DISEMPOWERED

SHEDDING LIGHT ON MYANMAR'S DEVELOPMENT CHALLENGES THROUGH NIGHT-TIME LIGHT

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Figure 1: The States and Regions of Myanmar

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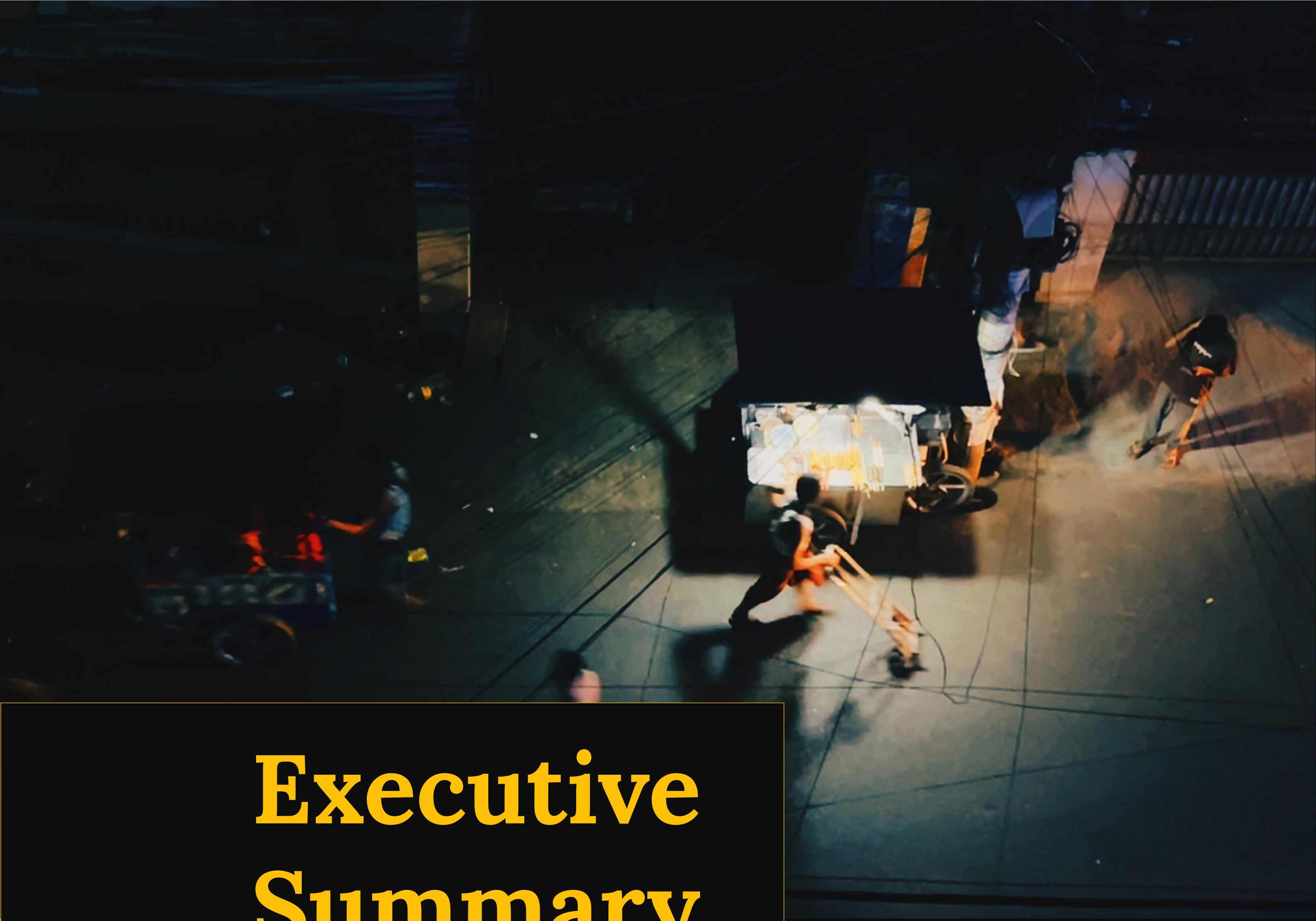
Abbreviations

DMSP-OLS	Defense Meteorological Satellite Program's Operational Linescan System
GDP	Gross Domestic Product
H-HDI	Household Human Development Index
IMF	International Monetary Fund
NTL	Nighttime Light
VCI	Vulnerability to Conflict Index
VIIRS	Visible Infrared Imaging Radiometer Suite



Executive Summary

Myanmar is experiencing a deepening economic crisis with devastating consequences for its population. Accurate assessments of poverty and vulnerability indices are increasingly needed to evaluate the current crisis. Given the data challenges, it has become essential to investigate proxy indicators that provide a greater understanding of the unfolding situation on the ground in Myanmar. One such proxy indicator that has been applied in other countries, including fragile states like Afghanistan and Yemen, is the analysis of Nighttime Light (NTL).[1] NTL satellite imagery measures the intensity of artificial light emissions, primarily from human settlements and economic activities. With traditional data sources potentially compromised or unavailable, nighttime light analysis offers an alternative means to monitor changes in the country's development landscape.

[1] Nightlights have been widely used as proxy measures of economic activity since the pioneering work of Henderson et al. (2011 and 2012) and the related discussion by Chen & Nordhaus (2011). Recent publications have made use of nightlights to study not only advanced economies like China (Liu et al. 2021, Zhou et al. 2022) and the United States (Gibson & Boe-Gibson 2021),but also the effects of conflict in countries such as Afghanistan (Sänger et al. 2023) and Yemen (Jiang et al. 2017) and the reliability of GDP estimates published by dictatorships (Martinez 2022). Further sources are Chi et al., 2022, Wang et al., 2021, Shah et al., 2020, Coscieme et al., 2017, Li et al., 2017, Jean et al., (2016), Li et al., 2013, Witmer et al., 2011.

This report leverages NTL satellite imagery to shed light on Myanmar's development challenges. Key findings of the report include:

- **Localized analysis and perspectives:** NTL data offers a strong evidence-base for conducting localized analysis and provides insights into the dynamics and disparities across different administrative levels in Myanmar.

- **Economic Activity:** There is a strong relation between NTL intensity and economic activity. From 2013 to 2021, Myanmar experienced a steady increase in NTL, indicative of economic growth and development. The post-2021 decline in NTL intensity (with over 70% of the townships facing a decline) corroborates the severe economic downturn.

- **Urban & Rural Development:** NTL data revealed significant urban & rural development trends prior to 2021, with notable growth especially in rural areas. Post-2021, the decline in both urban & rural NTL suggests a regression in overall development.

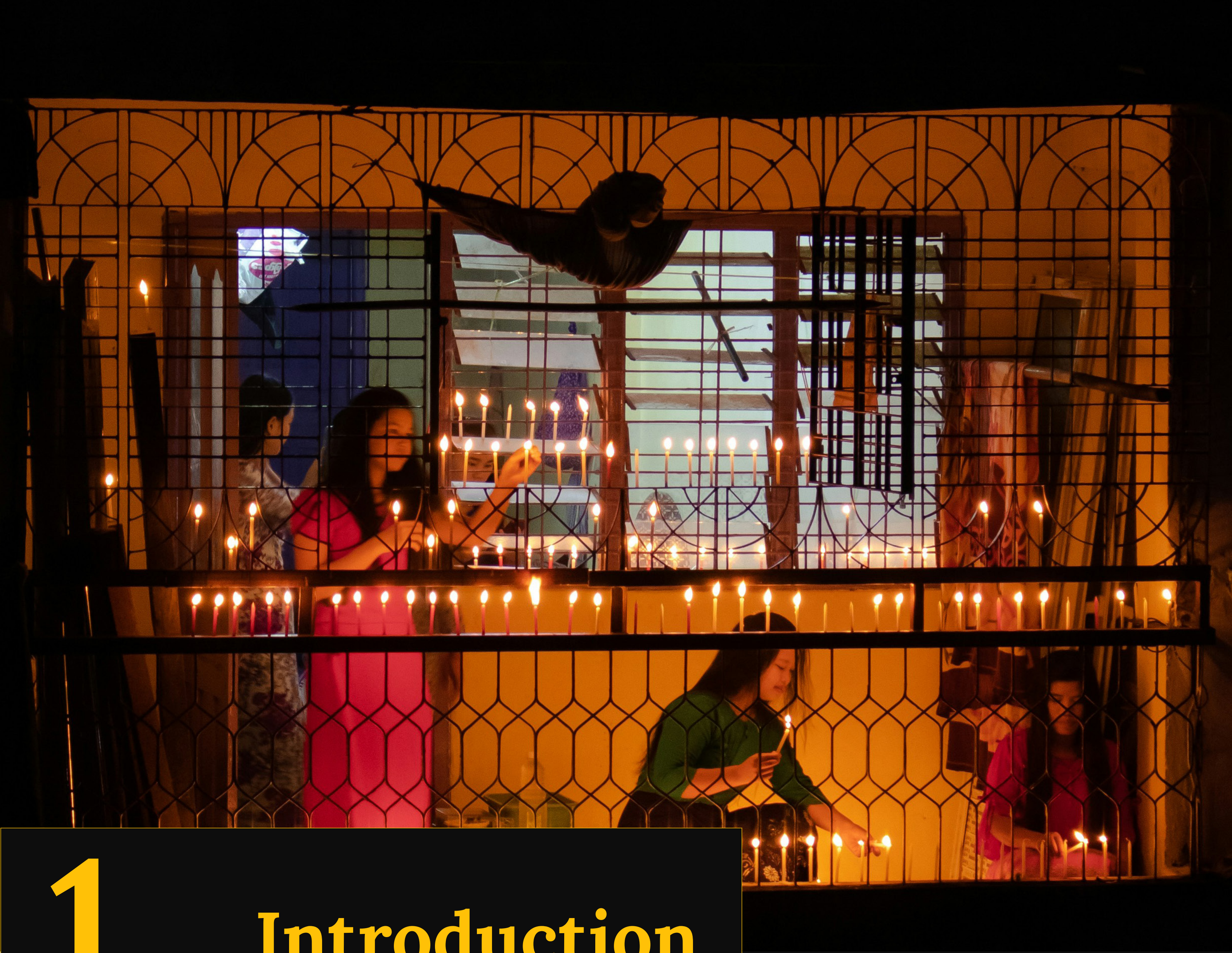
- **Electricity Access and Consumption:** There is a stark discrepancy between the latest 2021 electricity access rate of 72.5% and the projected rate based on UNDP's NTL data of 48%, showing a difference of 24.5 percentage points. It is argued that Myanmar's access to affordable and reliable electricity has decreased drastically, as illustrated by the country's frequent power outages, reduced usage to save costs, and disconnections from the grid due to an inability to pay.

- **Socio-economic Inequality and Human Well-being:** NTL intensity variations between regions underscore existing socio-economic inequalities. Regions with higher NTL growth pre-2021 saw improved economic conditions and development, while post-2021, the decline in NTL exacerbated existing inequalities, particularly in conflict-affected and vulnerable areas. A positive correlation was also found between NTL changes and changes of the Household Human Development Index (H-HDI) — a multidimensional indicator combining education, health, and assets — proving NTL can serve as a proxy indicator for H-HDI, and consequently, for human well-being.

- **Conflict and Social Distress:** Nearly 90% of the townships with a high vulnerability to conflict experience a drop in NTL, compared to a national average of 70%. This observation underscores that townships with a high vulnerability to conflict are disproportionally affected by electricity outages and declined economic activity.

The report highlights the value of NTL as a proxy indicator for assessing the impact of political turmoil, economic decline, and social distress in Myanmar. The human cost to the already vulnerable communities is high. Though a response requires a holistic approach, specific actions regarding electricity access and use can be taken into consideration: enhancing household level coping and adaptation strategies, application of alternative energy sources, and strengthening of local energy governance.

It is imperative to continue leveraging innovative data sources for accurate monitoring and targeted interventions. Comprehensive recovery and resilience strategies, informed by high-frequency data, will be essential in fostering localized sustainable development and resilience amidst Myanmar's ongoing adversity.



1. Introduction

Myanmar's unfolding political crisis has also led to a data crisis. High-frequency information through Nighttime Light (NTL) satellite imagery could be a valuable addition to the data landscape in Myanmar. Overall, alternative methods of data collection and innovative data are much needed in a context of data scarcity. Georeferenced data, allowing to 'localize' data, is especially valuable as it can generate data down to a specific administrative constituency. NTL data can localize data with high representativeness down to township and village tract level, something that national surveys are unable to do[2].

[2] In the case of surveys in Myanmar, most are conducted by telephone nowadays. Townships are often recorded, but the number of interviews per township is statistically insufficient to represent the entire township.

By analyzing changes and patterns in NTL over time, valuable insights can be gained into the distribution and magnitude of various activities and processes, including:

Economic activity: Nighttime light is strongly correlated with economic development, reflecting industrial, commercial, and residential activities.

Urban & rural Development: The intensity and spread of nighttime light can help identify urban and rural areas, and the extent of urban sprawl.

Access to and consumption of electricity: Areas with access to electricity are usually illuminated at night. Thus, nighttime light can be used to map and monitor electrification progress or regression. At the same time, nighttime light can illustrate a regression in areas that are electrified and highlight diminishing consumption patterns.

Socio-economic inequality and human well-being: Disparities in nighttime light intensity between regions can indicate socio-economic inequalities, such as differences in wealth and access to services. Correlations can also be found with wider human development indicators and indices, proving the value of NTL as a proxy for human well-being.

Conflict and social distress: Taking the above elements into consideration, nighttime light can also measure the intensity of conflict, as seen in diminishing economic activities, houses being disconnected and people leaving the area.

The objective of this report is to investigate whether NTL satellite imagery can be applied as a proxy indicator to provide insights into the dynamics and disparities across Myanmar over the last decade, especially since the events of February 2021.

NTL data was meticulously collected and analyzed at different administrative levels (national, state/region, and township), as well as by urban/rural classification, industrial and special economic zones, and seaports. The following chapter will delve deeper into the methodology, issues, and limitations, while chapter three will provide the observations at the different levels and categories. The report will conclude with key findings and some recommendations for the way forward.

2. Methodology

NTL images are captured by satellites equipped with sensors to detect artificial light emissions from Earth's surface during the nighttime. These images have evolved significantly over the years. In the past, data from the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS) sensor, with about a 1-kilometer spatial resolution, was commonly used. These observations were collected monthly, providing a broad overview of nighttime lights from 1992 to 2014. After 2014, the primary source for NTL data became the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor. VIIRS offers a much higher spatial resolution, with each pixel representing an area of 500 square meters on the ground, and with daily observations. In this study, particularly the Day-Night Band (DNB), was utilized, enabling an investigation into patterns of nighttime illumination and its temporal variations. This advancement allows for a more detailed, real-time analysis of changes in NTL, making it a valuable tool for studying urbanization, energy consumption, and economic development. The unit of radiance is expressed in watts per square meter per steradian ($W/m^2/sr$), but for simplification reasons, we'll refer to 'NTL intensity'.

Besides the widespread established use of NTL in various fields, including urban planning, environmental monitoring, and disaster response, and across a wide range of countries, including fragile states, there are some issues and limitations to be considered. These include the impact of cloud cover on data availability and quality, challenges in capturing areas with minimal nighttime lighting, and potential interference from sources like gas flaring and wildfires. A brief overview of the study's approach and mitigation strategies towards these issues and limitation is provided below, with further elaboration in appendix 1.

