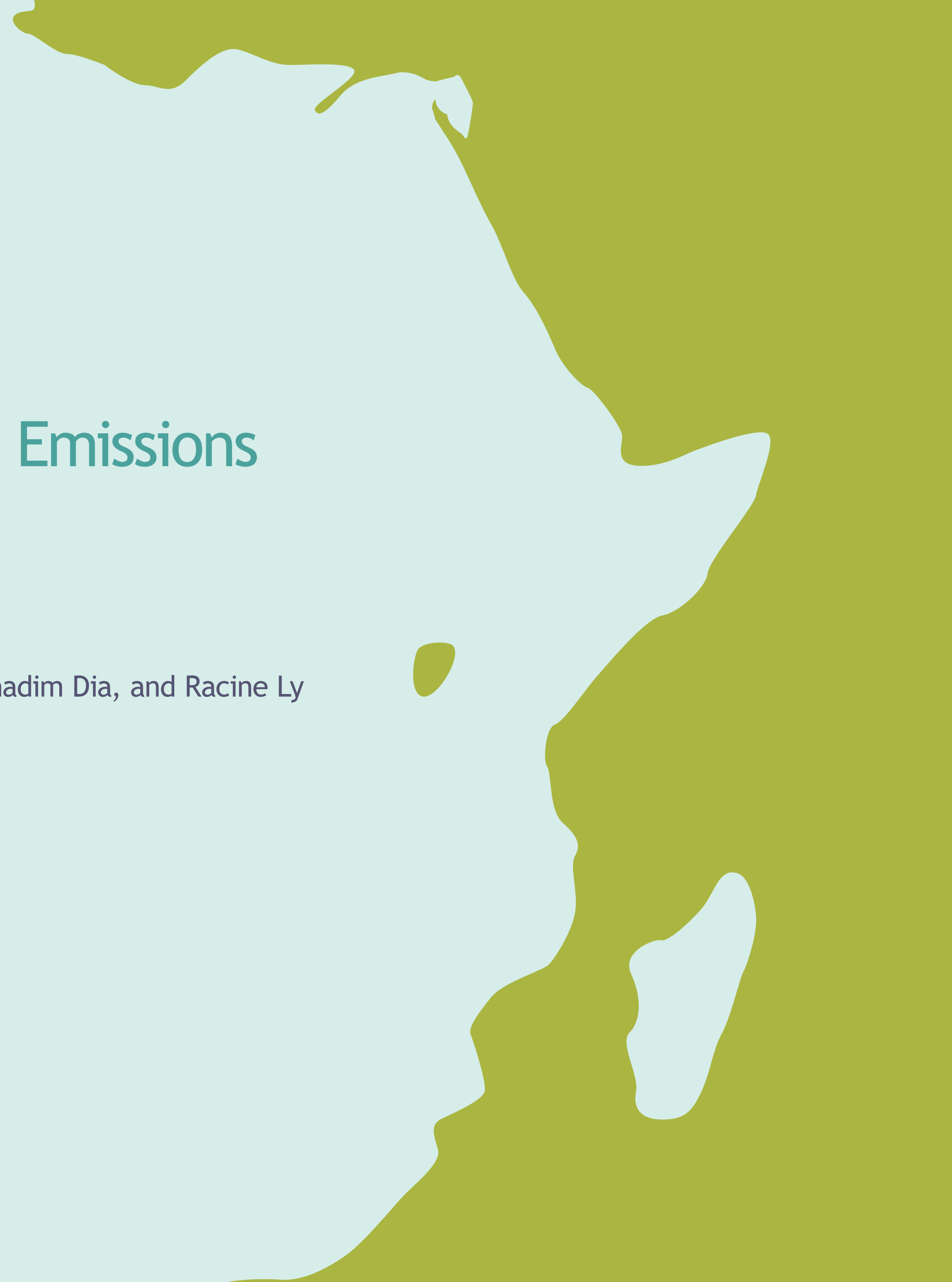
CHAPTER 4

Exploring Methane Emissions in Africa

Jean Paul Latyr Faye, Mansour Dia, Khadim Dia, and Racine Ly



Introduction

In the 21st century, climate change has emerged as one of the most pressing human and environmental crises. The primary driver of this global challenge is the accumulation of greenhouse gases (GHGs), such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), in the atmosphere. In analyzing Africa's contribution to the global GHG budget,1 it is essential to consider two factors: the absolute emissions of the continent and their role in the global carbon cycle. It is well known that Africa's GHG emissions are relatively low on a per capita basis, but they are rising due to population growth, urbanization, and increased human activities. According to new studies (Mostefaoui et al. 2024), Africa's methane emissions are steadily increasing. This trend reflects both agricultural development and environmental factors, such as increased forest fires due to aridity and climate variability, including the effects of El Niño.

Climate change is a global phenomenon, but its impacts vary across continents, with Africa being particularly vulnerable (Kogo, Kumar, and Koech 2021; Malhi, Kaur, and Kaushik 2021). The greater impact on African countries can be attributed to numerous factors, such as the changes in weather patterns, including more frequent and intense heatwaves (Parkes, Buzan, and Huber 2022) and the increase in droughts (Cook, Mankin, and Anchukaitis 2018), floods (Winsemius et al. 2018), and storms (Allen 2018).

Most discussions of climate change mitigation and adaptation in Africa have focused on CO_2. This focus is understandable, given that the concentrations of CH_4 (~1,750 parts per billion [ppb]) and N_2O (~310 parts per billion [ppb]) are significantly lower than those of CO_2 (~386 parts per million [ppm]) (Reay, Smith, and van Amstel 2010). However, reducing methane emissions has recently attracted substantial attention as a potentially more effective strategy to mitigate global warming, due to methane's capacity to absorb and re-emit infrared radiation (heat) and its relatively short lifetime in the atmosphere, of around 12 years (Skytt, Nielsen, and Jonsson 2020). Indeed, the removal of 1 metric ton2 of CH4 corresponds to the removal of around 84 to 86 tons of CO2 over 20 years and 28 to 34 tons over 100 years (Lee et al. 2023).

In addition, in climate change projections, the impact of rising temperatures and rainfall on CH_4 emissions is greatly underestimated. For example, in examining the global methane budget (Reay, Smith, and van Amstel 2010), it appears that a wide range of natural and anthropogenic sources are balanced with very few, often radiative reinforcing sinks. The sources are estimated to emit between 500 and 600 teragrams (Tg; 1 teragram = 1 million tons) of CH_4 per year on average, while the sinks are estimated to remove between 460 and 580 Tg of CH_4 per year. Based on the above figures, the global community must deal with a balance of between +20 and +52 Tg of CH_4 per year (Reay, Smith, and van Amstel 2010). However, this analysis does not consider the impacts of rising temperatures and rainfall on the emissions of methane. Indeed, methane is also known to have climate-positive feedback, which means its presence in the atmosphere will also lead to more methane emissions. For instance, the methane emissions growth rate was almost null from the late 1990s to the beginning of the 21st century, and then it increased in 2007 and 2008 due to a temperature increase that melted permafrost. Heavy rainfall during the same period also enhanced methanogenesis in many areas (Dlugokencky et al. 2009). Another example of positive feedback for methane can be found in wetlands. Research has shown that wetland methane emissions depend mainly on temperature, water table depth, and substrate availability. While the degree of sensitivity of wetlands' methane emissions to those parameters is poorly understood, temperature is often the dominant factor of the three. The logic of methane's positive feedback is that methane contributes to global warming (increased temperature), and the increased temperature contributes to even more methane emissions.

In Africa, despite the political will to combat climate change, various barriers can impede the effective design and implementation of policies and interventions to combat climate change and climate variability. One of the most prominent barriers is the lack of data on the dynamics of GHG emissions to inform those policies and interventions. Indeed, accurate measurement and tracking of greenhouse gas emissions are critical for developing effective climate policies and mitigation strategies. While the Intergovernmental Panel on Climate Change has provided comprehensive good practice guidance (Yaman 2024) to aid researchers

1 "Budget" refers to the absolute difference between emissions and removals of a particular GHG.

