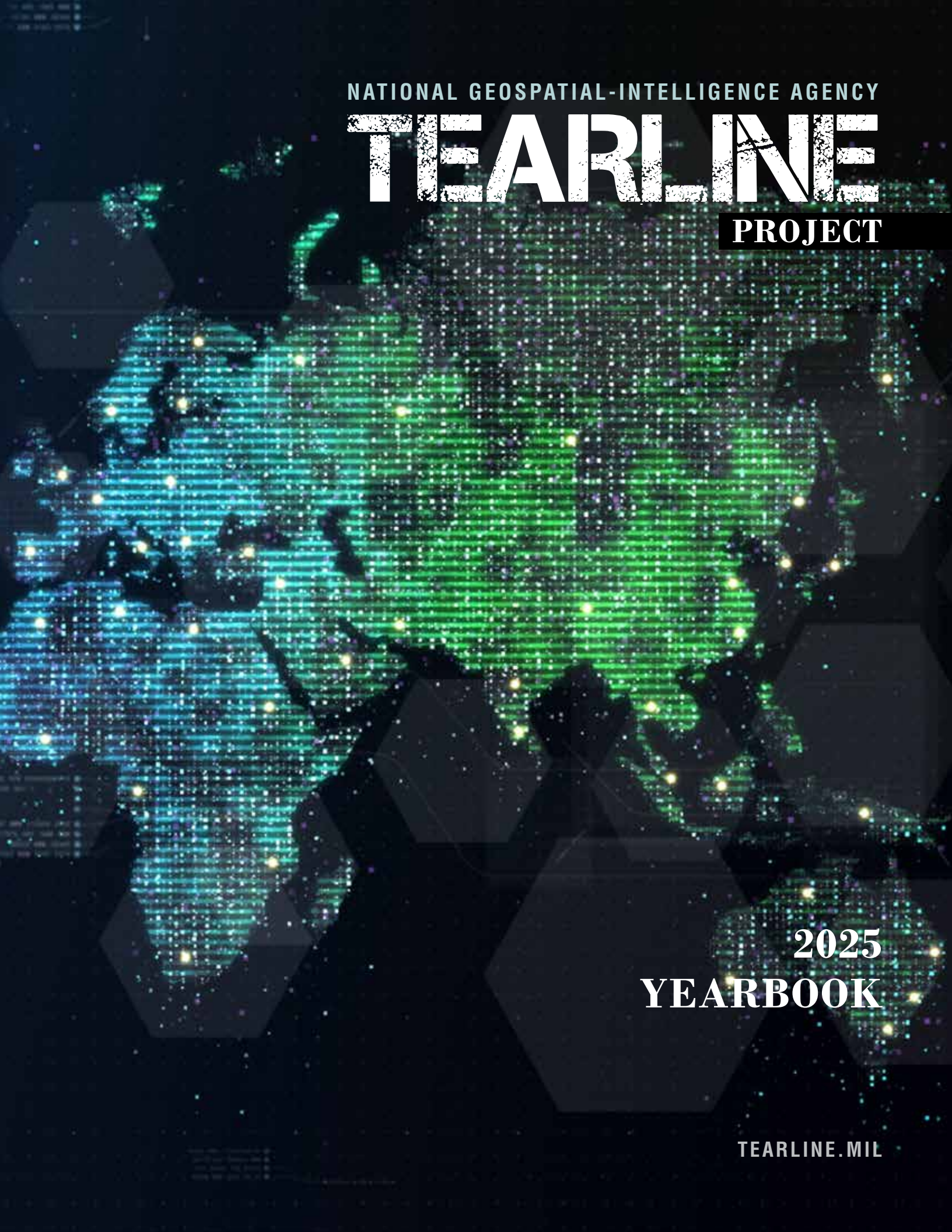
NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY
TEARLINE
PROJECT
2025
YEARBOOK
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ABOUT

The Tearline Project is an NGA-sponsored, congressionally supported program that enables authors from academic and non-profit institutions to partner with the agency in order to develop unclassified geospatial-intelligence reports. The reports deliver transparent, real-world analysis on varying topics of value to NGA and the federal government through the use of open-source information and commercial imagery. The Tearline Editorial Board, made up of National System for Geospatial Intelligence (NSG) members from NGA and the Armed Services, provides peer, subject matter expert reviews for each article.

All Tearline Project articles are available for the general public at www.tearline.mil or within the Tearline mobile app available in both the GooglePlay and Apple App stores. If you are interested in submitting a proposal or manuscript to the Tearline Project, please direct inquiries to Tearline@nga.mil.

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FOREWORD

Welcome to the National Geospatial-Intelligence Agency's third annual Tearline Project Yearbook.

Within the Intelligence Community, the National Geospatial-intelligence Agency (NGA) is the premier intelligence agency for geospatial intelligence (GEOINT) and is relied on to provide a decisive advantage to military commanders and national policy makers. The demand for GEOINT data and associated information has expanded far beyond classified applications. Open-source GEOINT data has proven useful to non-traditional professionals who seek the same expertise in the field using commercial, unclassified data and sources.

The Tearline Project is a coordinated effort with outside expert contributors across academia, nonprofit organizations and think tanks. As unclassified sensors and data proliferate, NGA partners with these experts to analyze open and commercial GEOINT data and deliver unclassified intelligence on the Tearline Project website. The aim is to combat the data deluge and promote the next generation of GEOINT talent.

This publication highlights important work on challenging national security problems, culminating in the nine enclosed Tearline Project articles published in 2025. Working with NGA, the contributors explored a spectrum of techniques, from automated data processing to traditional imagery analysis.

Contributors delivered valuable information through detail-oriented research and well-crafted articles on a variety of subjects. Topics include the environmental and human security risks of China's petrochemical industry, the expansion of Chinese-owned cobalt and copper mines in the Lualaba Province in the Democratic Republic of Congo and foreign involvement in Syria's electrical grid.

However, the highlight of this year's entries exhibited the expansion of the Tearline Project's article formats with the first ever Tearline Methods article, "Quantifying Increases in Maritime Activity in Information-Denied Environments Using Open-Source SAR Data." The continued expansion of the Tearline Project demonstrates the increasing utility and adaptability of the unclassified work done by outside expert contributors on critical subjects for the geospatial and national security communities.

NGA is proud to sponsor this program. Please be sure to visit the Tearline website at www.tearline.mil or download the Tearline Project mobile app for the latest NGA Tearline reporting.

Ms. Cheryl B. Gilbert
Deputy Director, Analytic Tradecraft & Technology

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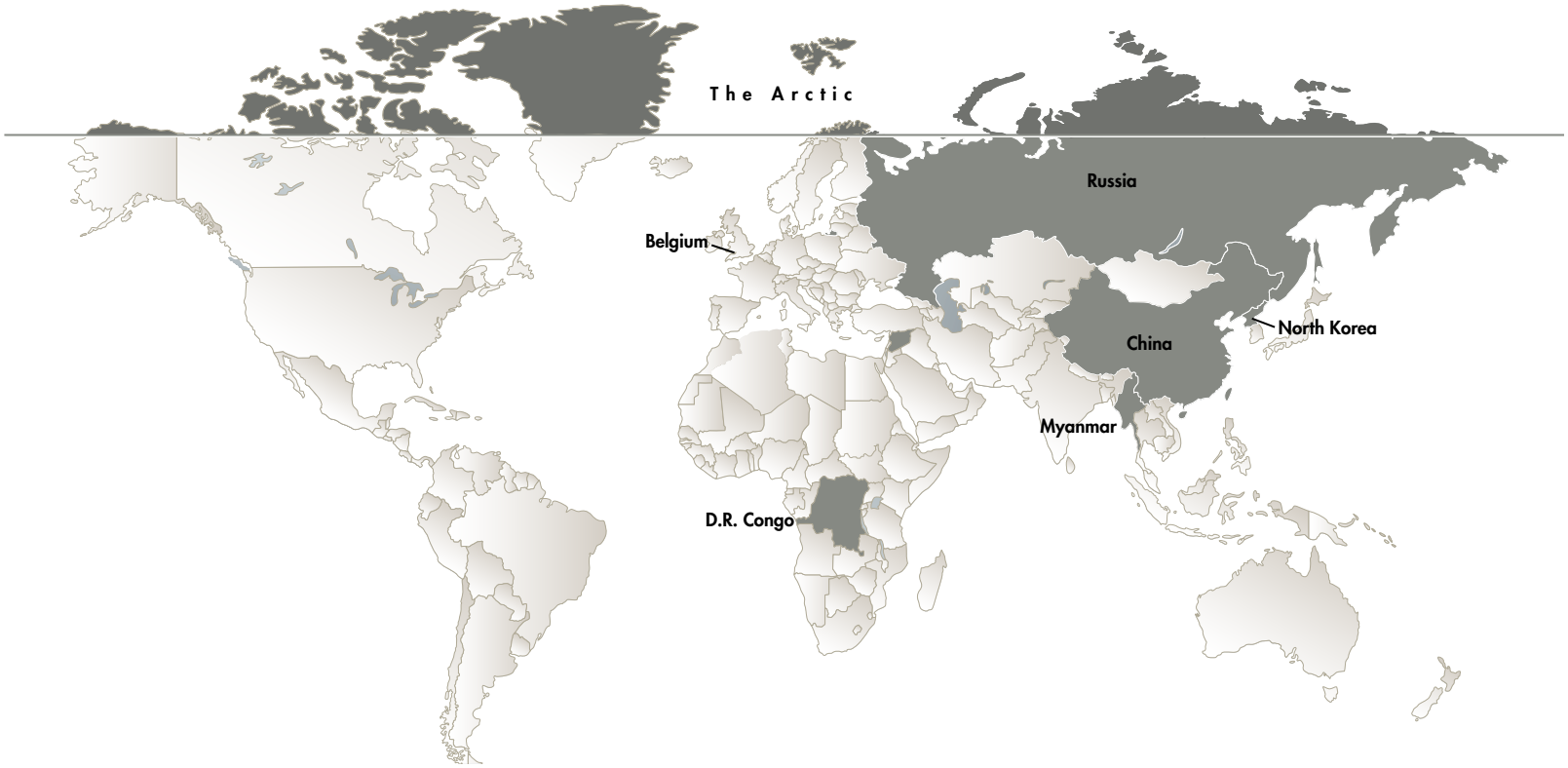

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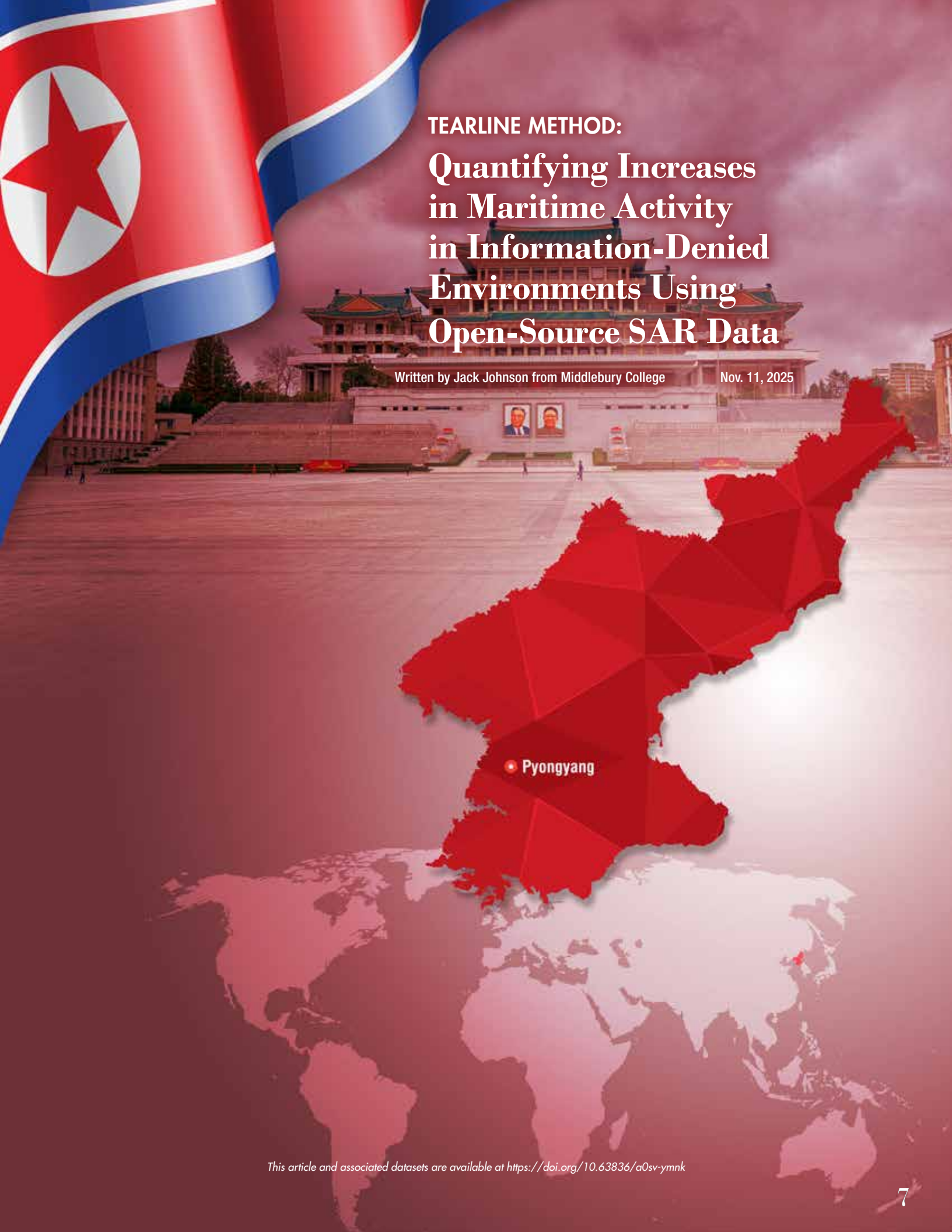


TEARLINE METHOD:

Quantifying Increases in Maritime Activity in Information-Denied Environments Using Open-Source SAR Data

Written by Jack Johnson from Middlebury College Nov. 11, 2025

This article and associated datasets are available at https://doi.org/10.63836/a0sv-ymnk

SUMMARY

The application of a basic geographic information system (GIS) workflow and cloud-based processing of publicly available Sentinel-1 synthetic aperture radar (SAR) images, within a Google Earth Engine environment, demonstrates the ability to track large maritime vessel activity patterns on the Taedong River proximal to Nampo Port in Nampo, Democratic People's Republic of Korea (DPRK) with a high degree of accuracy. This maritime vessel activity was observed over a period of 10 years (2015-2025). The automated methodology utilized to analyze this activity has no statistically significant bias (95% CI -0.22 – 0.45) with a mean absolute error of 0.81 ships per image across the entire area of interest.