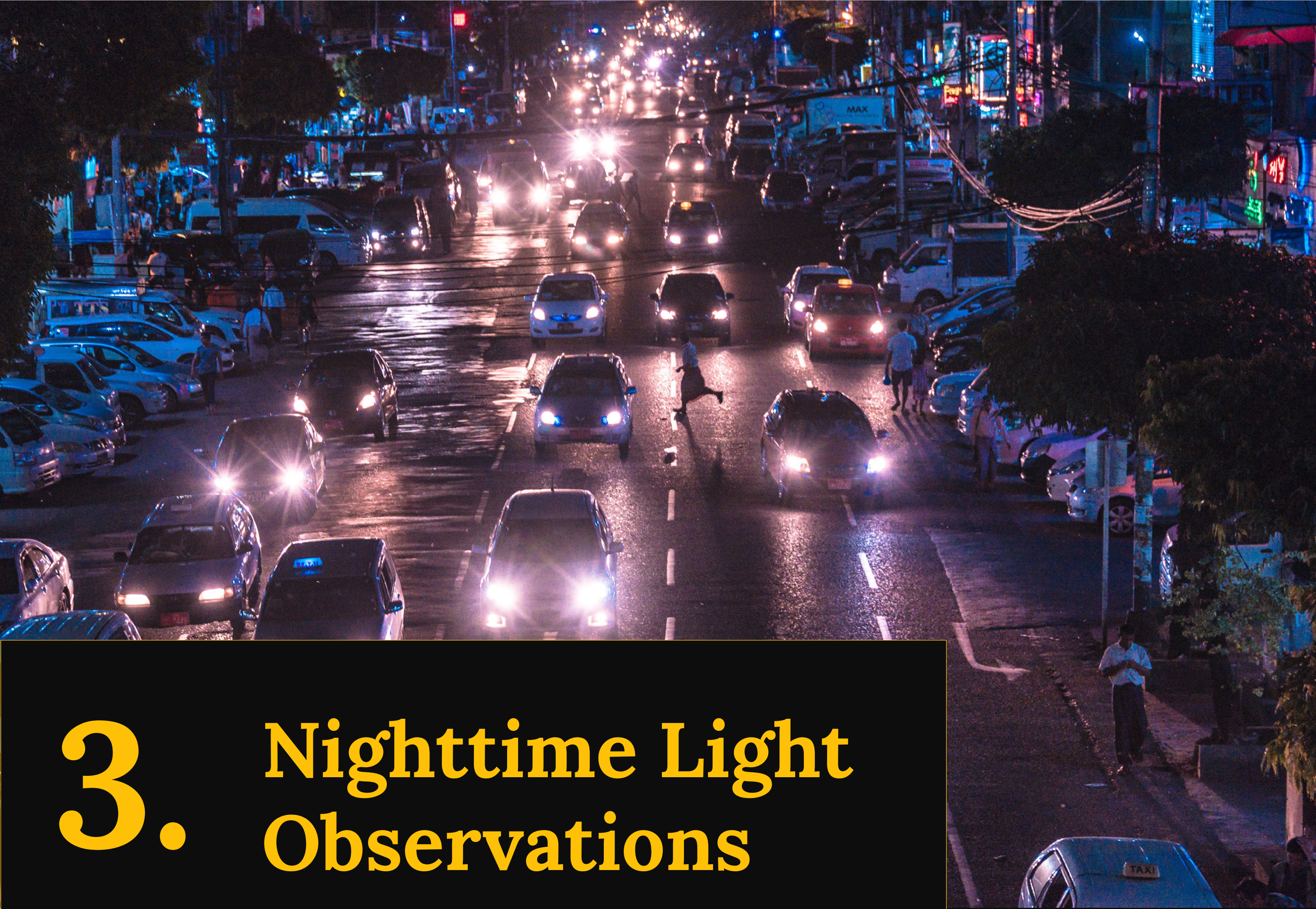
Seasonality and Timeframe: The methodology focuses on images from the dry season months (December to February) to mitigate the effects of seasonality on NTL measurements. This period spans the dry season and is considered for each individual year, aligning with the annual cycle of NTL variations (e.g. the '2021 data' spans from December 2020 to February 2021).

Clipping NTL Images and Data Aggregation: Each year's NTL image is clipped within the settlement area of interest. The unit of analysis is the pixel, and aggregation is performed to calculate average intensities for the entire area of interest, such as townships, states/regions, etc.

Temporal Filtering for Consistent Time Series Data: To ensure data consistency and mitigate spikes, a temporal filter is applied. This filter analyzes mean and median NTL intensity over a five-month period (November to March) and maximum monthly light intensity during a three-month span (December to February). Any values in the December to February time series surpassing the mean from November to March and exhibiting a maximum-to-median ratio exceeding 3 are masked [3]. This step helps eliminate outliers and ensures a consistent annual average NTL intensity for each year. To calculate the NTL value for each township, the pixels within the township area are selected and the average NTL intensity for each year computed.

Calculation of NTL for Specific Geographic Areas: The NTL value for each township and other specified areas (states/regions, urban/rural areas, etc.) is calculated by selecting pixels within the respective area boundaries and computing the average NTL intensity for each year.

[3] The methodology for generating consistent time series data for nighttime light draws on concepts from Elvidge (2017 and 2021).



3. Nighttime Light Observations

Interesting findings are made at different administrative levels. Analysis is conducted at the National, State/Region, and Township administrative levels, as well as within urban and rural classifications, industrial zones, and seaports.

3.1. National

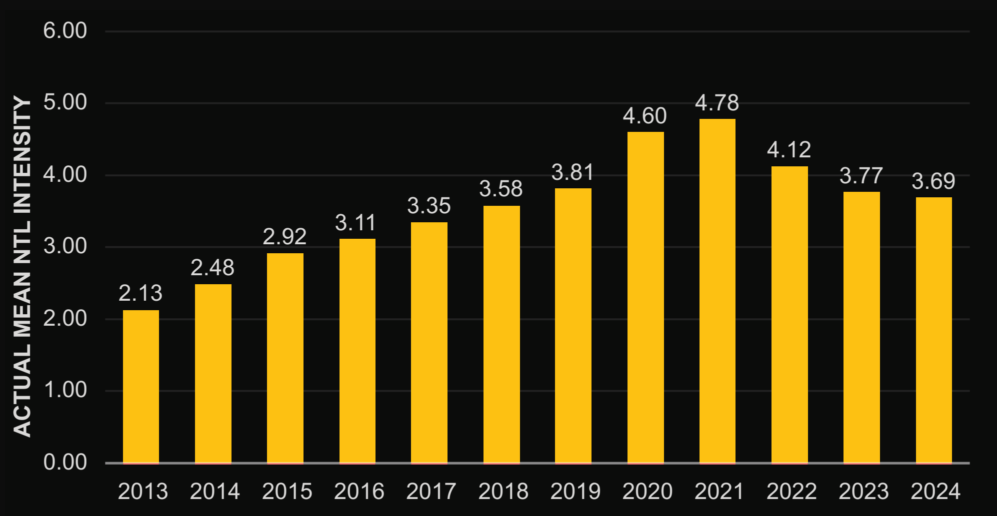
Key Findings

- **Global and Regional Comparison:** Myanmar's NTL intensity is low compared to neighboring countries, indicating lagging electrification and economic activity.
- **NTL Intensity and economic trends:** Substantial NTL growth from 2013 to 2021, and a decline after 2021, corroborating the economic trends in these periods.
- **Electricity Access:** Myanmar had already a low access to electricity rate compared to other countries in Southeast Asia, but the projected rate, based on NTL data, for 2024 of 48% makes Myanmar the least electrified country in Asia, comparable to some Sub-Saharan countries.

The NTL intensity trend for Myanmar shows substantial growth from 2013 to 2021, with a gradual drop after, as depicted in figure 2. The consistent NTL increases from 2013 to 2021 indicate sustained efforts to enhance electrification across the country and increased economic activity. The sudden decline after February 2021 underscores the existence of (an) external factor(s) that have contributed to this decline. While COVID-19 surely had an impact, the ongoing decline suggests a more structural impact. Simultaneously, it is no secret that the post-military takeover period faced huge challenges with power outages due to insufficient generation capacity, as reported by the World Bank. In two recent reports, they highlight that 'the electricity sector in Myanmar is grappling with a critical situation marked by severe supply constraints and significant unmet demand. Many of the challenges in the power sector are structural, fundamental, and linked with political instability, conflict, and macroeconomic conditions'[4]. The second report details the diminishing operational capacity and the significant drop in 2022 and 2023. For 2024 it mentioned that 'the operational capacity in early 2024 is so low as it was in 2015, meaning that years of progress has effectively been undone'[5].

Figure 2 shows the mean NTL intensity at the national level from 2013 to 2024[6].

Figure 2: Mean NTL at the national level (2013-2024)



It is well known that countries like China and India have developed rapidly over the last decade. However, even when comparing Myanmar with Southeast Asian countries (Cambodia, Indonesia, Lao PDR, Malaysia, the Philippines, Thailand, Timor-Leste, and Vietnam), it is evident that Myanmar has always had and still has the lowest NTL intensity in the region.

4 World Bank (2023) 'In The Dark: Power Sector Challenges in Myanmar,' August 2023 and World Bank (2024) 'Myanmar Energy Sector Update: Energy Poverty Amid Plenty', June 2024

5 Ibid.

6 The unit of 'radiance' is watts per steradian per square meter ($W/m^2/sr$), but for NTL analysis the more precise nanowatt per steradian per square centimeter ($nW/cm^2/sr$) is used. The range is roughly between 0 and 200 for cities, with, for example, New York and Bangkok on the higher end. The highest NTL intensity measured in Myanmar is in downtown Yangon, Kyauktada, with a mean radiance of 69.8

Figure 3: Nighttime light satellite imagery comparison 2014 and 2024

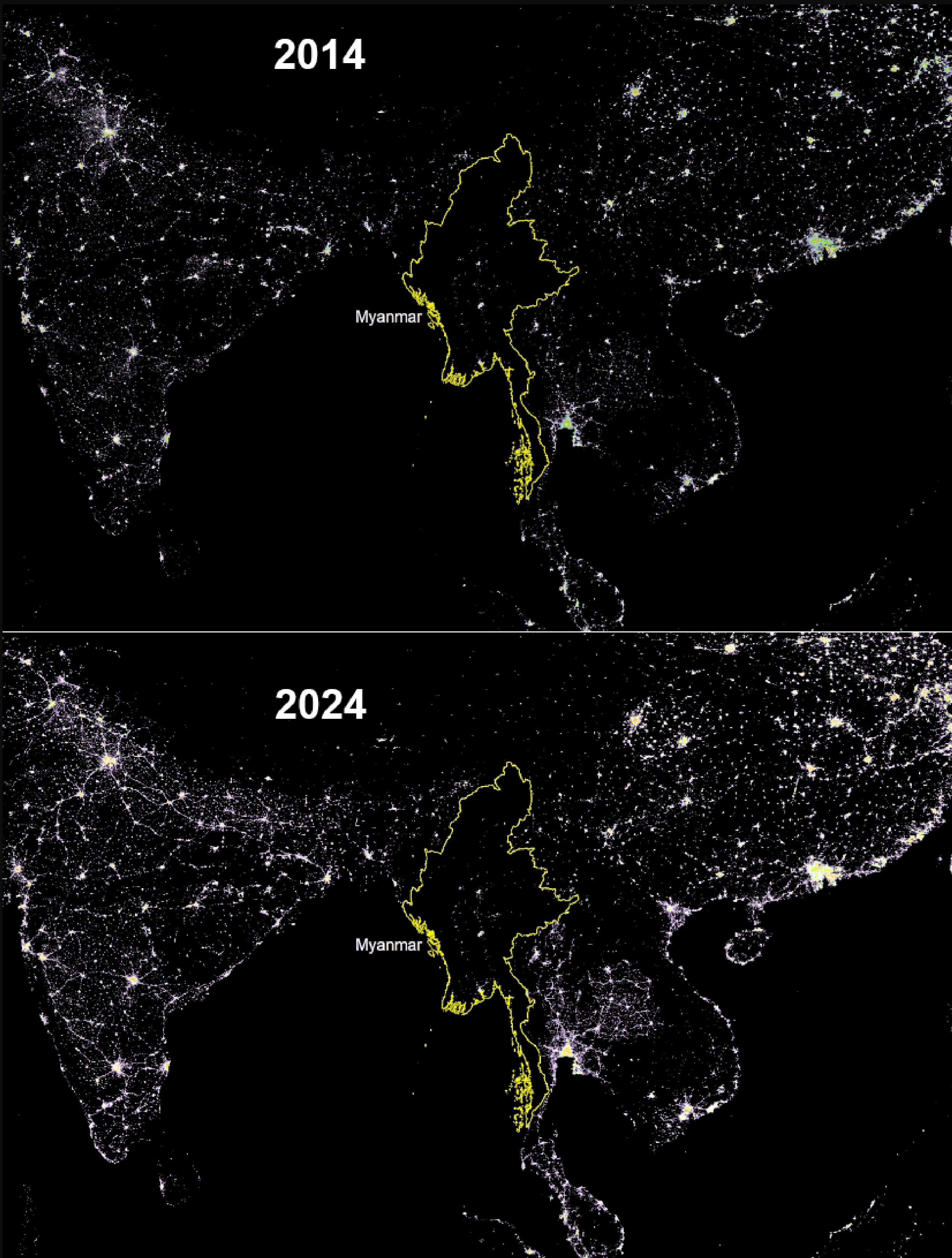
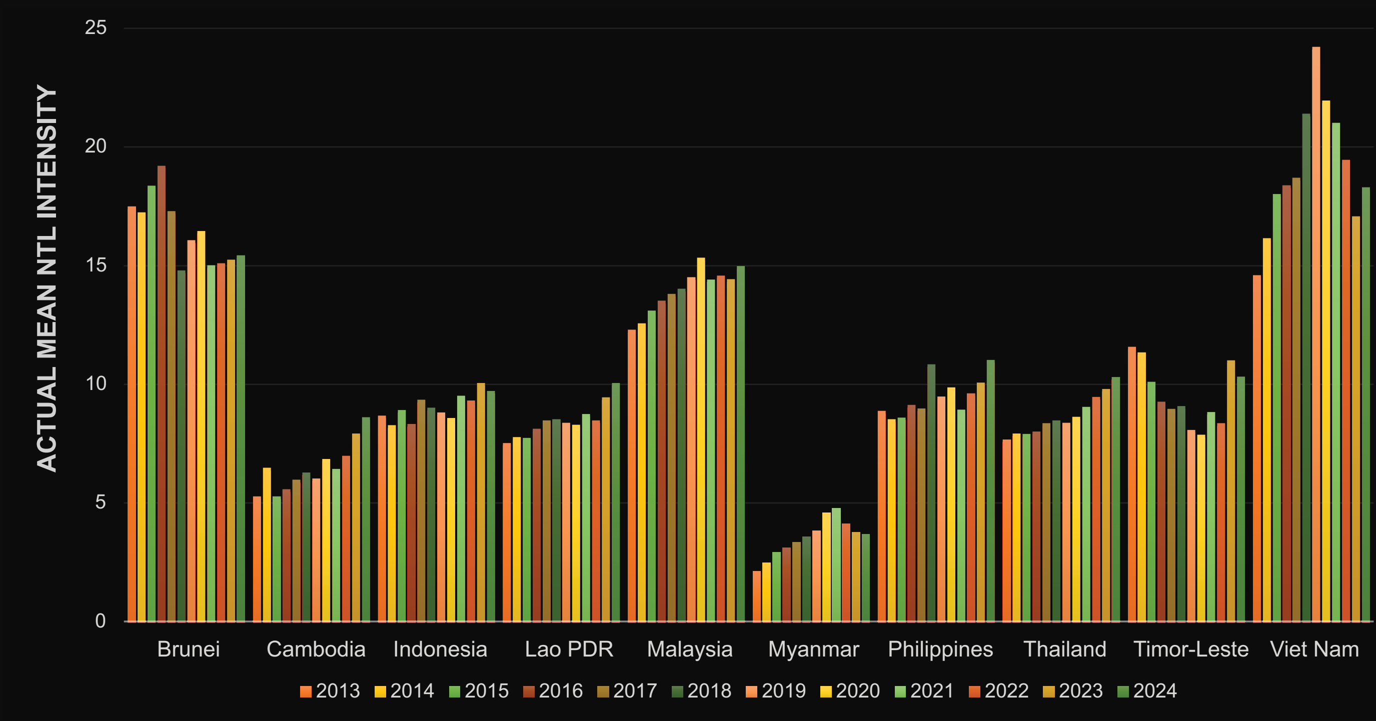
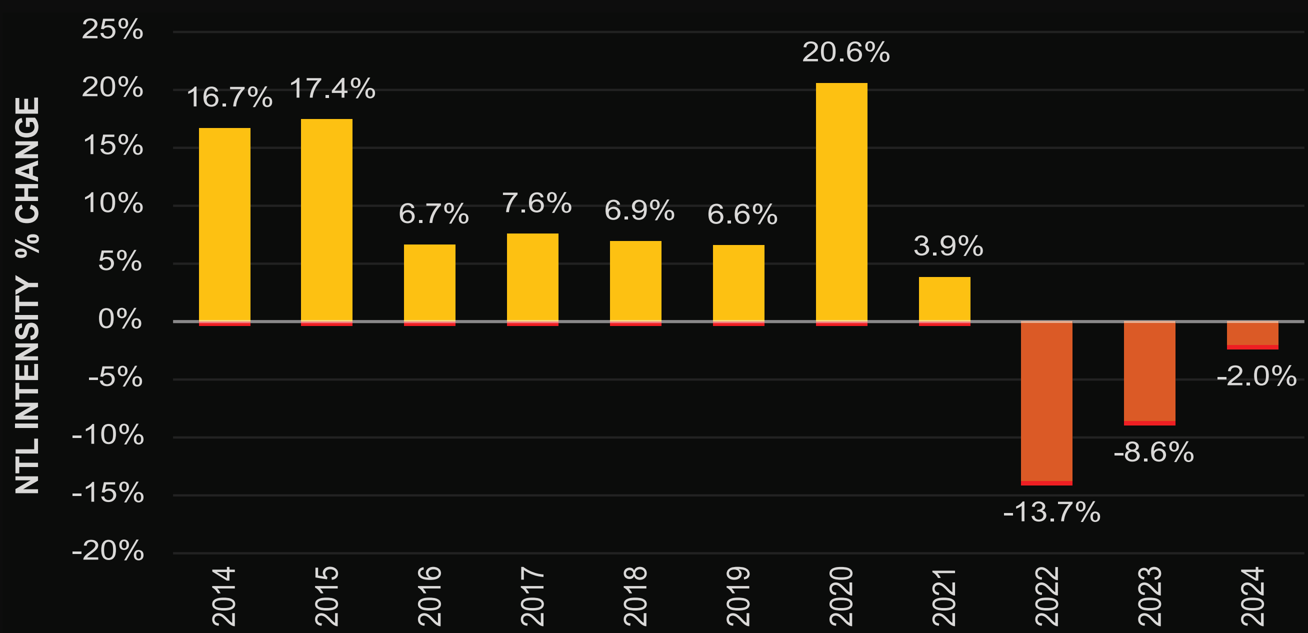