2 All tons are metric tons throughout.

and governments in estimating and reporting GHG emissions, there remains a significant gap in primary data collection, particularly in African countries. This gap is especially pronounced when applying Tier 1 methods,[3] which are often based on conservative assumptions and generalized data and can lead to potential under- or overestimations of actual emissions. Such a lack of data makes climate reporting subject to inaccuracies, leading to under- or overestimation in the GHG budget, particularly with regard to methane, in African countries.

In this chapter, we use satellite remote sensing data to address the gaps in methane emissions data across African countries, in light of the growing recognition that reducing methane emissions might be a more effective strategy for mitigating global warming. The main objectives of this chapter are threefold: (1) to assess current methane concentrations across the entire continent using satellite remote sensing data, (2) to explore the relationship between methane emissions and crop types cultivated, and (3) to analyze the potential relationship between methane concentration trends across cropland and climate parameters such as temperature and rainfall. With this comprehensive data analysis, we aim to identify trends, patterns, and spatial distributions of methane emissions and examine their concentrations over time and across different geographical locations and crop types to uncover critical insights into the drivers of methane emissions. To accurately assess methane emissions from cropland, we selected reference sites with no human activities, in order to evaluate natural methane emissions. This technique helps us determine the amount of methane emitted from cropland due to anthropogenic activities.

Methodology

It is essential to clarify the sources of methane emissions to gain a deeper understanding of methane concentration measurements over croplands. This section explores the known sources and fundamental mechanisms of methane emissions. It also describes the measurement techniques, specifically remote sensing, used to assess methane concentrations across African croplands.

Sources of Methane Emissions in Africa

Methane emissions can originate from natural and anthropogenic sources. The primary natural sources of methane emissions are wetlands, termites, and onshore and offshore geological releases.

Among natural sources, wetlands are the most significant contributors to methane emissions, accounting for more than a quarter of global CH_4 emissions (Määttä and Malhotra 2024). The wetlands environment encompasses various waterlogged ecosystems such as marshes, swamps, and peatlands, which serve as fertile grounds for methanogenesis, a microbial process that occurs in oxygen-deprived conditions. Wetlands emit methane through the anaerobic decomposition of organic matter, including plant material and soil organic carbon. The three main factors influencing methane emissions from wetlands are temperature, water table depth, and substrate availability. Though the extent to which methane emissions are affected by changes in these factors is still poorly understood, the dynamics of methane emissions from African wetlands are closely intertwined with climate change (Abdelkrim, Laila, and Ahmed 2022; Bandh et al. 2021). Indeed, warmer temperatures can accelerate microbial activity and boost methanogenesis rates, increasing wetland methane emissions (Chen et al. 2020; Cui et al. 2015). Similarly, alterations in precipitation patterns and hydrological regimes can affect the extent and duration of wetlands' waterlogged conditions, thereby influencing methane production and emission dynamics (Chatterjee et al. 2024). For instance, prolonged drought followed by intense rainfall can create ideal conditions for methane release by promoting the decomposition of organic matter in waterlogged soils. Furthermore, the cyclic relationship between wetland methane emissions and climate change exacerbates the situation.

While generally less significant than wetland contributions, methane emissions from geological sources still play a role in the overall methane cycle. These emissions primarily originate from natural phenomena such as seeps, mud volcanoes, and geothermal or volcanic areas. Additionally, other natural sources such as termites, oceans, methane hydrates, wild animals, and fires contribute to methane emissions, but their impact is relatively minor compared to that of wetlands.

3 Tier 1 refers to the first-level methodology provided by the Intergovernmental Panel on Climate Change and the application of default emission factors for GHG inventories.

Anthropogenic activities play a significant role in methane emissions across Africa. Agricultural activities, particularly rice cultivation and livestock farming, are substantial contributors to methane emissions on the continent (Van Amstel 2012). In modern agriculture, one of the most employed techniques in rice cultivation involves the application of organic amendments. These amendments enhance soil fertility, increase crop yields, and facilitate soil carbon sequestration.[4] This mechanism stands out as one of the most significant agricultural sources of methane, contributing approximately 8 percent of global anthropogenic emissions (Ouyang et al. 2023). In rice paddies, flooded fields create anaerobic conditions conducive to methanogenesis, resulting in substantial methane emissions during microbial decomposition of organic matter in soil and water.

Another agricultural source of methane emissions is enteric fermentation in ruminant livestock, such as cattle, sheep, and goats, which produces methane as a by-product of microbial digestion in their rumen (Joseph 2024). Livestock emissions account for a significant share of methane emissions from the agricultural sector in Africa.

Early natural and agricultural fires in conditions where biomass retains some moisture, as is often the case in Africa's fire-prone savannas, also lead to CH_4 release.

The energy sector is another important source of anthropogenic methane emissions in Africa (Usiabulu et al. 2024). Oil and gas extraction, processing, and distribution activities, as well as coal mining, contribute to methane emissions through fugitive emissions, leaks, and venting of natural gas. The incomplete combustion of biomass and fossil fuels in household cooking and heating also releases methane and other GHGs into the atmosphere. Waste management practices, including landfill disposal and organic waste decomposition, produce methane as a by-product of anaerobic decomposition processes (Cusworth et al. 2024).

In summary, methane emissions in Africa arise from natural processes, such as wetland emissions correlated with climate change and climate variability, as well as anthropogenic ones, including agriculture, energy production, and waste management.

Measurement Techniques and Quantification of Methane Emissions

This subsection details the measurement techniques employed for quantifying methane emissions and discusses the concentration parameter used to assess the amount of methane released into the atmosphere.

Techniques for Measurement of Methane Emissions

Two primary methods exist for measuring the methane emitted into the atmosphere. One approach is the bottom-up method (Desjardins et al. 2018), while the second approach, the top-down method (Desjardins et al. 2018), typically involves measuring atmospheric methane concentrations using airborne or satellite sensors to infer emission releases. The latter approach, the method used in this study, requires further discussion, especially with regard to its use in Africa. However, it is essential to first delineate the bottom-up approach more explicitly.

The bottom-up measurement approach can be used to assess methane emissions. It offers insights into methane production and release dynamics. It involves using ground-based measurement stations strategically positioned around the world, with the measurement outputs applicable for use in Africa. These stations employ sophisticated instrumentation to measure atmospheric methane concentrations directly, providing accurate and detailed data on local emissions sources and trends. Mobile measurement campaigns, where instruments are mounted on vehicles or aircraft, can offer spatially comprehensive coverage, allowing researchers to capture emissions variability across diverse landscapes and land use types (Shaw et al. 2022).

The top-down method for assessing methane emissions involves applying remote sensing techniques such as those deployed via satellites. Remote sensing techniques allow for the measurement of methane gas emissions from various locations on Earth, including cropland and non-cropland areas, without requiring direct physical contact. Measuring the emitted methane without direct contact offers numerous advantages, especially when the reference area is in a location with limited human access. Advancements in satellite technology have

4 For example, the use of nitrogen fertilizers can reduce microbial activities that consume methane in soil. This results in less methane being oxidized and removed from the atmosphere.

significantly enhanced our understanding of the extent and characteristics of methane emissions. Remote sensing techniques provide accurate and comprehensive data on a global and regional scale, allowing for continuous monitoring and precise measurement of methane emissions (Liu et al. 2021). The high resolution of today's satellite imagery and the advanced sensors enable the detection of methane leaks and sources with greater accuracy (Zhang, Comas, and Brodyle 2020).

In this study, we obtained our results using the TROPOspheric Monitoring Instrument (TROPOMI) on board the Sentinel-5 Precursor (S5P) satellite (Guanter et al. 2015; Vries et al. 2016), a mission initiated by the European Space Agency. TROPOMI samples the 675–775 nm spectral window with a high spectral resolution and a pixel size of 49 km^2. TROPOMI detects sunlight reflected or scattered by the Earth's surface and atmosphere. In this way, TROPOMI provides high-resolution measurements of methane concentrations in the atmosphere, enabling the monitoring of large-scale emission patterns across both cropland and non-cropland areas in African countries. Tracking methane emission concentrations via TROPOMI data necessitates processing and analyzing the retrieved spectra (Vries et al. 2016). The technique involves processing data from TROPOMI to quantify the concentration of methane emissions. This quantification provides insights into spatial and temporal variations of methane levels, enabling the identification of hot spots, trends, and potential emission sources, such as those from the agricultural sector. Moreover, TROPOMI data can be integrated with other environmental datasets, such as land cover maps and meteorological data, to better understand the factors influencing African methane emissions.

