Carbon footprint and solar and wind energy potential in Senegal

Source: Think Tank “INTERFACE” of the Cheikh Anta Diop University of Dakar (UCAD) on climate finance

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This group was established following several discussions between researchers, public and private stakeholders. Led by Professor Mamadou Lamine Ndiaye of the Electrical Engineering Department of the École supérieure polytechnique (ESP) in Dakar. The group is composed of 12 people, including 4 women. The group also includes several young researchers (doctoral and post-doctoral students)..

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Introduction

Africa, particularly sub-Saharan countries, is among the least developed countries in the world, mainly due to limited access to energy for all. Thus, in the quest for a better quality of life for their people, African countries face numerous challenges, including the lack of access to modern, affordable, and reliable energy, which hinders their socio-economic development. To meet this challenge, Senegal intends to rely on the energy sector through the energy mix/transition, to ensure universal access to reliable and affordable energy for all. However, with the new discovery of large gas and oil deposits on its coasts, Senegal is facing environmental issues related to the exploitation of fossil fuels in order to reduce greenhouse gas emissions. To meet its commitments to combat climate change, it is essential to turn to green (renewable) energy. It is in this sense that Senegal has made considerable efforts in the field of renewable energies, which today reach 30% of the energy mix (Heinrich-Böll, 2023). To achieve the energy mix objective (or ensure a reliable energy transition), it is important to understand the spatio-temporal evolution of climatic factors such as air temperature, solar radiation and surface wind, which condition the production of renewable energy.

Furthermore, climate change remains a major challenge, with direct repercussions on ecosystems, economies, and societies, particularly in developing countries like Senegal. Rising GHG emissions threaten sustainable development efforts and require a thorough understanding of historical and sectoral trends and future emission projections.

This work aims to provide a solid scientific basis on two key aspects: trends and distribution of GHG emissions by sector in Senegal between 1970 and 2022, and future projections up to 2100. It is based on EDGARv8.0 (Emissions Database for Global Atmospheric Research) data and RCP scenarios for a detailed understanding of emissions in major sectors, such as agriculture, energy, industrial processes and waste. In addition, this report examines variations in climate parameters related to solar and wind production, using ERA5 data (1970-2023). Temporal variations (anomalies) in climatic parameters and production were studied by comparison with the 1975-2004 period, considered as the reference period. The choice of this period was motivated by the prospect of using the outputs of regional climate models (CORDEX), whose historical simulations extend back to 2005, in order to study the future change in solar and wind production, and to quantify the impact of this climate change on these two types of renewable energy in Senegal.

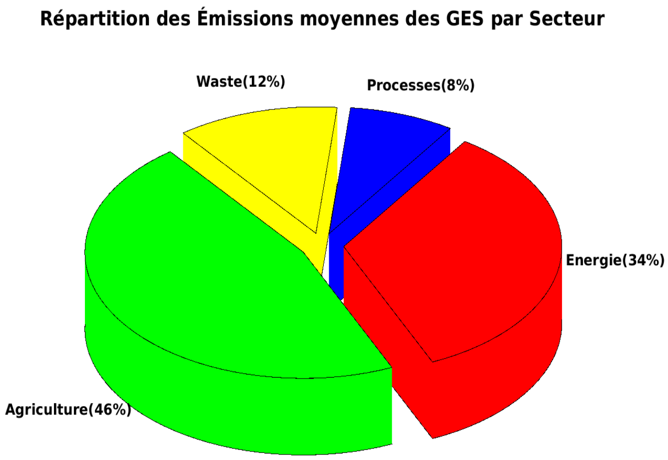
I Analysis of GHG Emissions in Senegal

I.1 Distribution of average GHG emissions from 1970 to 2022 in Senegal

Figure 1 shows the distribution of average GHG emissions by sector from 1970 to 2022 in Senegal. Analysis of this figure shows that agriculture is the largest sector in terms of GHG emissions, representing 46% of the total. This shows that agricultural practices contribute significantly to overall GHG emissions. This sector includes activities such as livestock farming, soil management, and fertilizer use. This figure also shows that the energy sector is the second largest contributor, representing 34% of emissions.

This percentage reflects the country's significant energy consumption, linked to electricity production, transportation, and industry. The waste sector accounts for 12% of GHG emissions. Emissions from waste can be due to the decomposition of organic matter in landfills, wastewater management, and other waste management practices. It is also noted that the industrial transformation processes (Processes) sector is the lowest emitter, with only 8% of total emissions.

