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When lights tell stories: The untold economic pattern of Java island

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Abstract

Purpose — This study evaluates the role of Nighttime Lights (NTL) as a complementary indicator of regional economic and socio-economic development across Java Island.

Method — Using VIIRS NTL data for 2016–2023, the study compares radiance patterns with GRDP per capita, Human Development Index (HDI), population density, and road infrastructure across six provinces. The analysis combines spatial visualization, growth comparison, and correlation analysis.

Findings — Results show that NTL effectively captures the spatial concentration and dynamics of economic activity, but its relationship with development indicators varies across regions. Strong alignment appears in highly urbanized provinces such as DKI Jakarta, while weaker or divergent patterns are observed in regions with service-based or dispersed economies.

Implications — NTL can support policy analysis by revealing spatial disparities and real-time economic dynamics, but it should be used cautiously as a complementary rather than standalone indicator.

Originality — This study provides a subnational, multidimensional assessment of NTL in Java, highlighting its context-dependent reliability as a proxy for development.

Keywords: Geographic information system, nighttime light analysis, regional economics
JEL Classification: R12; C55; Q56

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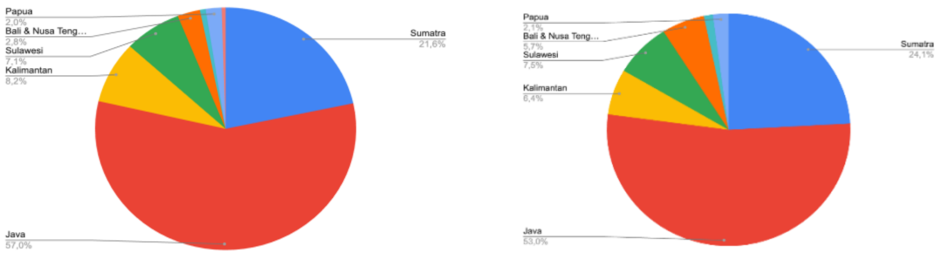
Introduction

Policy makers often face a dilemma in policy formulation: interventions risk being either insufficient or excessively forceful. Effective outcomes depend on sound judgment and reliable data, yet generating accurate statistics is resource-intensive. Incomplete or imprecise data may exclude those in need, making complementary sources valuable. Nighttime Lights (NTL) data provide timely and spatially detailed insights that can reduce gaps and errors, strengthening policy decisions. Java Island, as Indonesia's economic core, contributes the largest share of GDP and population.

Examining NTL at the provincial level in Java offers a means to test its value as a complementary indicator of regional development. This study focuses on Java not only because it dominates national output, but also because disparities within the island mirror broader development challenges.

Figure 1. GDP Contribution and Population Distribution by Island, 2024
(a) GDP contribution; (b) population distribution.



Source: BPS Statistics, Processed by Author (2024)

Java demonstrates dual dominance in Indonesia's economy and demography, accounting in 2024 for 57 percent of national GDP and 53 percent of the population, far exceeding Sumatra (21.6 and 24.1 percent) and Kalimantan (8.2 and 6.4 percent). This concen tration makes Java central to national development but also highly vulnerable, as evident during the COVID-19 crisis when the island faced sharp contraction, unemployment, and poverty (Hadist & Utomo, 2021). These dynamics underscore the need for spatial approaches, with Nighttime Lights (NTL) data serving as a valuable complement by capturing the distribution and intensity of activity, including informal sectors missed in official statistics.

This study employs NTL both visually and comparatively by examining illumination changes over time and relating radiance to GRDP, population density, infrastructure, and HDI, positioning NTL not merely as a supplementary dataset but as a reference for understanding interactions between economy, space, and welfare. Over the past two decades, NTL, particularly from the VIIRS sensor, has gained prominence as a proxy for economic activity, offering near real time coverage and resilience against political bias (Dasgupta, 2022). Foundational work by Henderson et al. (2012) confirmed the positive link between NTL intensity and growth in countries with weak statistical systems, paving the way for its widespread adoption at national and subnational levels.

Recent studies have refined the accuracy of NTL-based measurement. Beyer, Hu, and Yao (2022) estimated that in emerging economies a 1 percent GDP increase corresponds to a 1.55 percent rise in NTL intensity, even after adjusting for measurement errors, underscoring its ability to capture real-time dynamics.

Lin and Rybnikova (2023) found that while the NTL–GDP correlation weakened in the United States during COVID-19, adding crisis-specific variables restored explanatory power, raising model fit from $R^2 = 0.42$ to 0.62. Evidence from developing contexts reinforces this potential: Chaudhry et al. (2019) used NTL to fill provincial GDP gaps in Pakistan, while Barriga-Cabanillas et al. (2024) detected signs of recovery in Afghanistan despite official data showing contraction. At finer scales, NTL also proves robust. Liu et al. (2024) proposed the Nighttime Light Background Value (NLBV) to separate static from dynamic activity, improving urban economic and infrastructure measurement, and Millán-López and González-Olivares (2024) confirmed at the municipal level in Mexico that fluctuations in NTL reliably track local growth where statistics are scarce.

Beyond its correlation with GDP, recent studies show that NTL is a valuable tool for analyzing broader dimensions of development. Its ability to capture spatial patterns of human activity makes it effective for assessing demographic density, infrastructure, and human development. Mellander et al. (2015) found that NTL correlates more strongly with population density than with population totals or income, suggesting its utility in identifying settlement concentration. Unlike census data, NTL offers continuous and spatially detailed insights, while Levin et al. (2020) demonstrated its effectiveness in capturing urbanization trends, road networks, and even conflict-related damage. These applications underscore its role in tracking infrastructure growth and spatial connectivity essential for economic integration.