Analysis identified multiple temporal points of interest where there were significant changes in maritime activity, providing quantitative context for further in-depth qualitative research. The automated methodology described can be replicated on other ports or narrow maritime areas of interest to generate contextual quantitative data on large vessel movements and activity over long time periods.

BACKGROUND

Use of SAR for Maritime Surveillance

Applications of remote sensing—and SAR data analysis, in particular—for automated maritime activity surveillance have been extensively researched, and various algorithms have been developed in academic and operational settings for detailed vessel identification and classification. For example, the European Commission's Joint Research Center Search for Unidentified Maritime Objects (SUMO) program has been intensively developed for this purpose across a range of SAR data sources. More complex tools such as these are invaluable, especially when analyzing wide geographic areas or when the highest-precision measurements are imperative. However, less technical research teams who require contextual quantitative data on large vessel maritime activity may be hampered in implementing complex tools by a lack of technical resources, limited compute, or cost barriers to purchasing pre-processed data. These users require a simple, low-cost option to generate data that maintains a reasonably high level of accuracy and precision.

The methodology described below fulfills this need, enabling a less technical research team to easily generate contextual large vessel maritime activity data used for cross-referencing qualitative findings, providing background information, or other auxiliary purposes in a broader analysis of a specific site where absolute precision is not as critical as capturing overall patterns. In this case, Nampo Port in the DPRK was used as an area of interest for a geographically narrow longitudinal analysis of large vessel activity. The results of the approach were used as supporting data alongside more detailed qualitative analyses of infrastructure upgrades at the port.

Nampo Port

Nampo Port, situated about 15 kilometers upriver from the West Sea Barrage, serves as the DPRK's primary port on the Yellow Sea. It consists of multiple distinct sections, including a container terminal (the DPRK's only container terminal on its western coast), a bulk goods terminal that handles mixed goods as well as coal, and a petroleum, oil, and lubricants (POL) storage area and terminal. It is a key multi-modal trade hub with both rail and truck transport options to move goods into and out of the port area.

Due to its location and strategic importance to the DPRK economy, trade activity at the port has been the subject of research by various think tanks and research groups. However, the majority of these analyses often rely primarily on qualitative methods to measure changes in activity, using small numbers of manually interpreted satellite images. While manually interpreted methods are highly accurate and provide in-depth analysis over a small time frame, the addition of automated analysis of large vessel activity over a longer period would enable a more comprehensive understanding of activity at Nampo Port.

METHOD

Overview & Data Sources

This methodology has been refined and simplified into the fewest possible number of operations to accomplish the objective of detecting large vessels within an area of interest. The simplified methodology still achieves high accuracy and precision, as detailed in the following section. This methodology uses Sentinel-1 Ground Range Detected (GRD) SAR imagery in vertical transmit, horizontal receive (VH) polarization acquired in Interferometric Wide (IW) mode.

The specific boundaries of vessel grouping areas around each of the three major port terminals were defined by the researcher as vector polygons.

Analytical Process

The analytical process for quantifying maritime activity within an area of interest is encapsulated in a four-step approach. The following procedures were executed using JavaScript on an initial dataset of all Sentinel-1 images captured since 2015. All of these procedures were performed in a single Google Earth Engine script.

1. Image Collection Filtering

The collection of all Sentinel-1 GRD IW VH images is filtered to a set of 494 valid images that a) were captured between 1/1/2015 -9/1/2025; b) intersect an area of interest point at 38.6949°N,125.3208°E; and c) were not captured during the months of January or February. The exclusion of certain months is applied due to over detection during periods of heavy ice on the Taedong River, which is discussed further in the Analytic Confidence section.

2. Binary Mask Generation and Clipping

For each image in the filtered collection, a binary mask is generated where pixels with VH backscatter values >= -20 dB are assigned values of 1 and all other pixels are assigned values of 0. This binary mask is then clipped to the extent of the river itself using a manually created polygon of the water extent. This step produces a binary image of high backscatter clusters on the river for every image.

3. Cluster Vectorization and Filtering

For each binary image, every contiguous cluster of high back scatter pixels is reduced to a unique vector object. Vectors that have total sizes smaller than 15px or larger than 200px are filtered out. This controls for most artifacts and removes any small vessels outside the scope of the analysis. This step produces a set of likely ship vector objects for every image.

4. Terminal Grouping

Based on the researcher's expertise and long-term pattern observation of ship clustering locations, approximate polygons were developed around each of the three main terminals to include areas of the river in which any vessels were likely approaching or departing the given terminal. Separate large vessel vector counts were then generated for every image for each of the following sub-areas:

- Approach to the West Sea Barrage
- Entire River Adjacent to Nampo Port
- POL Terminal Proximal Area
- Bulk Goods and Coal Terminal Proximal Area
- Container Terminal Proximal Area
- Upriver Areas (From Nampo to Chollima)

APPLICATION

This methodology can be applied to any maritime area of interest with regular Sentinel-1 SAR imagery coverage to generate relatively high accuracy vessel detection counts over time. It is effective specifically for detecting large vessels (in this case, for example, tanker and container ships) which is a function of the spatial resolution of Sentinel-1 data. At 5x20m/px spatial resolution, smaller vessels are generally not detectable.

Certain areas of interest—like Nampo Port—are especially good candidates for this methodology based on specific spatial characteristics. The following three spatial characteristics aid in the implementation of this methodology, but are not required in their entirety to employ the automated methodology. First, there is a clearly definable maritime boundary for the area of interest. Because vessels entering the Taedong River must transit the West Sea Barrage, it can be used as a boundary for the extent of the river to monitor. Determining this boundary may be more difficult and potentially ambiguous at, for example, a port exposed directly to the ocean. Second, each specific terminal is spaced far enough apart that vessels cluster into obvious groups during their approach and departure. This makes the methodology more valuable since it allows trends related to specific terminals to be measured. Third, the upriver areas can also be clearly bounded and vessel traffic in them quantified. This is important because it enables the researcher to more confidently demonstrate that changes in patterns near Nampo Port are actually due to changes in traffic at the port itself and not vessels traveling upriver merely passing by.

Google Earth Engine was used to implement the methodology because of the ability to process imagery in the cloud, reducing compute requirements on the researcher's device and making it feasible to quickly deploy the methodology against any area of interest.

All data and systems used to deploy this methodology are fully accessible to researchers at no cost. Sentinel-1 SAR imagery is free and openly accessible through the European Union's Copernicus program.

Google Earth Engine is free for most nonprofit organizations and academic research institutions when used for non-commercial purposes.

Analytic Confidence

The principal advantage of this methodology is that it includes a limited number of computationally simple operations while maintaining very high accuracy and precision in detecting large vessels. The methodology was evaluated by randomly sampling a subset of 52 images from the 494 valid images analyzed by the program. For each of the 52 sampled images, all ships within the area of interest were manually counted based on Sentinel-1 imagery and any available high-resolution Planet Labs imagery captured within 30minutes of the given Sentinel-1 image. The following statistical analysis is based on comparison of manual and automated large vessel counts for images in this random sample (n = 52).

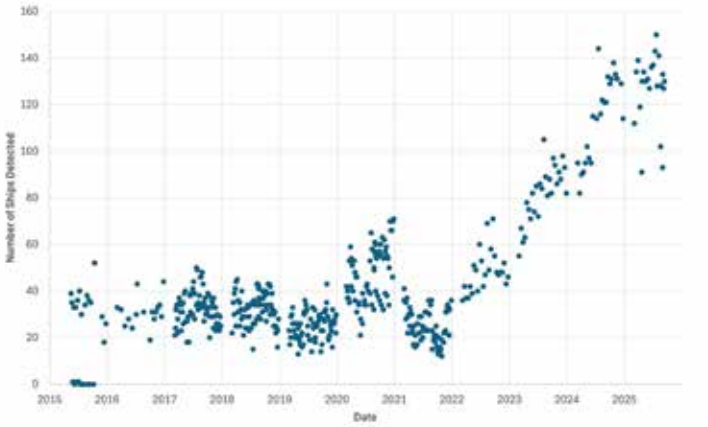
The sample mean signed error is 0.12 ships per image. The 95% confidence interval for the mean error, using a t-based interval, is[-0.22 - 0.45] ships per image. The mean absolute error is 0.81 ships per image, indicating that, practically, the automated ship count varies by about 0.81 ships from the manual count on average for any given image. The standard deviation of error is 1.19 ships per image. In 42%of the sampled images, the program returned ship counts that matched manual counts exactly. This methodology was specifically developed for and tested against ship activity near Nampo Port, and performance may vary on significantly different problem sets.

One additional advantage of this methodology is that by using SAR data, it is largely weather agnostic and can generate usable data during periods of heavy cloud cover. This is especially important in environments like the DPRK, where significant cloud cover for large parts of the year can preclude long-term remote sensing data collection by other methods.

There are a few analytical limitations of this methodology. First, heavy ice on the Taedong River produced major artifacts that significantly disrupted accurate counting of large vessels. For this reason, all images from January or February of any year were automatically excluded. Because the objective of the methodology is to identify macro-level inflection points or changes in maritime activity, missing two months of data each year is an issue but not prohibitive to analysis. However, this methodology likely could not be implemented effectively in a location with heavy ice during a larger portion of each year. Second, because of the spatial resolution of the imagery used,any detailed classification of individual vessels beyond rough size is difficult. This methodology is useful for detecting and counting large vessels in general but does not offer more detailed information on each vessel detected.

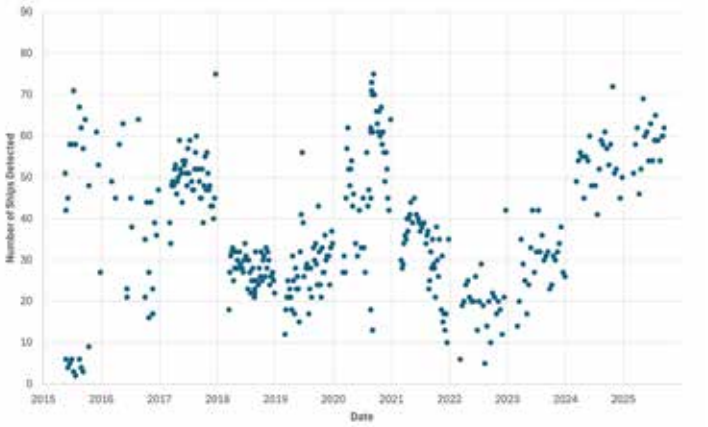
Case Study Findings

In this specific analysis, multiple temporal inflection points and periods of rapid change in maritime activity were identified for both the Nampo Port as a whole as well as specific terminals. Across the entire Taedong River from the West Sea Barrage up to Nampo Port,large vessel traffic remains relatively consistent from 2015-2019,experiences a brief increase in 2020, and then significantly increases beginning in 2022. That increase has continued for over three years,with current vessel counts ranging from 100-150 per image, a 200-300% increase from 2015-2019 levels.

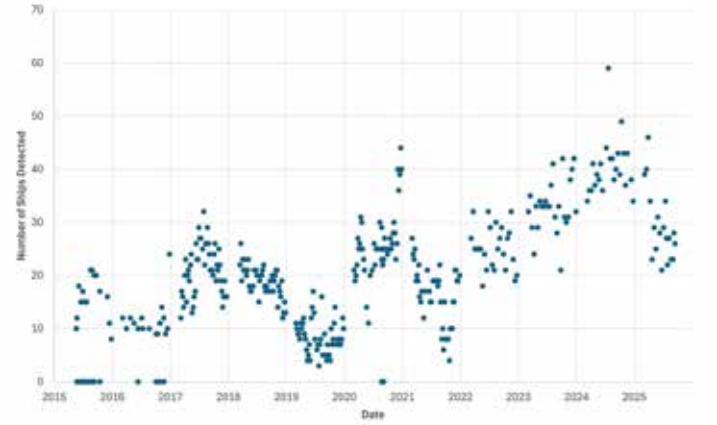


Ships detected per image in the Taedong River from the West Sea Barrage to Nampo, 2015-2025

Because the Taedong River continues inland, maritime activity in upriver areas from Nampo to Chollima were also analyzed to confirm that the increases detected at Nampo were not due to vessels bypassing Nampo to continue further upriver. Analysis of this area found no long-term changes in large vessel counts from 2015-2025, although there have been transitory increases and decreases throughout the period.

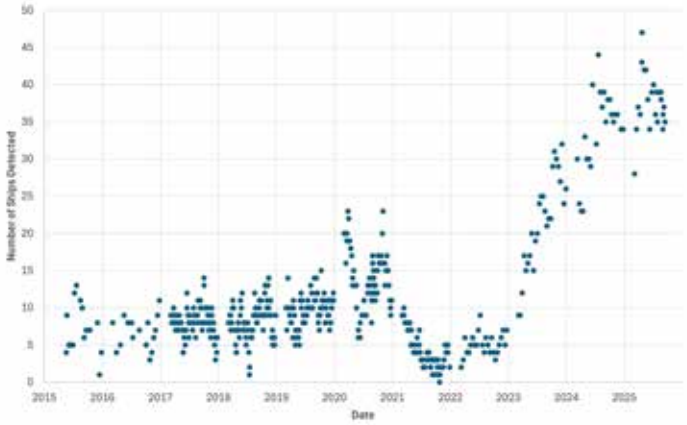


Ships detected per image in the Taedong River from Nampo to Chollima, 2015-2025



Ships detected per image in the Taedong River proximal to the container, bulk goods, and coal terminals at Nampo Port, 2015-2025

The overall increase in activity at Nampo Port was further dissected using the polygons bounding the specific areas proximal to both the Pol storage area and terminal, and the bulk and container terminals. While activity across both areas followed a generally similar pattern to the port as a whole, the bulk and container terminals showed a more steady, gradual increase in activity from 2015-2025, with transitory drops in activity in 2019 and 2021. The POL storage area and terminal, on the other hand, showed limited increases in activity from 2015-2020, a sharp decrease in activity from 2021-2023, and a rapid and continuous increase in activity from 2023-2025, with current large vessel counts up over 350% compared to pre-2020 levels.



