



ANÁLISE GEOESPACIAL COMPARATIVA ENTRE USINAS A CARVÃO E NUCLEARES NA CHINA

COMPARATIVE GEOSPACIAL ANALYSIS BETWEEN COAL-FIRED AND NUCLEAR POWER PLANTS IN CHINA

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RESUMO

Este estudo apresenta uma análise geoespacial sobre a transição energética na China, focando na substituição de usinas a carvão por usinas nucleares. Utilizando o software QGIS, foram aplicadas técnicas de geoprocessamento para georreferenciamento e manipulação de camadas espaciais, permitindo um refinamento da análise. Inicialmente, os dados foram organizados e georreferenciados para garantir a precisão cartográfica. Posteriormente, a ferramenta *Kernel Density Estimation* foi empregada para gerar mapas de calor, evidenciando padrões de concentração das usinas nucleares e térmicas a carvão. Os resultados destacam a distribuição geográfica das usinas e sua influência na matriz energética do país. A análise revela uma concentração crescente de novas usinas nucleares, especialmente em províncias costeiras, como Guangdong e Fujian, onde há maior demanda energética e infraestrutura avançada. Além da dimensão ambiental, que aponta para uma significativa redução de emissões de CO₂, o estudo aborda implicações sociais e econômicas. A transição para energia nuclear pode melhorar a qualidade do ar, minimizar conflitos territoriais e reduzir a dependência de combustíveis fósseis importados. Entretanto, desafios como o gerenciamento de resíduos radioativos e aceitação pública da energia nuclear ainda precisam ser enfrentados. Conclui-se que a energia nuclear representa uma alternativa viável à geração térmica a carvão, oferecendo maior eficiência na ocupação do território e contribuindo para a redução das emissões de gases do efeito estufa. O estudo reforça a importância do SIG como ferramenta estratégica para a análise espacial e o planejamento energético, fundamentando decisões que podem impactar a sustentabilidade e o desenvolvimento econômico da China.

Palavras-chave: energia; nuclear; carvão; QGIS; sustentabilidade.

ABSTRACT

This study presents a geospatial analysis of the energy transition in China, focusing on the replacement of coal-fired power plants with nuclear power plants. Using the QGIS software, geoprocessing techniques were applied for georeferencing and manipulation of spatial layers, allowing for a more refined analysis. Initially, the data were organized and georeferenced to ensure cartographic accuracy. Subsequently, the Kernel Density Estimation tool was used to generate heat maps, evidencing concentration patterns of nuclear and coal-fired power plants. The results highlight the geographical distribution of the plants and their influence on the country's energy matrix. The analysis reveals a growing concentration of new nuclear power plants, especially in coastal provinces such as Guangdong and Fujian, where there is greater energy demand and advanced infrastructure. In addition to the environmental dimension, which points to a significant reduction in CO₂ emissions, the study addresses social and economic implications. The transition to nuclear energy can improve air quality, minimize territorial conflicts, and reduce dependence on imported fossil fuels. However, challenges such as radioactive waste management and public acceptance of nuclear energy still need to be addressed. It is concluded that nuclear energy represents



a viable alternative to coal-fired thermal generation, offering greater efficiency in the occupation of the territory and contributing to the reduction of greenhouse gas emissions. The study reinforces the importance of GIS as a strategic tool for spatial analysis and energy planning, supporting decisions that can impact China's sustainability and economic development.

Keywords: energy; nuclear; coal; QGIS; sustainability.

1. INTRODUCTION

The energy transition represents one of the biggest global challenges today, especially for countries that are highly dependent on fossil fuel-based energy reserves and generation, such as China. In this context, nuclear energy has been considered a strategic alternative to coal, being a recurring theme in studies on sustainability and energy security. Research carried out in several countries has already explored methodologies to determine the suitability and installation of new nuclear power plants, using tools such as the Geographic Information System (GIS) to support strategic decisions. Previous studies have shown that geospatial, environmental, and socioeconomic criteria are fundamental for this assessment (SILVA et al., 2013; DAMOOM et al., 2019), allowing planners to make more assertive and sustainable choices.

To assess the feasibility for replacing coal with nuclear power in China, this study employed a GIS-based approach. The methodology covered the evaluation of energy sources considering their CO₂ emissions, land use, operating cost and continuity of supply. The QGIS program involved the integration of geographic data of the study area with technical, economic and environmental parameters of different energy technologies. The results obtained may be useful for future evaluations of the benefits of this transition, considering aspects such as emission reduction, energy stability, and socioeconomic impact.