Research also links NTL with welfare and social outcomes. Bruederle and Hodler (2017) concluded that nighttime lights proxy not only for economic activity but also for human development dimensions like education and health, reflecting quality of life beyond electricity access. Building on this relevance, NTL has become a key tool in urban studies: Zhang et al. (2013) mapped settlements and energy use, Wang et al. (2021) distinguished urban from rural landscapes, and Zhang and Li (2018) emphasized its value as a standardized global dataset for delineating urban footprints and monitoring urbanization.

Collectively, these findings show that NTL can capture demographic, infrastructural, and social development across multiple scales. Nonetheless, limitations persist. Addison and Stewart (2015) cautioned that earlier generations of NTL data, such as the Defense Meteorological Satellite Program (DMSP-OLS), were too noisy for short-term or within-country analysis. However, the advent of VIIRS data has addressed many of these concerns by offering higher resolution and improved temporal consistency. Moreover, Dasgupta (2022) demonstrated the predictive utility of NTL when combined with electricity consumption data, accurately forecasting India's 24 percent GDP contraction in Q2 2020 during the COVID-19 pandemic, closely matching official estimates.

Taken together, these studies demonstrate that NTL is not only a valid proxy for GDP but also a versatile tool for analyzing economic performance and broader development dimensions across scales and contexts. While much of the literature has treated NTL as complementary to traditional measures, its capacity to detect crises, informal activity, demographic concentration, infrastructure expansion, and social development highlights its unique comparative advantage. However, most studies have focused on global or national scales, with limited attention to subnational contexts like Java, where economic and human disparities remain pronounced. Moreover, research rarely integrates NTL with a multidimensional set of indicators such as GRDP, population density, road infrastructure, and HDI to capture both economic and social dynamics.

Building on this gap, the present study positions NTL as a primary framework for examining regional economic growth in Java, employing it alongside conventional indicators to evaluate its complementarities and distinctive strengths in capturing the dynamics of spatial and human development.

Methodology

This study focuses on the six provinces of Java, DKI Jakarta, Banten, DI Yogyakarta, Central Java, East Java, and West Java, covering the period from 2016 to 2023. As Indonesia's economic core, Java provides an ideal case for examining the relationship between satellite-derived nighttime light (NTL) intensity and socioeconomic development. The analysis proceeds in two stages. First, NTL imagery is used to visualize spatial changes in radiance between 2016 and 2023, thereby highlighting patterns of urbanization and illumination growth across provinces. Second, radiance growth is measured relative to the 2016 baseline and systematically compared against conventional socioeconomic indicators, including Gross Regional Domestic Product (GRDP) per capita, Human Development Index (HDI), population density, and total road networks.

While VIIRS provides near real-time and spatially granular information that complements conventional statistics, the dataset is not without limitations. Recognizing these limitations, this study does not attempt to construct a multi-decadal record but rather focuses on the robust eight-year window available for Java. By integrating NTL imagery with official socioeconomic indicators from Statistics Indonesia (BPS), the analysis aims to assess the extent to which NTL can complement conventional measures and provide fresh insights into regional economic dynamics. This study integrates two primary sources of data: satellite-derived nighttime light (NTL) observations and official socioeconomic indicators from Statistics Indonesia (BPS). The geospatial dataset consists of annual composites from the Visible Infrared Imaging Radiometer Suite (VIIRS) "Black Marble" product for the years 2016–2023. These composites provide calibrated radiance values expressed as Digital Numbers (DN) ranging from 0–63. The imagery was accessed through the MAP ID platform, which offers analysis-ready layers that can be clipped by administrative boundaries. For this study, the radiance values were extracted specifically for the six provinces of Java and exported as GeoJSON files to enable subsequent spatial and statistical analysis.

To establish a meaningful basis for comparison, four complementary socioeconomic indicators were obtained from Statistics Indonesia (BPS) for each province over the same period (2016–2023). These indicators capture different dimensions of regional development. Gross Regional Domestic Product (GRDP) per capita is used to represent economic performance and average income levels across provinces. Population density serves as a proxy for settlement concentration and the degree of urbanization, reflecting how population is spatially distributed. Total road length is included as an indicator of physical infrastructure and regional connectivity, highlighting the extent of transportation networks that support economic activity. Finally, the Human Development Index (HDI) is incorporated to capture broader welfare outcomes, encompassing key dimensions such as education, health, and income within a composite index ranging from 0 to 1.

All socioeconomic indicators were formatted into a balanced provincial panel dataset, ensuring temporal consistency with the annual NTL time series. This harmonized dataset enables direct year-to-year comparisons between satellite-derived radiance and official socioeconomic indicators, forming the basis for the subsequent analysis. The analytical phase was conducted in R Studio, leveraging a suite of spatial and statistical packages to process the NTL data and align it with BPS socioeconomic indicators. The exported GeoJSON tiles were ingested using the sf package, which provides a modern framework for handling spatial vector data.

To manage the large number of files efficiently, the purrr:map_df() function was employed to systematically read and combine the tiles for each province into unified spatial objects, automating a critical stage of data preparation (Patnaik, Shah & Thomas, 2022). Following data ingestion, the raw radiance values (Digital Numbers, DN) were classified into five quantile-based intervals (1.0–1.8, 1.8–2.6, 2.6–3.4, 3.4–4.2, and 4.2–5.0). This classification, guided by established methodologies for NTL calibration and correction (Liu et al., 2020), enabled a more nuanced interpretation by distinguishing between low, medium, and high illumination zones within each province. The classified spatial patterns were visualized using the tmap package, chosen for its capacity to generate both static and interactive choropleth maps, thereby facilitating a dynamic exploration of spatial trends.