While TROPOMI presents several advantages for assessing the methane emission concentration, it also entails certain limitations. Cloud cover, aerosol interference, and surface reflectance variations may affect the accuracy and reliability of methane measurements obtained from TROPOMI data (Kooreman et al. 2020). Despite these challenges, TROPOMI remains a valid option for Africa to monitor methane emissions extensively. In the following subsection, we describe how the emitted methane can be quantified in specific regions of the atmosphere.

Quantification of Methane Emissions

TROPOMI data offer the flexibility to employ various parameters for quantifying the amount of methane emitted into the atmosphere (Jacob et al. 2016; Reinelt et al. 2017). We focus on the concentration parameters to quantify the methane produced by cropland and animals during farming activities. The concentration parameters hold particular significance because (1) they are able to provide a direct measure of the density of methane molecules in the atmosphere at a given time and location, and (2) the quantification of methane emissions allows for the measurement of additional characteristics of methane emissions, including emission flux, emission rate, and isotopic composition. Moreover, methane concentration data from TROPOMI are easily accessible regardless of a country's conditions on the ground. The concentration is often expressed in units such as parts per million by volume (ppmv) or parts per billion by volume (ppbv), the number of molecules of a specific GHG per billion molecules of air. It offers a snapshot of atmospheric methane levels, allowing for comparisons across regions and periods. Thus, the concentration measurements serve as a fundamental basis for understanding the spatial distribution, temporal variations, and overall trends in methane emissions.

Results

This section presents the research results, including data collection and the average methane emissions concentration above croplands, both at the continental and country level, for 2023. Additionally, it explores the trend relationships between methane emissions and climatic parameters such as temperature and rainfall.

Dataset Collection and Interpretation

In this study, we used methane data collected from TROPOMI. This state-of-the-art instrument serves as the primary payload of the S5P mission operated by the European Space Agency. TROPOMI is a nadir-viewing shortwave spectrometer, meaning it captures data by looking directly downward from its orbit, covering a wide area of the Earth's surface. TROPOMI employs a passive remote sensing technique, which measures radiation reflected by or emitted from the Earth's surface and atmosphere.

The instrument operates at the top of the atmosphere, collecting data in multiple wavelength ranges, including the ultraviolet-visible, near-infrared, and shortwave infrared spectra. This broad spectral coverage allows TROPOMI to detect various atmospheric gases, including methane, with high sensitivity. TROPOMI has a sophisticated two-detector sensor that captures detailed information across these spectral ranges. Each measurement made by TROPOMI is taken within a swath, a strip of the Earth's surface that the instrument observes during a single pass. TROPOMI has a 7 km swath, allowing it to cover large areas in just a few seconds. The instrument continuously collects data as the satellite moves along its flight path, creating a comprehensive global dataset.

The data collected for each swath are organized into two key components. The first component provides the spatial positioning information, indicating the exact location within the swath where the measurement was taken. These geolocation data are crucial for mapping the distribution of methane concentrations across different regions. The second component contains the spectral information, which includes the specific wavelengths of light measured by the instrument. These spectral data are essential for identifying and quantifying methane concentrations in the atmosphere, as different gases absorb light at distinct wavelengths. Combining these two components, TROPOMI delivers highly detailed and accurate methane concentration measurements. The data are clipped to the region of interest (continental and country levels).

We also used the Global Land Cover dataset from Copernicus. Classes of land use / land cover (cropland, bare/sparse vegetation) are isolated into single TIFF files. We masked the methane data with the resulting TIFF files to obtain the methane emissions from a specific land use class. Then, to obtain the results of this work, we applied several spatial and temporal aggregations of the processed methane data. We used a seven-step rolling average for visualization to smooth the plots and remove internal fluctuations.

The study also uses rainfall and land surface temperature data collected by the Climate Hazards Center at the University of California and the Moderate-Resolution Imaging Spectroradiometer (MODIS), respectively. The data sources used in this chapter are summarized in Table 4.1.

TROPOMI provides direct measurements of methane concentrations in the atmosphere, with a particular sensitivity to the lower layers of the atmosphere. Unlike other methodologies of methane concentration measurement, TROPOMI data do not specifically account for industrial processes. Instead, they are more responsive to natural processes that emit methane, such as enteric fermentation from livestock, agricultural practices, wetlands, and other biogenic sources.

TABLE 4.1 — DATA SOURCES USED IN THIS STUDY

Indicator	Product name	Source	Spatial resolution
Methane	TROPOMI Total Column CH4	Copernicus	7 km x 7 km
Land use / land cover	Global Land Cover products	Copernicus Global Land Service	100 m
Rainfall	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	Climate Hazards Center, UC Santa Barbara	0.05 degree
Land surface temperature	Land Surface Temperature/ Emissivity 8-Day (MOD11A2) Version 6.1	Moderate Resolution Imaging Spectroradiometer (MODIS)	1 km x 1 km

Source: Authors.

Because TROPOMI is designed to capture atmospheric methane concentrations and not those associated with industrial activities, it will therefore likely detect emissions from natural processes.

As a result, the lower methane concentrations observed in some African countries via TROPOMI data do not necessarily indicate that these countries emit less methane overall. Instead, it reflects the types of methane-emitting processes detected by TROPOMI. Therefore, the results presented in this chapter should be interpreted with the following considerations:

- **High methane concentrations** detected by TROPOMI in each country suggest that natural processes contributing to methane emissions are prevalent and measurable through remote sensing techniques.
- **Low methane concentrations** in a country imply that either the natural processes emitting methane are less significant, or they are not as easily captured by TROPOMI's remote sensing capabilities. Thus, TROPOMI data should be understood as a reflection of methane emissions primarily

from natural processes rather than a comprehensive measure of all sources, including industrial processes.[5]

Average Methane Emissions at the Continental Level

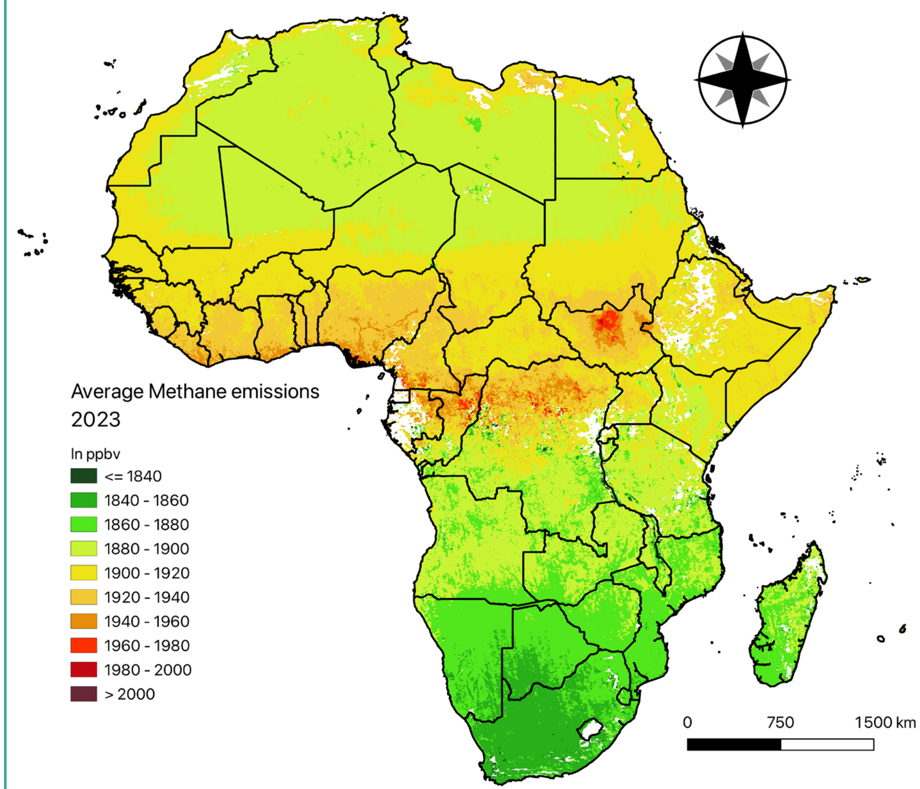
The continental average methane emission calculation is confined solely to African cropland areas to assess methane emissions specifically from agricultural activities.