Figure 4: Mean actual NTL of countries in Southeast Asia (2013-2024)



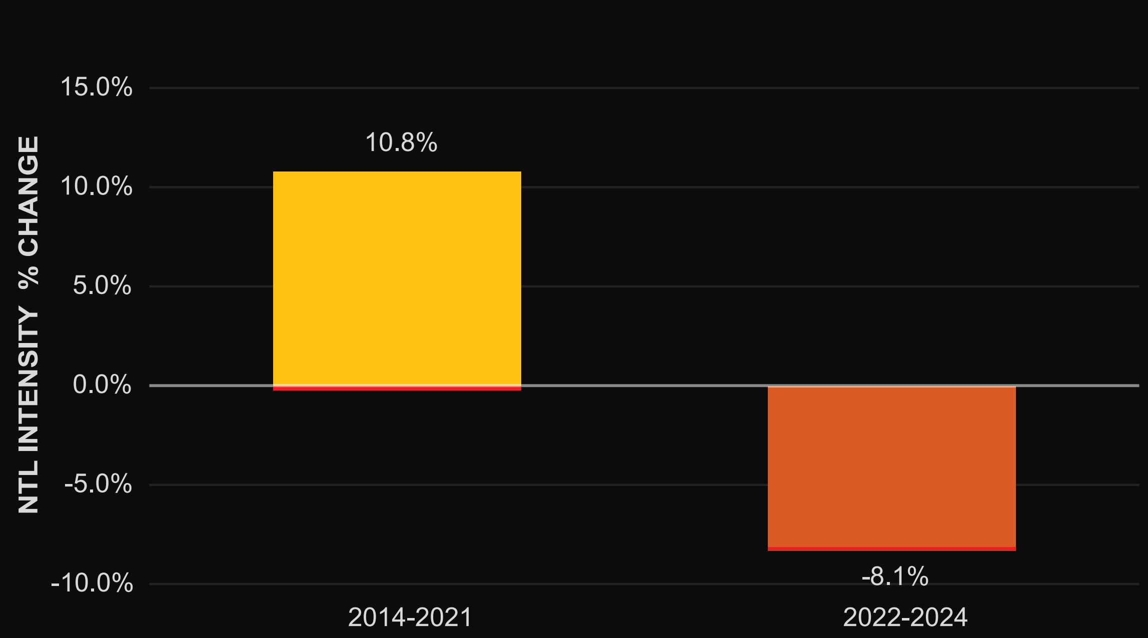
Given the high geospatial variance in NTL, population density and economic activities, a commonly applied method is to highlight the annual percentage change within a specific geospatial area. It thereby compares the NTL intensity of a certain year with that of the previous year. When applying this 'Annual NTL Intensity Change Rate', or simply 'NTL % change', to Myanmar, two periods in the last decade can be clearly identified: 2014-2021 and 2022-2024, as illustrated in figure 5.

Figure 5: National annual NTL % change by year (2014-2024)



For an enhanced overview and targeted analysis, the report will continue using these two periods and apply the average of the annual NTL intensity change rates, as shown in figure 6.

Figure 6: National average NTL % change, by period (2014-2021 and 2022-2024)



These two periods have specific socio-economic and political characteristics.
2014-2021: This period of 7 years is characterized by the consolidation of the country's democracy[7] and steady economic growth of around 6-10% annually. The annual NTL change rate has an average of +10.8%.
2022-2024: This period of 3 years is characterized by the military takeover with a steep economic decline of nearly -18% in 2021 and modest growth in 2022 and 2023. The annual NTL change rate has an average of -8.1%.

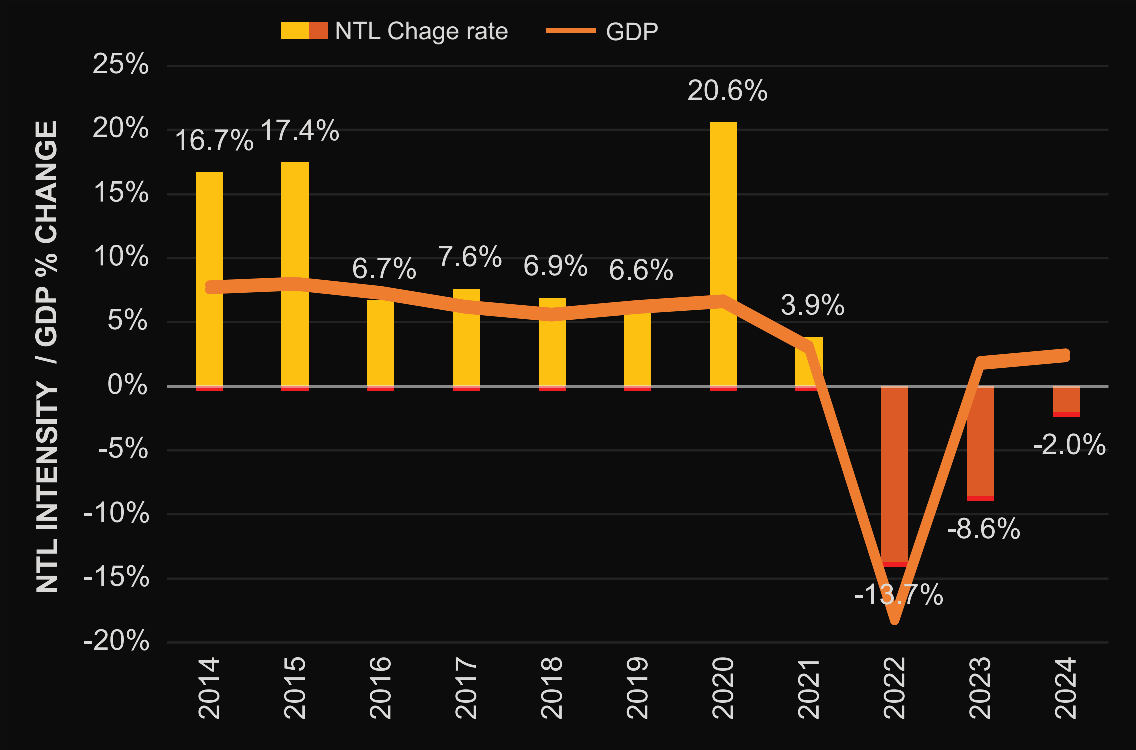
These two periods will be applied in the analysis of the other administrative levels and zones.

[7] Although there is no intent to make a direct correlation between 'democracy' and higher electricity use, a correlation can be found. For example, Brian Min highlights in Power and the Vote: Elections and Electricity in the Developing World (New York: Cambridge University Press, 2015) that electricity provision is an effective tool for winning votes during elections. Additionally, many studies conclude that there is a positive relationship between democracies and economic growth, suggesting that one fosters the other (e.g., Uk Heo and Alexander C. Tan (2001), Democracy and Economic Growth: A Causal Analysis; Acemoglu Daron et al. (2019), Democracy Does Cause Growth). Subsequently, the relationship between economic growth and electricity use/NTL intensity is obvious. Therefore, indirectly, democracies can also be positively linked to electricity use/NTL intensity.

Relation with GDP and electricity

When overlaying the annual NTL intensity with the GDP[8] for the respective year, a relation is visible, indicating that the contraction of the national economy in 2022 is well captured through the national level NTL intensity.

Figure 7: National annual NTL % change and GDP (2014-2024)



When it comes to electricity access and consumption, there is an obvious relation with NTL, but an elaboration on the situation in Myanmar is worthwhile. At a global level, the percentage of people with access to electricity has been steadily increasing over the last few decades to 90%.[9] Myanmar has always been one of the least electrified countries in Southeast Asia and the latest estimation in 2021 of the World Bank for Myanmar provides an access to electricity rate of 72.5%. Neighbouring countries show rates of 82.5% in Cambodia and 100% in Laos and Thailand. [10]

In applying the term 'access to electricity rate' to today's electricity challenges in Myanmar the qualitative aspects of 'affordability' and 'reliability' are particularly important given Myanmar's context of frequent power outages, reduced usage to save costs and disconnections from the grid due to an inability to pay.

8 IMF Real GDP Growth Rate: World Economic Outlook (October 2023) - Real GDP growth. Visited 2 April 2024.
9 https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=MM-KH-LA-TH-1W, visited April 2024.
10 Ibid.

Figure 8: Access to electricity in Myanmar, Thailand, Laos and Cambodia

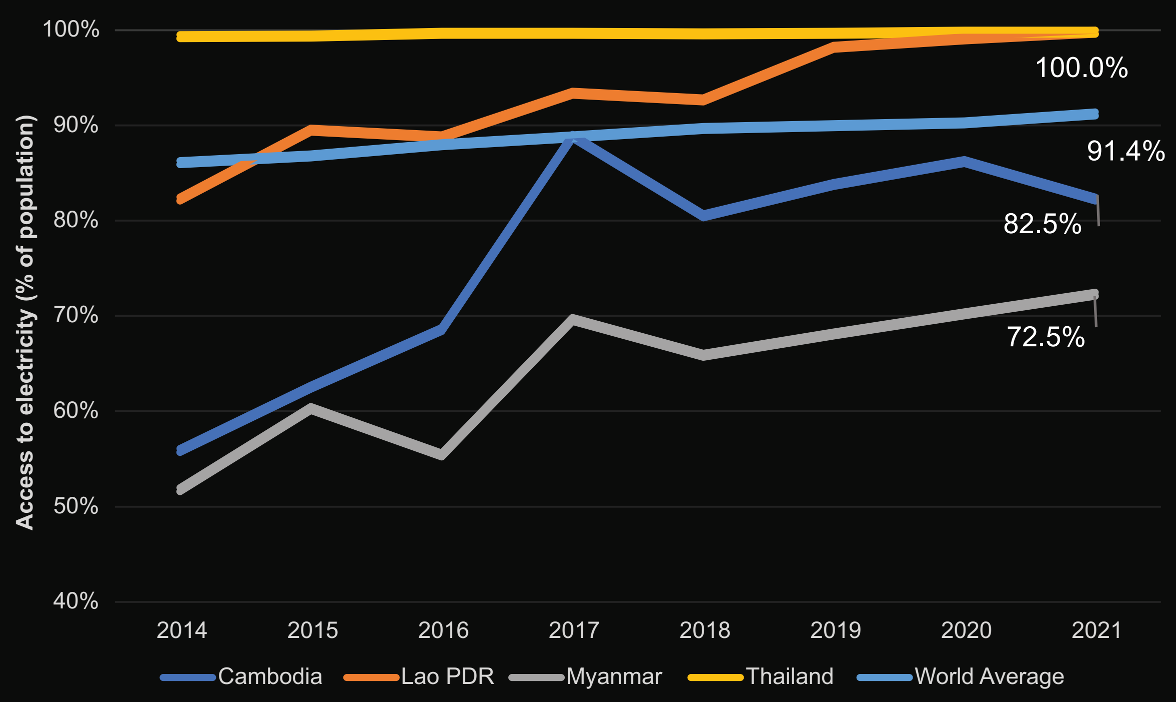
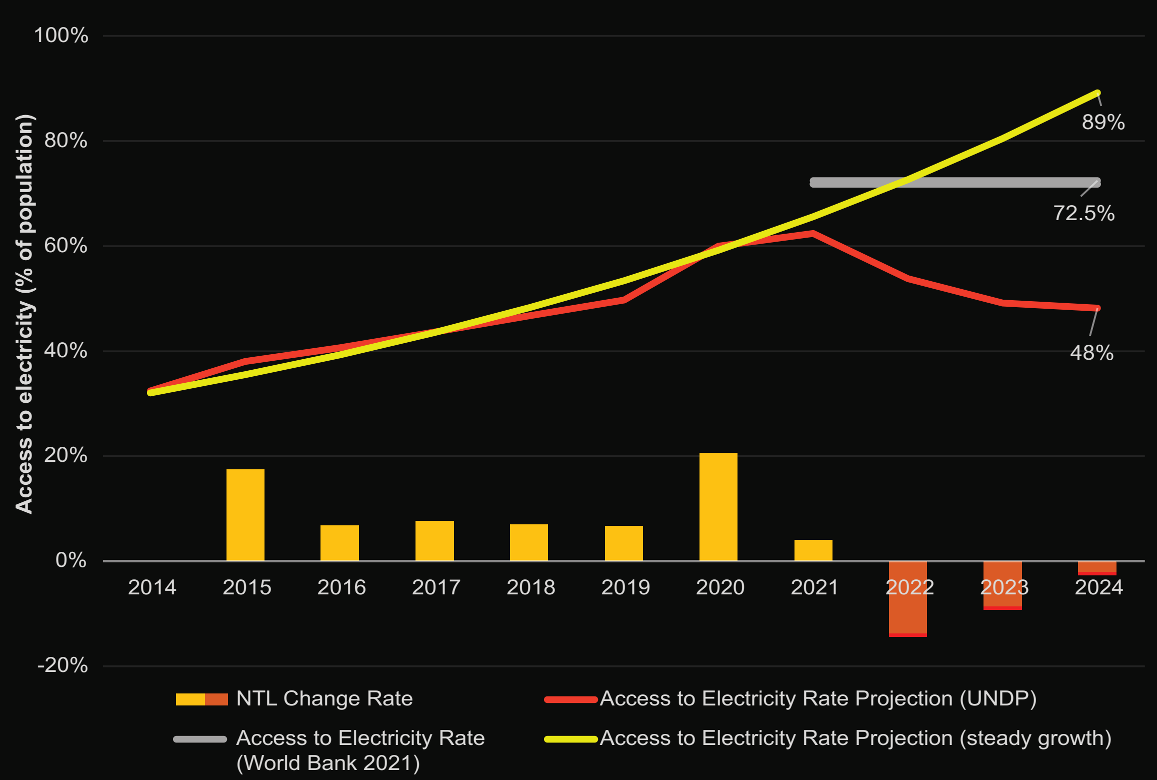


Figure 9: Access to electricity projections based on NTL



A projection based on the Myanmar's 2014 census data[11], multiplied with a steady average growth of 10.8% annually, estimates an access rate of 66% in 2021 and 73% in 2022, which is close to the World Bank estimate. If this growth would have continued, the access to electricity rate today would be 89% (figure 9, yellow line). This counterfactual data quantifies how Myanmar's access to electricity rate might have developed, and compared to neighbouring countries, this would not be an unrealistic estimation. However, when applying the individual NTL intensity changes, including those of 2022-2024, to the 2014 census data, the graph shows a clear drop post-2021 (figure 9, red line).

The 2024 value of the projected access to electricity rate (UNDP), compared to that of the projection with steady growth, illustrates a stark discrepancy. It is this gap between the current reality on the ground and the counterfactual of "what might have been" that captures the entirety of the post-2021 impact on access to electricity. However, there could be various reasons why the steady growth projection post-2021 does not hold, such as a prolonged impact of COVID-19, and an already challenged power sector infrastructure. Assuming no growth to the 2021 rate of 72.5% up to now, the discrepancy remains at 24.5 percentage points.

It can be concluded that people's access to electricity, whether due to affordability or reliability, is severely constrained. With a projected access to electricity rate of 48%, Myanmar would be the least electrified country in Asia, falling below North Korea (52.6%) and comparable to Sub-Saharan countries such as Angola (48.2%), Zimbabwe (49%), and Somalia (49.3%).[12]

3.2. State and Region

Key Findings

- **Growth and decline of NTL:** All states and regions, except Nay Pyi Taw, showed increased NTL intensity from 2014-2021, and all states and regions, except Kachin, experienced a decline from 2022-2024.

- **Relation with income and well-being:** Higher NTL is correlated with higher monthly incomes, and positive NTL changes are linked with positive H-HDI changes, and negative NTL changes with negative H-HDI changes, indicating NTL could be used as a proxy for monetary and non-monetary indicators.

The analysis of NTL intensity at the State/Region level provides valuable insights into the dynamics among the states and regions. It follows the same analysis into two distinct periods: from 2014 to 2021 and from 2022 to 2024[13]. Yangon and Mandalay experienced the highest absolute growth in the first period (Figure 10). However, Chin, Rakhine, and Tanintharyi experienced the highest relative growth (Figure 11). While absolute increases and decreases in NTL intensity are interesting and relevant, the impact on states and regions is best measured by the relative (percentage) change. For example, the steep absolute increase of Yangon from 2014-2021 is of less relative impact than the modest absolute increase of Chin. Similarly, the absolute decreases between 2022 and 2024 in Mon, Chin, Kayah, Magway, and Sagaing might look moderate, but the percentage change shows it had a drastic impact on these states and regions.

11 Myanmar Census Data (2014). https://themimu.info/census-data. Although dated, it is the most comprehensive dataset at the household level and provides an electrification rate of 32.4% in 2014.
12 https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=AO-ZW-SO-KP , visited April 2024
13 For absolute change the previous year is taken into consideration to avoid a data gap.