The main objective of this study was to develop a GIS based methodology as a means of analyzing the benefits of the predominant replacement of coal-fired power plants by nuclear power generation facilities in China. The proposed approach allowed the identification of locations with an expanding presence of nuclear power plants, which are contributing to the formulation of more sustainable and efficient energy policies, taking into account the generation capacity of few nuclear units compared to the significant number of coal-fired facilities.

2. CONSIDERATIONS FOR POWER GENERATION SOURCES

Studies such as the comparative analysis of greenhouse gas emissions (WORLD NUCLEAR ASSOCIATION, 2024) can use Geographic Information System (GIS) tools for complementary analyses. Nuclear energy emits only a few grams of CO₂ equivalent per kWh of electricity produced, considering its entire life cycle. The UN's Intergovernmental Panel on Climate Change (IPCC) has provided a median value of 12 g CO₂ equivalent/kWh for nuclear power, similar to wind power (SCHLÖMER, 2014). By contrast, pulverized coal (PC) plants have significantly higher lifecycle emissions. The analysis highlights the relevance of integrating environmental data with advanced tools to obtain a more detailed and comparative perspective.

2.1. Plugin Nuclear Facilities in QGIS

The use of GIS tools has been fundamental for the geospatial analysis of energy infrastructures. In the context of nuclear power plant mapping, one of the key resources available is the QGIS program's Nuclear Facilities plugin, which provides a global database of operational, under construction, and decommissioned nuclear power plants. This tool available in QGIS can be used for geospatial studies, offering a comprehensive view of nuclear distribution worldwide.



However, the plugin's database has significant limitations. First, much of the available data is outdated, not reflecting recent changes in the global energy mix, such as new plants under construction and recent closures. Second, the plugin takes a global approach, without prioritizing any specific region, which can make it difficult to analyze focused on strategic countries.

Updating this data provides detailed and current analyses, such as the analysis of energy generation capacity. In this way, the integration of this information through GIS allows the identification of essential nuances in the evaluation of the energy potential of nuclear structures, distinguishing them from the approaches employed in conventional energy infrastructures.

2.2. Updates in this study

Unlike the QGIS Nuclear Facilities plugin, this study seeks to apply two crucial enhancements:

The first continues with the updating of the data. A complete review of the available data on nuclear power plants was carried out, incorporating more recent information on plants in operation and new facilities, through the insertion of updated tables, ensuring greater accuracy in the analysis, as well as greater basis for future research.

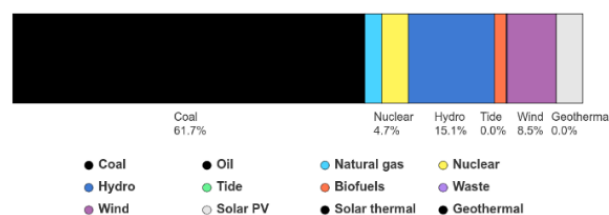
The second stage is related to the geographic cut. While the plugin deals with all nuclear power plants in the world, this work adopted a specific approach, focusing on the Asian territory, specifically China. In this way, analyzing its role as a current emerging power in the nuclear sector and its ability to minimize or replace the use of coal-fired power plants.

With this update and geographic focus, this study offers more detailed information applicable to the Chinese energy transition.

3. USE OF GIS AS A TOOL

The study uses a GIS tool, specifically QGIS, which provides a means to identify the geospatial suitability of replacing coal-fired power plants with nuclear facilities. The approach includes the collection, processing and visualization of data in the form of heat maps, allowing the evaluation of strategic areas where the expansion of the nuclear matrix in China is taking place. Despite the focus on decarbonizing the electricity sector, generation from fossil fuels, such as coal, has increased. For instance, in 2022, China generated 8,950,643 GWh of electricity (INTERNATIONAL ATOMIC ENERGY AGENCY, 2025). Figure 1 shows that about 62% of electricity generation in China comes from coal, which suggests a vast amount of installed capacity and, by implication, coal-fired power plants to meet this demand. The use of land for energy production considers life cycle assessments, which cover the area of the plant itself in operation, and the area excavated to obtain material for power generation, connections to the electricity grid and waste management. There are significant differences in land use between sources, in this regard, nuclear energy is the most efficient source per unit of electricity produced, requiring 50 times

Electricity generation sources, China, 2022



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Figure 1 - Electricity generation in China.