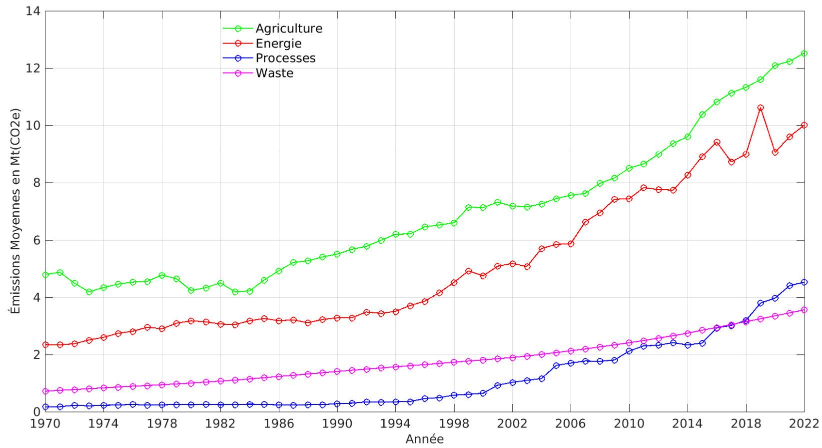
This breakdown shows that agriculture and energy are the main sectors to target for GHG emission reduction strategies in Senegal. This figure highlights the need to adopt sustainable agricultural practices, improve energy efficiency, and implement more efficient waste management to reduce GHG emissions in Senegal.



I.2 Evolution of average greenhouse gas emissions in Senegal

This figure represents the average greenhouse gas emissions (in Megatons of CO2 equivalent, $MtCO_2e$) of four different sectors (Agriculture, Energy, Processes, and Waste) in Senegal between 1970 and 2022. Among these sectors, the agriculture sector stands out with the highest emissions throughout the period studied. From 1970 to 1994, these emissions fluctuated between 4 and 6 $MtCO_2e$. However, from the 1990s, a notable increase was observed, reaching 12.4 $MtCO_2$ in 2022. This increase could be explained by the intensification of agriculture, the expansion of farmland and the increase in livestock farming. Analysis of emissions from the energy sector shows a steady upward trend since 1970, rising from 2.2 to 4 MtCO2e in 1996. From 1998 onwards, there is a significant increase in emissions reaching between 4 and 10 MtCO2e in 2022. This increase likely reflects increasing industrialization, energy consumption, and the expansion of energy infrastructure. Furthermore, from 2006 onwards, fluctuations appear, suggesting variations in energy consumption or energy efficiency. Unlike the previous two sectors, emissions from the industrial process sector are relatively low but show continuous growth. From 0.5 $MtCO_2$ in 1970 to approximately 3.8 $MtCO_2$ in 2022, this increase can largely be attributed to the development of the cement industry, mining, and agricultural processing industries, among others. Furthermore, we note that this growth is less marked than that observed in the agricultural and energy sectors.

Regarding emissions from the waste sector, they remained relatively low (around 0.2 Mt CO_2e) between 1970 and 1998. However, from 2002 onwards, they began to increase steadily, from 0.2 Mt CO_2e to 4.6 Mt CO_2e in 2022. This increase is probably due to urban population growth, increasing waste volumes, and possibly insufficient or ineffective waste management.



In summary, this figure clearly shows that greenhouse gas emissions in Senegal have increased significantly across all sectors since 1970. The agricultural sector is by far the largest contributor to emissions, followed by energy. Industrial processes and waste also show increases, although to a lesser extent.

