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CHANGE IN TERRITORIAL DYNAMICS, ENERGY TRANSITION, AND IMPACTS ON THE AGRICULTURAL SECTOR IN RIO GRANDE DO NORTE

Mudança na dinâmica territorial, transição energética e impactos no setor agropecuário no Rio Grande do Norte

Cambio en la dinámica territorial, transición energética e impactos en el sector agropecuario en Rio Grande do Norte

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ABSTRACT

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The research addresses electricity production in Rio Grande do Norte, analyzing changes in territorial dynamics caused by the installation of wind farms in a state that has traditionally focused on oil production. The shift in energy production has had direct consequences for agriculture, reducing the land area allocated to this activity in the regions where wind farms have been established. Wind farms affect approximately 20% of the area in the 10 municipalities with the highest concentration of these enterprises, where there has been a significant reduction in cultivated land and the number of farmers between 2006 and 2017. Making use of Milton Santos' theoretical-methodological approach, which considers space as a totality, the study evaluates the relationship between territories used for oil and wind energy production, as well as their impacts on the labor market and agriculture. The analysis reveals that the installation of wind farms—requiring a large workforce during the installation phase, followed by a sharp decline in labor demand during the operation and maintenance phase—leads to the loss of direct and indirect jobs in the municipalities where these enterprises are located. Additionally, it negatively affects the dynamics of agricultural activity by reducing cultivated land areas, further intensifying structural changes in the Potiguar territory.

Keywords: Energy; Oil; Wind farm; Agriculture; Rio Grande do Norte.

RESUMO

A pesquisa aborda a produção de energia elétrica no Rio Grande do Norte, analisando mudanças na dinâmica territorial ocasionadas pela instalação de parques eólicos no território de um estado que, tradicionalmente, voltava-se à produção de petróleo. A mudança de foco na produção de energia trouxe consequências diretas para a agricultura, com redução de área destinada a essa última atividade nos locais de instalação dos parques eólicos. Os parques eólicos afetam aproximadamente 20% da área dos 10 municípios com maior concentração desses empreendimentos, nos quais apresentam uma redução significativa na área plantada e no número de agricultores entre 2006 e 2017. Fundamentado na abordagem teórico-metodológica de Milton Santos, que considera o espaço como totalidade, o trabalho avalia a relação entre o uso do território para a produção de petróleo e de energia eólica, bem como seus impactos no mercado de trabalho e na agricultura. A análise revela que a instalação de parques eólicos, que demandam grande quantidade de mão de obra no momento de instalação, seguido por uma acentuada redução na fase de operação e manutenção, provoca perda de empregos diretos e indiretos nos municípios de localização desses empreendimentos, além de modificar negativamente a dinâmica da atividade agropecuária, com redução de área de lavouras, acentuando mudanças estruturais no território potiguar.

Palavras-chave: Energia; Petróleo; Parque eólico; Agricultura; Rio Grande do Norte.

RESUMEN

La investigación aborda la producción de energía eléctrica en Rio Grande do Norte, analizando los cambios en las dinámicas territoriales ocasionados por la instalación de parques eólicos en un estado que tradicionalmente se ha centrado en la producción de petróleo. El cambio en la producción de energía ha tenido consecuencias directas para la agricultura, reduciendo la superficie destinada a esta actividad en las regiones donde se han establecido parques eólicos. Estos parques afectan aproximadamente al 20% del área de los 10 municipios con mayor concentración de estos emprendimientos, donde se ha observado una reducción significativa en la superficie cultivada y en el número de agricultores entre 2006 y 2017. Basado en el enfoque teórico-metodológico de Milton Santos, que considera el espacio como una totalidad, el estudio evalúa la relación entre el uso del territorio para la producción de petróleo y de energía eólica, así como sus impactos en el mercado laboral y en la agricultura. El análisis revela que la instalación de parques eólicos, que requiere una gran cantidad de mano de obra durante la fase de instalación, seguida de una marcada reducción en la etapa de operación y mantenimiento, provoca la pérdida de empleos directos e indirectos en los municipios donde se localizan estos emprendimientos. Además, modifica negativamente la dinámica de la actividad agropecuaria, reduciendo la superficie de cultivo y acentuando los cambios estructurales en el territorio potiguar.

Palabras clave: Energía; Petróleo; Parque eólico; Agricultura; Rio Grande do Norte.

1 INTRODUCTION

Following the global course, in the early 2020s, Brazil has been marked by the dynamics of the energy transition. In the state of Rio Grande do Norte, this process has manifested through economic and labor shifts, changes in production chains, and transformations in territorial configurations, driven by the installation of wind farms in a region previously integrated into the oil production industry.

In 2017, the divestment actions in local oil activities (PETROBRAS, 2017a; 2017b) already indicates changes in the flows related to the national energy production, changing structures that had emerged from this activity.

From another perspective, wind farms in operation until 2023, supported by both federal and state governments, occupied approximately 1,300 km² (ANEEL, 2016 [2024]), which corresponds to 2,5% of the state's 52,8 mil km² (IBGE, 2023), and where located within the legal-administratives boundaries of 36 municipalities[1].

These wind farms occupied approximately 20% of the land area across the 10 municipalities[2] with the highest number of operational wind farms (189) in 2023 (ANEEL, 2024). Concurrently, these municipalities experienced a reduction of 32,000 hectares in planted area and a 27% decrease in the number of agricultural producers between 2006 and 2017 (IBGE, 2017).

In this context, it becomes relevant to question whether the installation of wind farms by introducing different technical, institutional, and labor systems compared to the previously existing energy production activities in Rio Grande do Norte—also alters the state's agricultural dynamics.

This research proposes an analysis of the changes in territorial dynamics resulting from the installation of wind farms, compared to the previously existing energy production structure in Rio Grande do Norte, which was characterized by oil production (Alexandre, 2003), with particular attention to their interaction with the use of arable lands.

The theoretical-methodological approach was grounded in the understanding of space as a totality, as proposed by Santos (1988a), which allows for the fragmentation and analysis of spatial elements and their interactions, enabling a deeper understanding of the used territory as a site where life materializes (Santos, 1999), establishing connections between surrounding structures (Castilho & Frederico, 2011; Dantas, 2016).