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less land compared to coal (RITCHIE, 2022). Figure 2 illustrates this scenario, comparatively demonstrating different types of power generation. The marked difference in land use per unit of electricity generated between coal and nuclear power provides a basis for analysis of the major transition from coal-fired to nuclear power plants.

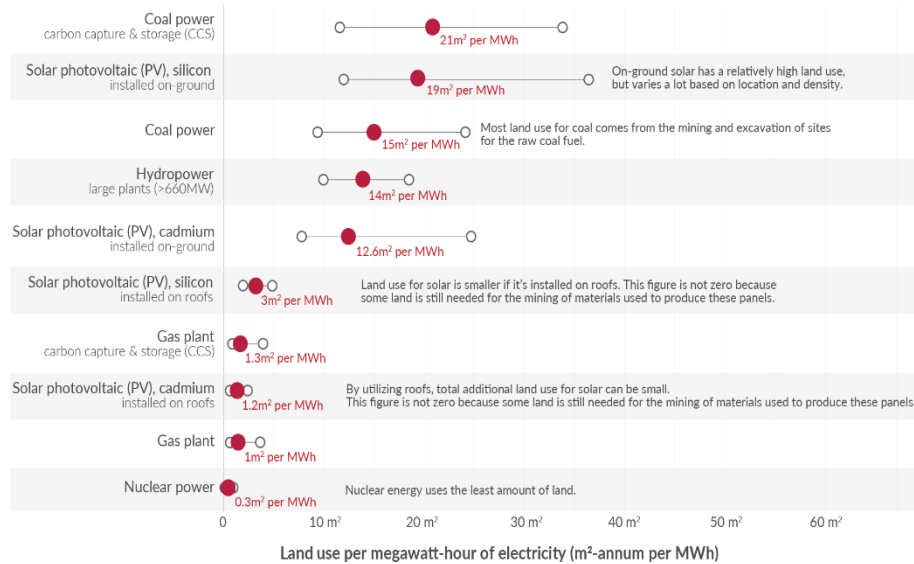


Figure 2 - Land use of energy sources

3.1. Methodology

Tables were used with information on nuclear and coal-fired power plants (name, location and generation capacity), extracted from databases such as KIRPAL (2018), GLOBAL ENERGY MONITOR (2025) and INTERNATIONAL ATOMIC ENERGY AGENCY (2025). The analysis focuses on nuclear power plants in operation and construction in China over the past five years, evidencing the country's progress in adopting clean energy. The processing and reprocessing of the data followed a methodology in three main stages:

Step 1 - Data Organization: .xls and .csv files were filtered to include only data from China and converted to .txt, to prevent import errors in QGIS. The layers were georeferenced in the WGS84 EPSG:3857 system.

Step 2 - Spatial Analysis and Layer Manipulation: The Chinese territory was isolated via *the Clip tool* and point layers were created for nuclear power plants (in operation and construction) and coal-fired power plants, exported as *shapefiles* to ensure accuracy.

Step 3 – Visualization: With the processed layers, a heat map was generated in QGIS to represent the spatial distribution of the plants.

The Kernel Density Estimation tool was applied to the point layers for both nuclear and coal plants, which analyzes the concentration of points in each area, creating a visual representation of the regions with the highest density. This tool was used to calculate the influence of the points in space, generating a continuous surface. Values such as radius of influence with their weight changed according to values referring to production capacity in MW were adjusted to ensure a more accurate visualization. As a result, a raster layer representing the density of the points was obtained, highlighting the areas with the highest concentration of plants. In addition, the color palette has been adjusted to facilitate the interpretation of the map, differentiating regions of high and low concentration. The result is a map that shows geographical patterns, helping in the analysis of the distribution of the plants over the territory. At the end of this study, it was possible to obtain two heat maps presented in Figures 3 and 4, one for the analysis of coal-fired power plants and the other for nuclear power plants. In this



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way, an updated and unified information base was generated in relation to the old databases provided in the QGIS plug-in for better parameterization and comparison between the geolocation of the different energy sources studied. A detailed legend accompanies the map, informing the ranges of values that correspond to the energy capacity density levels for each type of plant in GW. This visual resource allows you to intuitively and immediately identify areas with potential, in operation and future installations of nuclear power plants.

