LCOH[4] of USD 2/kgH2 on the 2050-time horizon (IRENA, 2022). Considering the highest cost contributors for global green liquid hydrogen potentials are the renewable sources and electrolysis, which account for around 65 percent of total costs (Franzmann et al., 2023), it is understandable that Brazil emerges as a great potential supplier.

In this context, the Brazilian Congress began processing the bill that will regulate the hydrogen industry in the country at the end of 2023. In the bill passed in the lower house and submitted for the review of the Senate, however, the nomenclature of "low-carbon hydrogen" instead of "green hydrogen" gained prevalence - jeopardizing the decarbonization agenda and opening space for incumbent energy systems to piggyback on this new industry. As a background, Brazil has been decreasing its hydrogen production since 2015 and 95 percent of what it produces is carried out by the country's state oil company Petrobras which fully comes from steam reforming of natural gas (Santana et al., 2023). In the meantime, considering hydrogen production only from new renewables curtailment, the economic costs of such investments in Brazil still face significant barriers. In other words, trading hydrogen produced in the country has so far proven to be more economically rewarding than converting it back into power (Macedo & Peyerl, 2022). This forces the scholarship to reflect on how Brazil will institutionally face this crossroads at the beginning of the industry's development, which will have fundamental impacts whether to deepen geoeconomic dependency relationships or expand the country's development opportunities through the domestic use of this source in energy-intensive industries, improving energy efficiency and competitiveness.

4. Conclusions

Scholarly works are still struggling to set a more comprehensive analysis of the institutional arrangements that might explain the stunning pace of renewable transition in the last twenty years. When resuming the concept of state capacity, it was possible to realize that Brazil's and China's central states have not kept the same ability to logistically implement its decisions over actual and potential opposition of entrenched socio-technical energy systems. It is evident that the scope of these capabilities has continually differentiated over the past decade, which can be observed both at the level of decarbonization and path dependence from incumbent energy systems. Whereas China's central state has deepened its capacity to implement the renewable transition through the unmatched state-owned banks funding and bureaucratic multilevel coordination mechanisms, Brazil's central state has partially abdicated its implementing institutions since the coup d'état that ousted an elected president in 2016. This has been clearly reflected in the differences between the two countries in terms of the technological upgrading of its industries and value capture in global chains. In other words, the transition policies toward new renewables seems to show a better institutional outcome in China than Brazil whether in terms of technological spillover effects or in relation to environmental mitigation.

The article adopted a cross-fertilization of institutional variables to differentiate wind energy implementation trajectories. The difference in the energy matrix and its distinct effects on the environment and the economy, constrained by both uneven bureaucratic coordination and financing tools, resulted not only in differences in the pace and scale of the wind transition but also in significant asymmetries regarding the industry's indigenous technological development. Against this backdrop, the main achievement was to qualify the state capacities of Brazil and China regarding their role in the asymmetric results of institutional reforms on incumbent energy systems, and

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whether, how and to what extent such reforms facilitated the wind transition in the two countries.

As a consequence, harnessing new renewables to develop the green hydrogen industry needs to be assessed within a comprehensive institutional scope. This means that the potential success that the development of the green hydrogen industry in Brazil may have in the short term as a provider of this energy carrier in international trade does not imply the best economic benefit for the country's productive regime in the long term. In other words, more than accelerating the domestic development of a green hydrogen industry to preferentially meet the demands of international trade, it would be more beneficial in the long term to avoid the commodity export trap and link this new industry economically and institutionally to the needs of the domestic green transition, such as a transport sector that is still highly carbonized. However, none of these predictions are feasible without institutional coordination, provided either by the stability of the political system or by instruments of state capacity. As we have seen throughout this work, the undermining of both in Brazil has reduced the opportunities for a renewable transition aimed at strategic development.

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