[1] The municipalities with operational wind farms in the state of Rio Grande do Norte (RN) in 2023 were: Afonso Bezerra, Angicos, Areia Branca, Bento Fernandes, Bodó, Brejinho, Caiçara do Norte, Caiçara do Rio do Vento, Ceará-Mirim, Cerro Corá, Currais Novos, Fernando Pedroza, Galinhos, Guamaré, Jandaíra, Jardim de Angicos, João Câmara, Lagoa Nova, Lajes, Macau, Parazinho, Parelhas, Pedra Grande, Pedra Preta, Pedro Avelino, Riachuelo, Rio do Fogo, Ruy Barbosa, Santana do Matos, São Bento do Norte, São Miguel do Gostoso, São Tomé, São Vicente, Serra do Mel, Tenente Laurentino Cruz, and Touros.

[2] The municipalities with the highest number of wind power projects by 2023, in descending order, were: Serra do Mel, Parazinho, João Câmara, São Miguel do Gostoso, Lajes, São Bento do Norte, Pedra Grande, Pedro Avelino, Jandaíra, and Touros.

Methodologically, the presentation of oil production areas and wind energy production areas—indicating the technical objects and flows associated with each productive activity—was carried out cartographically, incorporating the use of chorems as representations of the basic configurations observed (Brunet, 2021). In addition to the cartographic representation, a comparison was conducted between the energy production activities, specifically with regard to data on existing business establishments involved in oil production and electricity generation in the municipalities under study.

Given that one of the spatial characteristics of wind farms is the land area required for the installation of energy generation equipment, and that agricultural activity in the municipalities involved holds both economic and territorial relevance (Tavares, 2017), an analysis was conducted on the changes brought about by the expansion of wind energy in relation to agricultural activity.

To carry out the analyses, the following were considered: (a) the installation of wind farms in the state of Rio Grande do Norte (RN) beginning in 2011, with the highest number of operations commencing in 2014, 2015, 2016, and 2021 (ANEEL, 2023); (b) the National Classification of Economic Activities – CNAE 2.0 adopted by IBGE since 2006; (c) the year 2017 as the milestone marking the beginning of asset sales in oil production, and 2020 as the year in which the Potiguar cluster was offered, signaling the redirection of state-owned business activities in onshore and shallow-water oil production in RN; (d) that during the period of wind farm installation and state divestment in the oil sector, agricultural censuses were conducted only in 2006 and 2017; and (e) that the land market report for the state was produced in 2017 and 2022, based on data from the immediately preceding years.

Given the availability of data from agricultural censuses, land market studies, and key events related to the divestment in the oil sector and the record installation of wind farms, concentrated in the years 2006, 2017, and 2021, the research was anchored in these years in order to examine the maximum number of existing linkages.

The structure of the article is organized as follows: the first section addresses international theoretical approaches discussed within the context of the energy transition; the second presents aspects of geographic theory used to support the analyses; the third and fourth sections explore the different energy production activities investigated—oil and wind energy; the fifth provides an analysis of agricultural activity, followed by the final considerations.

2 THE ENERGY TRANSITION AND ITS BROADER PROCEDURAL CONTEXT

At the beginning of the 2020s, the energy transition has become an institutionalized and normalized fact on the global stage, driven by the 2030 Agenda and international climate agreements, most notably the Paris Agreement (UNFCCC, 2015), which establishes a conditional link between human life and environmental stewardship.

The energy transition is part of a broader global paradigm transition that seeks, among other goals, to generate energy from renewable sources in replacement of fossil fuels, which have historically dominated the energy system (Gitelman; Kozhevnikov, 2022; Harichandan et al.,2022), This transition is part of a broader sustainable transformation process, defined as a sequential process of implementing social and technical systems based on modes of production and consumption guided by sustainability (Markard et al., 2012).

The modification of energy matrices has been increasingly supported by institutions, which have elevated the relevance of climate and environmental factors (Gielen et al., 2019). This trend is also deeply interconnected with geopolitical, economic, technological, and social issues (Goldthau et al., 2019; Blondeel et al., 2021; Genc; Kosempel, 2023; Markard, 2018; Sovacool; Dworkin, 2015; Garcia-Casals et al., 2019).

This is a reorganization of the operational logic of societies worldwide through changes in energy generation technologies, existing infrastructure, consumption patterns, and especially the social behavior. This transformation requires a restructuring of the organizational systems built around fossil energy sources, occurring concurrently with the intensification of political and economic conflicts in the contest for leadership within the new global order (Jianchao, et al., 2021).

Sustainability is also reflected through the dimensions of energy access and security, including supply continuity as key elements in shaping and driving the debate (Jonsson et al., 2015; Sun et al., 2023).

The energy transition is addressed through its environmental, climate-related, access, and security dimensions, which serve as drivers of change to be implemented via a chain of technological advancements aimed at strengthening industrial production sectors (Fontes, 2021 while maintaining a focus on mobilizing industry and the necessary resources to accelerate the transition process (Fontes, 2022), which the structural dimension is just one of many factors to consider.

The energy transition process entails socio-economic costs and benefits that depend on the material and structural changes taking place in each location. These changes reflect natural and technological conditions as well as decisions made by actors operating across multiple scales (Stoeglehner et al., 2011; Coenen et al.,2012; Bridge et al., 2013).

As such, spatial specificities that were once considered contextual such as the ecological environment, institutional arrangements, pre-existing infrastructure, local economic activities, and the labor market, become critical when the energy transition process, which involves the extensive implementation of technical artifacts embedded with contemporary sustainability values, is not properly coordinated (Stoeglehner et al., 2011).

In these scenarios, socio-spatial costs, such as employment impacts, social well-being, the decline of other economic activities, and additional externalities, tend to move in a direction diametrically opposed to the integration of technical systems and the economic gains secured by actors operating at multiple levels.

It is important to note that the use of fossil fuels for electricity generation in Brazil is only 7.3%, with non-renewable sources totaling 13.9% of the 200 GWh produced a scenario that contrasts sharply with the global context, where fossil fuels represent over 60% of primary energy sources for electricity generation (EPE, 2024). Thus , the energy transition in Brazil exhibits characteristics that are distinct from those observed in most other countries.

3 THROUGH GEOGRAPHICAL LENSES

Given the broad scope of the subject, the importance of its analysis, and the diversity of scientific and epistemological foundations capable of addressing it, the choice of an appropriate approach tends to favor those that enable both comprehensive analysis and in-depth investigation.