To measure temporal dynamics, the total radiance for each province and year was calculated by summing all pixel values within the respective administrative boundary, a standard approach in VIIRS-based studies (Zhu et al., 2023). From this, year-on-year radiance growth was derived as the percentage change relative to the preceding year. This normalized metric enables equitable comparisons across provinces of varying sizes and baseline brightness levels, serving as a robust proxy for socioeconomic dynamics such as urbanization, infrastructure development, and economic activity (Bhattarai et al., 2023; Li et al., 2020). In the final analytical stage, the radiance growth series was merged with the BPS-derived socioeconomic indicators, including GRDP per capita, population density, total roads, and HDI. Comparative line charts were generated for each province using the ggplot2 package, allowing for a direct visual assessment of how NTL dynamics co-evolve with official development indicators.

In addition to the descriptive and comparative assessments, this study also conducts a correlation analysis to further investigate the relationship between socio-economic indicators and Nighttime Light (NTL) radiance across selected provinces in Java, Indonesia. The socio-economic indicators included are: Human Development Index (HDI), total roads, population density, and Gross Regional Domestic Product (GRDP) per capita. The dataset was transformed into a long format, and pairwise complete observations were used to ensure that missing values did not bias the estimation. For each province, the correlation coefficient was computed between NTL radiance and the socio-economic variables. The Pearson product-moment correlation coefficient was employed, expressed as:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x}^2)\cdot\sum_{i=1}^{n}(y_i-\bar{y}^2)}} \quad (1)$$

where:
r_{xy} = Pearson correlation coefficient between variable x (NTL radiance) and variable y (socio-economic indicator)
x_i, y_i = individual observations
$\bar{x}, \bar{y}$ = mean values of the respective variables
n = number of paired observations

The correlation coefficient ranges from −1 to +1. A positive coefficient indicates that higher socio-economic values are associated with higher levels of NTL radiance, while a negative coefficient suggests the opposite.

The magnitude of r reflects the strength of the relationship: values close to ±1 indicate strong associations, while values near 0 suggest weak or no correlation. Visualization of the results was conducted using heatmaps in R (ggplot2). The tiles represent the correlation values by color scale (red = negative, blue = positive), while numerical values are overlaid to provide exact coefficients. Labels for both provinces and socio-economic indicators were standardized into English for clarity and consistency.

To ensure the analytical integrity of this study, several validation steps were undertaken in response to the well-documented limitations of VIIRS/DNB nighttime light data. While VIIRS offers significant improvements over earlier DMSP-OLS datasets in terms of radiometric calibration and spatial resolution, it is not without shortcomings. First, temporal constraints limit the use of VIIRS data for long-term historical analysis, as its coverage only extends back to 2012 (Zhao et al., 2019). This discontinuity complicates efforts to link VIIRS records with earlier DMSP observations, thereby restricting the scope of analysis to the 2016–2023 period in this study. Second, measurement inconsistencies arise from variations in satellite overpass times, atmospheric interference, and lunar illumination, which can distort interannual brightness levels (Zhao et al., 2019).

Furthermore, the sensor demonstrates moderate calibration accuracy at low radiance levels, is sensitive to aerosols and cloud cover, and struggles to fully account for spectral mismatches with modern LED lighting, causing underestimation of emissions by as much as 34 percent in some contexts (Cao & Bai, 2024). Finally, despite its finer resolution compared to DMSP, VIIRS still encounters challenges in capturing small-scale features, with blooming effects around bright cores and difficulty representing very dim emissions (Chen et al., 2024). Therefore, to address these challenges, this study adopted several safeguards.

First, the analysis focused exclusively on a consistent eight-year VIIRS time series (2016–2023), thereby avoiding cross-sensor calibration issues with DMSP data and ensuring temporal comparability. Second, the study employed quantile-based classification of radiance values, which reduces the influence of extreme brightness saturation in urban cores while enhancing comparability across provinces of varying light intensities. Third, rather than relying solely on NTL as a proxy for socioeconomic activity, the analysis systematically contrasted NTL dynamics with official indicators from Statistics Indonesia (GRDP, population density, total roads, and HDI). To complement this comparison, a correlation analysis was conducted to formally assess the strength and direction of the association between NTL radiance and the socioeconomic indicators across provinces.

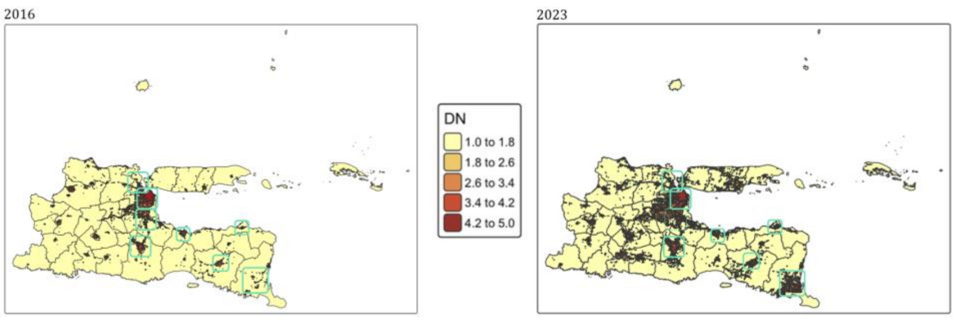
This quantitative step enables the study to evaluate not only visual correspondences but also statistical relationships, highlighting where NTL aligns with or diverges from conventional measures. This approach highlights instances where traditional indicators and NTL exhibit divergent growth patterns, allowing the study to uncover complementary insights into regional development dynamics that may be overlooked by conventional statistics alone. These steps strengthen the reliability of the study's findings while acknowledging the inherent limitations of VIIRS data. Rather than treating NTL as a perfect substitute for conventional statistics, the methodology positions it as a complementary lens through which regional economic and developmental patterns can be observed with greater temporal immediacy and spatial granularity.