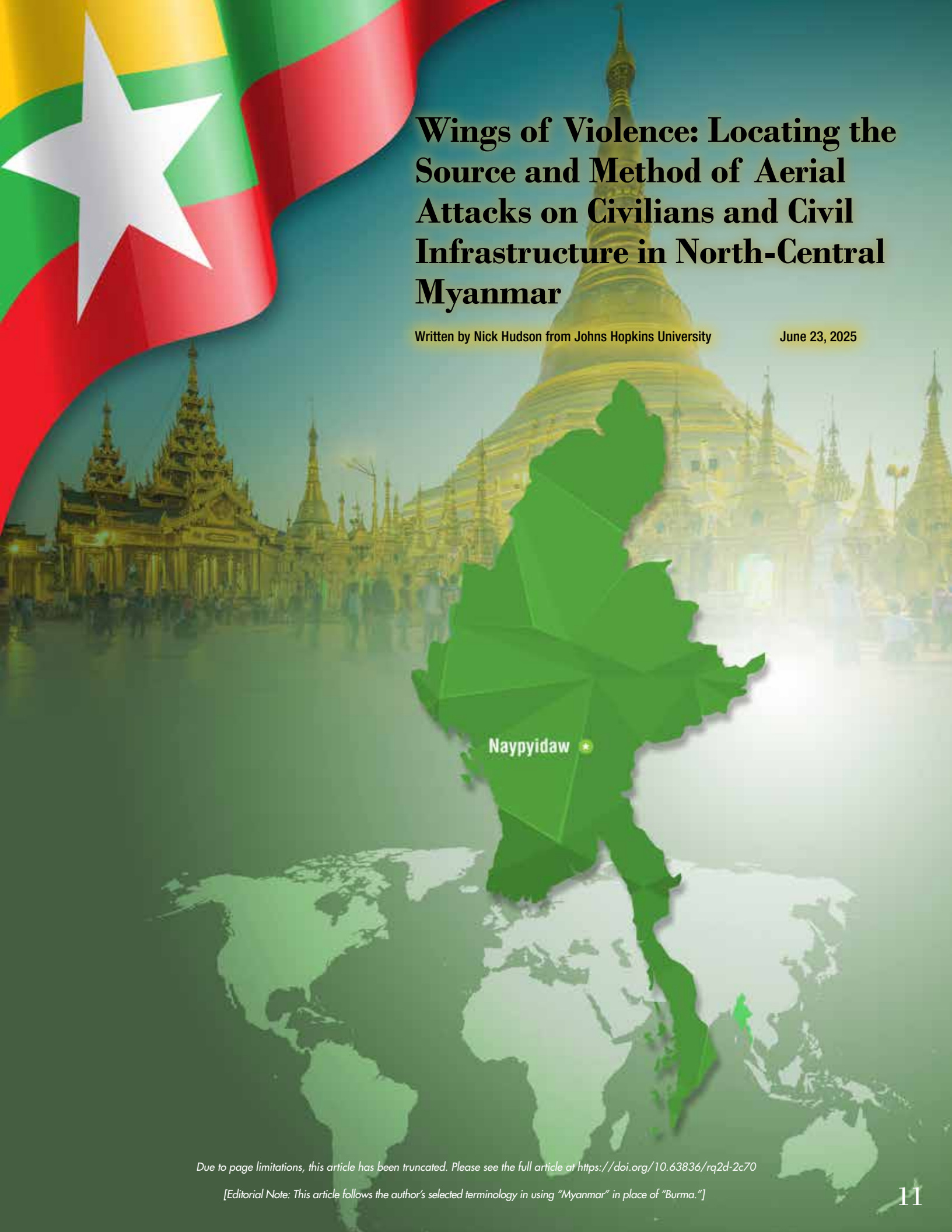
Ships detected per image in the Taedong River proximal to the POL storage area and terminal at Nampo Port, 2015-2025

In combination with qualitative analysis of infrastructure upgrades and expansions at the site, especially in the POL area, this data serves as valuable quantitative evidence of increasing exchange of POL, bulk, and containerized goods at Nampo Port. ■

Wings of Violence: Locating the Source and Method of Aerial Attacks on Civilians and Civil Infrastructure in North-Central Myanmar

Written by Nick Hudson from Johns Hopkins University

June 23, 2025



Due to page limitations, this article has been truncated. Please see the full article at https://doi.org/10.63836/rq2d-2c70

[Editorial Note: This article follows the author's selected terminology in using "Myanmar" in place of "Burma."]

SUMMARY

Myanmar has been embroiled in violence since the military staged a coup d'etat overthrowing the government in 2021. The country's air force has waged deliberate campaigns targeting rebel groups and civilians alike throughout the country, striking hospitals, schools, and religious buildings. In the years preceding civil war, the Myanmar Air Force (MAF) improved its aerial strike capabilities by upgrading infrastructure and procuring additional offensive aircraft, according to regional media.

Over the course of the civil war, and in violation of the Geneva Convention's Additional Protocols of 1977 prohibiting the attack of noncombatant populations, the MAF has used a wide variety of Russian and Chinese-made aircraft to intentionally strike civilians, according to human rights organization reporting. This analysis of air base infrastructure and aircraft upgrades can provide evidence for accountability in potential post-conflict human rights cases.

ACTIVITY

This geospatial report investigates the aircraft delivered, airbase facilities upgraded, and civilian infrastructure attacked by the MAF between February 2021 and March 2025, the first four years of the Myanmar civil war. Using strike-vector analysis from airbases to village strike locations in the Mandalay, Sagaing, and Magway (MSM) regions, the report finds MAF airstrikes targeting civilians occurred from all the airbases studied in north-central Myanmar during this time frame. While there exists no significant difference between the mean distance traveled by aircraft when targeting civilians versus rebels, each aircraft type possesses a different average attack radius. In order from largest to smallest in range, drones flew 212km, jet aircraft 148km (including Yak-130, A-5, MiG-29 and K-8), and the Mi-35P helicopter 94km on average from airbase to target in the MSM regions. The most frequently identified type of aircraft targeting civilians was the Mi-35P attack and transport helicopter with 33 airstrikes; the broad categories of jet and drone were responsible for 98 and 69 civilian targeting airstrikes. MAF aerial attacks predominantly occurred during the driest months of the year, between November and February/March, when there is the least cloud cover. According to the strike vector analysis, the primary airbase for jet airstrikes is Tada-U Airbase, Shante for drone operations, and Monywa for helicopters and staging before strikes in Sagaing.

BACKGROUND

On the morning of February 1, 2021, one day before Myanmar's Parliament was set to endorse an overwhelming majority national vote for Aung San Suu Kyi and the National League of Democracy, the military junta, led by Min Aung Hlaing, arrested the winning candidates and claimed control in a coup. Initial resistance began as peaceful protests that met harsh, deadly retaliation by government forces, leading the country on a path to civil war. The repression and violence compelled diaspora members to form a National Unity Government in exile while those who remained in Myanmar rallied together to form the Peoples Defense Force (PDF) in the north-central part of the country.

As of February 2025, the military crackdown on the rebelling civilian population has resulted in an estimated 13,500 'civilian targeting' deaths, over 20,000 arbitrary detentions, and more than 3.5 million internally displaced people (IDP) The *Tatmadaw* (local name for Myanmar's armed forces) has tried various different methods to 'fight fire with fire' by torching villages in north central Myanmar and a significantly ramped-up airstrike campaign against rebels and civilians over the past year and a half to "pacify through fear." See *Figure 1* for a visualized representation of increased air and drone strike activity since October 2023. One third of all MAF air and drone strikes hit Mandalay, Sagaing, or Magway, three administrative divisions which encompass *Anyar*.

Anyar, also referred to as the Dry Zone, is the main homeland for the Burmese ethnic majority Barnar people, and has a semi-arid climate in the rain shadow of the Arakan Mountains which catch the brunt of monsoons before they reach the valley. Two rivers, the Chindwin and Irrawaddy, act as main arteries for the transportation of goods in an area where road travel is unreliable. The Dry Zone is considered the area with the most intense ground fighting since February 2021 and accordingly 385 airstrikes were categorized as 'civilian targeting' in the Myanmar, Sagaing, and Magway (MSM) regions. Before the 2021 coup, the MSM region was comprised of Barnar Buddhists, Christian Chins, and other historically disregarded minorities. The younger generation took up arms against the government, joining the PDF and local militias, gaining significant territory in the Dry Zone, where the regime's foothold was weakest. Since the coup, 33.36% of MAF air and drone strikes have targeted civilians in the MSM regions. No drone strikes by rebel groups have targeted civilian populations.

The MAF aerial capabilities were made possible by a modernization campaign that started in 2014-2015, when the MAF's budget and procurement of aircraft significantly ballooned. Massive overhauls to airbase infrastructure, taxiways, aircraft aprons and the construction of new hangers and aircraft coverings had all been completed to accommodate the arrival of new, modern aircraft. The modernized air force has not been used for the defense of Myanmar's territorial integrity but instead in an offensive role against the domestic population and rebel groups. In a UN report from Spring 2023, the Myanmar military imported at least $1 billion USO in arms, equipment, and raw materials to manufacture weapons, mostly from Russia, China and Singapore, between the 2021 coup and May 2023.

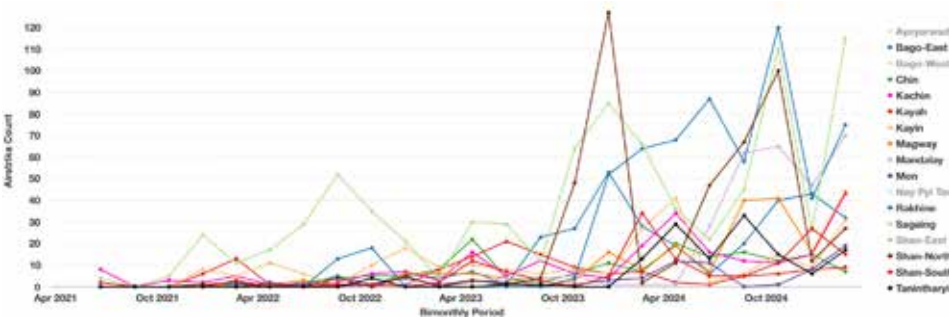
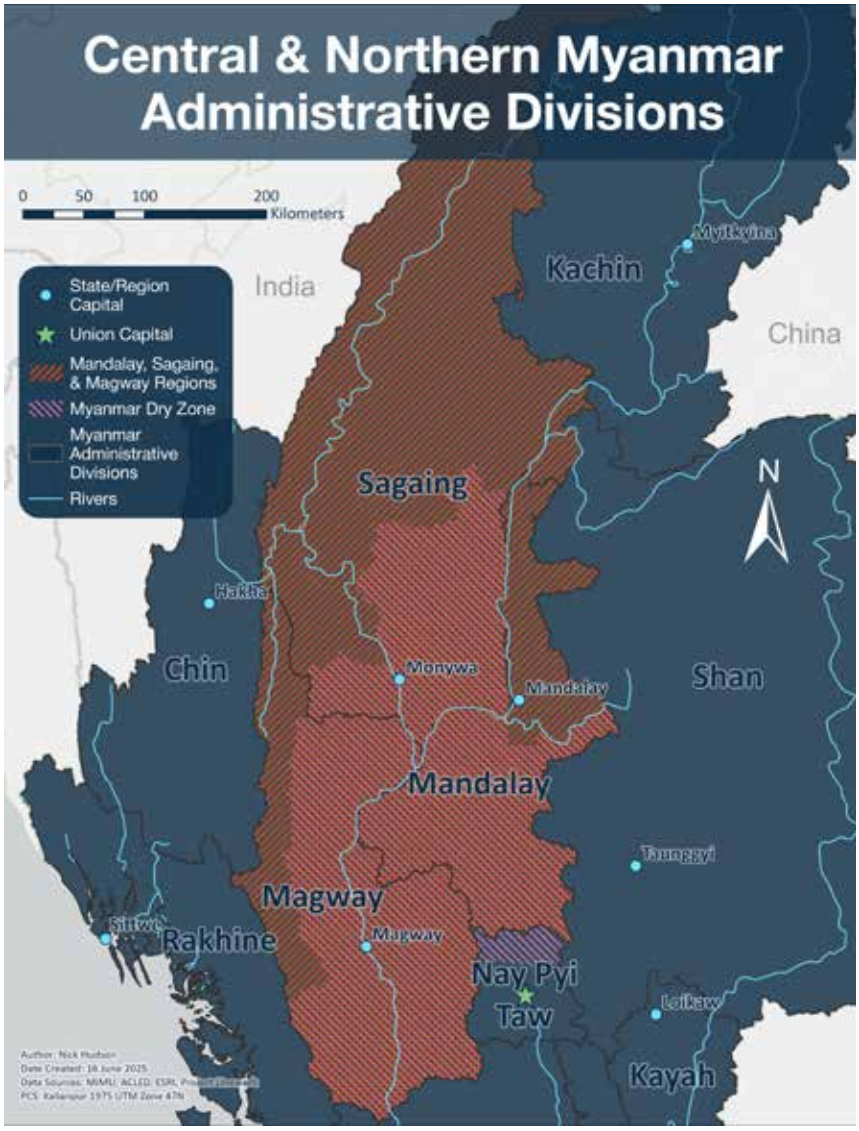


Figure I: Bimonthly MAF Airstrike Count by Administrative Division from May 2021 to March 2025

The use of this newly acquired weaponry by the military junta impacted both rebel groups and the civilian population. More than 17 different armed organizations are currently fighting against the Tatmadaw, another name for the military junta. The main factions involved in fighting the military junta are as follows: The PDF, with an estimated 100,000 fighters, maintains lofty aims of overcoming the well-equipped *Tatmadaw* using guerrilla warfare tactics to reinstate democratic governance at the national level. Competing regional ethno-nationalist rebel groups and alliances are simultaneously fighting to stake claims to different portions of territory currently controlled by the junta.