The epistemology of space developed by Milton Santos in the final decades of the twentieth century (Santos, 1988a; 1988b; 1994; 1999; 2006), proves particularly well-suited to offering a holistic vision that integrates multiple forms of existence through a spatial and temporal perspective of societies.

The articulation between geographic objects – natural and technical – and social life, enabled by his epistemological framework, allows for the observation of interactions among these elements in the formation and transformation of space, highlighting their mutual interdependence in shaping reality.

As a material entity endowed with values attributed by society (Santos, 1988b), space comes to be understood as territory. From this understanding emerges a visualization of space as shaped by the interests and aspirations of society, as expressed through its use.

Political, economic, institutional, and social interests embedded in the use of territory can thus be observed in an integrated manner. This occurs through a dialectical process that combines specific and selective elements, such as systems of technical objects oriented toward production (Castilho; Frederico, 2011; Dantas, 2016) with the flows of a spatial totality.

The use and value assigned to each portion of territory allow for the observation of distinct realities within the broader spatial construct, each playing a particularized role while remaining correlated with all other portions of space (Santos, 1988a).

The adoption of this epistemological and methodological framework enables a closer approach to the real dynamics of society, which entails the recognition of territory as a resource, particularly through its economic use.

Fluidity, linked to competitiveness, which underpins economic relations is operationalized by regulated and informed actions acting upon technical objects specifically designed to facilitate such flows (Santos, 2005), thus being understood as part of the processes of spatial formation and organization.

The economic use of space creates different territorial domains, both contiguous and distant (Santos, 2005), whose materialities are defined by the differentiated values imposed on each spatial fraction.

New objects are continually created, and new human actions, carriers of social intentions, assign new functions to places in an ongoing process of establishing links between productive activities and the structures that surround them (Castillo; Frederico, 2011).

The introduction of new materialities into territorial fractions, endowing them with new functions and values, causes these fractions to change; and, as with any relational phenomenon, their counterparts are also automatically transformed (Santos, 2014).

In this context, the relationship between the current moment of energy transition and the uses of territory in the constitution of productive energy activities and their networks reveals that this is not merely an ideological shift or a matter of environmental or political awareness. Rather, it represents a broad and profound reorganization of geographic space.

Grounded in geographical theoretical and methodological tools, this study enables the articulation between the local territorial sphere and the globally significant transitional phenomenon, which are intrinsically interconnected.

4 RIO GRANDE DO NORTE AND THE USE OF TERRITORY FOR OIL AND WIND ENERGY PRODUCTION

Following the socio-spatial formation process of Brazil during the colonial period and the early years of the Empire, the state of Rio Grande do Norte (RN) remained tied to traditional economic activities, such as livestock and agricultural production, which began on the eastern coast and later expanded inland (Tavares, 2017).

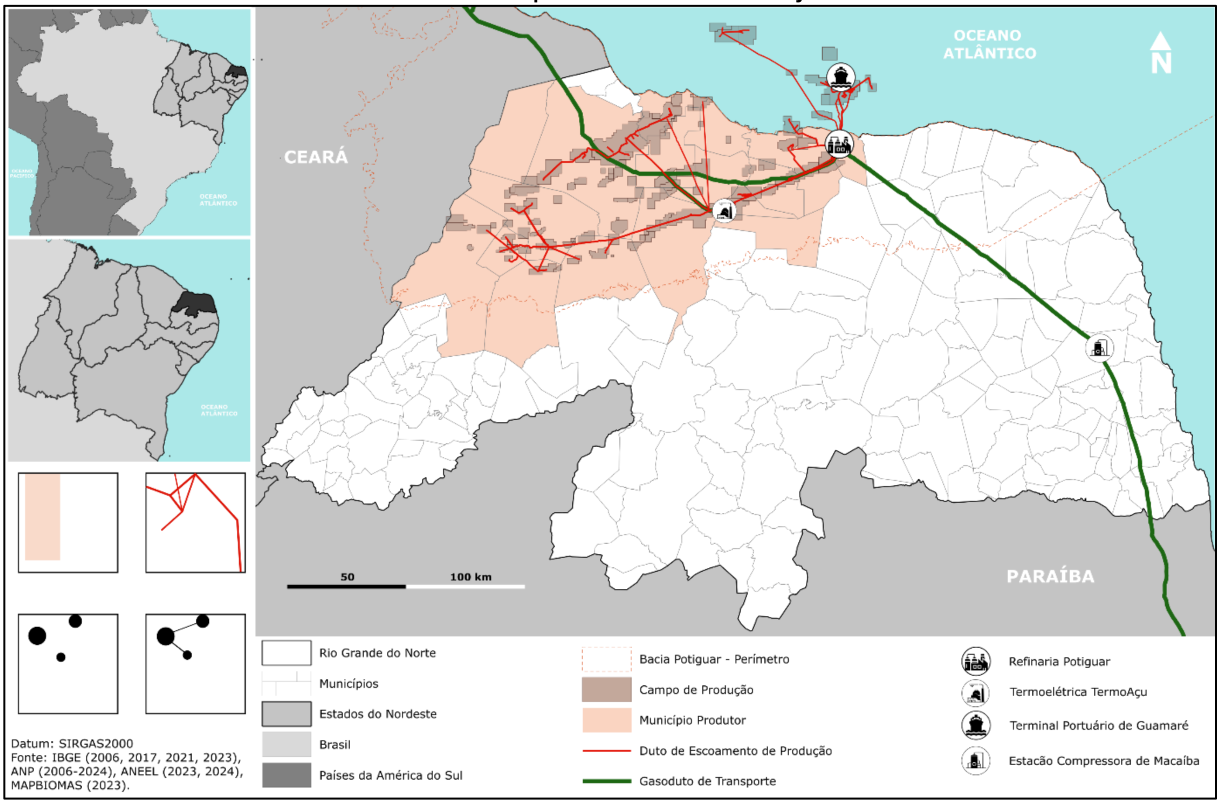
Between the 1970s and 1980s, in a somewhat belated alignment with the national industrialization process that intensified during the 1950s, Rio Grande do Norte received substantial state investments. These investments enabled the establishment and partial modernization of industrial economic production within the Potiguar territory, although this development continued to contend with the dominance of markets based in the country's central economic axis (Tavares, 2017).

In the 1980s and 1990s, as capital accumulation trends rapidly accelerated structural transformations in the national productive landscape (Azevedo, 2013), the state of RN also began incorporating technical systems aligned with integration into globalized production structures (Tavares, 2017).