Results and Discussion

In this section we leverage recent advances in VIIRS derived NTL analysis to provide a multifaceted view of Java's economic landscape. First we present detailed choropleth maps for each of the island's six provinces: Banten, DKI Jakarta, West Java, Central Java, DI Yogyakarta, and East Java, using 2022 and 2023 composites to spotlight the most current spatial reconfigurations of nighttime radiance. These high resolution visuals capture incremental infrastructure rollouts and emergent growth corridors that traditional statistics often miss (Gibson et al., 2021). Next, to quantify temporal dynamics, we calculate year on year percentage changes in total radiance across the full 2016 to 2023 span.

Employing this extended series both smooths transient anomalies and strengthens the estimation of subprovincial economic trends, a methodological refinement shown to enhance GRDP per capita estimation from NTL data (Ivan et al., 2020). We then align these radiance growth rates with corresponding annual shifts in provincial GRDP per capita, enabling a direct assessment of how luminosity dynamics mirror formal economic performance. Finally, we situate our findings within the broader remote sensing literature. Recent studies demonstrate that combining spatially precise NTL metrics with socio-economic indicators yields robust proxies for urban poverty and income distribution (Pérez-Sindín et al., 2021). By integrating both the latest maps and long term growth series, our methodology offers a comprehensive near real time toolkit for monitoring economic expansion, infrastructure diffusion, and persistent spatial disparities across Java's provinces.

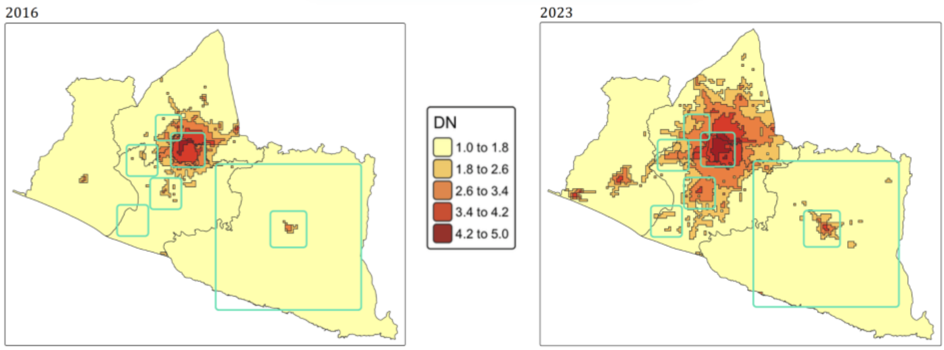
Figure 3. East Java Nighttime Lights of 2016 and 2023



Source: Processed by Author (2025)

From 2016 to 2023, the light footprint intensifies and spreads outward from the Surabaya, Gresik, Sidoarjo core. DN 4.2 to 5.0 areas that were compact in 2016 broaden by 2023, and DN 3.4 to 4.2 belts thicken along main transport and industrial corridors. The Malang to Pasuruan axis rises from DN 2.6 to 3.4 in 2016 to a more continuous DN 3.4 to 4.2 by 2023. New mid intensity clusters appear around Kediri and Jember in DN 2.6 to 3.4, suggesting secondary growth beyond the principal metropolitan triangle.

Figure 4. DI Yogyakarta Nighttime Lights of 2016 and 2023

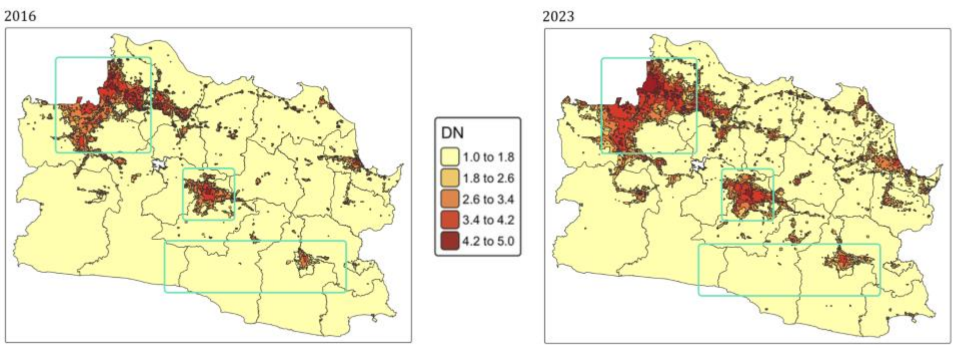


Source: Processed by Author (2025)

Meanwhile, highland districts such as Lumajang and Bondowoso remain largely in DN 1.0 to 1.8, indicating persistent gaps in electrification and sparse settlement. Overall, the six year comparison shows consolidation in established hubs with corridor led diffusion, while also reminding that nighttime lights under-represent low density economic activity (Pérez-Sindín et al., 2021). Yogyakarta's nighttime light footprint expands markedly from 2016 to 2023. The DN 4.2–5.0 nucleus that was concentrated around the Kraton, Malioboro, and UGM axis in 2016 becomes larger and more continuous by 2023, extending along Kaliurang Street and around the ring road.