Figure 4.1 presents the average methane emissions across the continent, with concentrations expressed in ppbv, representing the number of CH4 molecules per one billion molecules of ambient air. The spatial distribution of methane emissions from natural processes reveals distinct patterns, trends, and regional variations across Africa. The results show that southern Africa experiences relatively fewer natural processes that emit methane, with concentration levels ranging from 1,840 to 1,880 ppbv. In contrast, the countries in the Sahel region exhibit higher levels of methane emissions, driven by more significant natural processes, with concentrations reaching up to 1,980 ppbv. In northern Africa, methane emissions are moderate, with concentration levels between 1,880 and 1,920 ppbv, reflecting the limited presence of methane-emitting natural processes in the region.

Additionally, the continental analysis highlights some regions with high methane concentration levels. For instance, South Sudan shows methane concentrations reaching up to 2,000 ppbv, marking it as a region with exceptionally high emissions from natural processes. More investigation would be needed to better understand the reason for such a peak.

While our research for this chapter has not collected data to elucidate such a fact, the lower emissions level in the southern region could be partly attributed to a less intensive livestock presence and activities. In addition, there is a presumption of more "untouched" landscapes in the southern regions, where human influence is less, leading to a better equilibrium in GHG budgets. Other hypotheses that could explain the differences in methane emissions include the scale of farming operations, the use of advanced technology and machinery, investment in irrigation and fertilization, and the influence of governmental policies supporting agricultural development. Additionally, variations in land use practices, such as different approaches to crop rotation, soil conservation techniques, and land tenure systems, also play a significant role. The differences in geographical conditions, climate patterns, and economic priorities could also help explain the variations.[6]

FIGURE 4.1—AVERAGE METHANE EMISSIONS IN AFRICA, 2023



Source: Authors.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

5 Industrial processes should be understood as the associated processes and emissions of by-products in the course of production. Satellites can only measure the emissions of by-products, not emissions related to processes.

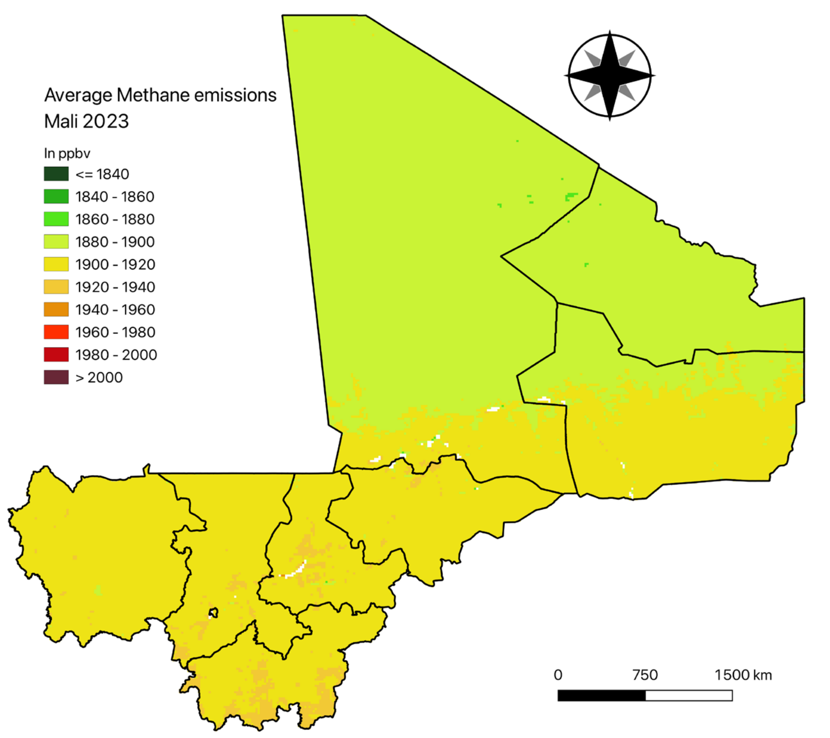
6 All these potential explanations show the need for more ground data to better elucidate the emissions sources and their geographical and temporal dynamics.

Average Methane Emissions at the Country Level

In the preceding subsection, we analyzed methane emissions at the continental level. This subsection focuses on four use case countries—Mali, Niger, Nigeria, and Namibia—to provide a more detailed examination at the national level. Conducting country-level analyses of methane emissions can provide more insights into the spatial distribution and magnitude of each country's emissions, highlighting areas of concern and opportunities for targeted mitigation efforts. Like the continental average analysis, data from TROPOMI for 2023 are used to investigate country-level methane emissions. It is worth noting that the investigation into methane emissions in these four countries was conducted alongside analyses of other countries; however, we cannot present all the results for every country in this chapter. It is also important to mention that the four countries were not chosen based on any rigorous selection criteria; instead, we simply aimed to show some use cases to analyze methane emissions across the continent. As the data necessary to explain the intensity of methane emissions across each country were not available when we were writing this chapter, we limit ourselves to presenting the observed results rather than providing rigorous explanations. However, we propose some hypotheses that could account for the variation in methane intensity in certain areas. These hypotheses will require further investigation in subsequent research.

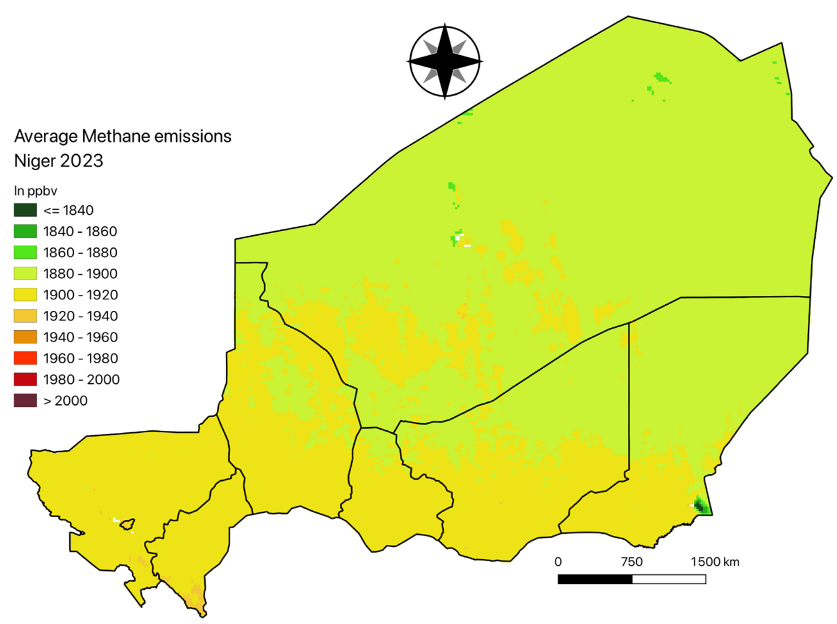
Figure 4.2 displays the average methane emissions for Mali in 2023. The results indicate that the southern region has the highest concentration of methane emitted by natural processes, reaching up to 1,960 ppbv, whereas the northern region has a moderate concentration of 1,840 ppbv. Mali's methane

FIGURE 4.2—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN MALI, 2023



Source: Authors.