The material modernization of the potiguar territory, made possible through public funding, fostered the regionalization of various economic activities. Notable among them were irrigated fruit cultivation in the Açu Valley, the modernization of the salt industry along the northern coast, the textile industry in the Metropolitan Region of Natal and the Seridó region, tourism along the eastern coast and the expansion of commerce and services in the capital and regional urban centers (Azevedo, 2013). However, oil production in the northwest of the state emerged as a particularly prominent activity.

After decades of mineral exploration aimed at discovering oil within Brazilian territory, Petrobras located oil reserves in the Potiguar region in the early 1970s, an effort spurred by the international oil crisis (Tavares, 2017). This discovery triggered the installation of a comprehensive set of facilities dedicated to production (Figure 01), research, and the training of a local workforce. These initiatives altered the territorial configuration and acted as drivers of economic and social dynamics characterized by job creation, technological development, and the generation of significant financial resources.

FIGURE 01 – Rio Grande do Norte: Representation of Major Oil Production Infrastructure



Source: IBGE (2006,2017, 2021, 2023) ANP (2006-2024), ANEEL (2021, 2024), MAPBIOMAS (2023).

In 2021, there were 83 oil production fields in Rio Grande do Norte, 77 of which were onshore and overlapped with administrative areas of 17 municipalities located in the northwestern region of the state. These areas were marked by the presence of technical infrastructure associated with natural resource extraction, including wells, pumping equipment, flow pipelines, primary processing units, and transport pipelines, in addition to offshore operations in six productive fields that required the presence of fixed production platforms.

Beyond the infrastructure for extracting raw materials, oil and natural gas, Rio Grande do Norte also incorporated, as part of its spatial development, the Guamaré Industrial Hub. This hub houses integrated technical structures such as the Natural Gas Processing Unit and the Potiguar Clara Camarão Refinery, both dedicated to the production of petroleum derivatives. Additionally, the Nordestão Gas Pipeline links the state to Ceará and connects Rio Grande do Norte to Southeastern Brazil via an extensive pipeline network.

The existence of these two facilities led to the development of associated transport and distribution networks, integrating raw material production with the distribution of refined products. These include the maritime terminal, oil pipelines, storage terminals, distribution centers, natural gas compressor stations, and gas delivery points for distributors and large-scale buyers.

Supporting the entire production chain, research units and academic programs were also established in educational institutions, aimed at fostering technological feedback and professional qualification tailored to the sector. Supplementary networks of suppliers were consolidated, alongside companies providing specialized services and an entire institutional framework of state agencies responsible for promoting and regulating this activity of strategic national importance.

Since the first discovery of a commercially viable reservoir, oil and derivative production has served to integrate Rio Grande do Norte into a globally scaled activity with strong national integration dynamics focused on energy supply.

Following the commercial discovery of oil reservoirs in the state, production capacity fluctuated over the decades. Between 1970 and 1980, the state emerged as Brazil's third-largest producer, following Rio de Janeiro and Bahia. Between 1990 and 2000, it rose to second place, a position it did not maintain. By 2006, other producing states had surpassed it, placing RN as the sixth-largest producer of oil equivalent in the country (ANP, 2020a [2024]).

By the most recent period of research, the state's production primarily served to meet its own demand for gasoline, fuel oil, LPG, aviation kerosene, and natural gas, while also contributing, during surplus periods, to maintaining national supply logistics (ANP, 2020b [2024], 2020c [2025]).

However, with the discovery of Brazil's pre-salt reserves in the deep waters off the Southeast coast, combined with a growing focus on cleaner and more efficient energy production under the energy transition framework, the oil fields of Rio Grande do Norte, already in a phase of production decline, were relegated to a marginal role due to their maturity and limited output (Resolução ANP nº 749/2018).

Petrobras, which until then held a de facto monopoly as the concessionaire of the Potiguar Basin's production fields, acted in accordance with legal provisions (Law No. 13.303/2016 and Decree No. 8.945/2016) to manage its assets in the state, offering them for sale in 2017 (Petrobras, n.d.).

This action, taken by the company responsible for the primary activity within Rio Grande do Norte's oil production chain, had a profound impact on business and labor markets in the sector, as reflected in the decline in the number of establishments and formal workers involved in the activity (Table 01).

Table 01 – Changes in the Number of Establishments and Formal Workers in Municipalities with Oil Production Activity in Selected Years (2006–2017–2021)

Área	Município	2006		2017		2021	
		Est.	Trab.	Est.	Trab.	Est.	Trab.
Produção Direta	Açu	0	0	1	1	0	0
	Alto do Rodrigues	2	522	3	335	4	686
	Apodi	1	25	0	0	0	0
	Areia Branca	1	25	0	0	0	0
	Gov. Dix-Sept Rosado	1	136	0	0	0	0
	Guamaré	2	507	1	364	1	122
	Macau	0	0	0	0	2	167
	Mossoró	19	1516	25	856	23	1398
Admin. e Apoio	Natal	13	1039	5	779	2	297
	Macaíba	0	0	1	11	1	13
	São José do Mipibu	1	29	1	2	1	1
Total		**40**	**3799**	**37**	**2348**	**34**	**2684**

Source: Prepared by the author based on RAIS/CAGED data (MTE, 2023).

This change led, in the short term, to a deceleration of oil-related activities, which for decades had been responsible for driving productive consumption in the state (Tavares, 2017).

Economic and statistical indicators for Rio Grande do Norte showed a significant decline in the share of extractive industries in the state's Gross Value Added (GVA), with their contribution falling from 7.6% in 2010 and 9.5% in 2012 to just 1.8% in 2017, followed by a partial recovery to 5.5% in 2022 (IDEMA, 2024a; 2024b).

On the other hand, Rio Grande do Norte, characterized by favorable physical and climatic conditions for solar energy production and, in particular, wind energy, began to be considered a priority area for the installation and expansion of these productive circuits within the framework of State Energy Planning (MME, 2022).

Consistent winds, with the ideal strength and quality for wind energy production, enabled by the state's geographic location, have made Rio Grande do Norte a target for development incentives (CERNE, n.d.) aimed at attracting investments in power generation and transmission infrastructure (Figure 02). These efforts are driven by the socioeconomic interest in converting the region’s natural potential into a resource to be exploited and developed.