I.3 Projection of average greenhouse gas emissions to 2100

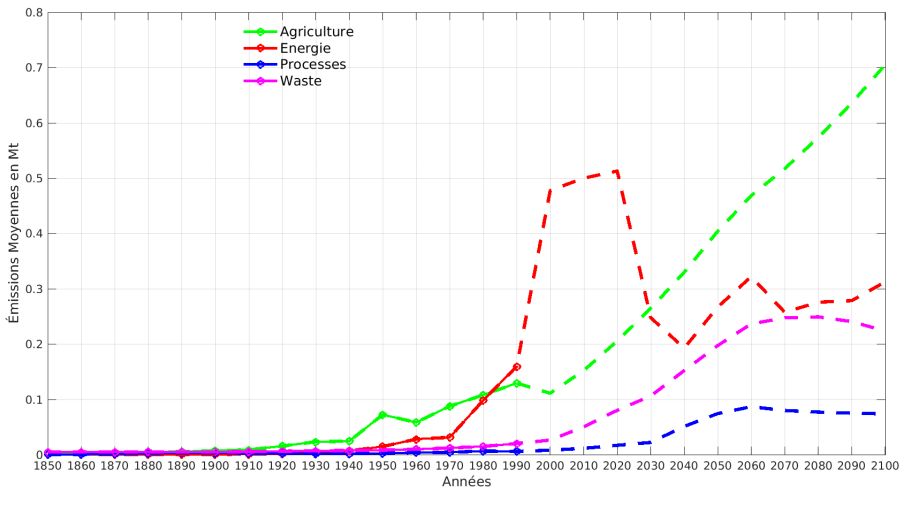
Figure 3 represents the evolution of average greenhouse gas (GHG) emissions, in megatons (Mt), for four sectors (agriculture, energy, industrial processes and waste) in Senegal, according to the RCP8.5 scenario, from 1850 to 2100. In the agriculture sector, we observe an increase in agricultural emissions that continues throughout the 21st century. Projections indicate that emissions will continue to grow, reaching approximately 0.8 Mt in 2100. To limit this growth, Senegal could adopt sustainable agricultural practices, promote agroforestry, and encourage the use of less carbon-intensive farming techniques.

Regarding the energy sector, there was a rapid increase in emissions from the 1970s to 1990, before stabilizing around 0.6 Mt from the 2000s. Emissions from the energy sector show significant growth until 2040, followed by a slight decline, before stabilizing around 0.30 Mt in 2100. To mitigate the impact of emissions from the energy sector, Senegal could invest more in renewable energy (solar, wind, hydroelectric), improve the energy efficiency of existing infrastructure, and promote energy-saving policies.

For the industrial processes sector ("Processes"), projections show an increasing trend in emissions, which should reach around 0.1 Mt by 2100. To control the increase in emissions in this sector, it would be crucial to adopt less GHG-emitting technologies in industries, as well as policies to encourage industrial decarbonization .

As for the waste sector, projections show a continued increase in emissions until 2100, reaching approximately 0.24 Mt. More efficient waste management, including recycling, composting, and waste reduction at source, could significantly reduce projected emissions in this sector. Implementing modern waste management infrastructure and educating the public on sustainable practices are also measures to consider.

This figure shows a general trend of increasing emissions across all sectors, with a more pronounced increase for agriculture and energy.