Mid-intensity belts in DN 3.4–4.2 thicken into Sleman and push south into Bantul, while DN 2.6–3.4 clusters appear along Wonosari Street and the western peri urban fringe, indicating residential infill, new commercial nodes, and expanded street lighting. In contrast, much of Gunungkidul and large parts of Kulon Progo remain in DN 1.0–1.8, reflecting sparse settlement and limited grid reach. Overall, the pattern shows consolidation in the urban core with corridor led diffusion into surrounding districts, consistent with how VIIRS nighttime lights capture subprovincial economic activity and its spatial spread (Khairunnisah et al., 2023).

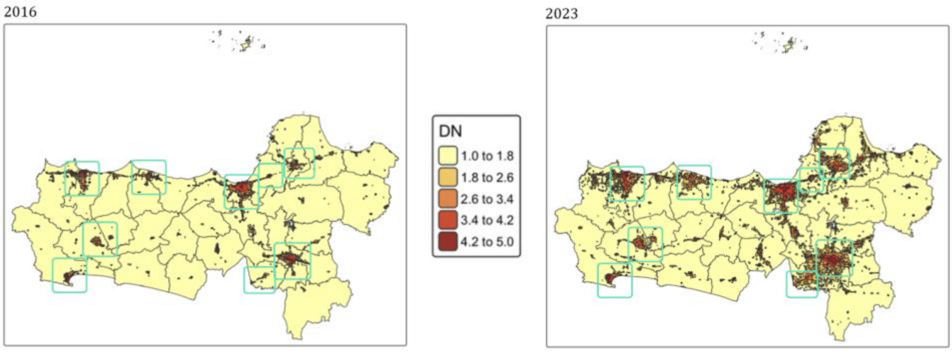
Figure 5. West Java Nighttime Lights of 2016 and 2023



Source: Processed by Author (2025)

West Java's nighttime light pattern between 2016 and 2023 shows both consolidation in existing hubs and diffusion along development corridors. The brightest radiance intensified in the northwest region connected to DKI Jakarta, extending eastward along the Jakarta–Cikampek corridor through Bekasi, Karawang, and Purwakarta, reflecting industrial and logistics growth.

Figure 6. Central Java Nighttime Lights of 2016 and 2023

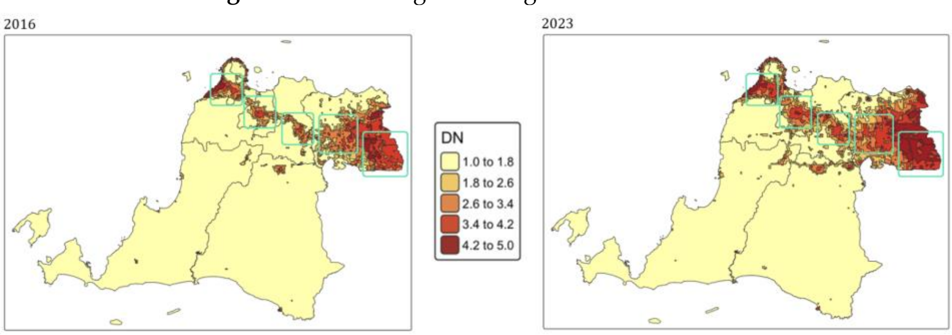


Source: Processed by Author (2025)

Bandung remained a secondary anchor with expanded mid-intensity zones around its urban core and peri-urban fringe. New mid-intensity pockets emerged along the north coast toward Subang, Indramayu, and Cirebon. In contrast, southern upland areas including Sukabumi and Garut interiors maintained minimal radiance. The spatial configuration demonstrates VIIRS lights effectively capture urban economic activity and infrastructure expansion while underrepresenting output in low-density rural regions (Elvidge et al., 2021).

Based on Figure 6, Central Java's nighttime light footprint significantly intensified and expanded between 2016 and 2023. The highest radiance class became denser and more contiguous around Semarang and Surakarta, indicating consolidated economic activity in these urban cores. Mid-intensity zones expanded along key transport corridors and secondary towns, reflecting development along the Semarang-Demak-Kudus axis and the Solo-Sukoharjo-Klaten corridor toward Yogyakarta. In contrast, interior highland districts maintained low radiance levels, highlighting persistent disparities between coastal development corridors and less accessible regions.

Figure 7. Banten Nighttime Lights of 2022 and 2023

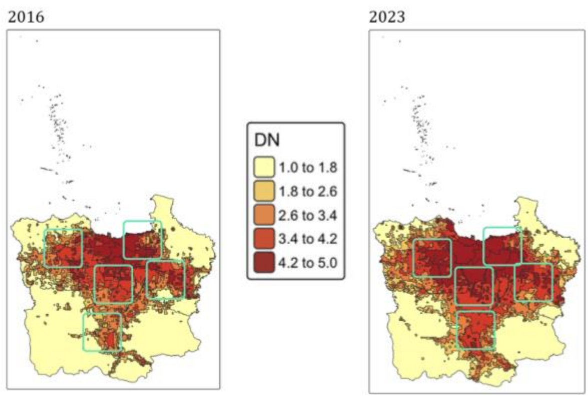


Source: Processed by Author (2025)

The spatial pattern demonstrates clear concentration of economic activity along infrastructure networks and urban centers, while upland areas showed limited development, consistent with VIIRS luminosity effectively capturing subprovincial economic patterns but being less sensitive in very low-density settings (Small, 2021). Banten's 2016 and 2023 nighttime-light imagery shows the brightest clusters (DN 4.2–5.0) tightly focused in Cilegon, Serang, and the Jakarta–Tangerang spillover zone, reflecting these areas' roles as major industrial and urban centers. Between 2016 and 2023, the adjacent DN 3.4–4.2 band expands markedly along the Serang–Pandeglang corridor, indicating new infrastructure projects and enhanced street-lighting initiatives.