Figure 02 – Technical objects of wind energy production and power transmission in Rio Grande do Norte

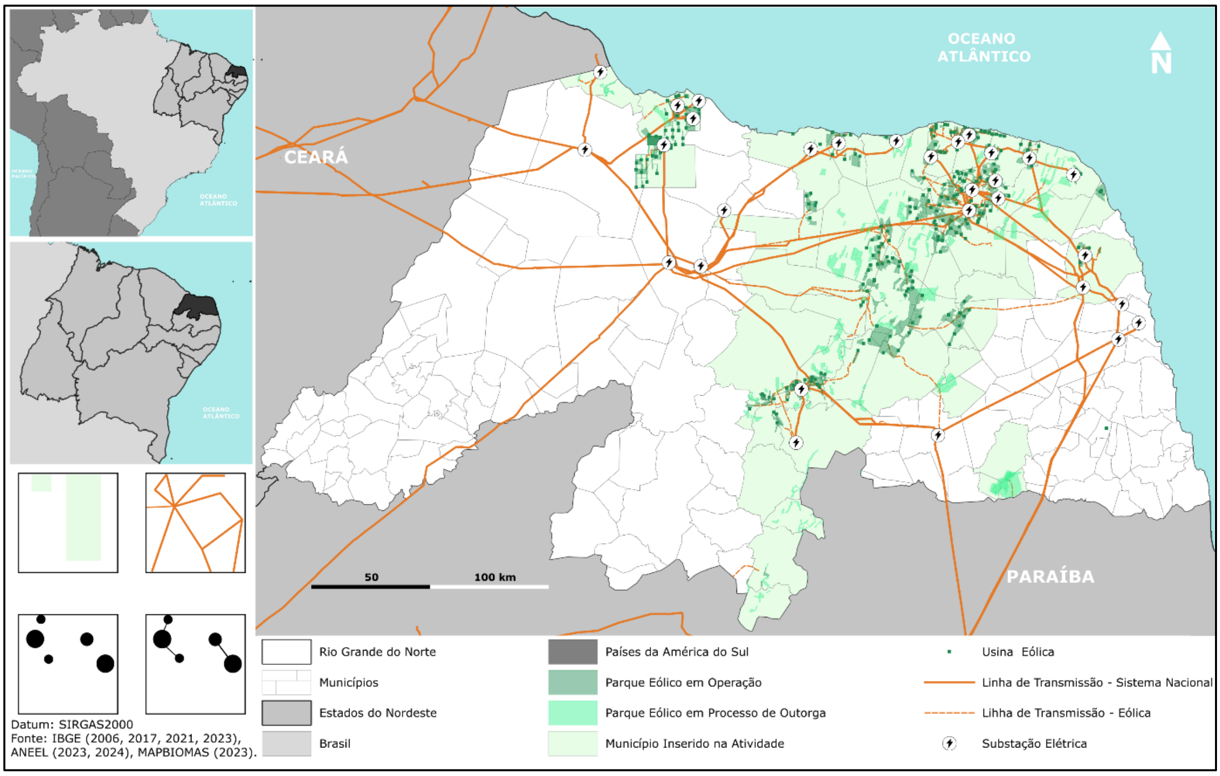
Source: Acervo do autor (2023).

Over a 15-year period (2001 to 2016), the territorial configuration of Rio Grande do Norte came to include technical infrastructure related to wind energy activities, such as wind turbine towers, transmission networks, and electrical substations. These developments altered the landscape and reshaped the dynamics involved in the establishment of 149 wind farms that began operations during that time frame.

In 2021, Rio Grande do Norte generated 6.33 GW of electricity from 208 operational projects, making it the second-ranking state in terms of the number of wind energy facilities and responsible for one-third of the nation’s electricity generation in this sector (ANEEL, 2024).

Two years later, in 2023, the state emerged as the leading national producer of wind energy while maintaining its second position in the number of operational projects, reaching a total of 280 active facilities. It also recorded the highest granted and supervised capacity in the country, reaching a peak of 9.07 GW (ANEEL, 2024), This confirmed the state’s territorial potential for wind energy development and gave rise to a new spatial configuration (Figure 3).

Figure 03 – Rio Grande do Norte: Representation of the main wind energy production infrastructures



Source: IBGE (2006, 2017, 2021, 2023), ANEEL (2023, 2024), MAPBIOMAS (2023).

The success in installing generation capacity did not necessarily translate into the consolidation of a productive circuit capable of significantly engaging the local socioeconomic dynamics. This is due to the fact that the manufacturing phase[3] is largely concentrated in the Southeast region of the country, with some suppliers operating in Bahia, Ceará, and Pernambuco. With the exception of a few companies responsible for tower construction, Rio Grande do Norte has played only a limited role in this phase of the activity (Araújo; Saavedra; Boeira, 2023).

With regard to the installation of wind farms and their subsequent operation and maintenance employment levels follow a pattern in which the peak occurs precisely during the installation stage. This initial phase accounts for more than 50% of all labor contracted throughout the wind energy production chain (Araújo; Saavedra; Boeira, 2023).

After installation is completed, Rio Grande do Norte experiences a sharp decline in both the number of companies and, more notably, the number of workers involved in the activity. When maintained, these jobs represent only 10% to 30% of the initial volume of

[3] According to Araújo, Saavedra, and Boeira (2023), “os fabricantes de aerogeradores (OEM) são os principais agentes da cadeia de valor e detêm a maior parte da tecnologia, das informações técnicas relativas à manufatura, logística e o transporte das peças, instalação, operação e manutenção” (p.175).

contracted labor.

A higher number of companies and workers is retained only at the main connection points of the generation and transmission network. In areas dedicated exclusively to energy production, the number of formal establishments and employees drops to zero once the construction phase ends.

Considering only production areas with active wind farms, the total number of establishments in the categories of electric power construction, generation, and transmission and distribution included eight establishments and 287 workers in 2006, 29 units and 802 workers in 2017, and by 2021, 37 companies in operation, but with only 507 formally employed workers (MTE, 2023).

Although limited to a direct analysis of formal employment ties in the electric power sector of the municipalities involved, which includes not only wind generation, but also solar and transmission activities, these figures for the country's largest wind energy producer and home to its second-largest wind farm differ significantly from those projected in studies modeling the employment index for Brazil's wind energy value chain. These studies estimated a national scenario for 2030, projecting the creation of 44,000 direct jobs that year and a cumulative total of 800,000 direct and indirect jobs, with a trend of continued growth (Araújo; Saavedra; Boeira, 2023).