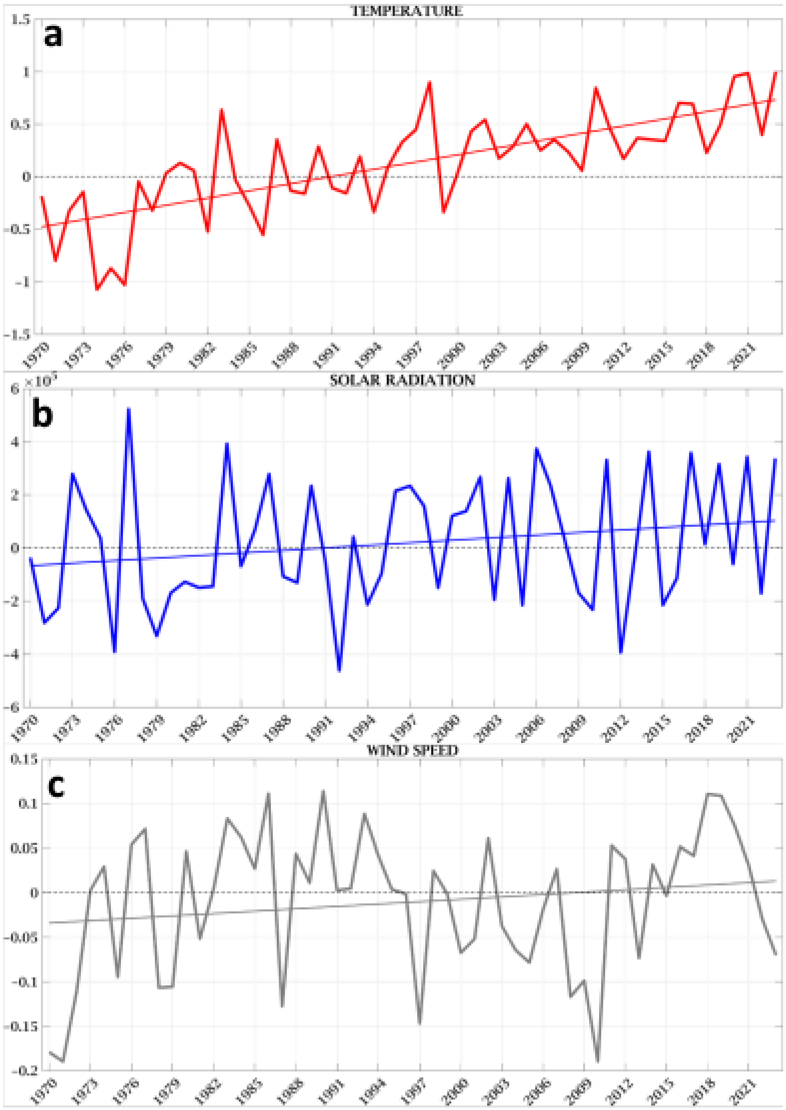


II Trends in climatic parameters in Senegal

II.1 Temporal trends in climate parameters in Senegal

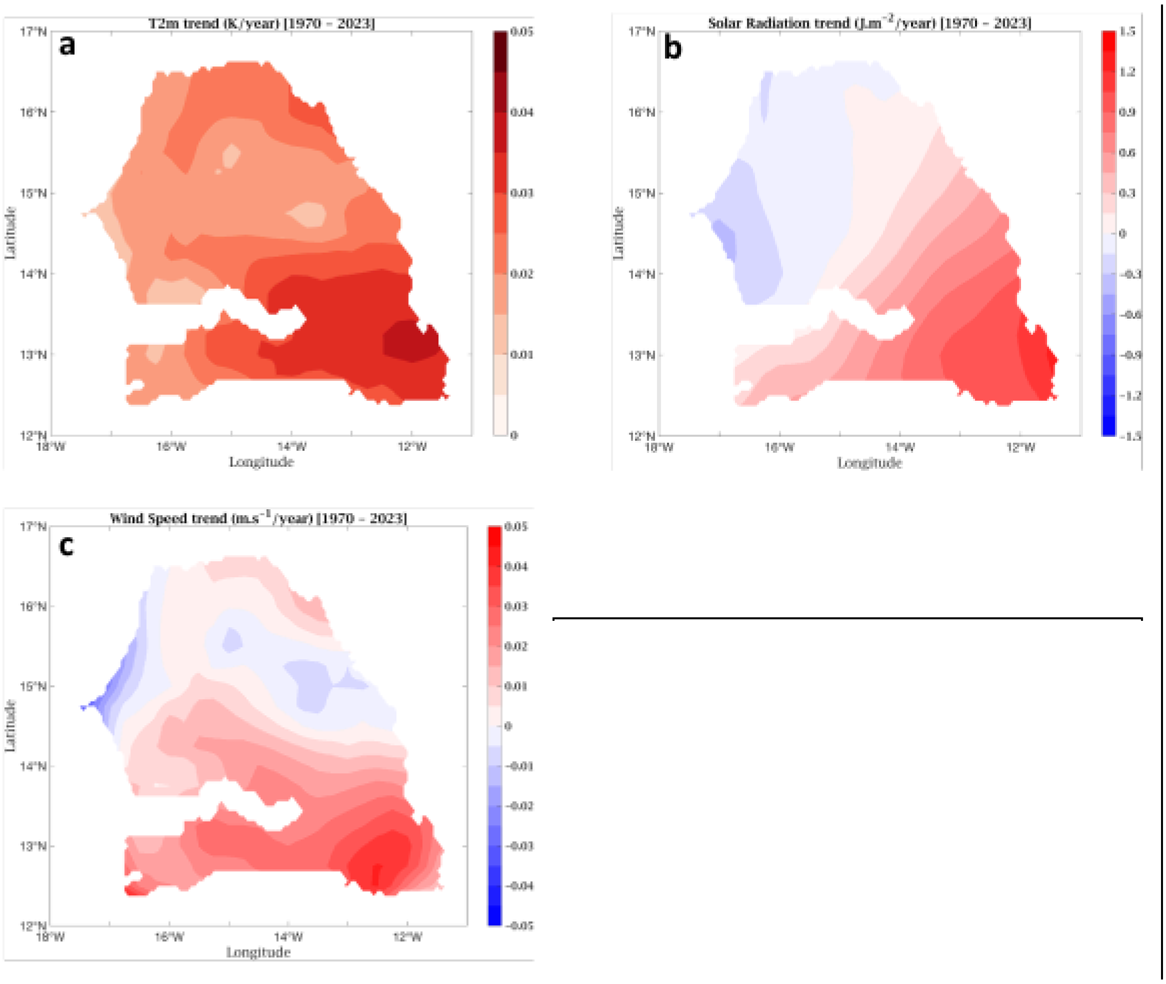
On average over our reference period, Senegal records a climatological average temperature of 28°C, with an average radiation of 249 Jm-2 and an average surface wind speed of 3.4 ms-1.