Another important player in the conflict is The Brotherhood Alliance. This faction was formed in June 2019, between the Arakan Army (in control of Rohingya area of Myanmar in Rakhine State), the Myanmar National Democratic Alliance Army (MNDAA), and the Ta'ang National Liberation Army. While the Brotherhood Alliance is currently allied with the PDF against the Junta, it has much more prominent nationalistic goals in the conflict. The Alliance only started to fight against the Junta in 2023 with a massive offensive called Operation 1027 in northern Shan State, conquering the city of Lashio in northern Shan State in August 2024.

This geospatial report analyzes the ACLED (Armed Conflict Location & Event Data) dataset documenting air base infrastructure, aircraft involved in MAF airstrikes, a subset of ACLED strikes that hit civilian infrastructure, and vector analysis from airbases to strike points in the MSM regions in north-central Myanmar.



DATA AND METHODOLOGY

Leveraging the ACLED dataset, which is trusted by a wide range of organizations reporting on Myanmar including the International Institute for Strategic Studies and the Centre for Information Resistance, all events between February 1, 2021 and March 21, 2025 were converted into point data using ArcGIS Pro. The ACLED dataset was used as the basis for the base air and drone strike calendar year and region analysis and in-part to determine common types of aircraft striking civilians and civil infrastructure in the MSM regions as mentioned in local news articles.

Each airstrike event is accompanied with an identifying event code, latitude and longitude, interaction type, geoprecision score, source name, fatality total, civilian targeting designation, and a summary of the event in the notes section. The determination whether an event is considered 'civilian targeting' is when "civilians were the main or only target of an event" and "events in which civilians were incidentally harmed are not included in this category." Data points with a geoprecision score higher than 2 were eliminated to ensure spatial analysis results would be meaningful (no more than 10 data points). An initial search for rebel vs civilian event interactions yielded no results but under half of the documented air or drone strikes in Myanmar are launched by rebels against Tatmadaw forces. The dataset was again subdivided to include only air or drone strikes occurring in Myanmar's MSM regions to focus on the area with the highest concentration of activity.

For temporal analysis, a Jenks natural breaks method was used to divide the frequency of air and drone strikes over a calendar year into five classes. The Jenks natural breaks method of data clustering minimizes the variation between ranges of values while leaving no gaps between classes.

Discovering what aircraft to look for at airbases was based on the ACLED database, Janes, Embraer's World Air Force Directory, and Myanmar Witness' geospatial reporting to identify those that carried out airstrikes in the MSM regions. Homalin Air Base, located in the northern part of Sagaing region, is assessed as having an operational 3780m runway, but is designated for civilian use and therefore will not be examined.

When documenting phenomena in the ACLED database, four decimal places are used in the latitude and longitude fields to identify approximate geolocation, meaning it would theoretically be possible to identify where airstrikes took place on a street within 12 meters of the actual location. However, the approximation used is at the level of the city, town, or village center instead of a specific building. Hypothetically it would be possible to use the ACLED coordinates to confirm airstrikes had indeed hit a particular building type, yet this requires both before and after imagery of airstrike locations, which is relatively difficult to find given that 58.2% of all airstrikes occurred between March 2024 and March 2025 and image catalogues are inconsistent. Therefore, a random subset of 50 from 187 airstrikes that hit schools, hospitals, clinics, or religious buildings occurring between May 31, 2021 and March 18, 2025 were selected from the MSM regions for verification. Nine of the fifty strikes in the sample have a geoprecision rating of 2, meaning the phenomena occurred generally within a designated township, since 18.64% of the strikes in this region had this level of observation precision. The geocoordinates for these events were then verified using panchromatic and multi-spectral imagery from either the Maxar GEGD imagery portal or Google Earth. An Excel spreadsheet including the ACLED Event ID, coordinates for the village center & more precise building coordinates, the most recent imagery, and sources for before and after each strike, observations, and original event notes is provided.

The requirements for choosing imagery are as follows: 1) the imagery must not cut off any part of the village being viewed and the target area should be largely cloud-free 2) imagery resolution size must be 50cm or better in either panchromatic or multispectral imagery 3) the "prior" image must be taken within a year before the airstrike date and 4) the "post" image must be taken within six months following the airstrike date. An assumption being made is that generally when the bombs fall in Myanmar, civilians are typically unable to make quick repairs to structures after an airstrike. The expectation is that post-airstrike imagery analysis should yield relatively good results in exposing war crimes against civilian infrastructure such as schools, hospitals/clinics, and religious buildings, yet this hypothesis proved difficult to confirm using only satellite imagery. 46% of the locations had no post-airstrike imagery in the selected libraries while four of nine 2nd level geoprecision-coded aerial strikes were unable to be found at all. Additionally, the transliteration of Burmese into Latin script is highly inconsistent.

AIR AND DRONE STRIKE ANALYSIS

The Tatmadaw's campaign against civilians has become increasingly violent, with the number of airstrikes delivered between 2024 and 2025 doubling from the previous year. From March 21, 2024 to March 20, 2025 the MAF launched 2,267 aerial strikes or 58.2% of all airstrikes in Myanmar and documented in ACLED, compared to 1,127 airstrikes from March 2023 to March 2024 (A 101% increase year-over-year). Accordingly, the average number of daily airstrikes increased from 5.1 to 10.82. Despite the marked increase in intensity, the distribution of aerial attacks is highly uneven throughout the course of a year. Employing a calendar heat chart revealed a seasonal pattern to air and drone strike activity during the Myanmar Civil War through mid-March 2025. 52.2% of aerial strikes by the MAF occurred during the country's dry winter season, which runs from November to February. March marks the beginning of the two-month hot season, when there typically was a drawdown in the frequency of airstrikes. For the majority of April through August there were relatively few airstrikes. For the first three years of the conflict, the MAF has maintained this seasonal pattern.

Analysis of ACLED event descriptions from March 2021 to March 2025 found 1154 airstrikes were executed in the MSM regions, with the broadest categories of jet, drone, and "aircraft" responsible for 242, 116, and 592 strikes, respectively. The three most frequently identified rotorcraft attacking ground targets were all Russian-made, with 159 airstrikes attributed to Mi-35s, 24 to Mi-17s, and 12 to Mi-2s. Understandably, identifying the type of jet fighter during an airstrike on civilian targets is difficult given the speed and concern for observer safety, therefore accurate aircraft type identification for fixed-wing aircraft is relatively rare. Only four types of fixed-wing aircraft are mentioned specifically in the ACLED dataset as being involved in strikes against targets in the MSM region; these include the Yak-130, MiG-29, K-8, and A-5. In 2015, the government initiated an air force modernization program to bring the MAF into the 21stCentury with modern aircraft and new facilities. Due to age and limited payloads, the Chengdu F-7 and Chengdu A-SC were largely phased out in favor of more modern alternatives such as the K-8 in 2015-2016, JF-17 in late 2017, and FTC-2000G being commissioned as of late 2024, which all fit a similar profile as the aircraft they replace.
See Table 1 for information on aircraft identification characteristics.

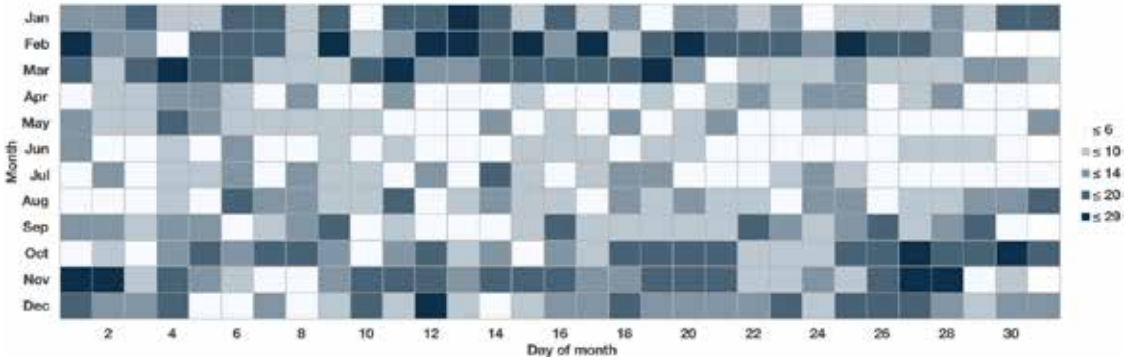


Figure 2 Frequency of MAF Air and Drone Strikes by Day and Month from March 2021 to March 2025

The most notable acquisition, however, is the Yak-130 which possesses 9 hardpoints, a larger operational range at a relatively low cost, and a 3000kg maximum payload (18 in MAF). Most importantly, the Yak-130 possesses optical weapon aiming systems and liquid crystal displays for navigation, enabling operations in low-light conditions. However, the addition of the Yak-130 is not the only improvement the MAF has made to enhance nighttime operations. Myanmar's Mi-35s, the MAF's most frequently spotted/ identified aircraft in operation, received FUR (forward-looking infrared) gimbal camera system upgrades by Russian engineers in mid-2017, enhancing the accuracy of air-to-surface missiles.

Aircraft name	Country of origin	Year introduced	Role	Presence at Air Base (ID'd in 2+ satellite images)	Quantity in service with MAF/ on order	Silhouette (not to scale) [34]
Mil Mi-2	Russia	?	Multi-purpose helicopter	Meiktila; Namsang	22 (SIPRI)	
CAC J-7/F-7 & FT-7	China	1990	Fighter aircraft	Magway; Myitkyina Nampong	18; 6 trainers (Flight Global)	
Nanchang Q-5/A-5C	China	1993	Ground attack	Magway; Myitkyina Nampong; Namsang; Tada-U	16-20 (Jane's; Flight Global)	
Mil Mi-17	Russia	1995	Transport helicopter gunship	Magway; Meiktila; Monywa; Myitkyina Nampong	13 (Flight Global)	
Mikoyan MiG-29	Russia	2002	Multi-role fighter	Magway; Shante	33 in various configurations (Flight Global)	
Mil Mi-24P/ Mi-35P	Russia	2010	Attack and transport helicopter gunship	Lashio; Magway; Monywa; Myitkyina Nampong	9 (Flight Global)	
CASC CH-3 UAV	China	2013	Surveillance and combat UAV	Shante	10-12 (Jane's)	
Yakovlev Yak-130	Russia	2017	Advanced training & light attack	Namsang; Tada-U	18 (Flight Global)	
CAC/PAC JF-17	China/ Pakistan	2019	Multi-role combat	Magway; Shante	?,[35,36] 9 ordered (Jane's; SIPRI)	
Hongdu JL-8/K-8	China	2021	Pilot-trainer	Magway; Myitkyina Nampong; Tada-U	36-37; 25 ordered (Flight Global; SIPRI)	
Guizhou FTC-2000G	China	2022	Trainer/combat	Namsang	5 (Jane's)	

Table 1: Primary MAF Aircraft & Drones used for Airstrikes in the MSM Regions

Figure 3: A Mil Mi-35P "Hind F" in operation over Naypyidaw on Myanmar Armed Forces Day in March 2015. (The Irrawaddy)

As of early 2025, the MAF is also looking to upgrade their CASC CH-3 UAVs with similar FUR capabilities to enable low light operations, as revealed by military-published UAV footage in the IR bands acquired over rebels in norther Kachin State. While night operations currently remain limited, as the Yak-130's strikes have often resulted in significant civilian as opposed to military casualties, it is likely the more widespread deployment of FUR technology will increase the future frequency of low-light airstrikes. It is unclear how the implementation of FUR technology will impact the rate of civilian fatalities by airstrike. Additionally, Russia sold Orlan-1 OE and Orion-2 surveillance drones to Myanmar in 2024 to bolster the junta's military operations. Collaboration with Russia continues to prove important for the Tatmadaw, as Putin, in a March 6, 2025 Myanmar State visit to Moscow, informed the media about the recent founding of a satellite imagery analysis center in Myanmar with Russian assistance. Russia offered to share GEOINT captured by their satellites with Myanmar for military purposes. It remains to be seen how quickly the MAF will begin using their newly upgraded surveillance capabilities.

In terms of munitions, an MAF defector from Mingaladon Air Base outside of Yangon estimates "95 to 98 percent of the bombs used are locally made. While imported bombs might exist, they would only be used for critical targets under specific conditions." A 2022 OSINT investigation with BalkanInsight revealed evidence of the MAF using imported larger "cruel weapons" such as 250kg bombs and unguided rockets from Serbia. Bombs weighing 250kg or more are capable of collapsing multiple floors and walls of concrete structures. Additionally, multiple reports have indicated the MAF has restarted their use of incendiary weapons, banned under the Chemical Weapons Convention that Myanmar ratified in 2015, during the Civil War.

ADDITIONAL INFORMATION ON THE MI-24P/MI-35P

The base Mi-35 has a 450km operational range without auxiliary fuel and rockets. The Mi-35P is a more heavily armed variant of the Mi-24V. The request was to replace the front-mounted machine gun with a bigger gun. The Mi-24V/Mi-35 Hind-E has a distinctly rounded front end, a large dielectric dome, unlike its predecessors. The Mi-35/P both possess intake filters that allow operation in extremely dusty environments, as was needed for fighting in Afghanistan.

The cannon was mounted on the starboard side of the forward fuselage because the recoil when fired from other fixed-wing strike aircraft was too violent for rotorcraft chin mounting. This meant that the pilot would have to rotate the helicopter to aim at the target, which became a liability for the Russian air force in Afghanistan. In the next evolution of the Mi-24, they opted for a rotatable cannon installation in the GSh-23L, but this mechanism was prone to jamming.