Figure 10: Absolute NTL % change, by state/region by period

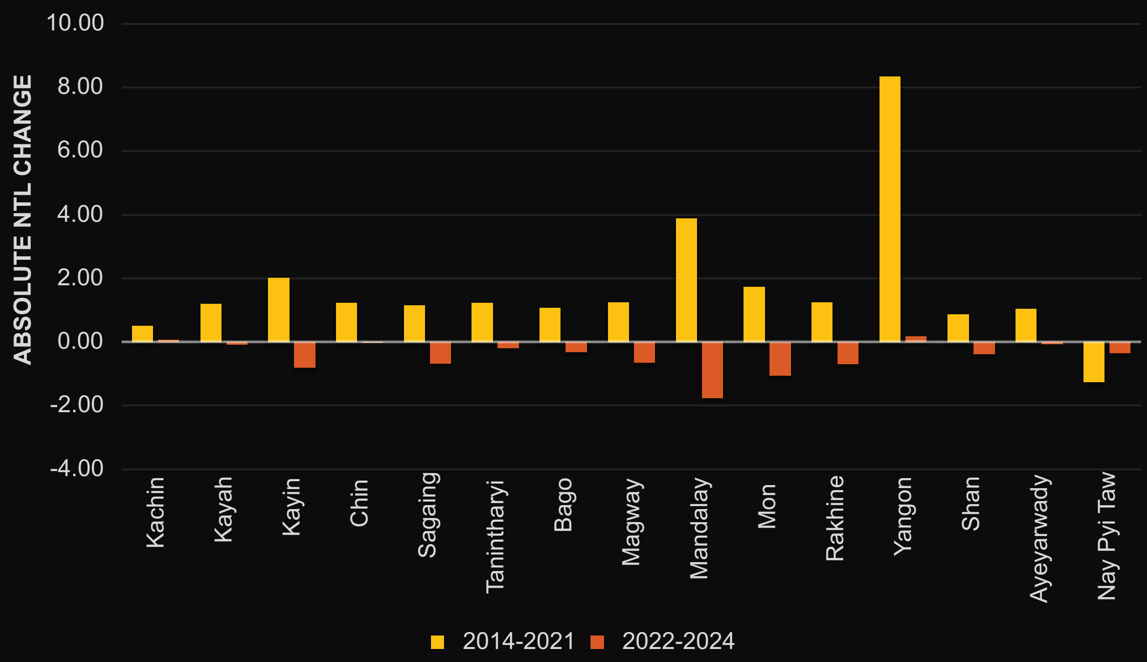
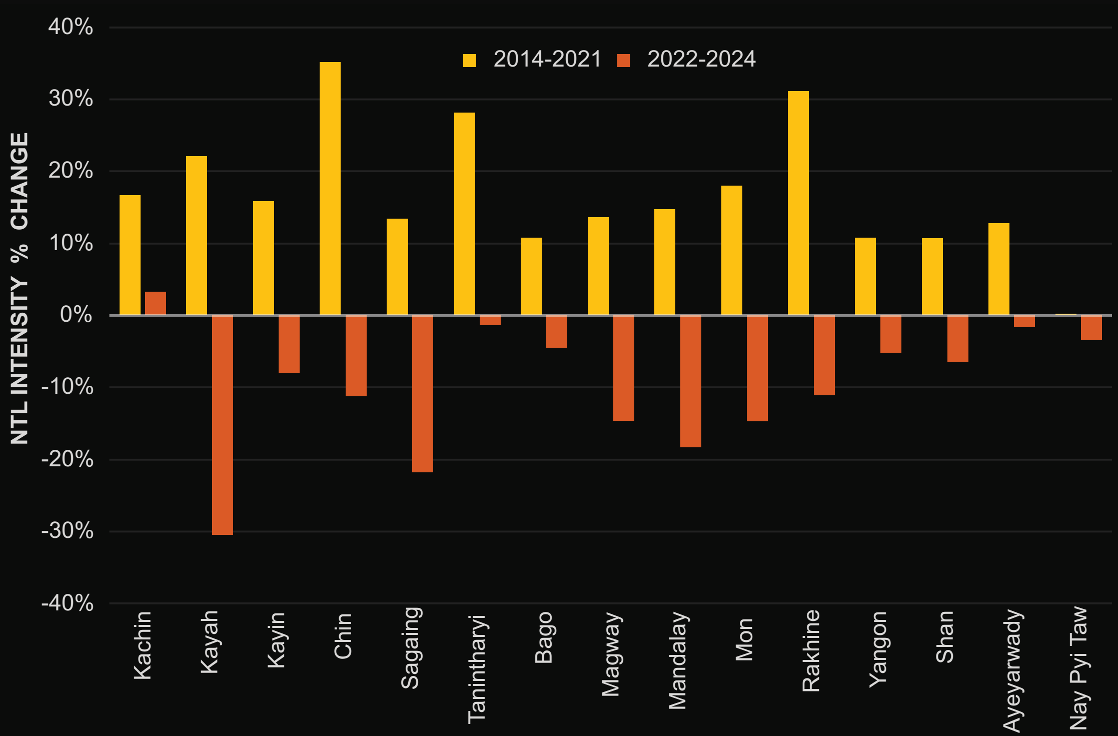


Figure 11: Average NTL % change, by state/ region by period



Given the higher relevance of the percentage change, the report will emphasize this in the analysis.

From 2014 to 2021, all states and regions, except Nay Pyi Taw, experienced a positive average annual NTL change, meaning that each year saw an increase in NTL intensity compared to the previous year, suggesting a rise in economic activity and electricity consumption. Four states and regions stand out particularly with rates above 20%: Chin (35.1%), Rakhine (31.1%), Tanintharyi (28.1%), and Kayah (22.1%). It signifies strong efforts in electrification, and increased economic activities over the specified period in these states and regions.

The other states and regions experienced a more moderate rate compared to the first group. It ranges from Shan, Bago, and Yangon, with an average annual NTL change of slightly below 11%, to Mon, with an average annual NTL change of 18%. The ones in between are Ayeyarwady (12.8%), Sagaing (13.4%), Magway (13.6%), Mandalay (14.7%), Kayin (15.8%), and Kachin (16.7%).

Conversely, Nay Pyi Taw experiences a slight decrease in NTL, both in absolute terms (-0.23) but it still maintains a positive average annual change rate. This decline may be attributed to the factor of dimming streetlights in this period, which is verified with anecdotal evidence.

The 2022-24 period is characterized by a negative average annual NTL change across all states and regions, except Kachin. Kachin experienced a slight absolute increase in NTL corresponding to an average annual percentage change of 3.3%. This relative positive picture for Kachin can most likely be attributed to the agreement made between the SAC and China to distribute less electricity from the 240-Megawatt (MW) Dapein hydropower in Bhamo to China. While earlier only 19% (46 MW) was used for Myanmar, a renegotiation in 2023 lifted it to 50% (120 MW)[14]. The raw data confirms there was a steep one-off increase of 2023 data compared to 2022. However, the 2024 data compared to 2023 shows again a decrease of 26.6%. It could mean an end of the agreement and higher export again to China, possibly due to political tensions in Kachin.

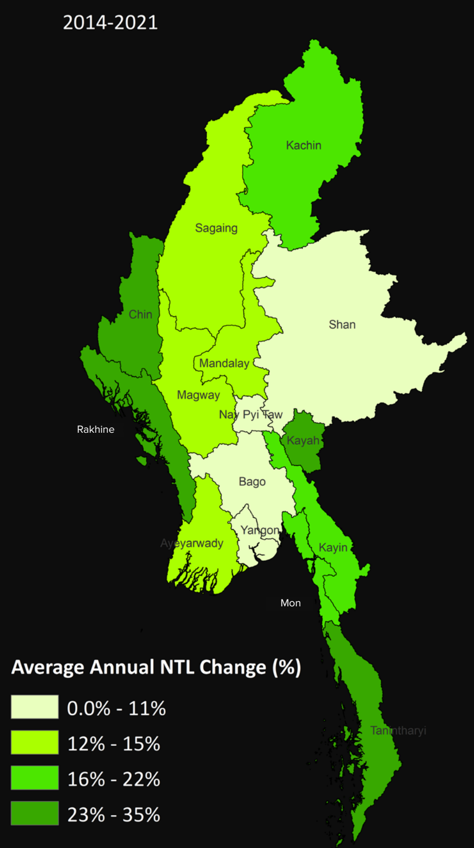
Conversely, Kayah, Sagaing, and Mandalay witnessed a notable absolute decrease in NTL, accompanied by a percentage change between -30.4% and -18.3%, indicating a significant decline in nighttime illumination, potentially reflecting economic downturn.

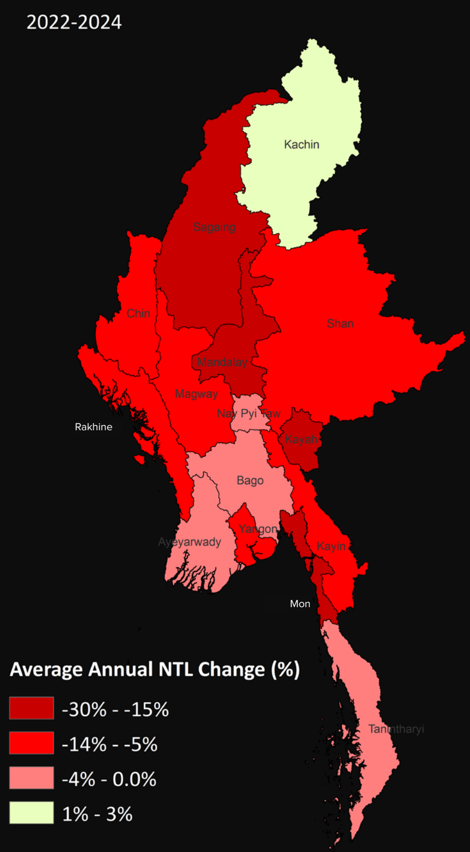
Similarly, other regions like Mon, Magway, Chin, Rakhine, Kayin, Shan, and Yangon also experienced decreases in NTL, with percentage changes ranging from -5.1% to -14.6%, suggesting varying degrees of decline in economic activity or development within these areas.

Some regions, such as Bago, Nay Pyi Taw, Ayeyarwady, and Tanintharyi, showed a decrease in NTL, with percentage changes less than -5% in this period.

14 https://www.irrawaddy.com/news/burma/myanmar-regime-signs-energy-agreement-with-china.html

Figure 12: Average annual NTL % change, by state/region by period





Relation with income and human well-being

When comparing monthly income data from the People's Pulse survey with the respective NTL in the data collection period, it shows there is a correlation between the two: the higher the NTL, the higher the monthly income.[15]

There is also a correlation with non-monetary indicators. In April 2023 UNDP launched a report diving deeper into Myanmar's household-based human development[16]. It combines the indices for the three sub-components of human development — education, health and assets — and offers a comprehensive measure of human well-being. When overlaying the NTL percentage change with the percentage change of the H-HDI[17], there appears to be a correlation between the two[18]. Positive NTL changes are closely linked with positive H-HDI changes and negative NTL changes with negative H-HDI changes. NTL changes seem to be a good proxy indicator for H-HDI changes, and so for the human well-being.

15 The correlation coefficient has a value of 0.65.
16 UNDP (2023) Myanmar-At-A-Crossroads_Past-Trends-Of-Human-Well-Being-And-A-Future-Outlook
17 For this purpose, the average % change rates of the H-HDI pre-2021 and post-2021 are calculated.
18 The correlation coefficient has a value of 0.88.

Figure 13: Correlation of NTL and income by state/region

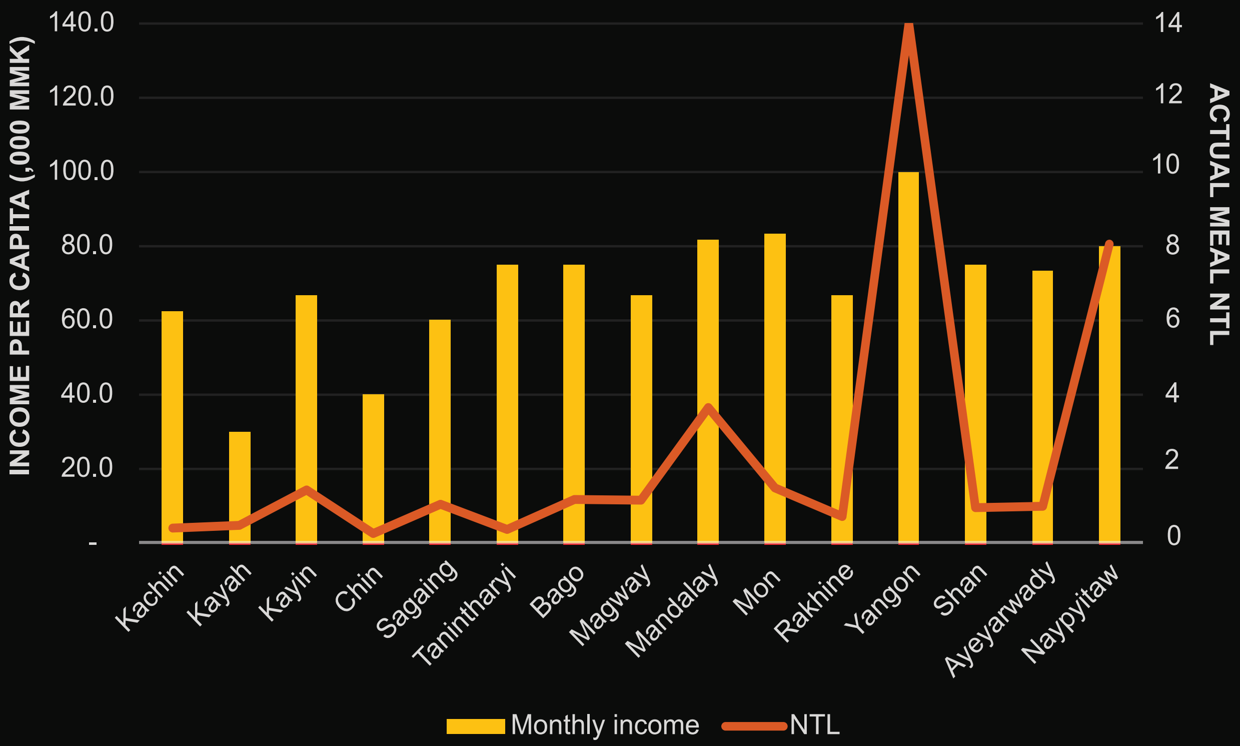
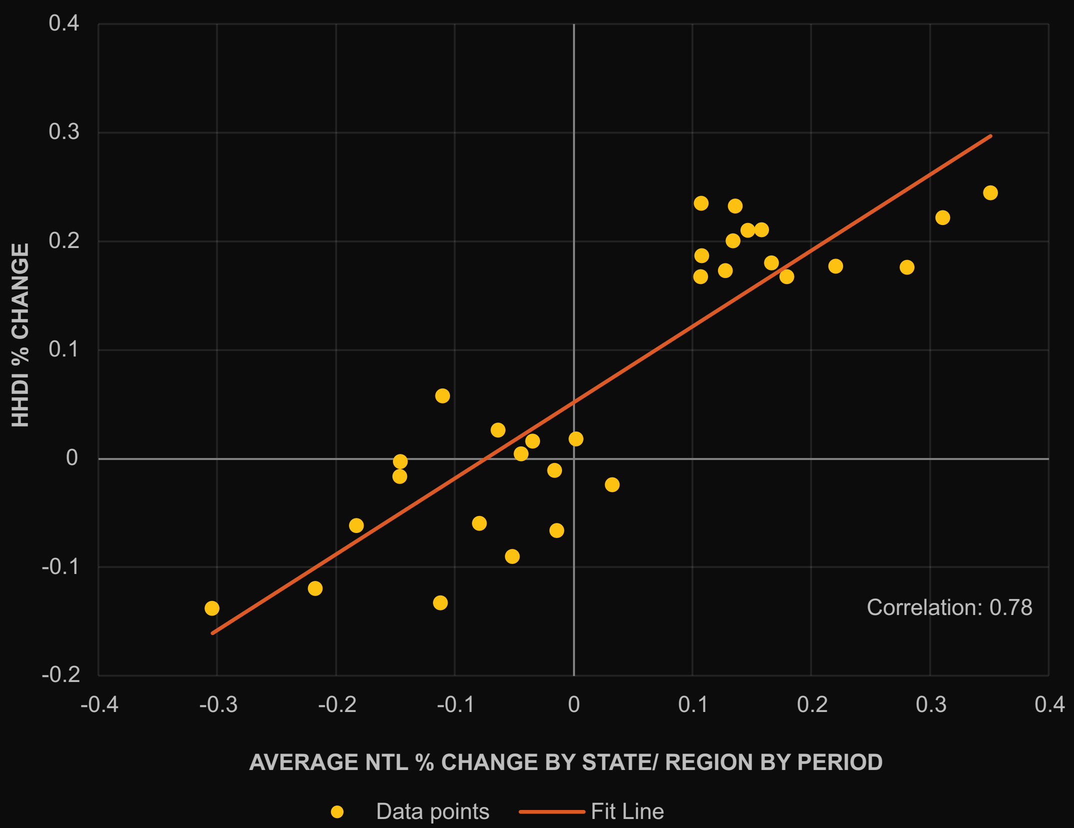


Figure 14: Average NTL % change by state/region by period, compared with average H-HDI % change



3.3. Township

Key Findings

- **Growth and decline of NTL:** NTL increased significantly across townships from 2013 to 2021, with only 5% of townships seeing a decline. Post-2021, 70% of townships faced declines in NTL.

- **Relation with vulnerability to conflict:** 89% of townships with a high vulnerability to conflict experienced a drop in NTL from 2022 to 2024, compared to a national average of 70%. This observation underscores that townships with a high vulnerability to conflict are disproportionally affected by electricity outages and declined economic activity.