Mid-intensity zones (DN 2.6–3.4) also grow in Lebak and southern Pandeglang, marking nascent rural development and increased nighttime electricity access. In contrast, the southwestern highland districts remain in the lowest DN 1.0–1.8 class, underscoring persistent gaps in rural electrification. These shifts mirror Small's finding that VIIRS nighttime-light variability accurately captures subnational economic growth and investment patterns at fine geographic scales, and they are consistent demonstration of NTL's effectiveness for mapping urban development dynamics.

Figure 8. DKI Jakarta Nighttime Lights of 2022 and 2023



Source: Processed by Author (2025)

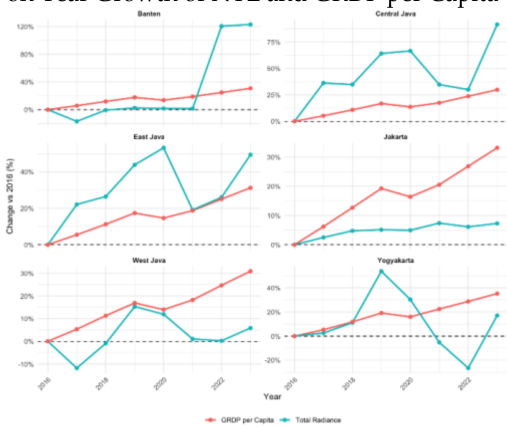
DKI Jakarta's 2016 and 2023 VIIRS-derived nighttime-light maps reveal an almost completely saturated urban core. In both years, the deepest red pixels (DN 4.2–5.0) blanket Central, South, and East Jakarta districts such as Menteng, Sudirman, and Cilandak, reflecting the intense commercial, administrative, and residential lighting in these areas. Encircling this core, the dark-orange band (DN 3.4–4.2) extends into North Jakarta's coastal zones and along the suburban corridors toward Depok and Bekasi, signaling the continuous outward sprawl of DKI Jakarta's industrial and commuter belt.

From 2016 to 2023 there is a subtle but discernible increase of DN 4.2–5.0 into fringe subdistricts like Pesanggrahan and Kebayoran Lama, indicating incremental densification. In stark contrast, the Thousand Islands archipelago and the southern forested hills remain in the lowest radiance class (DN 1.0–1.8), underscoring persistent gaps in electrification and economic activity outside the metropolitan footprint.

These patterns of radiance saturation and peripheral dimness are consistent with findings that VIIRS nighttime-light intensity serves as a robust proxy for urban economic intensity and infrastructure development in megacity contexts (Elvidge et al., 2021). Comparison of percent changes in nighttime light radiance and GRDP per capita across Java since 2016 (in figure 9) reveals distinct economic patterns, with GRDP showing steady growth while NTL exhibits sharper fluctuations that capture localized dynamics often missed in aggregate income data.

Initially, radiance grew faster than GRDP in DI Yogyakarta, East Java, and West Java, indicating spatial broadening of economic activity into manufacturing and tourism corridors, while DKI Jakarta's flat radiance alongside steady GRDP growth reflects its mature service-based economy where productivity derives from intangible sectors.

Figure 9. Year on Year Growth of NTL and GRDP per Capita of Each Region



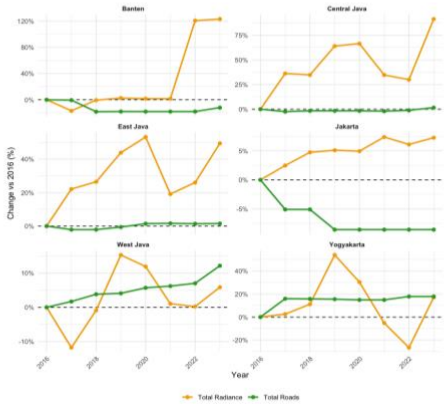
Source: Processed by Author (2025)

Initially, radiance grew faster than GRDP in DI Yogyakarta, East Java, and West Java, indicating spatial broadening of economic activity into manufacturing and tourism corridors, while DKI Jakarta's flat radiance alongside steady GRDP growth reflects its mature service-based economy where productivity derives from intangible sectors. The temporal and spatial sensitivity of NTL is further evidenced by DI Yogyakarta's volatility aligning with tourism and student mobility patterns, East Java's fluctuations corresponding to industrial lighting changes, and Banten's 2022 radiance surge without proportional GRDP growth indicating concentrated industrial activation rather than broad-based expansion, demonstrating how NTL effectively complements GRDP by revealing the timing, geography, and inclusivity of economic growth across Java's diverse regional economies.

The percent change since 2016 in total nighttime light radiance and total road length across Java’s provinces, revealing distinct patterns of development. Radiance fluctuates more sharply than incremental road expansion, reflecting dynamic economic activity beyond physical infrastructure. In DKI Jakarta, stagnant road length and radiance indicate a saturated service based economy, while Banten’s radiance surge without parallel road growth points to concentrated industrial activation. East and Central Java show steadier alignment, where road construction along key corridors supported radiance growth by enhancing mobility and activating new economic zones.

As Watson et al. (2023) emphasize, the link between infrastructure and NTL is strongest when transport effectively channels flows into urban and peri urban clusters. Conversely, Yogyakarta's modest road gains failed to stabilize radiance, which fluctuated sharply due to its reliance on tourism and student flows rather than infrastructure.