Rotorcraft Identification:

All helicopters identified in this report were identified by measuring the diameter of the rotor propeller. For example, the helicopter at the rounded landing pads in the Monywa report is determined to be an Mi-17 because of the wide, rounded shadow profile while the diameter of the main rotor was measured as roughly 21.25m. The Mi-35 has a slightly smaller rotor diameter of 17.3m and the small winglets for rocket pods are occasionally visible on both sides of the body of the helicopter.

Fixed-wing aircraft identification:

The A-5C was identified as it is the only aircraft Myanmar possesses with swept-back wings, flattened wingtips, a long pointed nose, and an elliptical tail configuration. The light blue camouflaged color scheme, two engines directly underneath the fuselage with their exhaust protruding at the back, a twin tail configuration suggest the middle aircraft is a MiG-29. The F-7M is distinguished by a flat nose, isosceles triangular wing shape, elliptical tail shape, and brown color scheme. The JF-17 multi-role combat aircraft is identified with a single engine behind the pilot and under a 3m wide fuselage, conventional tail shape and trapezoidal wings with flattened wingtips.

The CASC CH-3 UCAV has a canard layout, no tail, large winglets, and a propeller located at the rear. The export variant of the JL-10, known as the FTC-2000G, is still heavily influenced by the MiG-21/J-7 design but can be identified with two seats, two lateral engine intakes adjacent to the nose, leading-edge root extensions. Finally, the K-8 has rounded low wings that begin in line with the back of the cockpit, a 9.6m wingspan, and most of the aircraft's length being in front of the wings (including the protruding air pressure sensor).

Air Base Analysis

The eight MAF air bases used when striking the MSM region are Lashio, Magway, Myitkyina-Nampong, Namsang, Mandalay/Tada-U, Shante, and helicopter bases at Monywa and Meiktila. Many of these airbases received substantial infrastructure upgrades such as larger hangars, extended or improved runways/taxiways, and new aircraft to realize the goals of Myanmar's 2015 air force modernization program. Date ranges provided for imagery only reflect the images used in the airbase graphics and aircraft identification snapshots; larger imagery libraries outside of these date ranges were reviewed to determine aircraft presence at each base.

Lashio Air Base (22.979051°, 97.752486°)

Lashio Air Base is in North Shan State, surrounded by the Tatmadaw's Northeast Military Command. The air base possesses a dual-purpose runway and is the smallest air base mentioned in this report with only one aircraft hangar, used primarily by rotorcraft. Analysis of Maxar multispectral imagery from 28 November 2023 and 30 January 2024 obtained through the GEGD platform in recent years exposed the frequent presence of two different types of helicopters at this air base's military aircraft apron: the Mi-35P and Mi-17. Using mensuration via ArcGIS, it was possible to differentiate the helicopter rotor diameters which measured roughly 17.3m and 21¼m respectively. Most notably, the runway at Lashio Air Base has been extended twice in the last five years. The first runway extension added 380m of tarmac in 2020 and a second runway extension added an additional 370m in early 2024. The farmland to the immediate north of the runway was also leveled in mid-2024 but construction progress has been halted since the Brotherhood Alliance captured the Northeast Military Command and city of Lashio on August 3rd, 2024.

The main terminal at the airport in Lashio was notably damaged in October 2024 imagery of the site. A ceasefire agreement was negotiated between the junta and MNDAA in January 2025 with substantial Chinese involvement to reopen cross-border trade along Myanmar's National Highway 3 from Mandalay to China. In late April 2025, Tatmadaw troops reentered the city of Lashio in accordance with the ceasefire while the MNDAA forces remain in control of the rural areas surrounding the city. It is unclear if Lashio Air Base resumed operations since the Junta regained Lashio.

Meiktila Helicopter Base (20.888974°, 95.890169°)

Meiktila Helicopter Base is in the city of Meiktila in Mandalay Region. The base is surrounded by Myanmar's Central Military Command and is located four kilometers southwest of the MAF's main and largest air base, Shante. Despite its proximity to other more modern bases with paved runways, analysis of recent panchromatic Maxar imagery made available in the GEGD imagery portal supports the conclusion that this airbase is still active as of 14 December 2024. As the only runway at Meiktila has a dirt surface and no planes have been spotted in satellite imagery at Meiktila, it is unlikely the base is used by the MAF's fixed-wing strike aircraft. The helicopters found operating from Meiktila included the Mi-17 and Mi-35P, with operation of Mi-2s designated as probable. Due to cloud cover on the imagery on the date the Mi-2 was observed at Meiktila, it was not possible to confirm identification using only the main rotor's diameter. See the above section on Rotorcraft Identification for how the Mi-35P and Mi-17 were differentiated. Meiktila Helicopter Base provides three roughly 2900 m2 hangars for

covered rotorcraft storage, connected to an 1800m dirt runway. The dirt runway was re-leveled and additional aircraft aprons were added between 2014 and 2015.

Shante Air Base (20.939435°, 95.913419°)

Four kilometers northeast of Meiktila and next to Tatmadaw Central Command is Shante Air Base, Myanmar's largest air base. Analysis of Maxar imagery from Google Earth yielded significant results in identifying key aircraft used in domestic airstrikes. In April 2025 imagery, it was possible to confirm the presence of the K-8, A-SC, and Mi-17 helicopters at the airbase. Additional aircraft spotted with a level of uncertainty include the probable JF-17 and three possible Mi-2 helicopters, while a probable FTC-2000G was identified in January 2022. The A-SC was a well-equipped CAS and ground attack aircraft on arrival, needing no modifications, but is quickly being replaced by more modern aircraft. The MAF continues to receive spare parts for the MiG-29 and other aircraft from Russian suppliers. Three events designated as targeting civilians in the ACLED database specifically attribute airstrikes to fixed-wing aircraft originating from Meiktila Air Base, with one of these airstrikes attributed to a MiG-29.

Minor upgrades were made to Shante Air Base's facilities between 2019 and 2025, including the addition of a probable aircraft support facility and a large aircraft hangar. Helipads were painted onto the aircraft aprons in areas on the southern end of the airbase in 2022. Shante's 361Om runway was repaved along with part of the taxiway and aircraft apron in the southeastern corner in 2019.

The modern aircraft observed since the February 2021 coup include the JF-17, K-8, and CASC CH-3 UCAV. While the JF-17 has experienced significant operational issues, including structural cracks and technical problems, since its delivery in 2018, several other air assets give the MAF many other ground-attack options. The K-8 possesses a 23mm cannon and four hardpoints capable of carrying 943kg in guided or unguided payload, fulfilling the close-air-support role. In the first year and a half, the K-8 was one of the most observed aircraft behind the Mi-35, but as the civil war has progressed, the Yak-130 has supplanted its participation in a ground attack capacity The China Aerospace Science and Technology Corporation (CASC) CH-3, spotted on the northern aircraft apron in November 2022, is a UCAV which possesses the capability to carry and fire/drop both AR-1 air-to-ground missile and FT-9 guided bomb. There are also rumors that CASC has sold the CH-4, a externally looking copy of the MQ-9 Reaper, to Myanmar.

Magway Air Base (20.154580°, 94.965747°)

Magway Air Base is in Magway Township of the Magway Region in Central Myanmar and possesses a dual-purpose runway. Analysis of recent Maxar imagery from the GEGD platform revealed the presence of offensive aircraft including the MiG-29, K-8, A-SC, and the JF-17 before structural flaws and technical malfunctions resulted in their grounding. The identification of F-7BK aircraft is designated as probable given challenging shadow angles in many of the images viewed, although the mensuration yields wingspans and aircraft lengths that roughly match specifications. The F-7 is a Chinese modified version of the MiG-21 and generally considered ill¬ equipped for striking ground targets. According to analysis compiled by Israeli Australian military reporter Sol Salbe, the F-7s proved to be difficult for the MAF to maintain due to their high maintenance requirements and inadequate flt for the ground attack role and thus, the Tatmadaw turned to Israel for assistance. Accordingly, in the following years, Israel provided laser-guided bombs while Israeli defense manufacturing company Elbit won the contract to modify the F-7 fighters.17°1Within the ACLED dataset, there were two airstrikes, on February 23, 2025 and January 7, 2024, which are designated as "civilian targeting" and attributed to fixed-wing aircraft based at Magway.

Magway is another air base with improved infrastructure as part of the 2015 Myanmar Air Force modernization plan. New taxiways were built to connect the aircraft aprons and hangars at both ends of the runway in 2015 along with an additional six aircraft coverings beyond the northwestern end of the runway. These new aircraft coverings are believed to be used by the K-8 light attack aircraft which were delivered in the same year. In 2017, a large aircraft apron, support building, and the largest aircraft hangar at the base were constructed, possibly to accommodate logistics aircraft.

Monywa Helicopter Base (22.221500°, 95.093449°)

Located 12.5km north of Monywa city in Sagaing Region, Monywa Helicopter Base is surrounded by the Northwestern Military District Headquarters. Analysis of Airbus imagery from Google Earth showed the presence of two types of offensive helicopters at Monywa: the Mi-17 and Mi-35P. Uniquely, this base has no aircraft hangars to house the helicopters when they are not in use, therefore it is likely they come to the facility for rearming/ refueling before sorties. While Mi-35s have been spotted once at Monywa Airport, no additional evidence suggests that the terminal serves a fully military purpose as there are regularly scheduled flights from this airport to other cities in Myanmar every other day. Due to its proximity to the majority of Sagaing helicopter airstrike locations, MAF units based at Monywa are more likely than not responsible for the high level of civilian targeting.

In terms of infrastructure, Monywa has ample space for helicopter operations with three original landing pads (repaved in 2020) and added a 230m helicopter landing pad/ apron in 2022-2023. An additional clearing where helicopters had previously been imaged landing, south of the main three paved pads, was paved in a triangle pattern in 2024, possibly to accommodate another pair of rotorcrafts.

Myitkyina Nampong Air Base (25.353513°, 97.295557°)

Along the Irrawady River, Myitkyina Nampong Air Base is in Myitkyina Township of Kachin State, five kilometers southwest of the Northern Military Headquarters and roughly 50km west of the Myanmar-China border. Analysis of multispectral Maxar imagery between January 17, 2021 and January 5, 2024 from the GEGD imagery portal revealed the presence of several types of fixed-wing and rotorcraft believed to be stationed at Nampong Air Base, including the F-7BK/F-711K, K-8, Mi-35P, and Mi-17. One observation of note is the presence of a wide variety of seemingly cannibalized aircraft around the K-8 aircraft coverings at Nampong, including former F-7s, A-5Cs, while three four-rotor helicopters have been stationary south of the three main aircraft hangars for the last two years. While the K-8 was last seen at Nampong in February 2021, infrequent observations may be due to inconsistent imagery collection in recent years as Google Earth imagery consistently captured the aircraft between 2017 and 2022. As recently as January 2022, F-7s and an Mi-17 were lined up on main aircraft apron, presumably before a sortie. Mi-17s have also been observed at the airbase since 2021. The most frequently spotted aircraft at Nampong is the Mi-35P.

Nampong Air Base's infrastructure was upgraded in 2015 to include taxiways extending to both ends of the runway and additional aircraft coverings to accommodate the delivery of new K-8 trainer/light attack aircraft. A tower-defended compound was also added adjacent to the northern taxiway junction the same year.

Namsang Air Base (20.892187°, 97.733167°)

Namsang Air Base, with a dual-purpose 3660m runway, is in Namsang Township, South Shan State. Analysis of Airbus imagery from Google Earth and Maxar imagery shot between January 13, 2020 and March 22, 2024 from the GEGD platform exposed the presence of the FTC-2000G, A-5C, and Mi-2 helicopters at Namsang. The FTC-2000G was spotted on satellite imagery at the airbase for the first time in February 2024, shortly before the new aircraft were set to be commissioned at Namsang later that Fa11. The first round of delivery for the FTC-2000G was made in November 2022. The FTC-2000G augments the junta's striking abilities against ground targets with a 23mm cannon, four wing hardpoints, and a center hardpoint for bombs or extra fue1. A-5Cs have also been observed taxiing near the hangars southeast of the runway. Mi-2s have been spotted several times on the aircraft apron northwest of the runway. Minor upgrades to the airbase were made, with aircraft apron expansion occurring in 2017 near the largest aircraft hangar south of the runway. North of the

runway, near the rotorcraft and fixed-wing hangars, the taxiway was expanded to the passenger terminal apron.

Tada-U Air Base (21.705325°, 95.971248°)

Tada-U Air Base, sharing a runway with Mandalay International Airport, is in central Myanmar. Analysis of multispectral Maxar imagery shot between April 30, 2024 and February 26, 2025 from the GEGD platform revealed the base's location at the southeastern corner of the 4265m runway and the existence of offensive aircraft including the K-8, Yak-130, A-SC, and Mi- 35P attack helicopter. The most consistently observed aircraft at the airbase is the A-SC, spotted in imagery at Tada-U almost every year since 2014. A batch of Yak-130s was delivered to the airbase shortly after six aircraft coverings were completed early 2016. The Yak-130 is capable of being identified with cuts on the horizontal stabilizer, almost delta¬ shaped wings with extended wing roots, and large air intakes alongside the body of the aircraft. Yak-130s have been consistently observed in satellite imagery of the airbase since 2018. The K-8 with its rounded wings was first spotted at Tada-U in April 2024.

Between April 2015 and March 2016 six new aircraft coverings were constructed along with several support buildings in the following years. The airbase is one of the Tatmadaw's most active given it is one of the most equipped bases closest to rebel-controlled area. All Tada-U's aircraft hangars were constructed when the airbase was first commercially imaged for Google Earth in 2011.

INVESTIGATING THE DESTRUCTION OF CIVILIAN INFRASTRUCTURE

A total of 22 villages targeted by MAF airstrikes conducted between May 2021 and March 2025 were imaged before and after the strikes, even though 12 of these incidents had imagery that was beyond one year prior to the incident. Of these 22 instances where before and after satellite imagery existed at a resolution sufficient for damage assessment, only 9 were capable of being positively identified as damaged or destroyed based solely on satellite imagery (40.9%). The remaining 59% of buildings were unable to be confirmed as destroyed or damaged either because the building mentioned could not be found using open-source mapping services, other buildings around the location had previously been destroyed/ burned, the post-strike imagery was beyond a year after the occurrence, or a combination of the aforementioned factors.