At the township level, more detailed patterns can be established. The following paragraphs will elaborate on the main findings. From the larger picture, it stands out that NTL increased drastically from 2013 to 2021, as visible in Figure 15. However, 70% of the townships faced NTL declines after 2021.

Figure 15: Mean NTL by township (2013, 2021, 2022 and 2023)

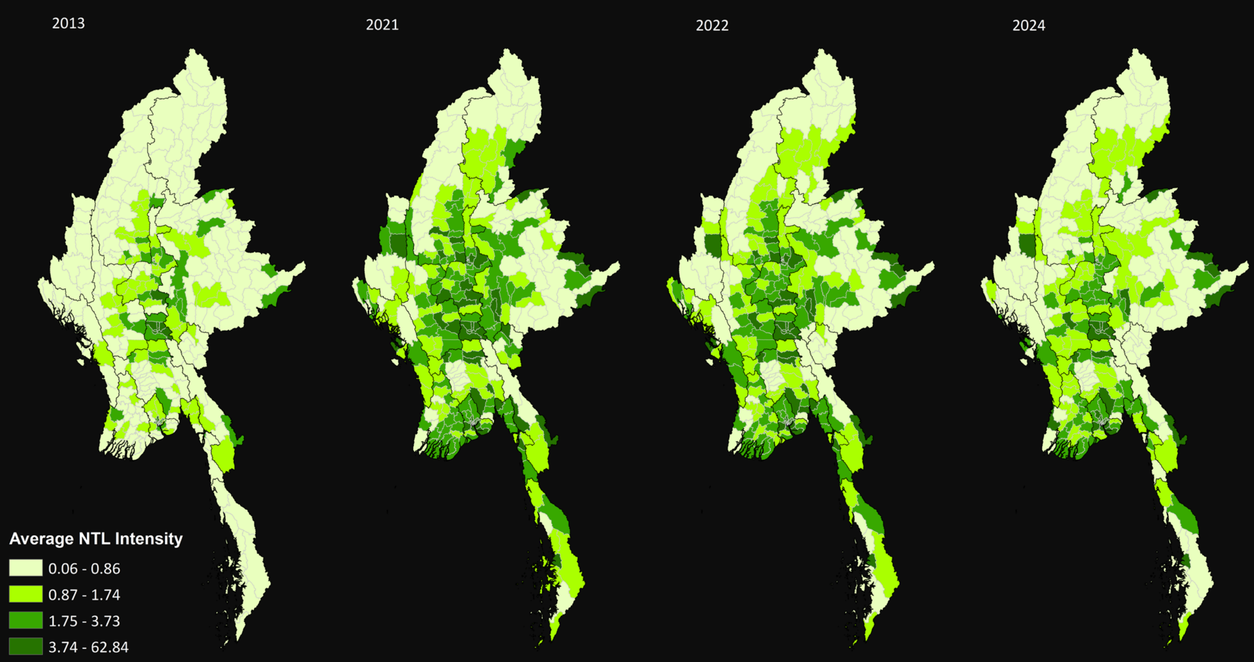
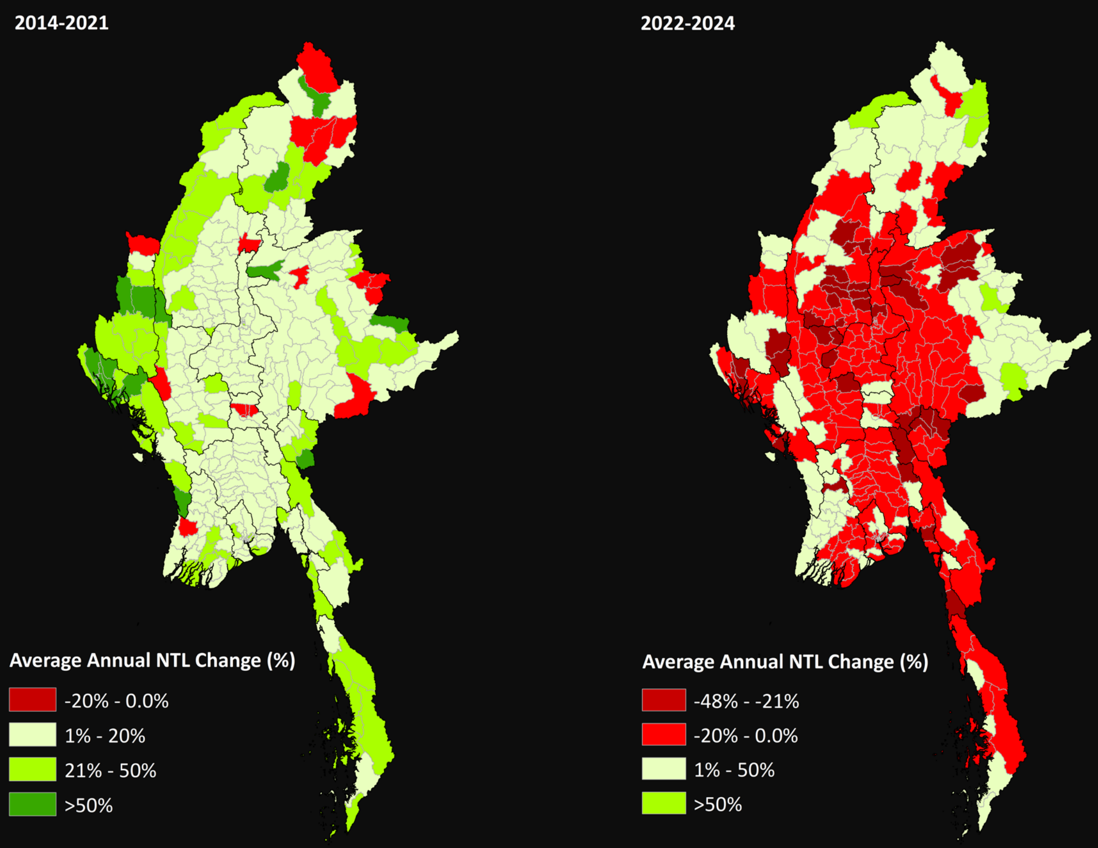


Figure 16: Average NTL % change by township by period



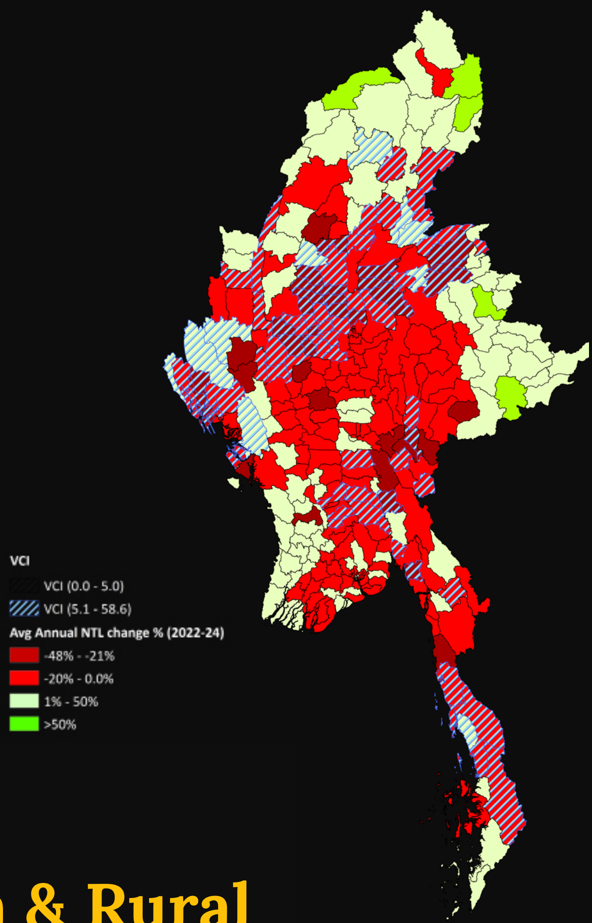
Relation with vulnerability to conflict

Data comparisons at the township level are challenging due to the lack of disaggregated data at this level. One dataset that is available for the post-2021 period is the Vulnerability to Conflict Index (VCI). The VCI is an index of indicators of how conflict is directly affecting civilians. The VCI allows to obtain an overview where civilians are most vulnerable to conflict, so that conflict-vulnerable people are better targeted for project implementation[19]. When overlaying the NTL changes with the VCI in a same period, a notable trend emerges: 89% of the high-VCI townships (above 5.1) experience a drop in NTL, compared to a national average of 70%. This observation underscores that townships with a high vulnerability to conflict are disproportionally affected by electricity outages and declined economic activity. Of the other 11% of high-VCI townships there are eight townships that exhibited positive average annual NTL intensity changes.[20] Based on anecdotal evidence, the use of independent community grids in these townships has increased in recent years, especially since 2021, due to the absence of the national electricity grid or to be less dependent on it.

19 For more information, see “Vulnerability & Conflict: Mapping Myanmar’s Civilian Vulnerability to Conflict”, undp-mdo.org/wp-content/uploads/2024/05/Vulnerability-Conflict-report-2024.pdf

20 These townships include Matupi and Paletwa in Chin, Bahmo, Mansi, and Hpakant in Kachin, Kyunhla in Sagaing, Namtu in Shan, and Thayetchaung in Tanintharyi

Figure 17: Average NTL % change overlayed with the Vulnerability to Conflict Index (2022-2024)



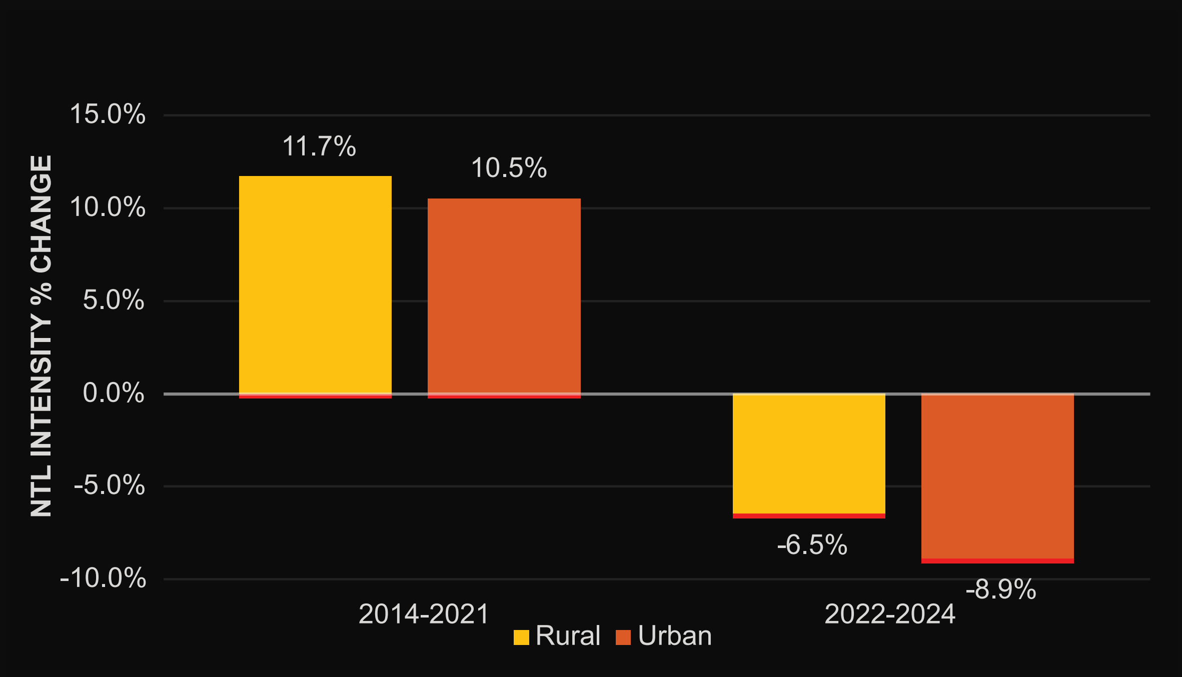
3.4. Urban & Rural

Key Findings

- From 2014 to 2021, both rural and urban areas experienced increasing NTL intensity rates, with rural areas showing a slightly higher growth rate of 11.7% compared to 10.5% in urban areas.
- However, the subsequent period from 2022 to 2024 witnessed a significant decline in NTL for both rural and urban regions, indicating a substantial reversal in the previous trend. The decline was more pronounced in urban areas, with a decrease of 8.9%, compared to a decrease of 6.5% in rural areas during the same period.
- The urban areas in the following states and regions showed the highest drops between 2022 and 2024: Sagaing (-25.0%), Kayah (-24.5%), Mandalay (-19.5%), Mon (-16.6%) and Magway (-16.4%).
- For rural areas, the most affected states and regions between 2022 and 2024 are: Kayah (-31.1%), Mandalay (-13.0%), Sagaing (-11.4%), Mon (-10.1%) and Chin (-9.7%).

Both urban and rural areas experienced growth from 2014 to 2021, followed by declines post-2022. Figure 14 shows a slight difference between the two categories: rural areas experienced higher growth from 2014 to 2021, while urban areas faced greater declines from 2022 to 2024. This finding is understandable, given the significant rural electrification efforts from 2014-2021 and the relatively greater impact of outages in urban areas on NTL intensity due to higher population density from 2022-2024.

Figure 18: Average NTL % change, by rural/urban by period

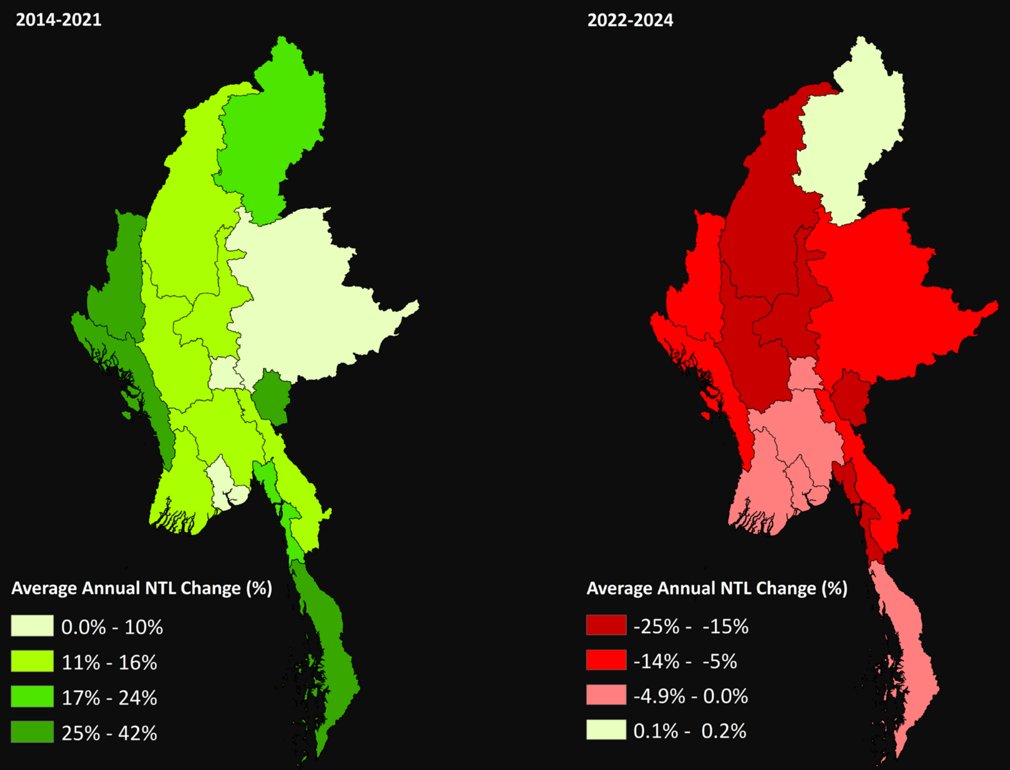


Urban

Between 2014 and 2021, urban areas across Myanmar experienced significant development and economic progress, as reflected in their average annual nighttime light changes (see Figure 19). Kayah and Rakhine emerged as standouts, with a remarkable average annual increase of 42%, indicating rapid urbanization within these states. Chin and Tanintharyi also demonstrated substantial growth rates of 38.4% and 34.4%, respectively, showcasing significant progress. Kachin and Mon exhibited notable growth as well, with average annual changes of 24.5% and 18.9%, respectively. Overall, the period from 2014 to 2021 witnessed considerable urban development across various regions in Myanmar, contributing to the country's economic growth and transformation.