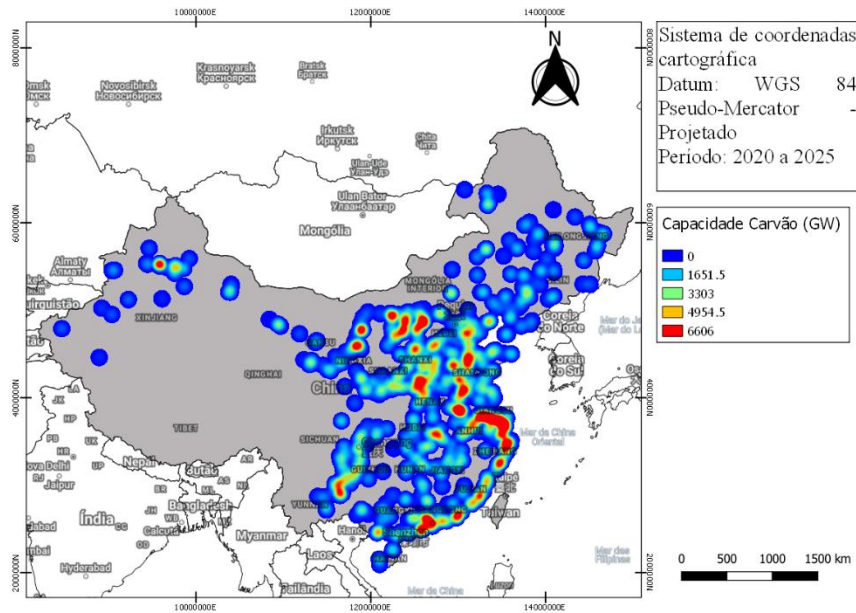


Figure 3 - Heat Map of Coal Plants in China

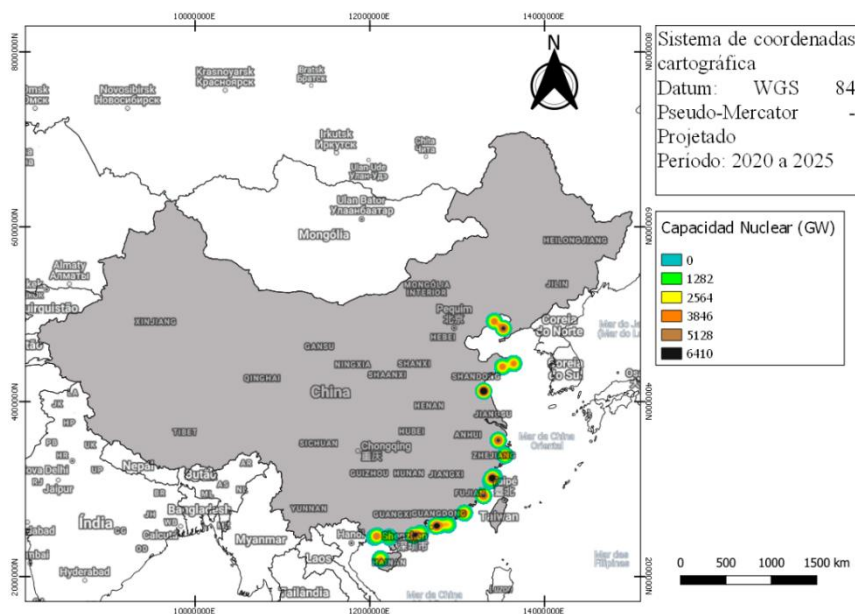


Figure 4 - Heat Map of Nuclear Power Plants in China

4. RESULTS

Analysis of this data reveals that the replacement of fossil fuel power plants in China is still in progress. The large installed capacity of coal-fired power plants highlights the permanence of this model, despite its inefficiency in terms of emissions and land use per unit of energy generated.



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The generated map also made it possible to visualize the high potential of nuclear energy to provide electricity, as it has low emissions (SCHLÖMER, 2014) and smaller land use (RITCHIE, 2022) it was possible identify a small but growing concentration of new nuclear power plants, mainly in coastal provinces, including Guangdong, Fujian, Zhejiang, and Shandong, regions with high energy demand and advanced transmission infrastructure.