Based on this context, it is worth questioning whether the transformations brought about by the use of Rio Grande do Norte's territory for wind energy generation—as a driver of sustainable energy transition—can in fact be considered positive, particularly when compared to the labor market dynamics of the oil-based energy production circuit.

5 REGULATIONS, OIL AND WIND

Although energy production from various sources is normatively defined as a matter of national interest, aimed at ensuring energy supply throughout the national territory (Law No. 9478/1997), the legal frameworks governing the exploitation of these resources differ significantly.

While oil activities are defined as a state monopoly, subject to a concession regime for private capital exploitation, wind energy, classified among renewable sources, may be produced without prior authorization or concession when it involves small-scale facilities (Federal Constitution of 1988). Furthermore, wind energy production benefits from a set of incentives for private agents, including guaranteed purchase agreements, facilitated access to credit, and integration into transmission systems (Law No. 10.438/2002).

The oil requires complex institutional action and materializes through the establishment of robust technical infrastructure in the localities involved, forming production circuits designed to endure over successive production cycles. In contrast, in wind energy production, the most intense socioeconomic flows associated with the producing territories are concentrated during the construction of wind farms and their connection to the National Interconnected System. The subsequent phases of the activity are largely limited to maintenance and security operations, which typically require minimal labor.

In both sectors, land leasing is a common practice, whereby landowners are compensated for the installation of production equipment on their properties. It is also common for land to remain in use for other purposes, allowing for coexistence with agricultural or livestock activities.

A key distinction, however, lies in the legal obligation imposed on oil exploration agents, who must pay a percentage of production revenues to landowners in addition to leasing fees (Law No. 9478/1997). The government revenues associated with oil activity, arising from the economic surplus imposed by the legal framework, include taxes, royalties, and special participation fees. These do not apply to wind energy production.

Under the incentive policy, the development of renewable energy infrastructure enjoys significant tax relief. From this perspective, the installation of wind energy infrastructure is supported by exemptions, reductions, or waivers of various taxes, including Import Tax (CAMEX Resolution No. 125/2016; GECEX Resolution No. 541/2023), Excise Tax on Industrialized Products (Decrees No. 7212/2010, No. 8950/2016, and No. 11.158/2022), Income Tax (Decree No. 4.213/2002), Value-Added Tax on the Circulation of Goods and Services (ICMS) (CONFAZ ICMS Agreements No. 109/2014 and No. 23/2024), as well as the PIS/COFINS social contributions (Law No. 11.488/2007). The only mandatory charges that remain are environmental licensing fees across different levels of government and the municipal service tax (ISS).

Finally, it is important to note that electricity generation, in itself, does not constitute a taxable event for ICMS, the primary state-level tax, which applies to the circulation of goods and certain services. According to Complementary Law No. 87/1996, the tax is collected in the destination state, i.e., where energy is consumed, not where it is generated, except in cases defined by law. Therefore, wind farms, as production sites, do not fall within the direct scope of ICMS incidence.

This regulatory and tax framework raises further questions for research into land use in this productive activity, since taxation, which could serve as an institutional mechanism to return generated economic value, does not benefit the territory where production occurs.

6. LOCAL AGRICULTURE BETWEEN OIL AND WIND

The prominence of wind energy generation capacity and the number of installed wind farms has, in addition to impacting the labor market and regulatory-tax aspects, drawn attention to the socioeconomic consequences associated with the activity, particularly due to the need for land availability and use (Gorayeb; Brannstrom; Meireles, 2019).

The areas occupied by wind energy ventures have been concentrated in regions traditionally dedicated to agriculture and livestock, key components in the territorial formation of Rio Grande do Norte, such as João Câmara, Serra do Mel, and Touros (Azevedo, 2013; Lima, 2015), This situation has made it necessary to reflect on the dichotomies in land use for different productive activities.

Traditional agricultural activity, which marked the state's historical development, most notably with the cotton cycles in the interior and sugarcane cultivation in the area just inland from the eastern coast, has gradually been replaced by subsistence farming and, in a few locations with better water availability such as the Açu Valley, Tibau, Baraúna, Apodi, Mossoró, and Upanema, by irrigated fruit cultivation (Azevedo, 2013; Santos, 2024).

Rio Grande do Norte has a total area of nearly 52,800 km², of which approximately 800 km² are urbanized. In 2017, land designated for agriculture and livestock totaled 27,000 km². However, the area actually harvested, where agricultural production effectively took place, represented only about 10% of that, reaching 2,900 km² (IBGE, 2019).

These data demonstrate that, proportionally, Rio Grande do Norte had a large area of arable land but a relatively small area under cultivation. Although the dominant narrative emphasizes natural limitations, such as soil types and the hot, dry climate, ultimately, the main limiting factor for agricultural production in the state is the low level of technology used in farming practices (Lima, 2015; Locatel, 2018).

Consequently, the limited use of arable land meant that in 2017, the state's agricultural and livestock production did not account for even 4% of Rio Grande do Norte's GDP (IBGE, 2023).

Historically, rural land in Rio Grande do Norte has ranked among the lowest in market value in Brazil, with wide variation across its microregions. In 2017, the Instituto