After 2021, urban areas faced decline of approximately -8.9%, signifying an overall decline in urban electricity access during this period. Some regions experienced substantial declines in their electricity consumption with Sagaing and Kayah witnessing a dramatic decrease of an annual rate of approximately -25%, highlighting severe challenges in maintaining electricity consumption in the region. Similarly, Mandalay, Mon, and Magway had a significant decline in the annual rate of

Figure 19: Average NTL % change for urban areas, by state/region by period

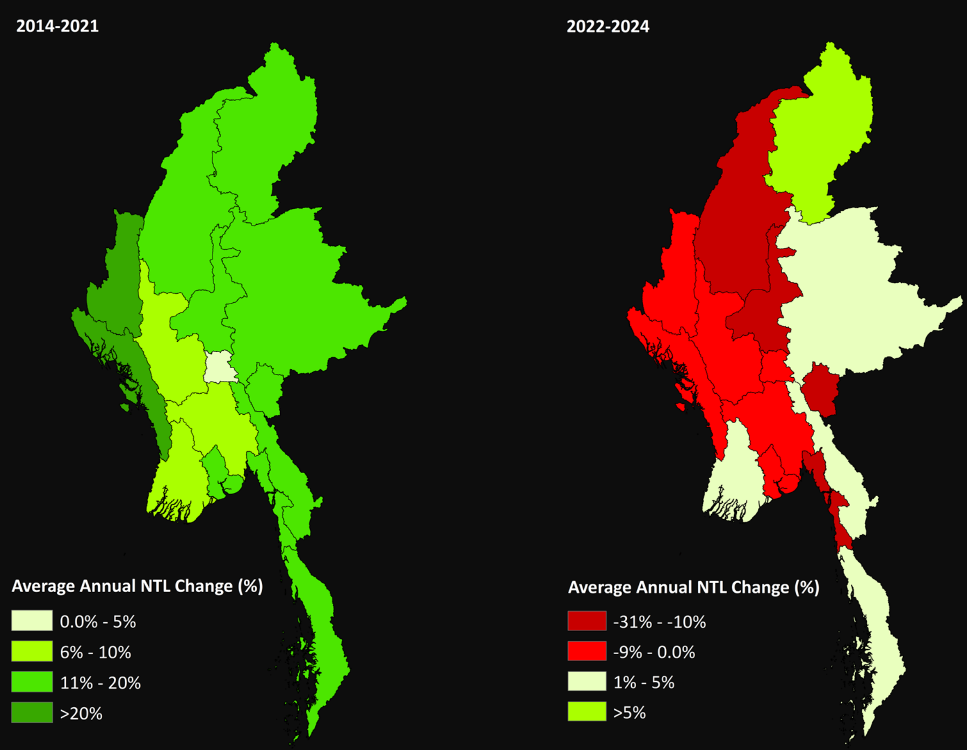


approximately over -15.0%, indicating notable difficulties in electrification. Furthermore, Rakhine, Kayin, Shan, and Chin also faced significant declines with decreases of approximately over -10.0%. These declines point to economic challenges that affected electricity consumption in these regions. Conversely, a few regions demonstrated relatively stable electricity access during this period. Kachin did not exhibit declines; however, there was a slight deceleration in their growth rates, with changes of only 0.2%.

Rural

Over the span of 2014 to 2021, rural areas in Myanmar experienced notable advancements in economic growth, as evident from their average annual changes in NTL (see Figure 20). Notable progress was observed in several areas, with Chin experiencing the most substantial annual growth of approximately 38.8%, indicating significant efforts to improve rural electrification. Rakhine, Tanintharyi, Kayah, Kayin, and Mon also showed significant annual increases, ranging from 16.0% to 26.3%, highlighting positive developments in extending electricity access to rural communities. Moderate growth in electricity access, ranging from about 10% to 15%, was observed in regions like Shan, Yangon, Kachin, Mandalay, and Sagaing. While these states and regions made progress, the rate of growth was more moderate compared to the aforementioned areas. Some states and regions such as Bago, Magway, and Ayeyarwady exhibited relatively lower NTL growth, with increases of approximately less than 10%. Nay Pyi Taw had the lowest NTL growth, recording only 0.4% during this period.

Figure 20: Average NTL % change for rural areas, by state/region by period



In the rural areas of Myanmar from 2022 to 2024, changes in NTL intensity highlighted the varying situations of rural electrification initiatives across different regions. The overall change in rural NTL during this period averaged around -6.5%, indicating a general decline in rural electrification. Kayah Region experienced a notable sharp decline in average annual NTL, with a decrease of approximately -31.1%, indicating potential challenges in extending electricity access to rural areas. Mandalay also faced a substantial decline of about -13.0%, pointing to significant setbacks in electrification efforts. Sagaing and Mon displayed declines of approximately -11.4% and -10.1%, respectively. Magway, Rakhine, and Yangon saw declines of -8.4%, -7.5%, and -6.5% respectively. Bago and Nay Pyi Taw also faced declines in NTL, with reductions of -3.0% and -1.5% respectively, further highlighting the difficulties in sustaining electricity consumption in these regions. Despite these declines, some regions, such as Tanintharyi, Shan, Kayin, Ayeyarwady, and Kachin showed growth in NTL, with increases ranging from 1.5% to 6.1%, highlighting resilience and ongoing development efforts in certain rural areas.

3.5. Industrial zones

Key Findings

- **Growth and decline of NTL**: From 2014 to 2021, all industrial and special economic zones saw an increase in NTL intensity, notably in Rakhine (67.5%), Tanintharyi (43.4%), and Kachin (40.0%). There was a steep decline in NTL intensity in industrial areas in 2022 and 2023, with a slight recovery in 2024, but still below 2021 levels.

The industrial zones in Myanmar encompass a diverse range of sectors, including garment manufacturing, warehouses, automotive services, machinery shops, plastic factories and juice factories. The NTL data for industrial zones is taken from the geographic areas designated as industrial zones within the states and regions, see figure 22 and appendix 2. When comparing industrial zones with non-industrial zones (or 'settlement area'), the data shows there is a higher NTL growth in the industrial zones until 2021 compared to the 'settlement area', but also a steeper decline in 2022 and 2023. In 2024, there is again some increase compared to 2023, but the absolute mean NTL intensity would still remain below 2021 (5.8 vs. 8.2).

Figure 21: National annual NTL % change in industrial & SEZ (2014-2024)

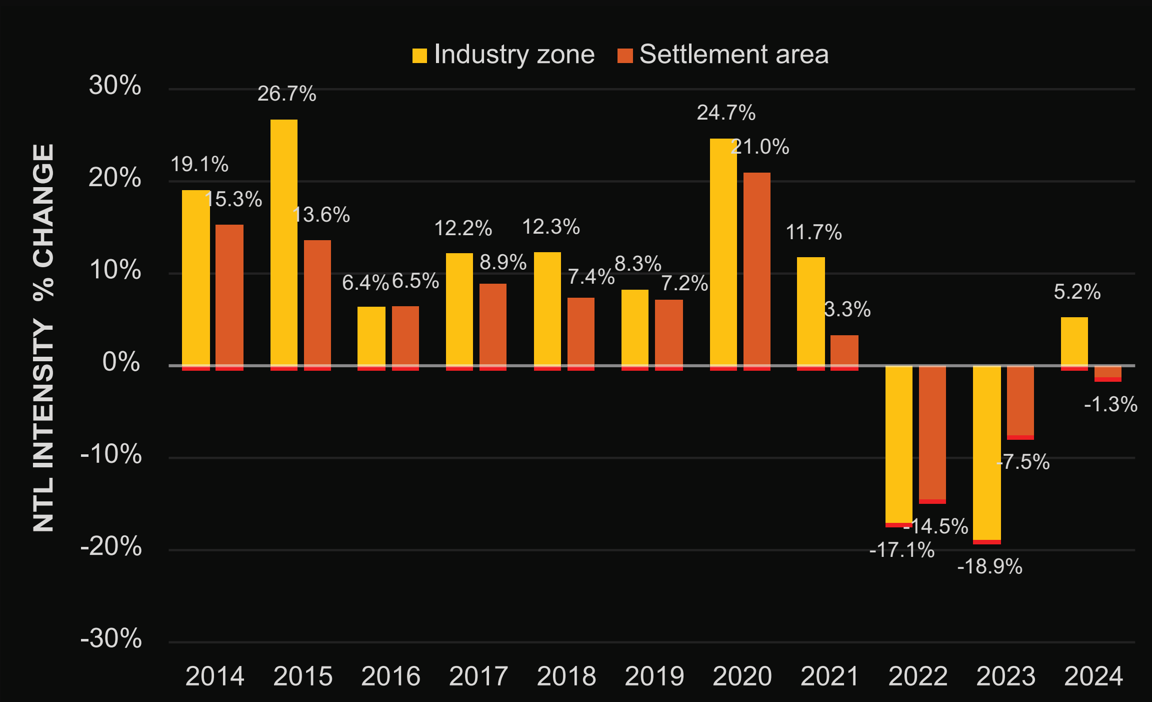
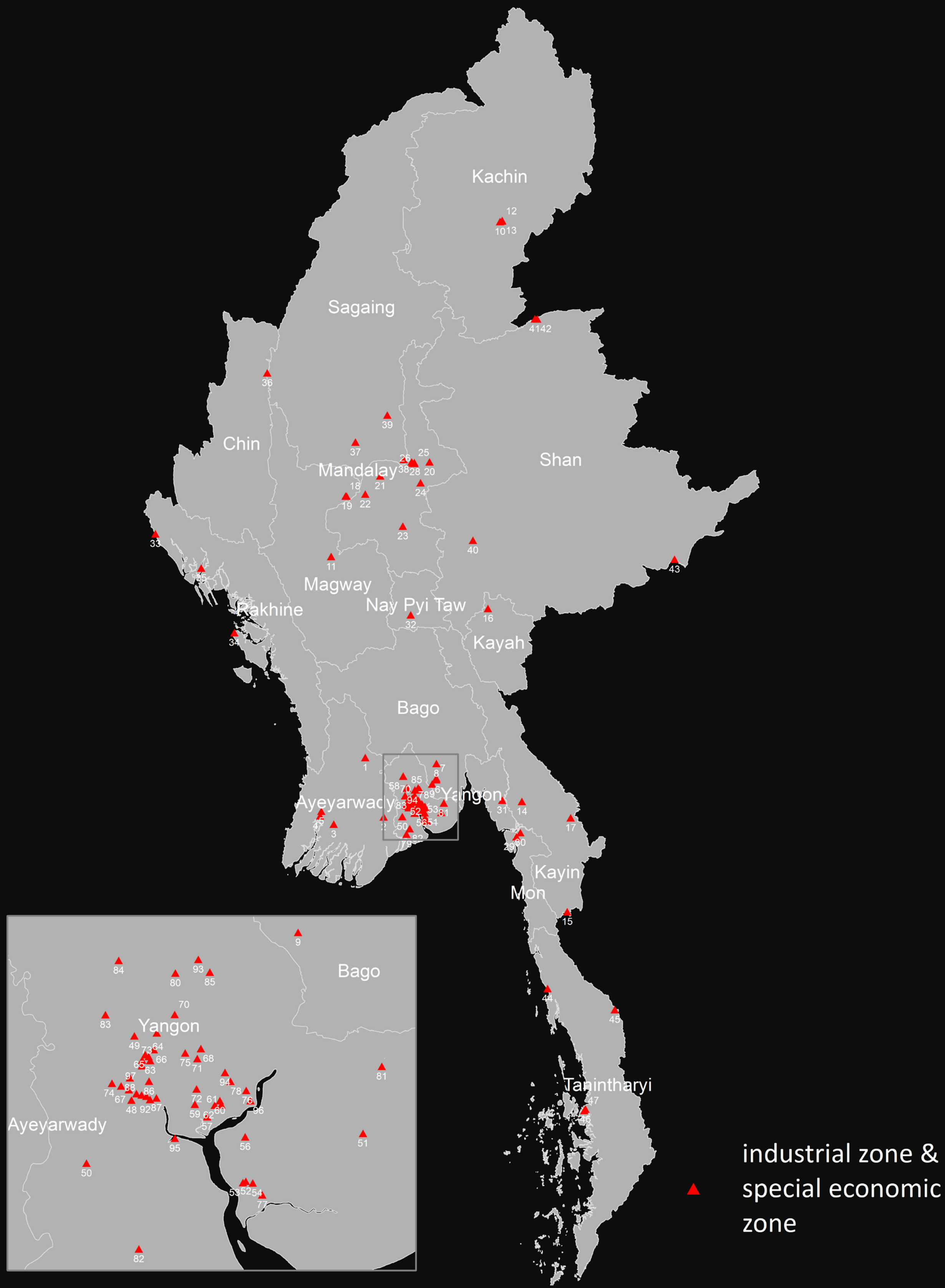
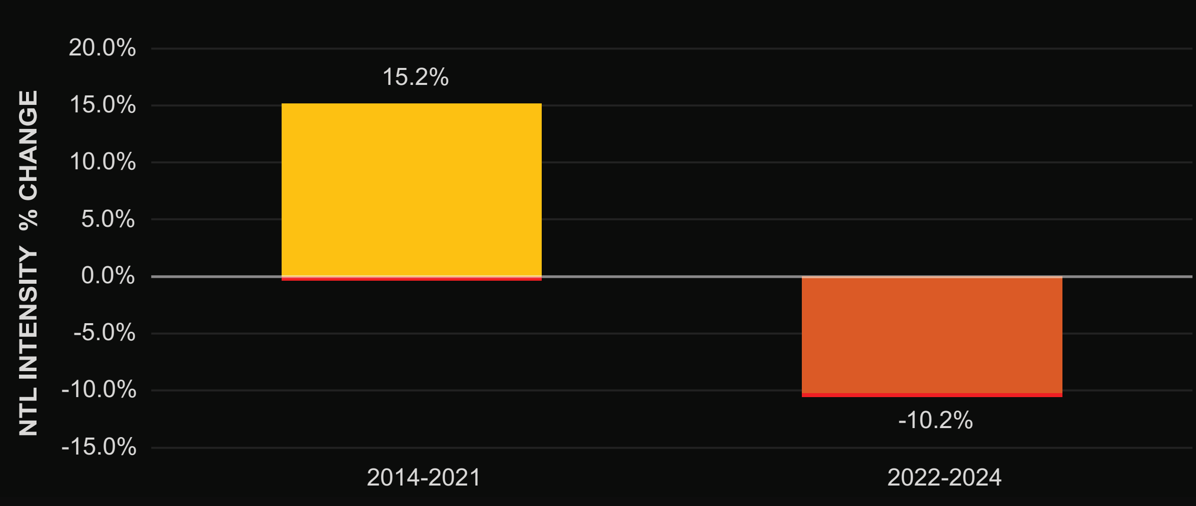


Figure 22: Map of the industries and SEZ across Myanmar



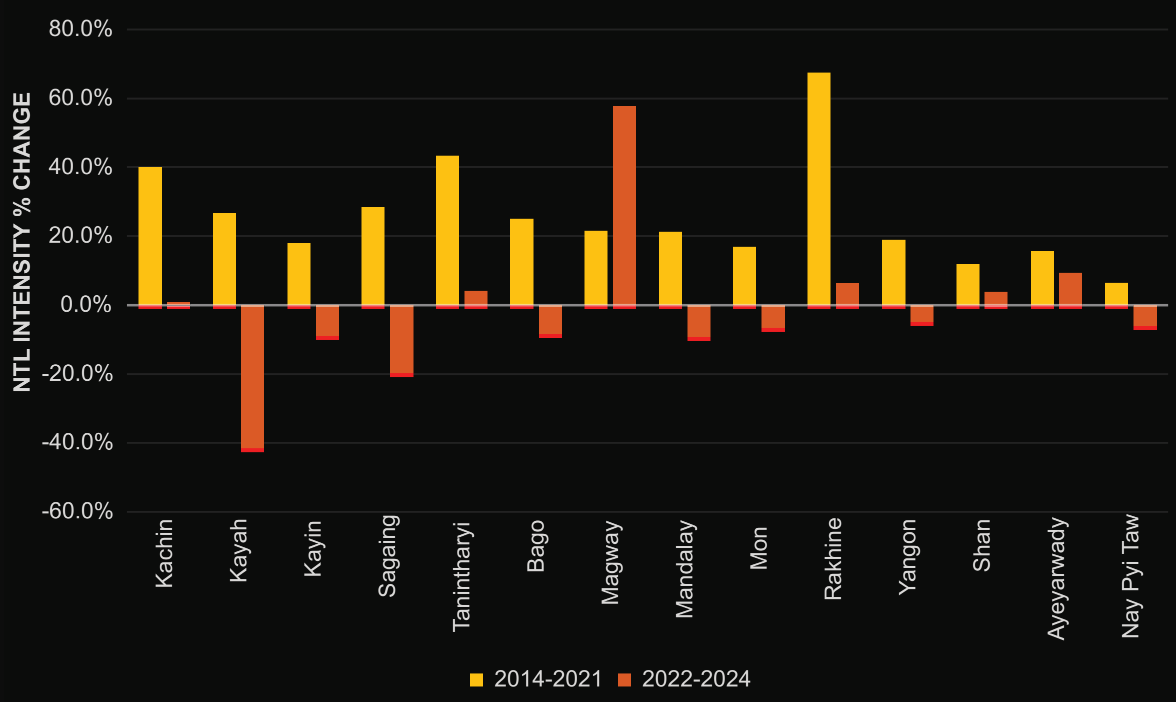
Applying the two periods, the difference is clearly visible with an average 15.2% increase between 2014 and 2021 and an average 10.2% decrease between 2022 and 2024.

Figure 23: Average NTL % change for industrial and Special Economic Zones, by period



When breaking it down by states and regions and featuring by period, it shows that during the period from 2014 to 2021, all industrial zones across the states and regions experienced increases in intensity, although in varying degrees.

Figure 24: Average NTL % change of industrial & SEZ, by state/region by period



Rakhine[21], Tanintharyi, and Kachin demonstrated significant growth rates in their industrial zones, with increases of 67.5%, 43.4%, and 40.0% respectively from 2014 to 2021. Similarly, Sagaing, Kayah, and Bago also exhibited notable growth in their industrial NTL, with increases of 28.3%, 26.7%, and 25.0% respectively.