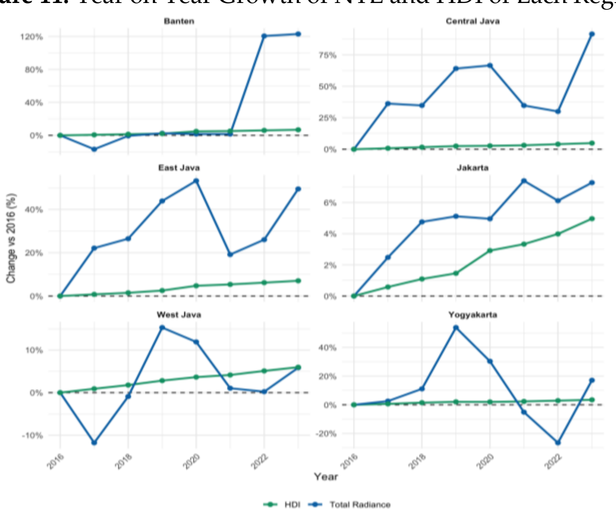
Figure 10. Year on Year Growth of NTL and Total Roads of Each Region



Source: Processed by Author (2025)

West Java presents a balanced trajectory, with steady road expansion supporting incremental radiance gains along industrial corridors. Overall, the comparison demonstrates that road expansion alone does not guarantee economic lighting growth. Effective synergy occurs where infrastructure enables broader activity, as in East, Central, and West Java, whereas radiance can spike independently in industrial zones or remain volatile in service driven economies, highlighting the nuanced relationship between physical infrastructure and economic vitality.

Figure 11. Year on Year Growth of NTL and HDI of Each Region



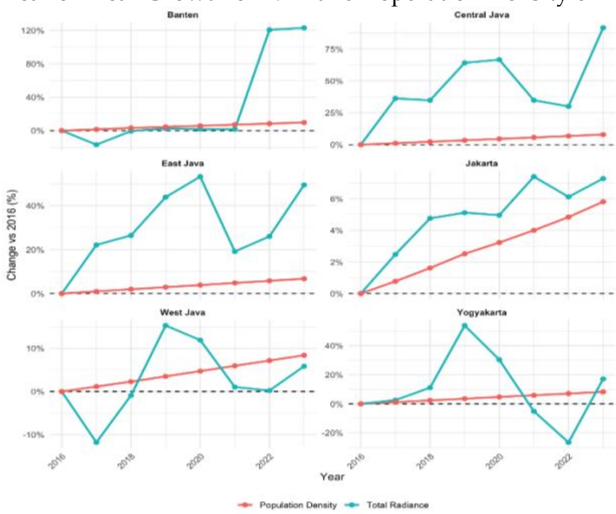
Source: Processed by Author (2025)

Reveals stark contrasts in the relationship between development and economic activity across Java. DKI Jakarta maintains the highest HDI alongside rising radiance, indicating balanced growth where robust economic activity supports strong welfare outcomes. In contrast, DI Yogyakarta achieves the second-highest HDI despite stagnant radiance, demonstrating that high human development can occur without parallel economic expansion.

Banten presents a paradox with high minimum wages but low HDI, suggesting that income gains are eroded by high living costs, while Central Java shows how low-wage, labor-intensive growth boosts radiance but fails to improve HDI, highlighting the limitations of an economic model devoid of technology transfer or high-value job creation. The divergence between demographic trends and development outcomes is further illuminated by population dynamics. Across all provinces, population density increases steadily, driving radiance growth and affirming that human concentration remains central to economic activity. However, this relationship does not automatically translate into welfare gains.

East Java shows sustained radiance growth with only modest HDI improvements, whereas West Java exhibits resilient HDI progress despite economic volatility, indicating that social development can withstand short-term shocks. These patterns underscore that population growth and economic expansion are insufficient without complementary policies such as inflation control, technological upgrading, and equitable public service provision to ensure that demographic and economic dynamism translates into broad based human development.

Figure 12. Year on Year Growth of NTL and Population Density of Each Region



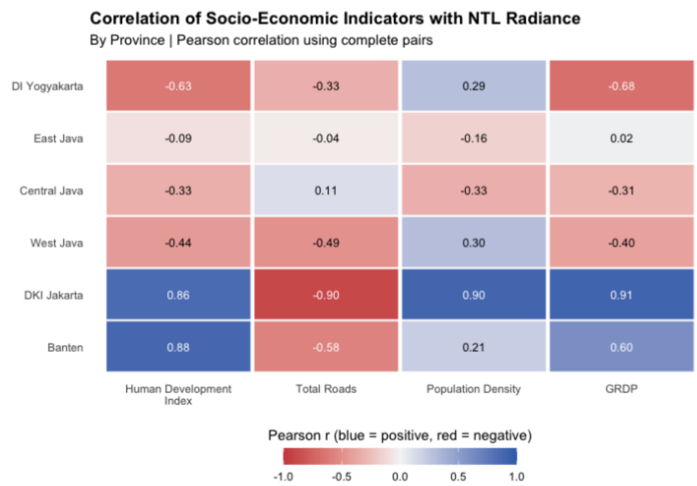
Source: Processed by Author (2025)

The evidence shows that demographic and economic growth alone are not enough to guarantee prosperity. While population expansion and increased economic activity can stimulate development, their benefits are limited without proper infrastructure, fair strategies, and investment in human capital. Provinces like East and Central Java illustrate the shortcomings of infrastructure led, labor intensive growth, where road network expansion and population growth have not led to significant improvements in human development.

In contrast, DKI Jakarta demonstrates how effective planning can turn demographic pressure into welfare gains, though its stable radiance levels indicate a mature, service driven economy that continues to progress without additional physical expansion. The provincial comparisons reveal an important gap between economic output and welfare outcomes. Banten's increase in radiance points to concentrated industrial growth, yet this has not resulted in widespread welfare improvements due to higher living costs.