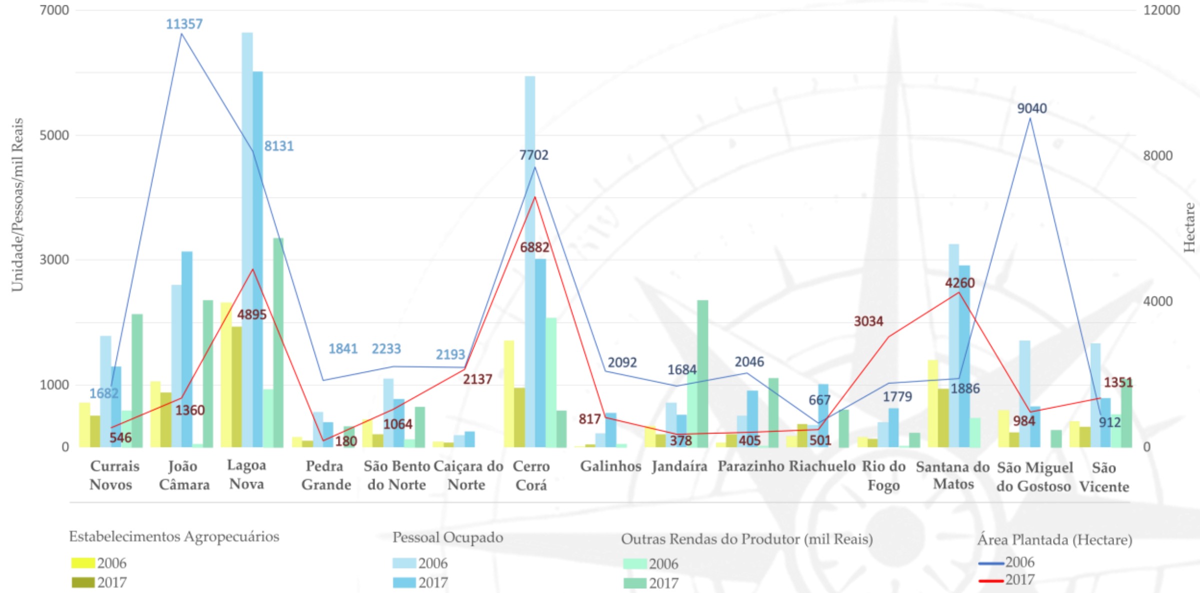
Nacional de Colonização e Reforma Agrária (INCRA) began classifying the state's land markets and conducted market research on land value per hectare to provide objective data for agrarian reform analyses (INCRA, 2017; INCRA, 2022). These diagnostic and monitoring tools made it possible to observe changes in land prices in areas where wind energy production has become prominent.

Across the state, land prices generally trended upward during the 2017 to 2022 when the studies were conducted (INCRA, 2017; INCRA, 2022). However, excluding the eastern coastal region, affected by the proximity to the capital, the areas where the highest increases were observed were precisely those where wind farms had been installed. In these localities, the average land price rose by as much as 109%, such as in the Seridó region, where the municipality of Cerro Corá is located and where average land values exceeded BRL 22,000 per hectare (INCRA, 2022)). This land appreciation contrasts with other areas of the state, which, despite recording increases of around 40%, maintained final average values below BRL 1,500 per hectare (INCRA, 2017; INCRA, 2022).

The increase in land prices directly correlates with the arrival of wind farms, being most pronounced in locations where these projects are already operational and beginning to influence land market behavior in expansion areas.

This phenomenon can also be analyzed using variables such as planted area, number of rural producers, employed personnel, and producer income from other activities in the main municipalities affected by wind energy activity (Figure 04).

Figure 04 – Planted area, number of agricultural establishments, employed personnel, and additional producer income in municipalities with operational wind farms (2006–2017)



Source: IBGE, 2017 (elaborated by the author)

It is important to note that, although other factors should be explored through qualitative research, the data analyzed, albeit limited, allowed for the inference of some changes already underway.

The number of agricultural establishments declined in most of the observed municipalities during the period, with the exception of Galinhos, Parazinho, and Riachuelo, which together increased by 348 establishments, contrasting with the overall reduction of 2,896 establishments recorded across the remaining municipalities.

The decrease in the number of agricultural establishments was correlated with a reduction in planted area in most municipalities, with a notable decline of approximately 90% in João Câmara and São Miguel do Gostoso. Parazinho, although it recorded a decrease in planted area, showed an increase in the number of agricultural establishments, suggesting a greater distribution of smaller landholdings in that locality. In contrast, Rio do Fogo and Santana do Matos experienced an increase in planted areas, indicating lesser influence from wind energy activity. However, this increase, when accompanied by a reduction in the number of agricultural establishments, points to greater land concentration.

The reduction in planted areas and the number of agricultural establishments, even in the absence of restrictions on agricultural use of land, indicates the susceptibility of the state's farmers to accepting land lease agreements, as noted by Traldi (2019), which helps explain the rise in other sources of income reported by producers (IBGE, 2017).

Thus, in municipalities where the largest number of wind farms were installed during the period and where land prices increased, agricultural dynamics were negatively affected by a decline in the number of agricultural establishments, a reduction in planted area, and a growing reliance on alternative income sources.

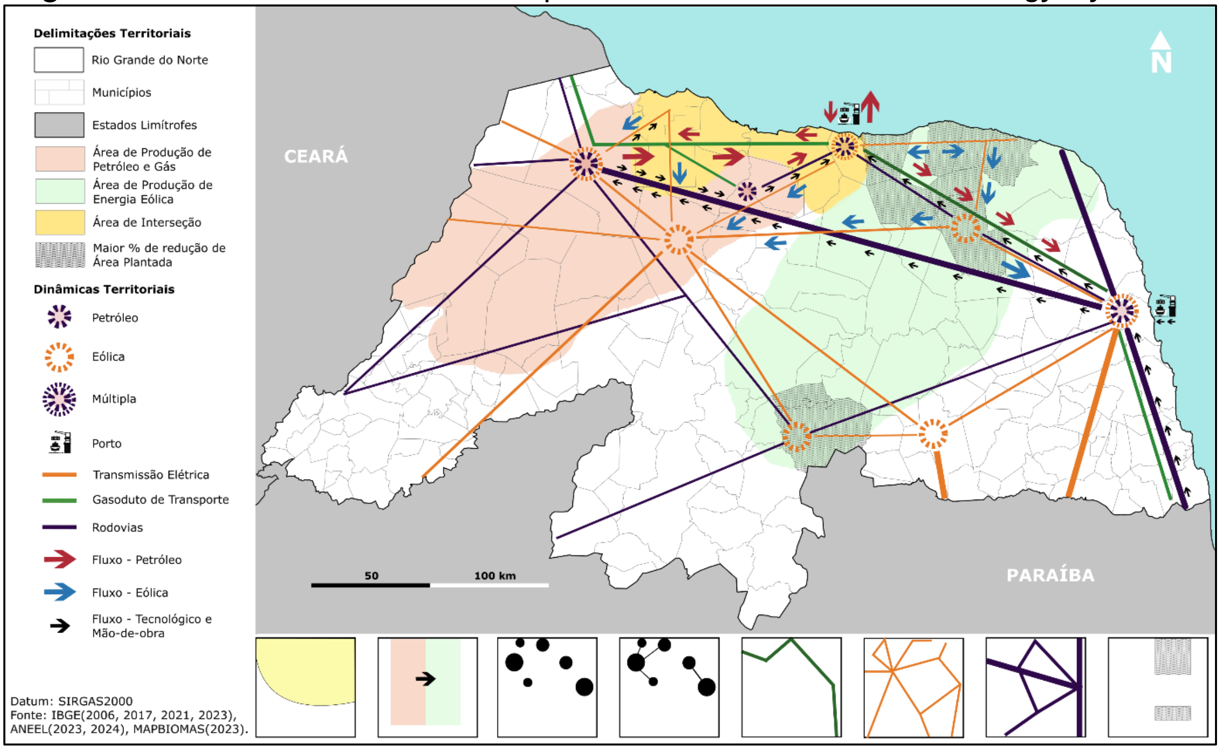
This reduction in agricultural activities has led to significant transformations at the local level, observable at smaller spatial scales. One example is the rise in property and rental prices in nearby urban areas, resulting in a higher cost of living (Traldi, 2019). Similarly, the decline in the production of agricultural goods, observed over the years 2006, 2017, and 2021 in eleven of the analyzed municipalities[4] (IBGE, 2023b), has directly affected the availability of these products in the local market.