However, from 2022 to 2024, the picture is very diverse. While some regions saw positive growth in NTL intensity, signifying ongoing and increasing economic activity, others faced declines. Kayah and Sagaing faced significant declines, with reductions of -41.5% and -19.7% respectively, indicating challenges to keep up the industrial development due to outages and conflict. Similarly, Mandalay, Kayin, and Bago also witnessed declines in their industrial NTL, with reductions of -9.1%, -8.8%, and -8.6% respectively. Despite these declines, some regions showed positive growth in their industrial zones during this period. Magway experienced a substantial increase of 57.8% in its industrial NTL. Ayeyarwady, Rakhine, Tanintharyi, Shan and Kachin also continued to demonstrate positive growth rates in their industrial zones, with increases of 9,5%, 6.4%, 4.2%, 3.9% and 0.9% respectively, indicating an economic resilience and ongoing business and trade efforts in these areas.

3.6. Seaports

Key Findings

- **Growth and decline of NTL:** From 2014 to 2020, Myanmar's seaports experienced significant growth in nighttime light (NTL) intensity, indicating economic growth, with Thilawa New Port and Wilmar Myanmar Port Terminal showing remarkable increases. The recent period, from 2021 to 2024, shows a notable decline in NTL intensity across all seaports, suggesting economic challenges, particularly due to the global COVID pandemic and the political situation, affecting especially Myanmar Integrated Port Limited Terminal and Thilawa New Port.

- **Comparison with Settlement Areas:** NTL growth at seaports outpaced the general ‘settlement’ growth in Yangon and Rakhine in 2014 and 2015, but was surpassed in 2016, 2018, and 2019. The ports saw a resurgence in 2020, indicating economic optimism, followed by the declines from 2021 to 2024.

Myanmar has nine seaports, seven in Yangon and two in Rakhine (see Figure 25). Economic growth and contraction in seaports are well captured through NTL intensity, especially as seaports tend to operate at night during times of economic growth[22]. Figure 26 shows the annual NTL intensity change rates from 2014 to 2024. Over this period, there is a fluctuating NTL trend. In 2014, the mean NTL intensity was 11.6, gradually increasing until 2020 to reach 32.1, signifying an average annual change rate of 13.7%. However, in the subsequent years (2021 to 2024), there is an average annual NTL decline of 8%.

The figure illustrates the change rates compared with the change rates of Yangon and Rakhine, referred to as the 'Settlement area'. It shows that in 2014 and 2015, the growth of the ports was much stronger than the average growth in Yangon and Rakhine. However, in some years (2016, 2018, and

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21 Rakhine – SEZ Kyaukpyu and Sittwe

22 Polinov, Semion & Bookman, Revital & Levin, Noam. (2022). A Global Assessment of Night Lights as an Indicator for Shipping Activity in Anchorage Areas. Remote Sensing. 14. 10.3390/rs14051079

Figure 25: Map of the main seaports in Rakhine and Yangon

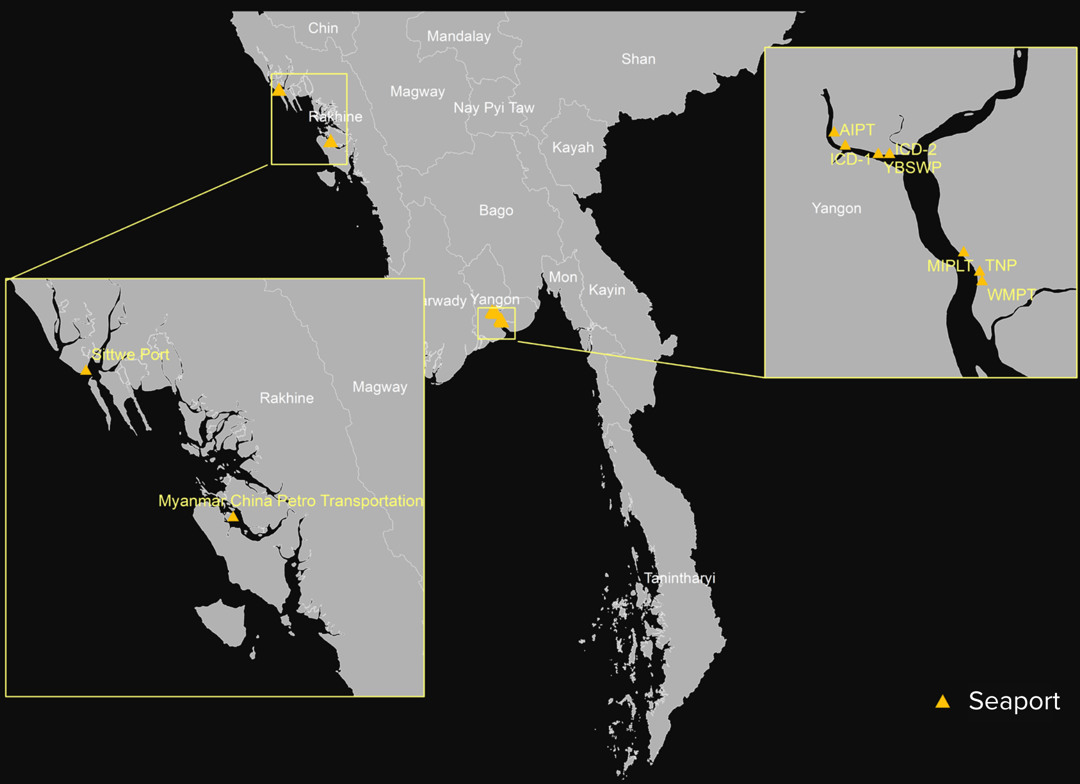
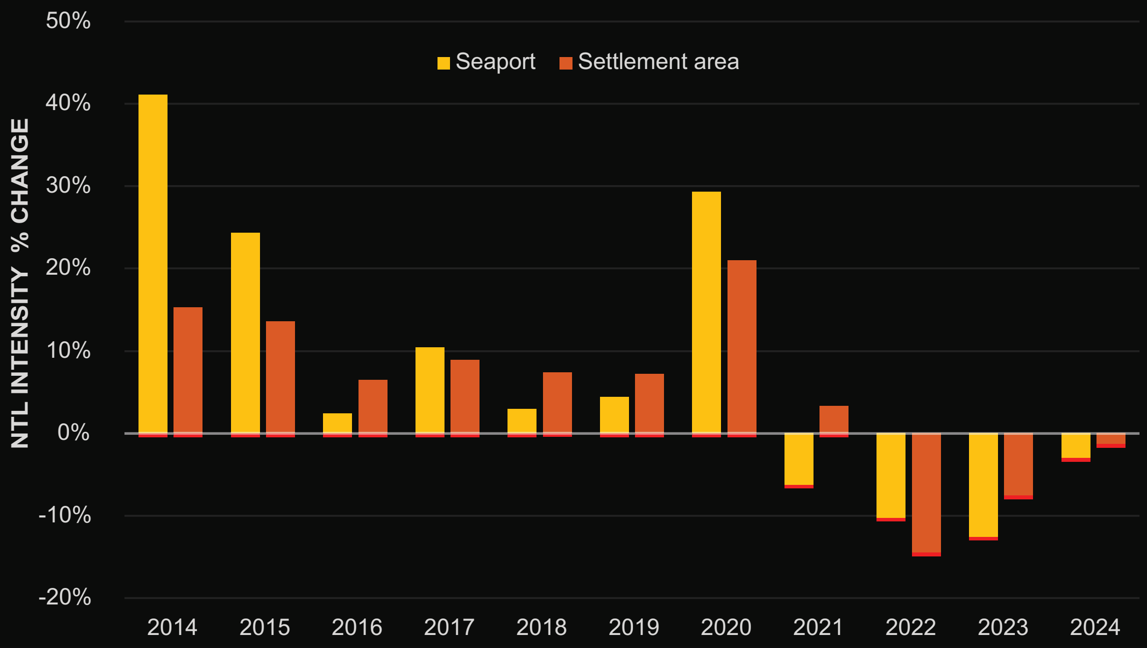


Figure 26: Annual NTL % change of seaports compared with settlement area (2014-2024)

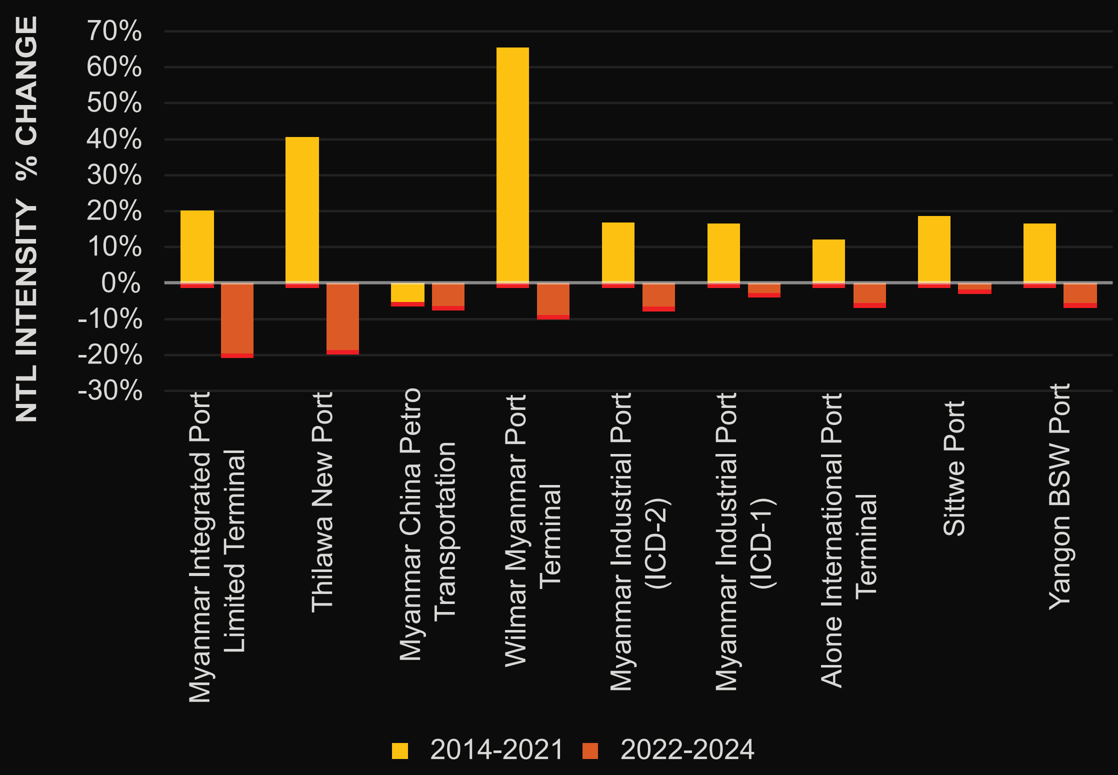


2019), the growth in Yangon and Rakhine was higher than that of the ports. In 2020, there was again an increase in NTL intensity, which can be interpreted as an optimistic sign for Myanmar's economy and trade. Overall, from 2014 to 2020, Myanmar's seaports experienced notable growth in their average annual NTL intensity. The only port with some decreases is the Myanmar China Petro Transportation (Kyaukpyu port)[23]. This port is linked to the Myanmar-China Oil and Gas Pipeline project, initiated in 2010[24]. Thilawa New Port stood out with a remarkable increase of 40.5%, reflecting substantial development and heightened expansion activity at the port.[25] Wilmar Myanmar Port Terminal also experienced significant growth with a change of 65.6% in NTL, reflecting increased maritime trade and economic activity following its opening in 2018.

In contrast, from 2021 onwards, there are overall declines in NTL intensity, indicating potential challenges to maritime trade during this period. Seaports are the only category in Myanmar showing an overall negative change in NTL intensity in 2021 compared with 2020. This can be attributed to the global COVID pandemic, which also had a major impact on Myanmar's economy. Despite the negative change in 2021, for comparative reasons, the same periods (2014-2021 and 2022-2024) are reflected below in figure 27.

The figure clearly shows the negative change on all ports in the 2022-2024 period, with the Myanmar Integrated Port Limited Terminal and Thilawa New Port being hit hardest with declines of -19.6% and -18.7%, respectively.

Figure 27: Average NTL % change of seaports, by period



[23] Data for Myanmar China Petro Transportation (Kyaukpyu port) is taken into account starting from its operational use in 2015.
[24] https://www.brimonitor.org/wp-content/uploads/2022/02/MyanmarPipe.pdf
[25] https://openjicareport.jica.go.jp/pdf/12244919_02.pdf
[26] https://www.mpa.gov.mm/ports/wilmar-myanmar-port-terminal/

4. Conclusion: Illuminating the Path Forward

The analysis of nighttime light satellite imagery has provided a comprehensive and nuanced understanding of Myanmar's development trajectory and ongoing challenges, particularly post-2021. NTL data has proven to be an invaluable tool in highlighting the intricate interplay between economic activities, urbanization, and socio-economic conditions. The significant decline in NTL intensity post-2021 at all administrative levels and categories corroborates the severe economic downturn and regression in both urban and rural development. The NTL decline is also reflective of reduced access to affordable and reliable electricity, exacerbating socio-economic inequalities and human well-being, especially in conflict-affected areas. The disproportionate impact on these conflict-affected areas further highlights the need for targeted interventions to support local economic activities and address development needs.

In navigating these challenges, several recommendations can be made:

1. **Enhanced Data Collection and Monitoring:**
Given the data challenges in Myanmar, it is crucial to continue leveraging alternative data sources like NTL satellite imagery for real-time monitoring of economic and social conditions. Collaborations across research entities on NTL will strengthen the methodology, mitigate data limitations and ultimately enhance the accuracy of assessments.

2. **Focus on Vulnerable Constituencies:**
Targeted interventions are needed in regions with the most significant NTL declines, particularly those with high VCI. Efforts should include improving electricity access, supporting local economic activities, and addressing the humanitarian and development needs of affected populations to fulfil the plight to leave no one behind, but also to reach the furthest behind first.

3. **Promotion of Alternative Energy Sources:**
The decline in NTL intensity highlights the need for diversified energy sources. Promoting renewable energy solutions and community-based power grids can enhance resilience and reduce dependency on centralized electricity supply, particularly in conflict-prone areas.

4. **Strengthening Local Energy Governance:**
Enhancing local energy governance and community-based management of resources can mitigate the impact of political instability. Empowering local authorities and communities to manage their resources will foster resilience and sustainable development.

5. **Comprehensive Recovery and Resilience Planning:**
Developing holistic recovery and resilience strategies that integrate economic, and social, dimensions is essential. Such strategies should be informed by high-frequency data from NTL and other sources to ensure targeted and effective interventions.

In conclusion, in addressing Myanmar's challenges and fostering resilience amidst adversity, nighttime light could be of great value in illuminating the path forward.

List of References

Chen, X. & Nordhaus, W.D. (2011) 'Using luminosity data as a proxy for economic statistics', Proceedings of the National Academy of Sciences, 108(21), pp. 8589–8594.

Chi, G., Fang, H., Chatterjee, S. and Blumenstock, J.E. (2022) 'Microestimates of wealth for all low-and middle-income countries', Proceedings of the National Academy of Sciences, 119(3).

Coscieme, L., Sutton, P.C., Anderson, S., Liu, Q. and Elvidge, C.D. (2017) 'Dark times: Night-time satellite imagery as a detector of regional disparity and the geography of conflict', GIScience & Remote Sensing, 54, pp. 118–139.

Elvidge, C.D., Baugh, K.E., Zhizhin, M. and Hsu, F.-C. (2017) 'VIIRS night-time lights', International Journal of Remote Sensing, 38(21), pp. 5860-5879. doi: 10.1080/01431161.2017.1342050.

Elvidge, C.D., Zhizhin, M., Ghosh, T., Hsu, F.-C. and Taneja, J. (2021) 'Annual time series of global VIIRS night-time lights derived from monthly averages: 2012 to 2019', Remote Sensing, 13(5), 922.

Gibson, J. & Boe-Gibson, G. (2021) 'Nighttime lights and county-level economic activity in the United States: 2001 to 2019', Remote Sensing, 13(14), 2741.

Gibson, J., Olivia, S. & Boe-Gibson, G. (2020) 'Night lights in economics: Sources and uses', Journal of Economic Surveys, 34(5), pp. 955–980.

Gibson, J., Olivia, S., Boe-Gibson, G. & Li, C. (2021) 'Which night lights data should we use in economics, and where?', Journal of Development Economics, 149, 102602.

Henderson, V., Storeygard, A. & Weil, D.N. (2011) 'A bright idea for measuring economic growth', American Economic Review, 101(3), pp. 194–199.

Henderson, J.V., Storeygard, A. & Weil, D.N. (2012) 'Measuring economic growth from outer space', American Economic Review, 102(2), pp. 994–1028.

Jean, N., Burke, M., Xie, M., Davis, W.M., Lobell, D.B. and Ermon, S. (2016) 'Combining satellite imagery and machine learning to predict poverty', Science, 353(6301), pp. 790-794.

Jiang, W., He, G., Long, T. & Liu, H. (2017) 'Ongoing conflict makes Yemen dark: From the perspective of nighttime light', Remote Sensing, 9(8), 798.