4.1. Social Dimension

One of the most direct and significant social implications of replacing coal with nuclear power is the dramatic improvement in air quality. The burning of fossil fuels, such as coal, to generate electricity is responsible for more than 40% of energy-related carbon dioxide emissions (WORLD NUCLEAR ASSOCIATION, 2024). These burns for energy generation cause CO₂ emissions into the atmosphere as well as other pollutants harmful to health. The transition to low-carbon power generation technologies, such as nuclear power, makes it possible to improve air quality. Other impact variables to be considered are the occupation of territory and relocation of communities.

The vast infrastructure required for coal mining, and the coal-fired power plants themselves, require extensive allocation areas, which can lead to communities being displaced, destruction of natural habitats, and land-use conflicts. Comparatively, a smaller number of nuclear power plants generating the same amount of energy would be needed, so smaller territories would be occupied mitigating these problems. On the other hand, since 2011, a moratorium on nuclear power plants has been implemented in the interior of the country that limits expansion in some regions due to the events that occurred in Fukushima (HUANG, 2024).

Social reservations can arise through misinformation and preconceptions, based on previous occurrences. However, the inclusion of these in discussions shows their relevance as a means of managing public acceptance and nuclear expansion.

4.2. Economic Dimension

In the economic dimension, there is a significant expansion of the installed capacity. Since 2020, China has added tens of gigawatts to its nuclear matrix, consolidating itself as the world's second largest producer of nuclear energy, behind only the United States, some recent media announcements allege China's rise to first place, but still without public statistical data from government sources in other countries to corroborate such statements (XI; CAIYU, 2025).

The country has invested heavily in the construction of new nuclear power plants, registering a record volume of investments in 2024, which totaled US\$ 20.2 billion, according to the China Nuclear Power Association (CNEA). This growth shows commitment to this energy source. In addition, the expansion of nuclear energy has played a key role in reducing dependence on imported fossil fuels, strengthening national energy security. China has also been betting on the export of nuclear technology, with advanced models such as Hualong One allowing the country to expand its influence in the global nuclear energy market and establish strategic agreements with other nations. Thus, the geospatial analysis shows that the implementation of nuclear power plants can be strategically planned to minimize socioeconomic impacts, creating employment opportunities in nuclear technology and in the management of energy infrastructure.

4.3. Environmental Dimension

The progressive replacement of coal-fired power plants with nuclear power plants has contributed significantly to the reduction of greenhouse gas emissions, helping China meet targets set in international agreements on climate change. In addition, nuclear energy allows for a more efficient use of the territory, as it requires less space compared to renewable sources such as solar and similar wind energy (RITCHIE, 2022). However, the management of radioactive waste represents a challenge that requires advanced solutions. China has adopted a closed-loop policy of nuclear fuel, optimizing the reprocessing



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of the material and minimizing the environmental impact. At the same time, investments in ultra-high voltage networks (WORLD NUCLEAR ASSOCIATION, 2025) have ensured a more efficient integration of nuclear energy into the national electricity system, reducing transmission losses and improving electricity distribution.

5. CONCLUSIONS

This analysis highlights the importance of using GIS tools, such as QGIS, to provide a broad and detailed visual foundation. The clear management of the information allowed the integration of the data, resulting in heat maps that show the disparity between the massive number of coal-fired power plants in China and the number of nuclear power plants already installed.

The analysis of the maps shows the distribution of coal plants, which occupy vast areas of Chinese territory, while nuclear facilities are concentrated in coastal regions, with less space demand. This study can serve as a basis for strategies to expand energy infrastructure, helping in decision-making for future constructions.

Inserted in the context of sustainability, this issue demonstrates its relevance. Regarding greenhouse gas emissions and the occupation of territory for the installation of electric power generation plants, nuclear energy is a competitive alternative, with extremely low emissions throughout its life cycle, in addition to the land use being lower than that of coal-fired power plants, considering the land use per unit of electricity produced.

In view of these aspects, it is concluded that the expansion of nuclear energy in China since 2020 has promoted profound social, economic, and environmental impacts. The country's energy transition has proven to be strategic for strengthening energy security, reducing pollution, and technological modernization, consolidating nuclear energy as a central piece in the Chinese electricity matrix. With projections of simultaneous construction of 40 new nuclear power plants by the end of 2025, this share is expected to continue to grow, driving advances in sustainability and energy innovation.

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