The temporal evolution of these climate parameters averaged over Senegal (Figure 4) shows a strong interannual variability marked by years that are weaker or stronger than the reference period. Figure 1a shows that Senegal is marked by an upward trend in surface temperature of around 0.023 °C/year over the period 1970 – 2023, while for solar radiation there is a trend of 0.037 Jm-2/year. However, the change is weaker in surface wind marked by a very weak upward trend.



II.2 Spatial trends in climate parameters in Senegal

The spatial distribution of temperature change over Senegal over our study period (Figure 5a) shows a warming across the entire country, with maximum warming in the southeastern part of the country (Tamba and Kédougou). In addition to the southeastern regions of the country, the northeastern part also experienced a considerable upward change in surface temperature. In contrast, the lowest warming is noted in the coastal regions and in the center of the country.



Unlike temperature, which shows a warming throughout Senegal, Figure 5b shows a heterogeneous distribution of solar radiation change over Senegal. This distribution is characterized by a trend towards increasing solar radiation in the south and southeast of the country, while the northern and western regions record a decreasing trend. The largest decrease in solar radiation is noted in the southern coastal part of Senegal. As with solar radiation, the change in surface wind also shows a non-homogeneous distribution over the country with a tendency towards wind intensification in the southern half of the country (south of 14.5°N). Overall, the northern half of the country shows a trend towards weakening surface wind, except in the northeast area of the country (Podor-Matam). However, the strong downward trend in surface wind intensity is noted on the Dakar-Saint Louis axis.

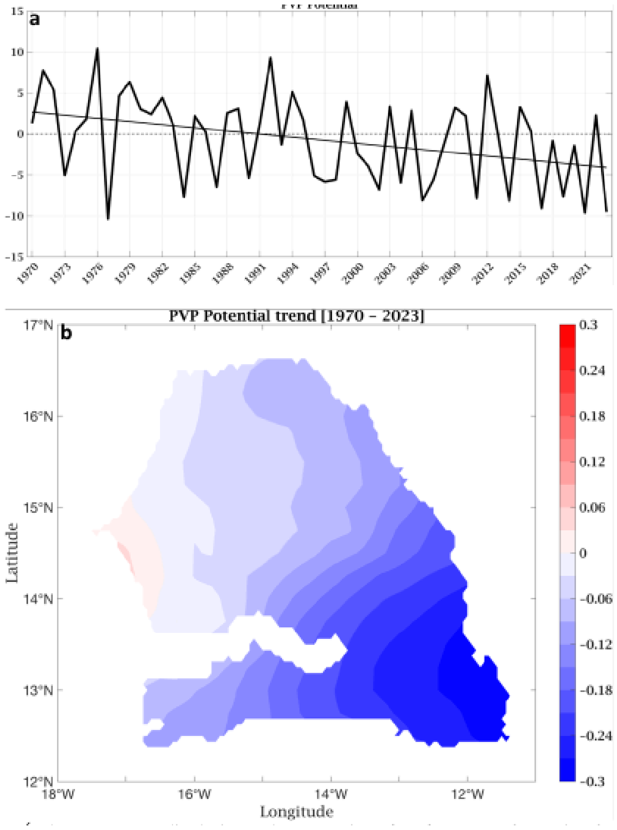
III Solar and wind production

In terms of renewable energy production, we note a climatological average of 79.77 kWh for solar and 63.05 kWh for wind. Since renewable energy production is directly influenced by environmental (climatic) conditions, these observed changes in temperature, solar radiation and wind have a strong impact on this production over time. To quantify their impacts, we calculated the trends associated with solar and wind production in Senegal (Figures 6 and 7).

III.1 Spatio-temporal trends in solar production

On average over Senegal (Figure 6a), solar potential shows an evolution opposite to those of temperature (Figure 4a) and solar radiation (Figure 4b). This opposition is characterized by a downward trend in average solar potential of the order of -0.127 kWh/year.