However, through this analysis, it was possible to geolocate airstrike phenomena on 60% of the village locations down to a particular building. Often it was possible to identify the purpose of buildings in a particular village using informational layers included in Google Maps and OSM.

During the analysis of satellite imagery from 50 random airstrike locations, a 7.7 magnitude earthquake hit on March 28th, 2025, 10km north of the city of Sagaing and 17km west of Mandalay (1.5 million population). Despite the earthquake and calls from numerous rebel factions in the conflict, the MAF has continued its aerial campaign against civilian and rebel ground targets alike, impeding efforts to rescue survivors across Myanmar.1771As of April 7th, 2025, the death toll from the earthquake is 3,600 and still climbing.1781Any additional satellite imagery analysis of airstrikes in Myanmar would need to attempt to differentiate damage caused by the earthquake and aftershocks from bombs or rockets.

Airstrike Vector Analysis

All 1354 airstrikes in the MSM regions between March 21, 2021 and March 21, 2025 were evaluated. Although in most of the ACLED events the perpetrating aircraft is not identified, the raw data in this region provides unique insights into how the MAF wages its air campaign in the heartland of the Barnar people. ACLED's event descriptions are condensed parts of longer articles detailing battles and atrocities in the Civil War from local news outlets.

When the aircraft type was established in the database's entry, 44% of airstrikes were attributed to "jet" aircraft/ fighters. Aircraft that would fall into this broad category include all fixed wing aircraft in service by the MAF, including the F-7, A-5, MiG-29, K-8, Yak-130, JF-17 and FTC-2000. In a few cases these aircraft are specifically identified in the articles. 27% of airstrikes were carried out by an upgraded version of the Mi-35P Hind-F attack helicopter. Drones were the third most used type of aircraft in the first four years of the conflict. Before January 2025, the MAF was only known to use two types of drones for airstrikes, one of which is the CH-3 stationed at Shante Air Base and the other the CH-4, a Chinese Reaper UCAV replica. Since January, the MAF has adopted a tactic from the rebel groups which use smaller drones to drop mortars on targets. 2024, Russia sold upgraded Orlan-10E and Orion-2 surveillance drones to the Tatmadaw, but the "extent to which Russia has assisted in the ...limited development of a small first-person-view (FPV) rotary suicide drone program is unclear. Additionally, some aerial bombings have been attributed to piloted paragliders, a low-tech alternative to counter the frequently rebel-jammed low-altitude airspace. The next two aircraft that were most frequently identified in articles were both rotorcraft: the Mi-17 and Mi-2 were spotted in 24 and 12 airstrikes respectively. The rest of the aircraft were spotted striking targets in the MSM regions fewer than 5 times.

Of the 1354 MAF airstrikes that occurred between March 2021 and March 2025, 467 were designated "civilian targeting" in the MSM regions within the ACLED dataset. Again, in most of the strikes targeting civilians the type of aircraft was not stated. The percentage of airstrikes targeting civilians attributed to "jets" remained just above 45%, while the proportion of strikes attributed to drones accounted for a third and the Mi-35 16% where the aircraft perpetrating the violence was identified.

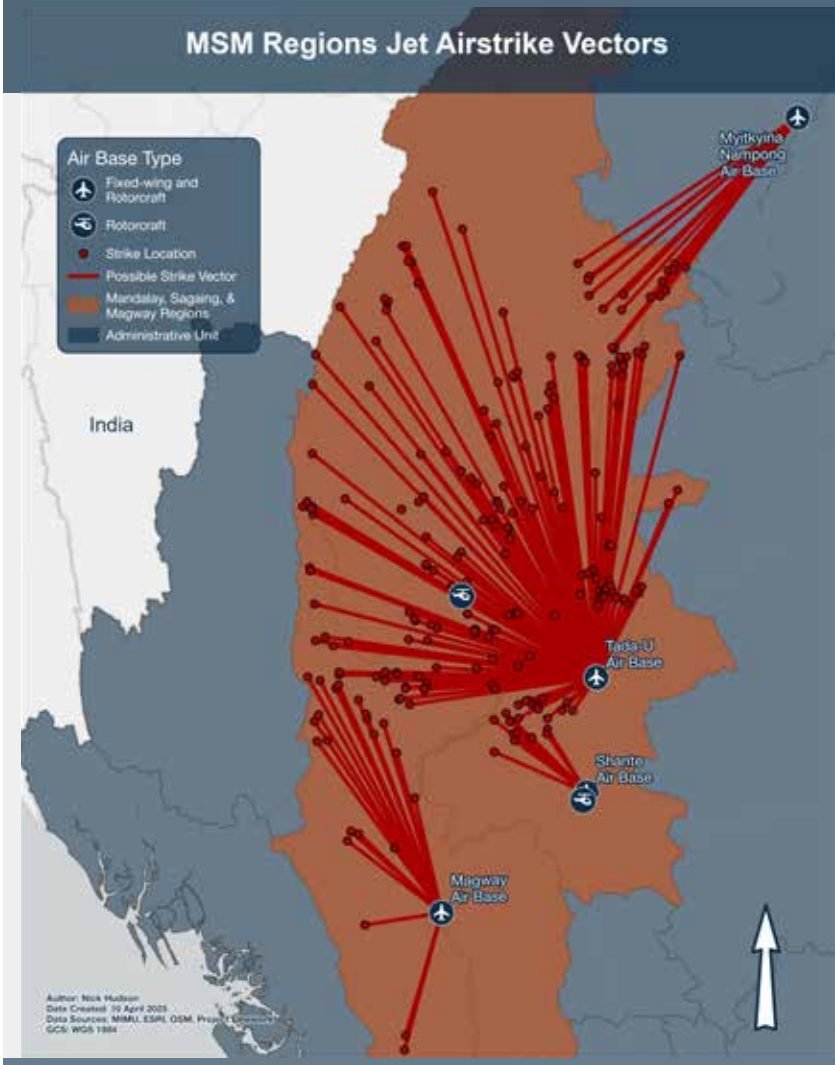
When the aircraft carrying out an airstrike was identified in the ACLED dataset as a "jet," the mean distance traveled was 148 km and median 137 km to the strike location. Unlike the piloted counterparts, Tatmadaw drones went 212 km on average with a median distance of 217 km. Unlike fixed wing aircraft, the Mi-35 attack helicopter flew an average of 94 km with a median 72 km geodesic distance from base to strike location.

This raises the question whether the Myanmar Air Force travels further on average to target civilians than rebels? An OSINT investigation, leveraging social media posts, completed by Myanmar Witness on the January 7, 2024, airstrike on civilians in Kanan village of Sagaing Region, near the India border, suggests the MAF is not dissuaded from striking from afar. The strike vector graphics included below display possible paths taken from the closest base to each respective airstrike location that was categorized as targeting civilians. The Kanan village airstrike by an A-SC from Tada-U is highlighted by an orange square. The mean and median geodesic distance traveled from air base to target by "jet" aircraft, including when fixed-wing aircraft are identified, are 138 km and 132 km traveled, with the leading airbase being Tada-U using the minimize weighted distance method to assign responsibility for airstrikes.

The average geodesic distance for drones to travel between base and strike point was considerably more at 210 km and a median of 214 km. Only Shante is known to host the CH-3 UAV/drone which operates at high altitudes in north-central Myanmar. The MAF has at least 10 CH-3s. The CH-4, an external copy of the US-made Reaper drone, is rumored to be manufactured and in operation in Myanmar but was not found in satellite imagery of airbases in nor adjacent to the MSM regions as of March 2025.

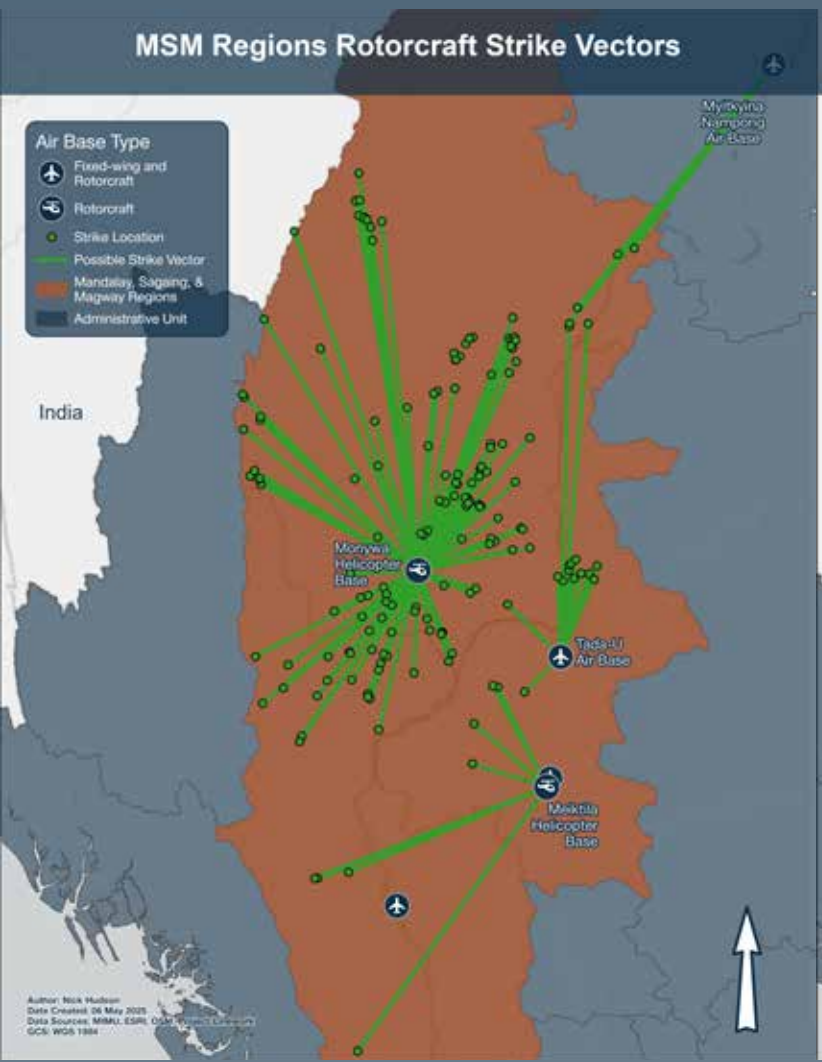
Finally, rotorcraft were found to average traveling 86 and a median of 62 geodesic km from airbase to village when targeting civilians. The MAF's most used rotorcraft, the Mi-35P, was reportedly involved in 166 airstrikes in the MSM regions and 33 of these strikes targeted civilians. One of the most high-profile cases where Mi-35s were probably used against civilian infrastructure was a multi-day air campaign against Pyin Taw U village in Kale Township, Sagaing Region between March 30 and April 6, 2023. Footage from the first day of sorties is clear enough to identify the helicopters in the sky as Mi-35s. Shiloh Baptist Church was damaged in airstrikes where remnants of Soviet-designed S-8 rockets were found in the courtyard, according to an investigation by Centre for Information Resilience's Myanmar Witness program. The S-8 rockets are employed by the Mi-35, attached to the stub-winged pylons, lending credibility to the claim that the MAF more likely than not used these rotorcraft to target the village.

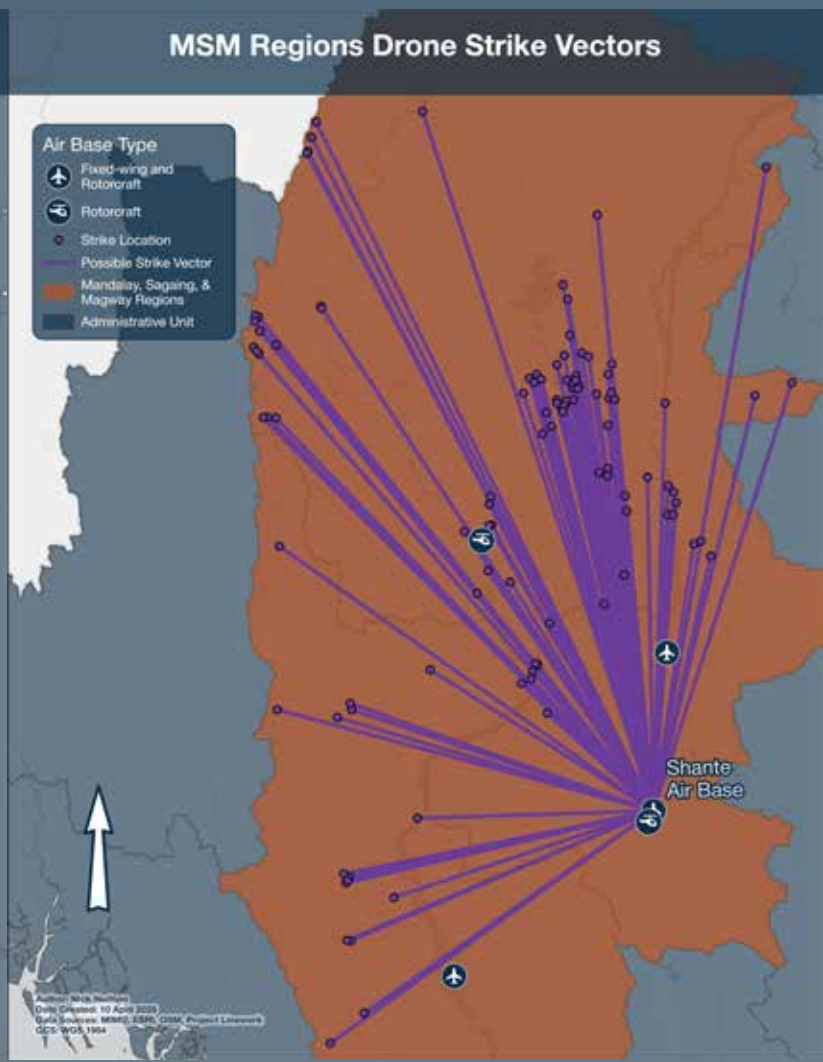
Aircraft Type	Total Strikes	Targeting Civilians	Color
Mi-17	26	1	
Mi-2	12	5	
Mi-35	166	33	
Rotorcraft Subtotal	203	39	
Yak-130	3	1	
A-5	2	2	
MiG-29	4	2	
K-8	2	0	
Jet	277	98	
Fixed-wing Subtotal	288	103	
Drone	133	69	
Subtotal Excluding Unspecified Aircraft	**625**	**211**	
Unspecified Aircraft	729	256	
Total	**1354**	**467**	



From the strike vector graphics, several determinations can be made about the airbases used predominantly by certain aircraft types. Jet aircraft attacking targets in the MSM regions predominantly originate from Tada-U Airbase, Shante is the origin for drones, and airstrikes by the Mi-35P are likely staged from Monywa. Civilian targeting by MAF aircraft occurs from all airbases studied and no one unit is responsible for all airstrikes.