FIGURE 4.3—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NIGER, 2023



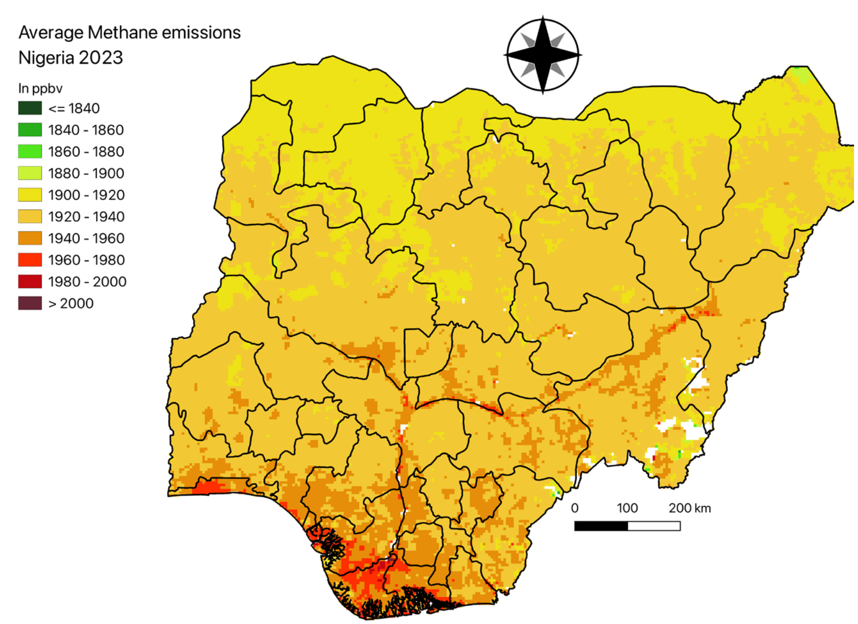
Source: Authors.

concentration level is likely produced primarily through enteric fermentation from livestock and anaerobic decomposition in irrigated rice farming.

Figure 4.3 illustrates the spatial distribution of methane concentrations for Niger. The southern region has the highest methane concentrations, ranging from 1,920 to 1,940 ppbv, while the northern region has the lowest concentrations, ranging from 1,880 to 1,900 ppbv. These concentrations of methane could be attributed to various processes such as agricultural practices, waste management, and natural sources, necessitating further investigation. The 2021 United Nations Environmental Programme report (UNEP 2021) underscores the urgent need for improvements in agricultural practices and urban waste management to address these emissions of methane effectively.

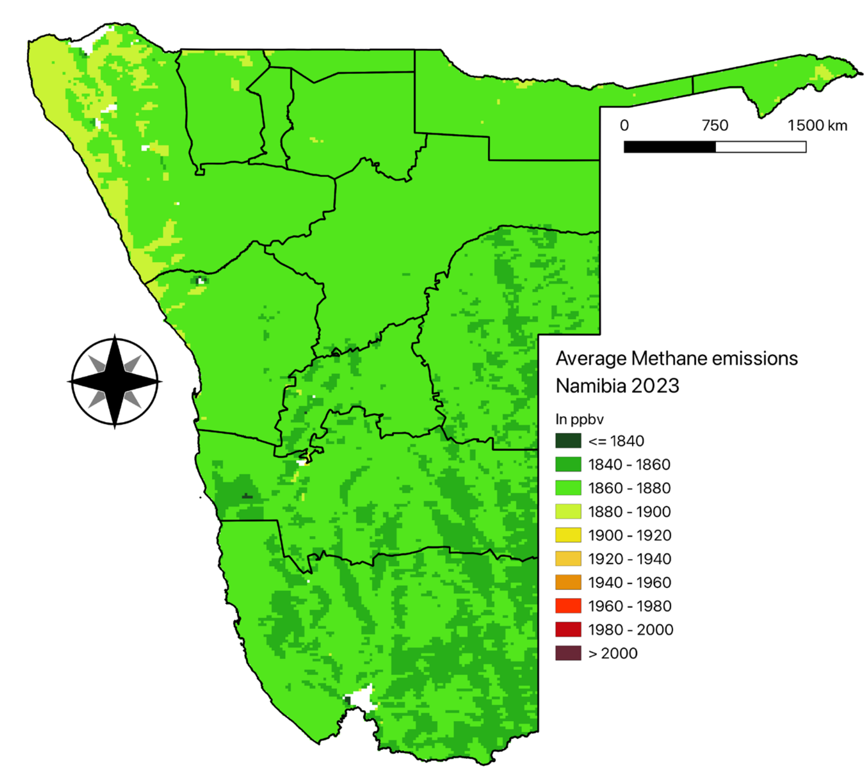
Figure 4.4 shows the average methane concentrations in Nigeria. The southern region exhibits the highest concentrations, ranging from 1,980 to 2,000 ppbv, whereas the northern region has the lowest concentrations, from 1,900 to 1,940 ppbv. Even if southern Nigeria is known for its higher forest density and mangroves, the sinks of methane gases may not be sufficient to reduce the amount of CH4 released. Nigeria exhibits the highest average methane emissions of the four use-case countries. The geographical disparity in Nigeria suggests that regional variations in climate, land use, and socioeconomic factors may influence methane production and release. Intensive agricultural practices, urbanization, and industrial activities in the southern regions contribute to higher methane emissions (Nwaneke and Chude 2015). Indeed, Nigeria's methane emissions are closely tied to its status as Africa's largest oil producer. The oil and gas sectors and the wetlands, particularly in the Niger Delta, are significant contributors, with practices such as gas flaring and oil leaks prevalent (IEA 2023).

FIGURE 4.4—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NIGERIA, 2023



Source: Authors.

FIGURE 4.5—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NAMIBIA, 2023



Source: Authors.

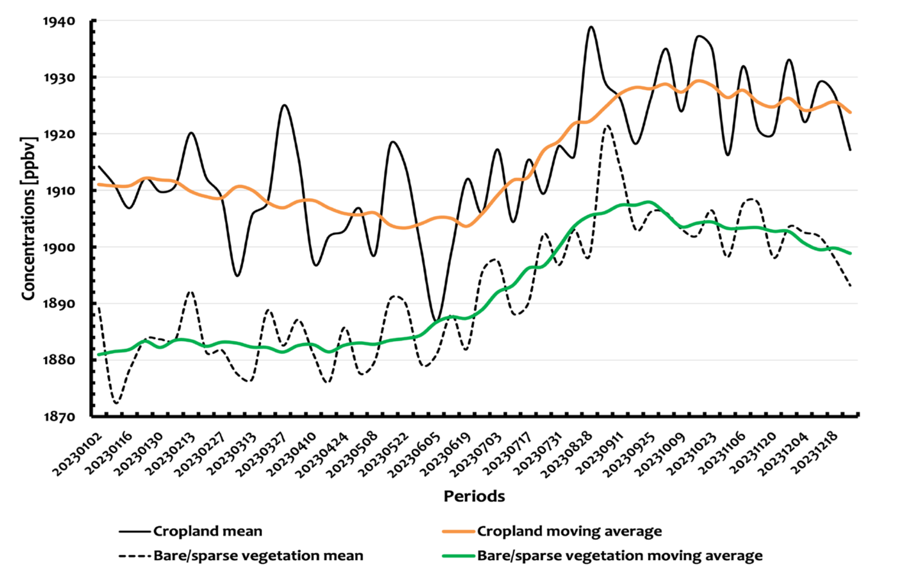
Figure 4.5 depicts the methane concentration in Namibia. With the lowest methane emissions, Namibia's situation reflects its lower natural processes. As previously discussed, the lower methane concentrations observed by TROPOMI are primarily due to natural processes and do not account for methane produced as a by-product of industrial activities. In other words, the methane concentrations shown here reflect only the emissions from natural processes, which does not imply that Namibia emits a lower total amount of methane than other African countries. In fact, according to the African Development Bank report on methane emissions in Africa, southern Africa remains one of the top methane-emitting regions on the continent.

Agricultural Methane Emissions

In analyzing methane emissions from natural processes in Africa, a crucial aspect is comparing emissions from agricultural (anthropogenic sources) and nonagricultural (natural sources) land. Nonagricultural land areas are sites free from human interference that remain untouched by activities such as construction, farming, or urban development. These sites provide a natural environment, allowing for the observation of ecological processes and environmental conditions without the influence of human activities. The agricultural sector, mainly rice cultivation, is a significant source of methane emissions, anaerobic decomposition, and other processes. By subtracting methane emissions from agricultural land with those from nonagricultural land, we can discern the extent to which human activities amplify methane emissions.