Figure 6b shows that the spatial distribution of solar production over Senegal is strongly correlated, in opposite sign, to that of solar radiation (Figure 5b). In other words, areas that tend to receive more solar radiation are associated with a downward trend in solar production. Thus, the largest decline in production is noted in the southeast of the country, while it is only in the area with a downward trend in radiation that there is an increasing trend in solar potential. This can also be explained by the distribution of surface temperature, as temperature varies inversely with the efficiency of solar panels. For example, the strong warming observed in the southeast of the country (Figure 5a) is associated with a downward trend in solar potential in this region (Figure 6b). This figure thus shows the strong dependence of solar potential on weather conditions.

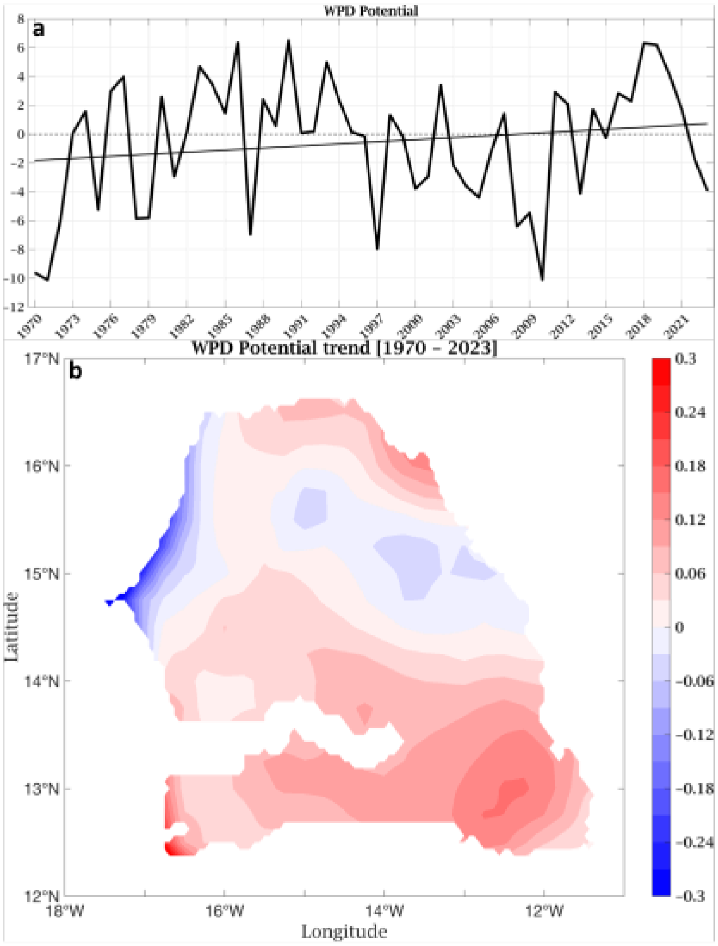


III.2 Spatio-temporal trends in wind power production in Senegal

Since Africa, and Senegal in particular, is also characterized by wind resources, we also calculated the wind potential in Senegal in order to identify areas with high wind potential and make a comparative study with solar potential. Figure 7 shows wind production in Senegal over the period 1970–2023.

Unlike solar production, wind production shows the same evolution (trend) as surface wind (Figures 4c, 5c). On average in Senegal there is an increase of 0.048 kWh/year in wind production (Figure 7a).

However, this general trend varies across regions of Senegal (Figure 7b) in response to the spatial distribution of wind across the country (Figure 5c). Due to the positive correlation between wind and wind power generation, the southern half of the country shows a positive trend in wind potential with a maximum in the southeast. While the minimum (strong negative trend) is observed along the Dakar-Saint Louis axis (Figure 7b). In addition to the southern half of the country, the northeast of Senegal (Podor-Matam) also shows an increasing trend in wind power generation over our study period.



Conclusion

This study highlights the significant evolution of greenhouse gas emissions in Senegal, with major contributions from the agriculture and energy sectors. Future projections, based on the RCP8.5 scenario, show a general trend of increasing emissions across all sectors, with a particularly marked increase in agriculture and energy. These trends underscore the urgent need for Senegal to adopt emission reduction strategies, focusing on sustainable agricultural practices, improved energy efficiency, and effective waste management. Integrating these measures into national policies is essential to mitigate the impacts of climate change and promote sustainable development.

At the same time, this study has shown the trends in dominant climate factors (air temperature, solar radiation and surface wind) on renewable energy (solar and wind) in Senegal since 1970 until now. We have also identified areas with high wind and/or solar potential in Senegal. In the future, we plan to use the outputs of climate models, which provide changes in these climate factors in the future, to study and quantify the effect of climate change on solar and wind production in Senegal.