Meanwhile, Yogyakarta achieves high human development scores despite limited radiance growth, emphasizing strong human capital that does not depend on light intensive economic expansion. West Java further demonstrates this disconnect, as human development continued to improve steadily despite short term fluctuations in economic activity, showing that welfare can withstand economic volatility. These patterns highlight that radiance and economic output measure the speed and location of growth, while human development reflects long term welfare. Their frequent misalignment underscores that without inclusive policies focusing on wages, affordability, and technology, growth may become uneven, leaving human development either vulnerable or disconnected from economic progress.

Figure 13. Correlation of Socio-Economic Indicators with NTL Radiance across Java's Provinces



Source: Processed by Author (2025)

The analysis reveals a clear divergence in the relationship between nighttime light (NTL) radiance and socio-economic development across Java's provinces. In highly urbanized and dense capital regions like DKI Jakarta and Banten, NTL radiance serves as an excellent proxy for development, showing very strong positive correlations with HDI, GRDP, and population density. This indicates a high concentration of light-intensive economic activity. Conversely, in the central and eastern regions like DI Yogyakarta, Central Java, East Java, and West Jawa, the correlations are negligible to strongly negative. This suggests that socio-economic progress in these provinces is not dependent on light-emitting infrastructure, likely due to their reliance on cultural, educational, traditional, and service-based economies, as well as dispersed settlement patterns that dilute the NTL signal.

The findings highlight that the usefulness of NTL data as a proxy for socio-economic indicators is highly context-dependent. In provinces with diverse economic structures or those dominated by non-industrial sectors, NTL radiance is a weak or even inverse indicator of development. Therefore, policymakers should exercise caution, using NTL data primarily for granular analysis within specific, highly urbanized contexts rather than as a standalone measure for regional development across all of Java.

Conclusion

The combined evidence from the graphs and NTL maps underscores that Nighttime Light (NTL) data provides a valuable, complementary perspective to conventional socioeconomic indicators such as GRDP per capita, HDI, population density, and infrastructure growth. While GRDP and HDI offer smoothed averages of welfare and income, NTL captures the timing, geography, and intensity of economic activity, exposing disparities that traditional indicators often mask. For instance, DKI Jakarta illustrates a case where strong HDI and GRDP trends align with consistently rising radiance, reflecting balanced and sustained growth.

By contrast, DI Yogyakarta reveals a divergence, strong welfare achievements reflected in HDI but stagnant radiance, signaling limited economic dynamism. Similarly, Banten demonstrates that high wages do not automatically translate into improved welfare outcomes, while Central Java highlights the structural limits of low-wage development models despite rising radiance from industrial activity. Meanwhile, East and West Java show different patterns of resilience, with the former achieving steady radiance growth without proportional welfare gains, and the latter maintaining welfare improvements despite volatile radiance during economic shocks.

The comparative NTL maps of 2016 and 2023 further strengthen this analysis by visually demonstrating how urban expansion and economic activity have evolved spatially across Java. These maps make disparities more tangible, showing where growth has been concentrated and where stagnation persists, thereby offering a clear, geographic lens to interpret development dynamics. Taken together, these findings illustrate that NTL can act as a diagnostic tool for policymakers, revealing the spatial and temporal dynamics of development that static socioeconomic metrics may overlook.

By combining NTL with conventional indicators, decision-makers gain a more granular understanding of economic activity, welfare resilience, and infrastructure impact, allowing policies to better target structural gaps, enhance inclusivity, and ensure that growth translates into real improvements in human well-being. Based on the findings of this research, a set of integrated policy directions can be articulated for the Government of Indonesia and relevant stakeholders, emphasizing the strategic use of Nighttime Light (NTL) data as an innovative and complementary economic proxy. First, there is a strong imperative to institutionalize the systematic integration of NTL data with the National Unified Socio-Economic Data (DTSEN).

Such integration would significantly enhance the robustness of national statistics by enabling cross-verification mechanisms, revealing spatial economic disparities at a finer granularity, and ultimately supporting more accurate, evidence-based targeting of public policies and resource allocation.

Furthermore, NTL data offers substantial potential to strengthen strategic planning within the tourism and creative economy sectors. By leveraging the spatial distribution and intensity of light emissions, the Ministry of Tourism and Creative Economy can more effectively identify emerging economic hotspots and clusters of activity. When combined with tourism indicators and cultural metrics, this approach enables a more dynamic mapping of growth areas, supports more targeted infrastructure investment, and facilitates the development of tailored policy interventions that move beyond the limitations of conventional datasets.

In parallel, the application of NTL data can significantly improve the monitoring of trade and industrial dynamics. The Ministry of Industry and Trade can utilize this tool to capture near real-time patterns of economic activity, including the evolution of industrial corridors and logistics networks. This capability allows for more adaptive policy evaluation and supports efforts to promote balanced regional development by identifying both leading and lagging areas with greater precision. From a fiscal perspective, NTL data provides a novel analytical instrument for strengthening oversight and improving revenue mobilization. For the Ministry of Finance, discrepancies between light intensity and reported economic activity can serve as an indirect indicator of informal or underreported economic activities.

This enables a more accurate estimation of the shadow economy, facilitates the identification of potential tax leakage, and contributes to the design of a more equitable and efficient tax system. Finally, the financial sector stands to benefit from incorporating NTL-based insights into its analytical frameworks. Commercial banks can use this data to refine credit allocation strategies by identifying regions with latent or underreported economic potential, thereby improving financial inclusion. At the macro level, Bank Indonesia can integrate NTL indicators into its macroprudential surveillance toolkit, enhancing its capacity to monitor regional economic conditions and to design policies that support financial stability while fostering inclusive and sustainable economic growth.

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