We used moving averages to enhance the interpretation by smoothing out short-term fluctuations, highlighting underlying patterns and possible correlations between cropland and non-cropland methane concentrations within the studied countries. Our results show a clear difference between methane emissions from agricultural and nonagricultural land, with cropland exhibiting higher concentrations. The substantial increase in methane emissions observed during the growing season is particularly striking. However, it is noteworthy that this disparity also persists both before and after the growing season, albeit to a lesser extent. This suggests that while growing-season activities predominantly drive the significant surge in methane emissions, other environmental factors may also exert influence. The differences observed outside the growing season may be attributed to correlations between methane emissions and climatic parameters such as temperature and rainfall.

FIGURE 4.6—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN MALI, 2023



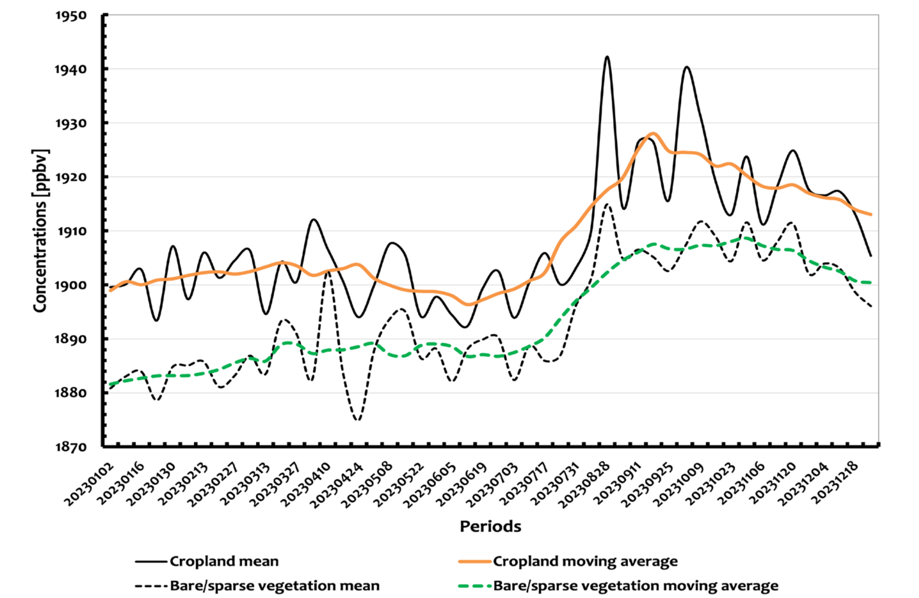
Source: Authors.

In Figure 4.6, we show the concentration of methane over time on cropland and non-cropland in Mali. An increase in methane emissions during the growing season is observed in Mali. The country's agriculture-driven economy relies heavily on livestock rearing and rice cultivation, significantly influencing its methane emission profile. These sectors are particularly methane-intensive due to the prevalence of enteric fermentation in cattle and the anaerobic conditions in irrigated rice paddies, as illustrated by the growing-season data presented in the figure.

Figure 4.7 presents the evolution of methane emissions as a function of time for Niger. As in Mali, a significant amount of methane is released due to agricultural activities. During the rainy season, the increased soil moisture accelerates the natural processes of organic decomposition, leading to a peak in methane emissions. This explains the rise in methane emissions observed during the growing season.

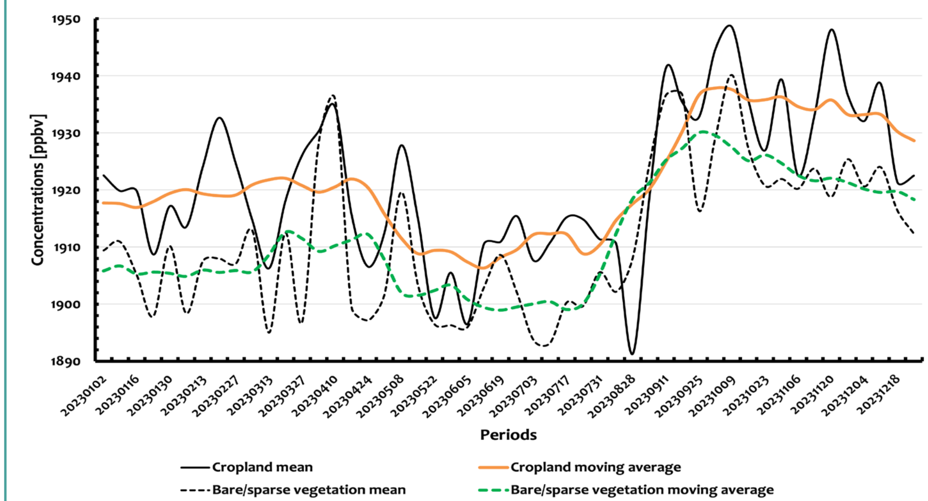
Figure 4.8 illustrates the progression of methane concentration in Nigeria. Extensive livestock holdings and widespread cultivation of methane-intensive

FIGURE 4.7—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGER, 2023



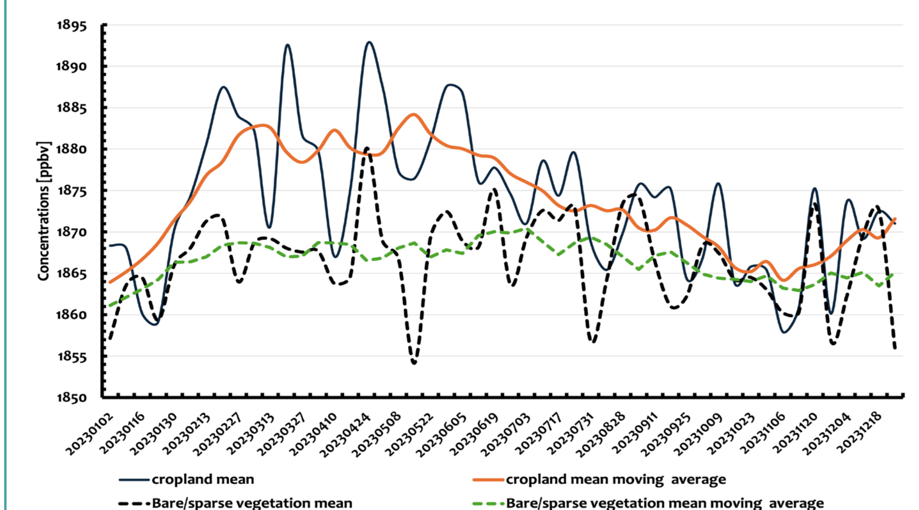
Source: Authors.

FIGURE 4.8—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGERIA, 2023



Source: Authors.

FIGURE 4.9—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NAMIBIA, 2023



Source: Authors.

crops such as rice and yams characterize Nigeria's agricultural landscape. This combination leads to high methane emissions, particularly in the wet seasons, when runoff and waste accumulation peak. These conditions facilitate the anaerobic decomposition of organic material, significantly increasing methane output.

Finally, Figure 4.9 presents the methane emissions in Namibia over time. Here again, there is an increase in methane emissions during the growing season. The anaerobic decomposition of organic material significantly influences this rise.

Correlation Between Climate Parameters and Methane Emissions

This subsection examines the relationship between climate variables—specifically, temperature and rainfall—and methane emissions throughout the year. Our primary focus is understanding how these climate factors influence methane release from cropland, particularly by comparing the differences in methane emissions between cropland and non-cropland areas. This comparison to natural landscapes helps to reveal the extent to which agricultural activities contribute to methane emissions. Additionally, we aim to explore the simultaneous correlation between these climate variables and methane emissions resulting from the methanogenesis process during the agricultural season, including the sowing, growing, and harvesting phases.