The most frequently targeted building types are typically monasteries which are generally adjacent to several tall stupas enclosed in a compound with gates facing in all cardinal directions. According to the State Sangha Maha Nayaka Committee in 2016, a quarter of Myanmar's 1479 pagodas over 8.2m (27 feet) in height are in Sagaing Region, making them easy to spot for MAF aircraft. 111 of 323 (34%) airstrikes that hit religious buildings were in the Mandalay, Sagaing, or Magway regions. 72 of the 208 airstrikes that impacted schools in Myanmar were in the MSM regions. Of the 107 hospitals or clinics that were damaged or destroyed in Myanmar, 33 medical buildings are in the MSM regions.





CONCLUSION

The Tatmadaw's emphasis on stabilizing the situation in Myanmar through air supremacy and perpetrating violence against its own civilians warrants international attention. By upgrading MAF's air bases, and purchasing new attack aircraft, the Tatmadaw enabled their strategy of terror and expanded their capability to conduct operations with new taxiways, extended runways, new hangars, and aircraft coverings. Now that the MAF aircraft and the bases they use have been identified, the OSINT community and people on the ground in Myanmar can continue identifying and documenting the aircraft being used to strike civilians.

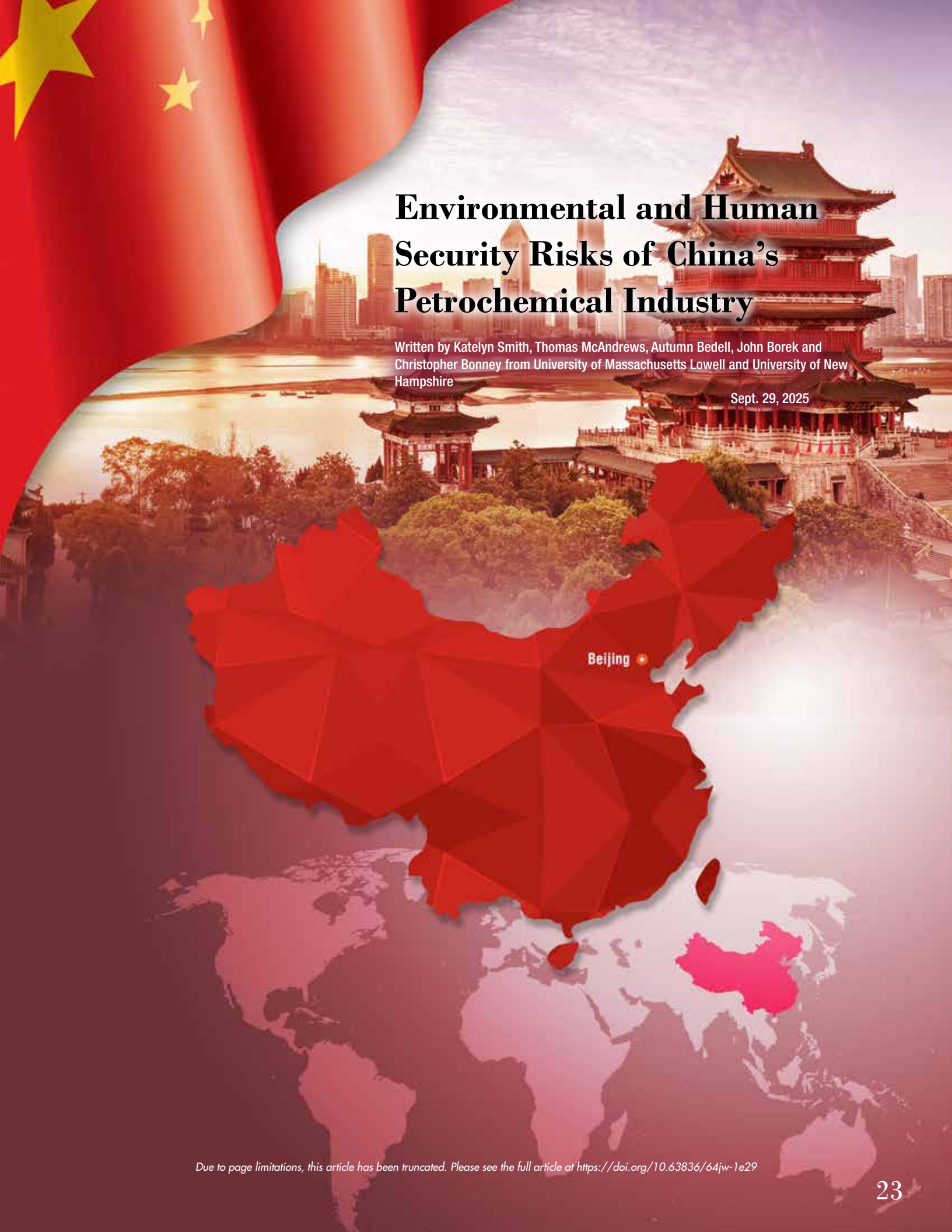
Verification of a random sample of civilian infrastructure airstrike impact locations from the ACLED database using only satellite imagery proved difficult to complete due to a lack of high-resolution post-strike imagery for most of the incidents. While 22 of the 50 randomly selected strike locations had pre- and post-strike imagery, at only 9 of the villages it was possible to confirm airstrike damage to hospitals, clinics, religious buildings, and schools. However, using the village coordinates provided, the geolocation of phenomena could be enhanced to a particular building with 60% of the sample locations. There were additional cases where off- nadir imagery might have been beneficial given the MAF typically uses relatively small-sized munitions, and not all civilian infrastructure had observable roof damage below at the 50 cm spatial resolution.

The distance traveled by MAF aircraft to strike rebel targets vs civilian targets is not substantially different. While the difference between all airstrikes and those designated civilian targeting when "jet" and drone aircraft were employed was less than 10 km, the MAF's Mi-35P traveled roughly 30 km shorter on average when targeting civilians. MAF units operating the Mi-35P from Monywa Helicopter Base, fixed-wing jet aircraft from Tada-U Air Base, and drones from Shante Air Base are responsible for targeting civilians most frequently in the MSM Regions. There is an expectation that the frequency of drone use in combat scenarios by the Tatmadaw will increase in 2025 as senior officials have hailed it the 'year of the drone.

In the future, projects focusing on Myanmar could build OSINT identification profiles for airstrikes carried out by new additions to the MAF, conduct comprehensive arson mapping investigations, and expose civilian targeting while Myanmar continues to recover from the catastrophic earthquake which struck Sagaing in March 2025.

LOOK AHEAD

The time it took to complete this report spanned roughly 6-7 months of cumulative work over a year-and-a-half period related to establishing the type of geospatial report that would be created, devising a color palette for the creation of maps, icon creation, searching libraries and downloading imagery, identifying aircraft, digitizing airbase upgrades, verifying strike locations, separating datasets by aircraft/ civilian targeting, and many other functions. If another analyst was to repeat this type of analysis in another country, it would be possible to complete a similar report in 4-5 months with an aggressive timeline. For future analysts, the percentage of time spent envisioning the report's focus was 10%, 35% spent on discovering, 25% spent comprehending, 10% tracking new <50cm spatial resolution imagery added to libraries, and 20% reporting findings. I recommend a similar blend of time spent on these tasks if the analysis were replicated in another region or country. The workflow that was implemented for this project leveraged imagery libraries from the GEGD Maxar and Google Earth platforms and utilized ArcGIS Pro for statistical analysis and map creation. While the Maxar library was made available to the researcher at no cost, another team working independently of Tearline would need to fund a large imagery bill through a site that permits the purchasing of imagery slices such as UP42. Ideally, future analysis in this conflict zone should leverage a larger library of commercially available satellite imagery, explore a host of available Telegram channels covering the conflict like "enemyairroute" and Myanmar Witness, and join local Facebook groups documenting atrocities. Since the March 28 earthquake that struck central Myanmar there have been four ceasefires negotiated, two of which were extended. However, without robust ceasefire enforcement mechanisms and the continuation of junta-enforced limitations on internet access and the transport of humanitarian aid to impacted regions, there is no clear path to a resolution. The MAF continues to wage an aerial campaign against civilians, a pattern that increased in intensity after the Brotherhood Alliance launched Operation 1027 in late October 2023, resulting in significant territorial losses for the Tatmadaw. ■



Environmental and Human Security Risks of China's Petrochemical Industry

Written by Katelyn Smith, Thomas McAndrews, Autumn Bedell, John Borek and Christopher Bonney from University of Massachusetts Lowell and University of New Hampshire

Sept. 29, 2025

Due to page limitations, this article has been truncated. Please see the full article at https://doi.org/10.63836/64jw-1e29

SUMMARY

China's rapid expansion in the petrochemical industry is likely to present significant environmental and human security challenges over the next decade. This study investigates the risks associated with China's petrochemical industry and highlights policies targeting risk management and prevention. Using synthetic aperture radar (SAR) imagery from NGA's Unclassified Data Lake, we look at a case study on the Yangpu Economic Development Zone (EDZ) in Hainan, China's largest island.

Our findings indicate despite strict and plentiful environmental and regulatory policies, enforcement remains weak and petrochemical sector pollution violations will exacerbate risk in the EDZ - an area at high risk of disaster and with the possibility for major human and environmental fallout. Lessons from the Yangpu EDZ offer broad implications for areas around the world balancing industrial growth with human and environmental security.

ACTIVITY

Using synthetic aperture radar (SAR) imagery from NGA's Unclassified Data Lake, we looked at a case study on the Yangpu Economic Development Zone (EDZ) in Hainan, China's largest island. We used SAR to differentiate between organic and inorganic structures, paying especially close attention to industrial-level buildings that could suggest factory or major shipment operations. To supplement SAR data from January 2025 and add granular detail and more recent information to our investigation, we employed data from Google Earth (updated May 2025).

We paired open-source and geospatial intelligence with the collection of policies regarding petrochemical industry compliance with safety and environmental standards. A case study of the Yangpu Economic Development Zone (EDZ) in Hainan, China, found policymakers must balance economic expansion with adherence to sustainability commitments and the preservation of human security sectors. We present policy recommendations for not only legislators and diplomats addressing environmental security issues but also practitioners within the petrochemical industry itself, and propose strengthening monitoring systems, increasing regulatory transparency, and integrating dependent oversight with multinational collaboration to ensure sustainable development while protecting human and wildlife populations.

BACKGROUND

This report employs a variety of terms spanning the breadth of the literature on security and environmental and industrial policy, and we chose to adhere to standard hazards terminology to ensure clarity and consistency. We define hazard as a potentially damaging physical event or process, whether to people, property, or the environment. Threat is the likelihood and capability of that hazard to cause harm, while exposure is the presence of people, assets, or ecosystems in places that could be adversely affected. Vulnerability is the susceptibility of those exposed elements to harm, and risk is the potential for loss resulting from the interaction of hazard, exposure, and vulnerability. We use the term human security to denote the protection of individuals' lives and livelihoods across physical, economic, environmental, and health dimensions.

While *safety* is less common in natural hazards research, here we use it to narrowly mean the condition of minimized, acceptable risk to people and critical assets. In our methodology, *threat* and *exposure* are the components most amenable to remote assessment via high-resolution SAR and Google Earth imagery, which enable systematic delineation of hazard footprints (or threats) and precise estimations of population and infrastructure within those footprints (exposure). We integrate this with ancillary data from open-source information to characterize vulnerability and quantify overall risk projected across the next decade.

The petrochemical industry is a critical component of modern economies, providing materials essential for infrastructure, manufacturing, and national defense. However, it also carries significant risks: chemical spills, fires, and explosions that can threaten not only economic stability but human and environmental health. These risks are not unique to China. The United States experiences one petrochemical incident every three days and pays more than $477M annually just to address the immediate fallout of these incidents. These patterns underscore the importance of monitoring industrial hazards and assessing vulnerabilities, which we approach using geospatial intelligence.

Petrochemical plants produce commodities around the world in the form of plastics, preservatives, cosmetics, fertilizers, rubber, and safety glass. As the largest producer in the petrochemical industry, many of China's strategic alliances have been forged by their need to gain access to necessary precursor materials like oil, ethylene, and natural gas. Figure 1, below, displays China outpacing other regions of the world in demand for oil-based petrochemical precursors.

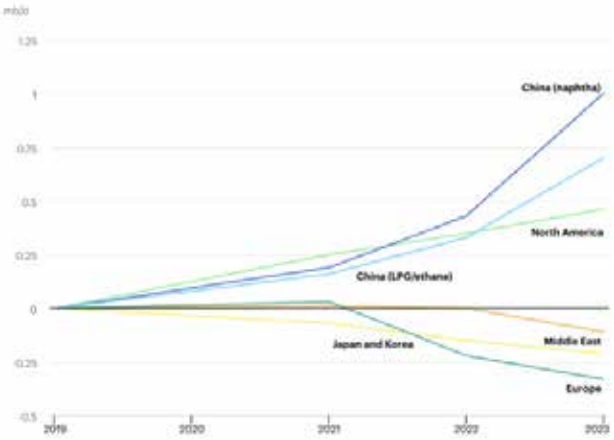


Figure 1. Regional Demand for Oil-Based Petrochemical Precursors (Healy, 2023)

China's petrochemical demand is expected to continue at this pace and more than triple by 2050. China is on track to experience a 50-60% increase in petrochemical manufacturing capacity by the end of 2025 and is likely to continue growing around 30-35% annually. Not only is China's petrochemical industry continuing to expand at a rapid rate, but their chemical yield outputs are at around 40% - a staggering number, considering similar industries around the world only produce a combined 15-20% output.