JICA (2014) The Preparatory Survey for the Project for Expansion of Yangon Port in Thilawa Area.

Li, X., Chen, F. & Chen, X. (2013) 'Satellite-observed night-time light variation as evidence for global armed conflicts', IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 6, pp. 2302–2315.

Li, X. & Li, D. (2014) 'Can night-time light images play a role in evaluating the Syrian crisis?', International Journal of Remote Sensing, 35, pp. 6648–6661.

Li, X., Li, D., Xu, H. & Wu, C. (2017) 'Intercalibration between DMSP/OLS and VIIRS night-time light images to evaluate city light dynamics of Syria's major human settlement during Syrian civil war', International Journal of Remote Sensing, 38, pp. 1–18.

Li, X., Zhou, Y., Gong, P., Seto, K.C. and Clinton, N. (2020) 'Developing a method to estimate building height from Sentinel-1 data', Remote Sensing of Environment, 240, 111705.

Liu, H., He, X., Bai, Y., Liu, X., Wu, Y., Zhao, Y. & Yang, H. (2021) 'Nightlight as a proxy of economic indicators: Fine-grained GDP inference around Chinese mainland via attention-augmented CNN from daytime satellite imagery', Remote Sensing, 13(11).

Martinez, L.R. (2022) 'How much should we trust the dictator's GDP growth estimates?', Journal of Political Economy, 130(10), pp. 2731–2769.

MIMU, UNDP (2014) 'The 2014 Myanmar Population and Housing Census', Myanmar Census Data. Available at: https://themimu.info/census-data.

Myanmar Port Authority Ports in Myanmar. Available at: https://www.mpa.gov.mm/yangon-ports/.

Räsänen, Timo & Sawdon, John & Ketelsen, Tarek (2019) 'Spatio-temporal assessment of electrification in Myanmar in 2012-2018 using nightlight satellite data'. DOI: 10.13140/RG.2.2.18946.02240.

Sandhi Governance Institute (2021) Belt and Road Monitoring Project: Myanmar-China Oil and Gas Pipeline Projects. Available at: https://www.brimonitor.org/wp-content/uploads/2022/02/MyanmarPipe.pdf (Accessed: January 2024).

Sänger, T. et al. (2023) 'Estimating the collapse of Afghanistan's economy using nightlights data', ESOC Working Paper No. 34. Empirical Studies of Conflict Project. Available at: [March 6, 2023].

Shah, Z., Hsu, F.C., Elvidge, C.D. and Taneja, J. (2020) 'Mapping disasters & tracking recovery in conflict zones using night-time lights', 2020 IEEE Global Humanitarian Technology Conference (GHTC), pp. 1-8.

Tracking SDG7: The Energy Progress Report (2022). Chapter 1 Access to Electricity, July 2022.

UNDP (2023) Myanmar at a crossroads: Past trends of human well-being and a future outlook.

UNDP (2024) Vulnerability & Conflict: Mapping Myanmar's Civilian Vulnerability to Conflict 3 Years after the Military Takeover.

Wang, Z., Román, M.O., Kalb, V.L., Miller, S.D., Zhang, J. and Shrestha, R.M. (2021) 'Quantifying uncertainties in night-time light retrievals from Suomi-NPP and NOAA-20 VIIRS Day/Night Band data', Remote Sensing of Environment, 263, 112557.

Witmer, F.D.W. (2015) 'Remote sensing of violent conflict: Eyes from above', International Journal of Remote Sensing, 36, pp. 2326–2352.

Witmer, F.D.W. & O'Loughlin, J. (2011) 'Detecting the effects of wars in the Caucasus regions of Russia and Georgia using radiometrically normalised DMSP-OLS night-time lights imagery', GIScience & Remote Sensing, 48, pp. 478–500.

World Bank (2023) In The Dark: Power Sector Challenges in Myanmar, August 2023.

World Bank (2024) 'Myanmar Energy Sector Update: Energy Poverty Amid Plenty', June 2024

Zhou, Y., Xue, L., Shi, Z., Wu, L. & Fan, J. (2022) 'Measuring housing vitality from multi-source big data and machine learning', Journal of the American Statistical Association, 117(539), pp. 1045–1059.

Appendices

Appendix 1: Methodology - Issues and Limitations

Issues

To analyze the time series of NTL data from 2014 to 2024, several key issues were identified:

- **Seasonality:** The NTL data exhibited clear seasonal variations linked to the quantity and quality of observations each month. During the monsoon season, when persistent cloud cover prevails, NTL intensity notably decreases across both urban and rural areas. This decrease can be attributed to issues with the quality of observations rather than reflecting genuine changes in NTL. To mitigate this variability, the analysis focused on the dry-season months (December to February), ensuring a consistent annual NTL time series by aggregating average light intensity for these months. For instance, in the case of 2021, NTL imagery is applied from December 1, 2020, until the end of February 2021. For convenience and overview reasons, the data of these three months is referred to as 2021 data, even though there is one month of data collected in 2020.

- **Positive Spikes:** Random spikes in NTL intensity, occurring in both rural and urban areas, were observed in the monthly time series. These spikes were assumed to result from undetected clouds or water bodies reflecting moonlight. To address this issue, a temporal filter was applied, considering mean and median NTL intensity over five months (November to March) and the maximum monthly light intensity over three months (December to February). Any values in the three-month time series that exceeded the mean of the five-month period and exhibited a ratio of max (Dec-Feb) to median (Nov-Mar) greater than 3 were masked[27]. This approach led to a consistent time series by eliminating up to two outliers when constructing the annual average NTL intensity for the December to February period.

- **Systematic Error:** Each pixel in an NTL image corresponds to a specific geographic location (roughly a 30m x 30m area). For each pixel, the NTL intensity was assessed over time (annual or monthly). A systematic error was identified in the time series, resulting in an increasing trend in light intensity in recent years. A correction is applied individually to each pixel's time series. Systematic errors can arise from various sources, including sensor calibration, changes in urbanization patterns, or external factors affecting light intensity. In the context of NTL data, systematic errors might lead to trends that don't reflect actual changes in human activities. Detecting these errors involves comparing the observed data with expected patterns and identifying deviations. To address this issue, analysis was focused on remote areas that are at least five hours away from any built-up areas (cities, towns, villages, roads, etc.). These remote areas were assumed to have consistent NTL intensity over time (i.e., no significant variation). For each year in the time series, the median NTL intensity over these remote areas was calculated. The median was chosen because it's robust to outliers and extreme values. Finally, the calculated median NTL intensity was subtracted from the entire time series. This adjustment effectively removed the systematic error, resulting in a consistent time series of annual NTL intensity.

A systematic error was identified in the time series, resulting in an increasing trend in light intensity in recent years. To rectify this issue, the median NTL intensity in remote areas, defined as those at least five hours of travel time away from any built-up areas, was assessed for each year. These remote areas were assumed to exhibit no variance in light intensity over time. The median light intensity over these remote areas was calculated for each year and subtracted from the time series to eliminate the systematic error.

[27] The threshold value of 3 was selected based on iterative testing and analysis to effectively identify significant deviations in NTL intensity while minimizing the masking of legitimate variations. This value was found to strike a balance between capturing meaningful changes in nighttime illumination patterns and maintaining data integrity. https://www.mdpi.com/2072-4292/13/5/922

Limitations

To analyze the time series of NTL data from 2014 to 2024, several key issues were identified:

- **Satellite Acquisition Time & Resolution:** Variations in satellite data acquisition times can influence NTL data, potentially introducing fluctuations in calculated real electricity access rates. The NTL satellite data provides snapshots at specific time points, potentially missing variations in nightly activities. As such, the results might reflect a lower magnitude than actual ground survey data, which captures real-time dynamics and nuances in the local context. The coarse spatial resolution of satellite data also may not capture fine-grained variations, particularly in small communities.

- **Cloud Cover:** Despite data collection in the period with the least cloud cover (Dec-Feb), mountainous areas like Kachin, Shan, and Chin may face clouds in this period as well, which can obstruct satellite observations and affect the data availability and quality.
  Light Source: It is important to note that the source of light cannot exactly be established. The main source, electricity, can also originate from a government grid, community grid, or border grid. NTL analysis is not able to differentiate these light emissions. The main government gridlines were overlayed and it could be established that nearly 90% of NTL was emitted within 30 kilometers distances from the main government gridlines, indicating the high reliance on government provision of electricity.

- **Spatial Filtering for Settlement Areas:** The study applies a spatial filtering technique to remove extraneous sources of light from streetlights, pagodas, and other sources in the NTL satellite images. This process focused on isolating the light emissions specifically from settlement areas in urban and rural regions. While this approach helped enhance the accuracy of real electricity access calculations, it is important to acknowledge that the effectiveness of spatial filtering can vary depending on the quality of the NTL data and the precision of the settlement area delineation. Additionally, this method may not entirely eliminate all non-residential sources of light, potentially introducing minor inaccuracies into the analysis.

- **Rural and Urban Definition:** In this research, the World Settlement Area dataset, and MIMU's admin 5 (ward) boundaries were applied to categorize rural and urban areas. Settlement areas are labeled inside these wards as urban and the rest as rural. However, it's essential to understand that this classification might not perfectly match traditional definitions of urban and rural. The method, based on administrative boundaries, may miss variations in population density and socio-economic features, impacting the accuracy of the urban-rural classification.

Appendix 2: List of industrial zones across each State and Region

No.	Name	Type	State and Region
1	Hinthada Industrial Zone	Industrial Zone	Ayeyarwady
2	Maubin Industrial Zone	Industrial Zone	Ayeyarwady
3	Myaungmya Industrial Zone	Industrial Zone	Ayeyarwady
4	Pathein Industrial City	Industrial Zone	Ayeyarwady
5	Pathein Industrial Zone	Industrial Zone	Ayeyarwady
6	Bago Industrial Complex (Foreign Industrial Zone)	Industrial Zone	Bago
7	Bago Industrial Complex (Local Industrial Zone)	Industrial Zone	Bago
8	i-Land Park Myanmar Industrial Park	Industrial Zone	Bago
9	Inntakaw Industrial Zone	Industrial Zone	Bago
10	Myitkyina Industrial Park	Industrial Zone	Kachin
11	Yenangyaung Industrial Zone	Industrial Zone	Magway
12	Myitkyina Industrial Quarter	Industrial Zone	Kachin
13	Myitkyina Industrial Quarter	Industrial Zone	Kachin
14	Hpa-An Industrial Zone	Industrial Zone	Kayin
15	Hpayarthonesu Industrial Zone	Industrial Zone	Kayin
16	Loikaw Industrial Zone	Industrial Zone	Kayah
17	Myawaddy Economic Zone	Other	Kayin
18	Pakokku Industrial Zone 1	Industrial Zone	Magway
19	Pakokku Industrial Zone 2	Industrial Zone	Magway
20	Yadanarbon New Resort City	Other	Mandalay
21	Myo Thar Industrial Park	Industrial Zone	Mandalay
22	Myingyan Industrial Zone	Industrial Zone	Mandalay
23	Meiktila Industrial Zone	Industrial Zone	Mandalay
24	Mandalay Industrial Zone 4	Industrial Zone	Mandalay
25	Mandalay Industrial Zone 3	Industrial Zone	Mandalay
26	Mandalay Industrial Zone 2	Industrial Zone	Mandalay
27	Mandalay Industrial Zone 1	Industrial Zone	Mandalay
28	Mandalay Industrial Trade Center	Other	Mandalay
29	Kyauk Tan Industrial Zone - Mawlamyine	Industrial Zone	Mon
30	Mawlamyine Industrial zone	Industrial Zone	Mon
31	Thaton Eco-Industrial Park	Industrial Zone	Mon
32	Det Khi Na Thi Ri SME Industrial Zone (Nay Pyi Taw)	Industrial Zone	Nay Pyi Taw
33	Ka Nyin Chaung Trade Zone	Other	Rakhine
34	Kyaukpyu Special Economic Zone	SEZ	Rakhine
35	Ponnagyun Industrial Zone	Industrial Zone	Rakhine
36	Kale Industrial Zone	Industrial Zone	Sagaing
37	Monywa Industrial Zone	Industrial Zone	Sagaing
38	Sagaing Industrial Zone	Industrial Zone	Sagaing
39	Shwebo Industrial Zone	Industrial Zone	Sagaing
40	Ayetharyar Industrial Zone	Industrial Zone	Shan

No.	Name	Type	State and Region
41	Muse Economic Zone	Industrial Zone	Shan
42	Muse Industrial Quarter	Industrial Zone	Shan
43	Tachileik Industrial Quarter	Industrial Zone	Shan
44	Dawei Special Economic Zone	SEZ	Tanintharyi
45	Mae Tha Mee Khee Industrial Estate	Industrial Zone	Tanintharyi
46	Myeik Economic Zone	Other	Tanintharyi
47	Myeik Industrial Zone	Industrial Zone	Tanintharyi
48	Yangon New City industrial component	Other	Yangon
49	War Ta Yar Industrial Zone	Industrial Zone	Yangon
50	Twantay Industrial Zone	Industrial Zone	Yangon
51	Thongwa Industrial Zone	Industrial Zone	Yangon
52	Thilawa SEZ (Zone B)	SEZ	Yangon
53	Thilawa SEZ (Zone A)	SEZ	Yangon
54	Thilawa Industrial Zone	Industrial Zone	Yangon
55	Thar Du Kan Industrial Zone	Industrial Zone	Yangon
56	Thanlyin Industrial Zone	Industrial Zone	Yangon
57	Thaketa Industrial Zone	Industrial Zone	Yangon
58	Taikkyi Industrial Zone	Industrial Zone	Yangon
59	South Okkalapa Industrial Zone	Industrial Zone	Yangon
60	South Dagon Industrial Zone (3)	Industrial Zone	Yangon
61	South Dagon Industrial Zone (2)	Industrial Zone	Yangon
62	South Dagon Industrial Zone (1)	Industrial Zone	Yangon
63	Shwepyithar Industrial Zone (4)	Industrial Zone	Yangon
64	Shwepyithar Industrial Zone (3)	Industrial Zone	Yangon
65	Shwepyithar Industrial Zone (2)	Industrial Zone	Yangon
66	Shwepyithar Industrial Zone (1)	Industrial Zone	Yangon
67	Shwe Than Lwin Industrial Zone	Industrial Zone	Yangon
68	Shwe Pauk Kan Industrial Zone	Industrial Zone	Yangon
69	Shwe Lin Ban Industrial Zone	Industrial Zone	Yangon
70	Pyin Ma Pin Industrial Zone	Industrial Zone	Yangon
71	North Okkalapa Industrial Zone	Industrial Zone	Yangon
72	North Dagon Industrial Zone	Industrial Zone	Yangon
73	Ngwe Pin Lae Industrial Zone	Industrial Zone	Yangon
74	Mya Sein Yaung Industrial Zone	Industrial Zone	Yangon
75	Mingaladon Industrial Zone	Industrial Zone	Yangon
76	Kyi Su Industrial Zone	Industrial Zone	Yangon
77	Kyauktan Industrial Zone	Industrial Zone	Yangon
78	Kyansitthar Industrial Zone	Industrial Zone	Yangon
79	Kungyangon Industrial Zone	Industrial Zone	Yangon
80	Korea-Myanmar Economic Cooperation Industrial Complex	Other	Yangon
81	Kayan Industrial Zone	Industrial Zone	Yangon
82	Kawhmu Industrial Zone	Industrial Zone	Yangon

No.	Name	Type	State and Region
83	Htantabin Industrial Zone	Industrial Zone	Yangon
84	Hmawbi Industrial Zone	Industrial Zone	Yangon
85	Hlegu Industrial Zone	Industrial Zone	Yangon
86	Hlaingtharya Industrial Zone (7)	Industrial Zone	Yangon
87	Hlaingtharya Industrial Zone (6)	Industrial Zone	Yangon
88	Hlaingtharya Industrial Zone (5)	Industrial Zone	Yangon
89	Hlaingtharya Industrial Zone (4)	Industrial Zone	Yangon
90	Hlaingtharya Industrial Zone (3)	Industrial Zone	Yangon
91	Hlaingtharya Industrial Zone (2)	Industrial Zone	Yangon
92	Hlaingtharya Industrial Zone (1)	Industrial Zone	Yangon
93	Eco Green City	Other	Yangon
94	East Dagon Industrial Zone	Industrial Zone	Yangon
95	Dala Industrial Zone	Industrial Zone	Yangon
96	Dagon Seikkan Industrial Zone	Industrial Zone	Yangon
97	Anawrahta Industrial Zone	Industrial Zone	Yangon

Appendix 3: List of Seaports across each State and Region

No.	Name	Type	State and Region
1	Myanmar Integrated Port Limited Terminal	Container, general and bulk cargo terminal	Yangon
2	Thilawa New Port	Container, general and bulk cargo terminal	Yangon
3	Wilmar Myanmar Port Terminal	Agribusiness and food products terminal	Yangon
4	Myanmar Industrial Port (ICD-1)	Container terminal	Yangon
5	Myanmar Industrial Port (ICD-2)	Container terminal	Yangon
6	Alone International Port Terminal	General and specialized cargo terminal	Yangon
7	Yangon BSW Port	General and bulk cargo terminal	Yangon
8	Myanmar China Petro Transportation	Oil terminal	Rakhine
9	Sittwe Port	General and bulk cargo terminal	Rakhine

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