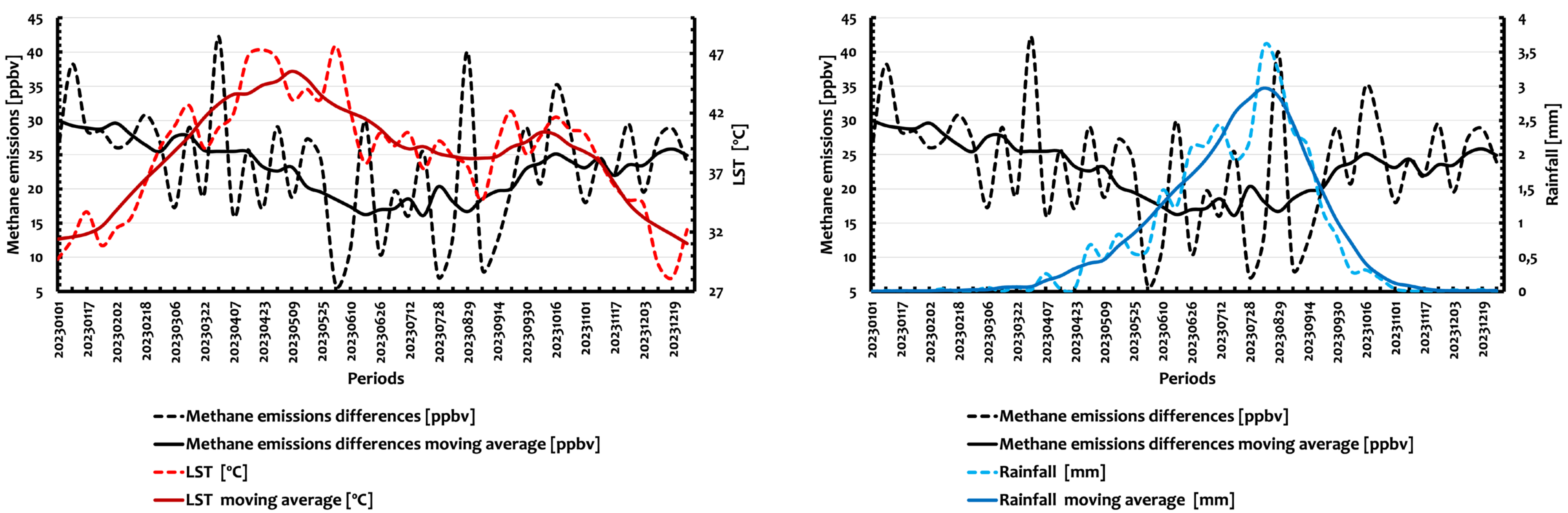
Evolution of Temperature, Rainfall, and Methane Emissions

As discussed in the introduction, it is evident that climate parameters have numerous impacts on agriculture and are likely to affect methane emissions (Omotoso and Omotayo 2023). Therefore, examining the correlation between methane concentrations above croplands with temperature and rainfall anomalies, as a function of time, becomes important. The goal is to investigate the relationship between methane concentration and temperature on one hand and methane emissions and rainfall anomalies on the other to identify trends in methane dynamics. Understanding these trends is essential for clarifying the interactions between methane emissions, climate variables, and emissions from the agricultural sector.

Figures 4.10 and 4.11 show the temporal evolution of temperature and rainfall, alongside the difference in methane emitted between cropland and non-cropland, respectively, in Mali and Nigeria. The figures also incorporate the moving averages with a lag of four months. This multidimensional approach enables an exploration of how variations in temperature and rainfall influence methane emissions from diverse ecosystems and anthropogenic activities.

In Mali (Figure 4.10), the results show a strong correlation between temperature, rainfall, and methane emissions. During the dry season, as temperatures rise, methane emissions decrease. This can be attributed to the lack of water,

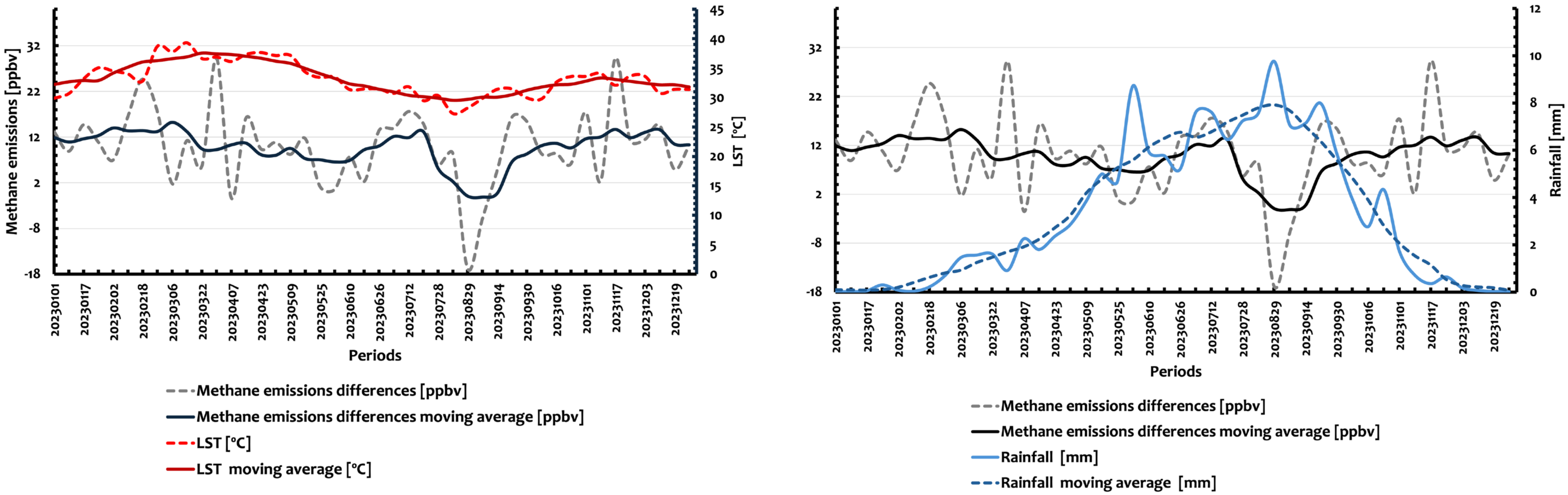
FIGURE 4.10—INFLUENCE OF CLIMATE PARAMETERS ON METHANE EMISSIONS IN MALI



Source: Authors.

Note: Temperature is on the left and rainfall on the right. The black, red, and blue curves represent the methane concentration difference between cropland and non-cropland emissions, temperature, and rainfall, respectively. The solid lines depict the moving averages for each parameter. LST = land surface temperature.

FIGURE 4.11—INFLUENCE OF CLIMATE PARAMETERS ON METHANE EMISSIONS IN NIGERIA



Source: Authors.

Note: Temperature is on the left and rainfall on the right. The black, red, and blue curves represent the methane concentration difference between cropland and non-cropland emissions, temperature, and rainfall, respectively. The solid lines depict the moving averages for each parameter. LST = land surface temperature.

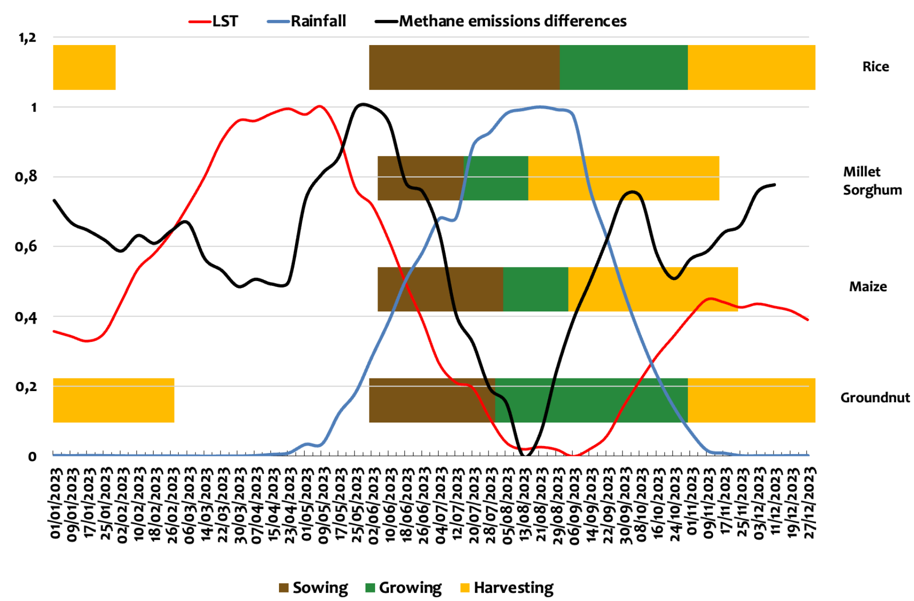
which is essential for the methanogenesis process; as rainfall increases, methane emissions decrease, eventually reaching their lowest point at the peak of rainfall. This decline in methane emissions is associated with the simultaneous decrease in temperature due to the increased rainfall. However, after the maximum rainfall is reached, the conditions become optimal for the methanogenesis process in suitable areas, as there is now sufficient water combined with a gradual temperature rise. This combination of adequate moisture and heat stimulates the methanogenesis process, increasing methane emissions.