In terms of territorial changes in the state, a cartographic representation is presented below, summarizing the dynamics of oil and wind energy production activities, and

[4] The municipalities and the percentage reduction between 2006 and 2021 in the amount of tons produced in permanent and temporary crops Currais Novos (76%), João Câmara (89%), Lagoa Nova (75%), Pedra Grande (24%), São Bento do Norte (84%), Caiçara do Norte (25%), Parazinho (4%), Riachuelo (70%), Santana do Matos (72%), São Miguel do Gostoso (64%) e São Vicente (63%)

identifying, with respect to the latter, the locations most affected in relation to agricultural activity (Figure 05).

Figure 05 – Rio Grande do Norte: Representation of Oil and Wind Energy Dynamics



Source: IBGE (2006, 2017, 2021, 2023); ANP (2006–2024); ANEEL (2023, 2024); MAPBIOMAS (2023).

It is noted that the dynamics of oil and wind energy production activities are concentrated along the state's coastline, with a slight inland extension from the northeast toward the center of the state.

Within this delimitation, it can be observed that oil production activity has been predominantly concentrated in the western region of the state, with its production operations connected to the port terminal integrated with the refinery. Wind energy activity, on the other hand, toward which current investment flows are directed, is primarily located along a center-to-northeast diagonal across the state.

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hand, toward which current investment flows are directed, is primarily located along a center-to-northeast diagonal across the state.

Although there is an overlapping zone between these two dynamics, this area also hosts infrastructure linked to other economic activities, such as irrigated fruit farming and mineral extraction, which influence local territorial dynamics (Santos, 2024).

Mossoró, as the second-largest consumption center in the state (ANP, 2022; ANP, 2020c [2025]. Potigás, 2025; Araújo, 2019; ONS, n.d.) and a reference municipality in western Rio Grande do Norte, influences nearby municipalities such as Areia Branca, Porto do Mangue, Serra do Mel, Carnaubais, Alto do Rodrigues, and Guamaré. These municipalities have historically been linked to oil production, although their economic activity is not limited to that sector (Santos, 2024).

Natal influences the dynamics of both activities. In addition to being the state's largest consumer of petroleum-derived fuels produced at the local refinery (ANP, 2022; ANP, 2020c [2025]; Potigás, 2025) and of the electricity fed into the National Interconnected System (Araújo, 2019; ONS, n.d.), it also serves as a scientific hub and center for workforce training (Oliveira, 2017). This proximity effect extends to the municipality of João Câmara, which has emerged as a center of wind energy activity and currently hosts a large number of service companies focused on wind farm maintenance.

Finally, it is important to note that João Câmara, which holds the highest concentration of service providers in the wind energy sector (Araújo, 2019), experienced an 88% reduction in planted area and a 16% decrease in the number of agricultural establishments (IBGE, 2017), resulting in a 92% drop in agricultural production between 2006 and 2017 (IBGE, 2023b). When compared with the 42-fold increase in other producer income, from BRL 54,000 in 2006 to BRL 2.3 million in 2017, these figures serve as a barometer of the territorial changes in the state driven by wind energy production.

7. FINAL CONSIDERATIONS

The context of energy transition, along with the technical, social, political, and especially geographical changes it entails, has intensified globally and, in the case of Rio Grande do Norte, in Brazil’s Northeast region, has demanded closer examination.

The existence of local oil activities, which played a significant role in the territorial formation of Rio Grande do Norte but have experienced economic decline since the early 2000s, has become emblematic of the transformations discussed on a global scale. This is particularly evident following state-led disinvestment beginning in 2017, which has resulted in a clear reduction in both the number of dedicated companies and employed personnel in the sector.

The rapid and progressive installation of wind farms, which in just two decades positioned the state as a national leader in electricity generation, initially reinforced its strategic role in Brazil's energy transition process.

In this context, new energy production zones have either overlapped or diverged from former energy-producing areas. Portions of the territory previously used for other purposes have been repurposed for renewable energy generation, driven by a rationale prioritizing generation efficiency, distribution, and expanded access. Areas once considered to have low economic value are now reinterpreted through the lens of technology implementation tied to the energy transition. Observed in an integrated manner, all these processes point to shifts in the socio-spatial characteristics of the territory.

Wind energy production achieved through the efficient conversion of an inexhaustible natural resource in a region that once relied heavily on electricity transmission from Brazil's Southeast and South has emerged as a coordinated response to environmental concerns and the need to ensure energy access.

However, the resulting consequences for the localities involved in production are already evident in some quantitative indicators, particularly in how they have altered the established dynamics of other productive sectors, especially agriculture and livestock.

Ultimately, wind energy production dominated in both Brazil and Rio Grande do Norte by foreign companies relies on technology, technical materials, and labor largely sourced from outside the producing regions. By occupying arable land and reducing agricultural production, it reveals, even if only partially, a disaggregating effect on previously existing local activities.

In this regard, it remains to be seen whether the territorial dynamics brought about by the installation of wind farms specifically in the places of production will maintain the profile observed in this study, whether they will be reversed over time, or whether other factors will emerge that bring about new changes, concentrating the activities of this expanding productive circuit within these locations.

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