In Nigeria (Figure 4.11), during the dry season, rising temperatures decrease methane emissions from natural processes, primarily due to the lack of water, which is essential for methanogenesis. As the rainy season begins, increasing rainfall causes temperatures to drop, resulting in fluctuating methane emissions. These emissions decrease significantly at the peak of rainfall when water availability is at its highest. However, abundant water and gradually increasing temperatures after the peak rainfall create favorable conditions for the methanogenesis process. This process is responsible for the subsequent rise in methane emissions, as the interaction between sufficient moisture and warmth promotes methane production in the environment.

Correlation Between Climate Parameters and Methane Emissions at Sowing, Growing, and Harvesting

To better understand the methane emissions from cropland, we examine methane concentrations at each stage of the agricultural season. The main objective is to elucidate the temporal dynamics of methane emissions in cropland environments. In addition, this study will investigate the possible relationship between crop types and methane emission concentrations. As previously discussed, different crops affect methane emissions to varying degrees.

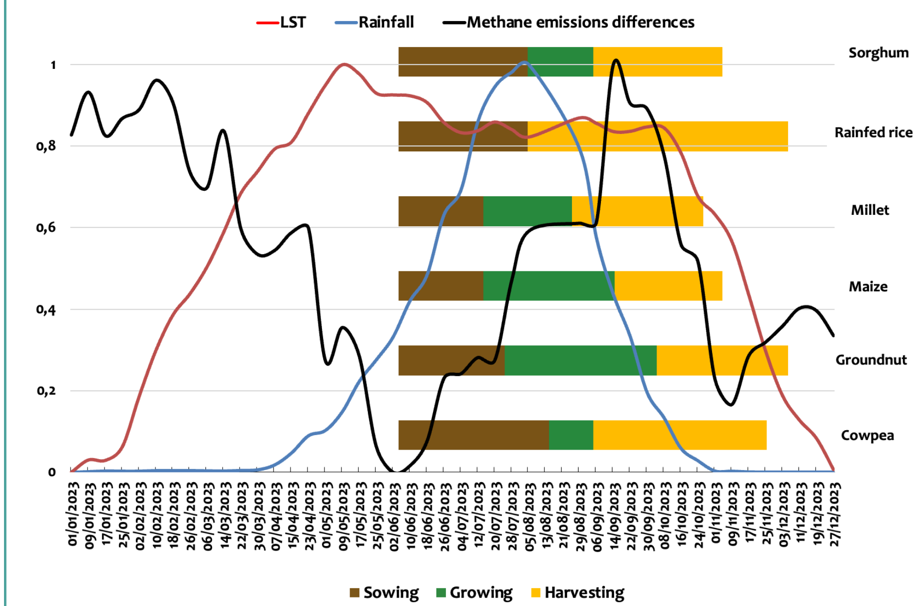
FIGURE 4.12—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN SENEGAL, 2023



Source: Authors.

Note: The agricultural seasons are shown in bar plots, with the sowing season highlighted in brown, the growing season in green, and the harvesting season in yellow, alongside various crop types. The red curve visualizes the temperature and the black curve the methane emissions concentration. The blue curve represents rainfall data for the year 2023. Note that the data have been normalized to the dataset's maximum and minimum values in the global dataset. LST = land surface temperature.

FIGURE 4.13—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGER, 2023



Source: Authors.

Note: The agricultural seasons are shown in bar plots, with the sowing season highlighted in brown, the growing season in green, and the harvesting season in yellow, alongside various crop types. The red curve visualizes the temperature, and the black curve shows the methane emissions concentration. The blue curve represents rainfall data for the year 2023. Note that the data have been normalized to the dataset's maximum and minimum values in the global dataset. LST = land surface temperature.

In Figures 4.12 and 4.13, the relationship between the agricultural season, temperature, and rainfall is shown for Senegal and Niger, respectively. During the sowing season, rainfall can significantly impact methane emissions. Increased rainfall leads to higher soil moisture levels, which may enhance methane production by creating anaerobic conditions that favor methanogenic microbes. This effect is particularly pronounced during the preparation of fields for crops such as rice, where waterlogged conditions are essential. Temperature also plays a role; warmer temperatures can accelerate microbial activity and organic matter decomposition, thus potentially increasing methane emissions. Effective irrigation management during this time can help mitigate excessive methane production by avoiding overly saturated soil conditions.

In the growing season, adequate rainfall is essential for crop growth, but excessive water can lead to conditions that support the anaerobic decomposition of organic matter, thereby increasing methane emissions. Conversely, insufficient rainfall might reduce methane emissions at the cost of increased crop stress and lower yields. Temperature influences are dual; higher temperatures increase microbial activity and organic decomposition rates, boosting methane emissions. However, plant physiological responses to higher temperatures can also alter root exudation patterns, potentially affecting soil microbial communities and their methane-producing capabilities. Managing these conditions through controlled irrigation and the selection of crops adapted to local climatic conditions can help reduce methane emissions.

In the harvesting season, the impact of rainfall is predominantly linked to the moisture content of the soil and crop residues. Wet conditions can slow the decomposition of organic material left in the field, temporarily reducing methane emissions. However, if these residues remain wet for prolonged periods, particularly in warmer conditions, they can become hot spots for methane production as they eventually decompose anaerobically. Temperature effects during harvesting are also significant, as warmer temperatures can increase the rate of residue decomposition, potentially leading to higher short-term methane emissions. Strategies such as timely harvesting to avoid rainy periods and managing residue treatment can effectively control methane outputs during this season.

Conclusion and Future Directions for Research

In this chapter, we address methane emission concentrations in Africa. We first present the results for the continental mean average of methane emissions, calculated for 2023. This average reveals a significant presence of methane emissions throughout the continent. The pronounced methane emissions from natural processes in almost all African countries is particularly striking, reaching its peak in the region of the Sahel. The analysis also indicates a number of discernible patterns, trends, and regional disparities.

We calculated the mean average methane emissions at a countrywide level to further investigate the disparities in methane emissions between countries. The results show that the amount of methane emitted varies significantly between different countries.

To assess the amount of methane emitted from the agricultural sector, we compared methane emissions from agricultural (cropland) and nonagricultural (non-cropland) land, focusing on areas characterized by natural processes. This comparison provides valuable insights into the relative contributions of different land use types to methane emissions, serving as a baseline reference for understanding the impact of human activities on methane production. The differences in methane emissions demonstrate the agricultural sector's significant contribution to methane emissions. The quantity of methane emitted was notably higher during certain months of the year.

We then introduced climatic variables to explore the possible correlation between methane emissions and changes in these variables throughout the year. Our findings indicate that temperature and rainfall significantly impact methane emissions. Additionally, we examined the relationship between the cultivation of specific crops, climatic variables, and methane emissions. We found that atmospheric methane levels vary according to the sowing, growing, and harvesting seasons, with more pronounced methane emissions during the harvesting season.

In this chapter, the use of TROPOMI primarily focuses on measuring methane emissions from natural processes, such as wetland emissions and agricultural activities, while not accounting for other significant sources of methane, such as industrial activities, waste management, and fossil fuel extraction. This limitation means the data presented do not capture the full spectrum of African methane emissions.

Future research should aim to investigate these additional sources of methane emissions to provide a more comprehensive assessment of Africa's net contribution to global methane emissions. By integrating data from other sources and measurement techniques, such as ground-based sensors, satellite data that can capture industrial emissions, and inventory methods, researchers can develop a more accurate methane budget for the continent. This expanded approach will be crucial for understanding the overall impact of African countries' emissions on global methane levels and for formulating effective mitigation strategies that address all significant sources of emissions.