The processes associated with petrochemical manufacturing - be it the production of materials, the transportation of its output, or workplace accidents- have significant potential for disaster. China has experienced a consistent recurrence of petrochemical accidents resulting in at least 1,273 deaths and more than 3,400 injuries between 2000 and 2020.

From 2016 to 2018 alone, 620 chemical accidents occurred and at least 728 people died- many incidents involved leaks or explosions of hazardous materials into surrounding areas. China experiences one major petrochemical incident approximately every 15 days, and due to their workplace safety standards may be more likely to experience incidents that result in injury or death.

In addition to the human cost, petrochemical disasters in China can devastate local and far-reaching ecosystems and cause billions of dollars in economic losses. Stabilizing these incidents puts incredible strain on first responders and emergency personnel, with one such incident spanning three buildings requiring 563 firefighters and 113 fire engines. Figure 2-4 in the carousel below contain examples of the devastation caused by petrochemical accidents in China. Chemical spills like the Songhua River incident can contaminate vast water systems and threaten drinking water supplies, fisheries, and agricultural use for years, creating long-term ecologic damage that is costly and difficult if not impossible to remediate. Large-scale explosions like those in Tianjin and Jiangsu can cause catastrophic loss of life and mass injuries, overwhelm regional medical systems, and displace surrounding communities. Beyond the immediate devastation, these disasters often cripple local economies and disrupt or destroy critical infrastructure, potentially disrupting global supply chains. In each case, recovery is prolonged, complex, and costly, involving hazardous material cleanup, environmental restoration, and reconstruction, all while eroding public trust in both industry and regulators.

Industrialized coastal areas in China have a higher rate of petrochemical disaster and may suffer some of the greatest consequences. Their coastal regions are highly desired areas for real estate, tourism, and manufacturing companies needing easier access to ports. Coastlines are also more likely to be home to major fishing industries in China, which produce 60% of the world's farmed fish. Petrochemical industries are known to diminish the capacity of local ecosystems to sustain life and significant chemical pollutants are increasingly found in nearshore and offshore locations across China.

To analyze how the petrochemical industry in China may develop over the next decade and present challenges for environmental health and human security, we conducted a case study of the new EDZ in Hainan, China and performed a risk assessment of how its petrochemical expansion may present challenges for local and regional safety. Lessons learned may help to inform China's adoption and implementation of policies related to the petrochemical sector. Figure 5 below provides the location of the EDZ on the island of Hainan.

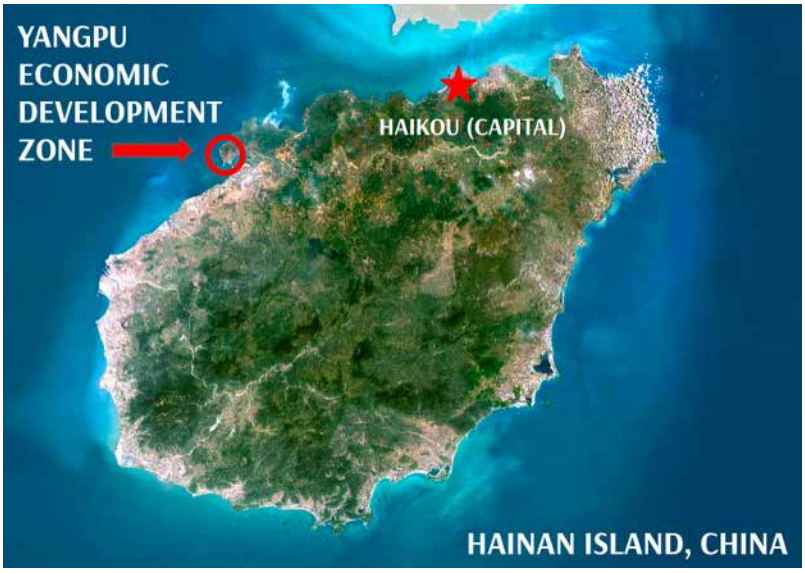


Figure 5. The Yangpu Economic Development Zone (Source: Hainan, China -Fine Art America, Science Photo Library)

Research Statement

By conducting a case study and risk assessment of the Yangpu EDZ and integrating satellite imaging from the National Geospatial-Intelligence Agency's (NGA) Unclassified Data Lake (NUDL), we project the potential environmental and human security challenges China may face over time with its expanding petrochemical industry. Specifically, we examine how patterns of land use and land cover within the EDZ may shape societal risk by influencing both exposure to and potential impact from petrochemical incidents, focusing on the proximity of residential areas, public facilities, and critical infrastructure to petrochemical sites. We highlight relevant policies targeting risks and identify policy voids that must be addressed to mitigate these challenges.

METHODS

To project challenges China may face over the next decade with its expanding petrochemical industry, we conducted a case study and risk assessment of the Yangpu EDZ across three main phases:

1. Conduct a case study of the Yangpu EDZ to identify relevant stakeholders across the petrochemical industry, human security (housing, schools, recreation, hospitals, etc.) and ecosystem and environmental zones.

2. Collect geospatial intelligence (GEOINT) from NUDL and Google Earth to identify vulnerable stakeholders and project risk of disaster fallout from local petrochemical industries.

3. Document preventative, regulatory, and monitoring policies relevant to the regional petrochemical industry.

To collect data for the case study and policy analysis, we pulled documents from open-source locations including peer-reviewed academic publications (PDFs and HTMLs) sourced from both Western/United States and Chinese journals; Chinese-language public forums (text posts); Chinese policy documents and government reports (PDFs); news publications (HTMLs); statements from the Chinese government and political leadership (HTML, PDFs and text); and business records (CSV and PDFs) on petrochemical manufacturers in Hainan, published by Dun & Bradstreet, Inc. (N = 2,852).

For geospatial data extracted from NUDL obtained as high-resolution raster imagery (JPEG and GeoTIFF formats suitable for manual and software-assisted analysis), we bounded our spatial search parameters within a five-mile radius of each edge of the 12-sq mile Yangpu EDZ to capture both coastal and land imagery and performed multiple searches to ensure depth of coverage, returning a total of 53 images across 10 days from 12/14/2024 to 1/29/2025. Returns included both electro optical (panchromatic/multispectral) and synthetic aperture radar (SAR) scenes. For each return, we recorded standard metadata, like the platform, modality (SAR), and any provider quality flags. We then applied a uniform filtering rubric:

1. De-duplicate near-identical collects;

2. Exclude scenes with poor quality, perhaps due to weather conditions;

3. Ensure images were compared during similar tidal stages to minimize changes in coastal imagery.

The highest-resolution image within the January 2025 collection window was selected for analysis. To support accurate imagery-based identification of petrochemical infrastructure, we also consulted industry reference materials, including Marine Insight's Guide to Oil Terminals and other technical documentation to familiarize ourselves with common facility layouts, storage tank configurations, and related operational structures.

DISCUSSION

Case Study

Established in 1992 as a major stakeholder in the Hainan Free Trade Port, the Yangpu EDZ was the first in China to open to foreign businesses and has an operating capacity of more than 100 million-tons, with 42 shipping berths catering largely to the petrochemical industry. Situated on the tropical island of Hainan, the EDZ is also home to a booming tourism industry, foreign real estate investment and international schools, and domestic homes and businesses. The EDZ's industrial planning layout, designed by the Yangpu Economic Development Zone Administrative Committee and displayed in Figure 6 below, calls for isolating human living spaces away from the petrochemical functional area. The layout was designed to minimize risk to the population from petrochemical incidents and to preserve the EDZ's tourist industry and resident quality of life.

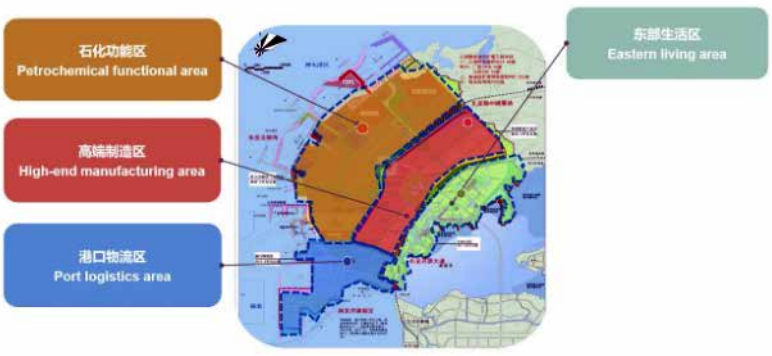


Figure 6. Yangpu EDZ Industrial Planning Layout

Human Security Stakeholders:
Foreign businesses; tourism and hotels; residential areas; small businesses; meat and food processing; community farms; schools; hospital; sports

Using information from satellite imagery, we confirmed the spatial relationship illustrated in the graphic was only partially accurate: petrochemical facilities occupy a contiguous industrial zone along not only the EDZ's north coast and inland area, but its related processes stretch down into its southernmost coastal areas. Residential, educational, and commercial zones within the eastern living area bordered many petrochemical sites, for uses including storage, industrial runoff, and shipment zones. Moreover (and discussed further below), we found evidence of residential areas even within the petrochemical functional area displayed in orange in Figure 6. The failure of imagery to support this mapping underscores the importance of highlighting areas at risk of exposure and risk in the event of a petrochemical incident.

Based on our analysis of open-source information, we found the Yangpu EDZ has a meat processing industry that works with more than 100,000 tons of product a year, alongside more than five other international food processing plants that reach $78 in production value annually. There are also community farms, a large English-language university scheduled to open in September 2025, other international schools, a hospital, hotels, and leisure areas like sports arenas and theaters.

Ecosystem & Environmental Stakeholders:

Migratory birds; seafood industry; natural water scarcity; coastal and groundwater pollution; air pollution

Despite the saturation of residential and related zones, satellite imagery and open-source reports indicate persistent chemical and heavy metal pollutants in both groundwater and ocean water sources, harming the seafood industries across Hainan and creating the potential to devastate migratory birds that use Hainan as a winter haven. Using satellite imagery to overlay industrial infrastructure with natural resource locations, we identified areas where proximity to petrochemical facilities intersects with sensitive environmental zones including coastal wetlands, fisheries, and groundwater recharge areas. Imagery-assisted mapping also revealed water-scarce regions that coincide with industrial demand, highlighting zones where human and ecosystem exposure to contamination (and the harm caused by it) may be greatest. Seasonal variations in ocean and air currents visualized through combined satellite and environmental datasets show potential pathways for pollutants from the EDZ to spread across southwestern Hainan, northward to China's mainland, and even toward Vietnam's east coast, emphasizing the regional scale of environmental risk.

The potential for natural disasters in the Yangpu EDZ is also high, which could exacerbate risk of disaster for petrochemical industries. Hainan is situated near major fault lines and Yangpu itself has experienced many earthquakes, some severe, and is less than a hundred miles away from two major active volcanoes.126l Moreover, Hainan has the highest prevalence of lightning strikes and related casualties in China, with the EDZ in a high-risk zone.l271To convey the severity of the EDZ's risk of natural disaster, Figures 9 and 10 (image carousel) present information on volcanoes, earthquakes, and lighting strikes in Hainan.

Petrochemical Industry Stakeholders:

Based on publicly available business records, we found the three largest petrochemical stake-holders in the area are Sinopec Hainan Petrochemical, with a more than 25-million-ton output; Sinopec's Yangpu Oil Terminal, the largest petroleum reserve in China; and the Hainan Jinhai Pulp & Paper Co. which receives more than $3.38 annually from the Chinese government.

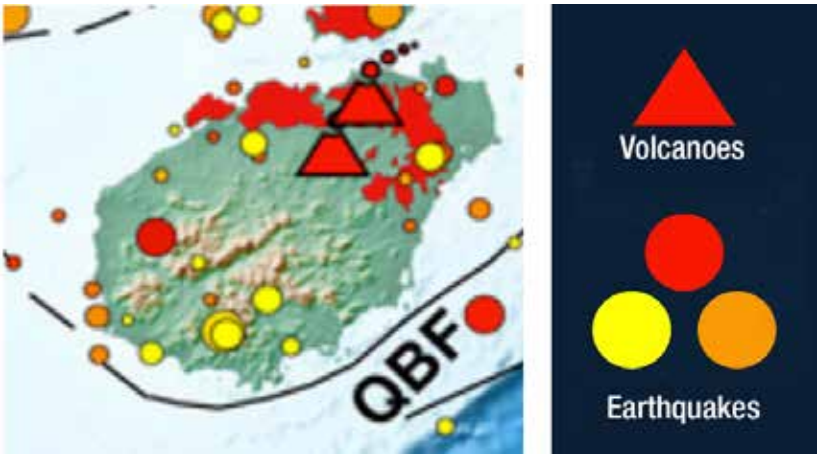


Figure 9. Earthquakes recorded and active volcanoes (Source: Hongbin et al., 2022)

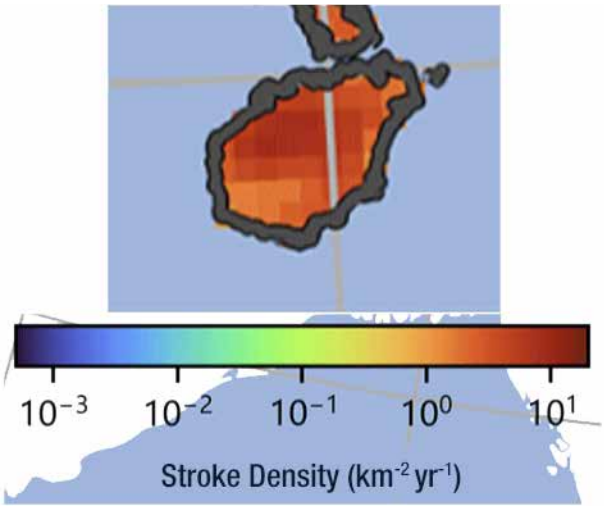


Figure 10. Annual lightning frequency & fault lines (grey) (Source: Jiang et al., 2023)

NUDL & Geospatial Intelligence (GEOINT)

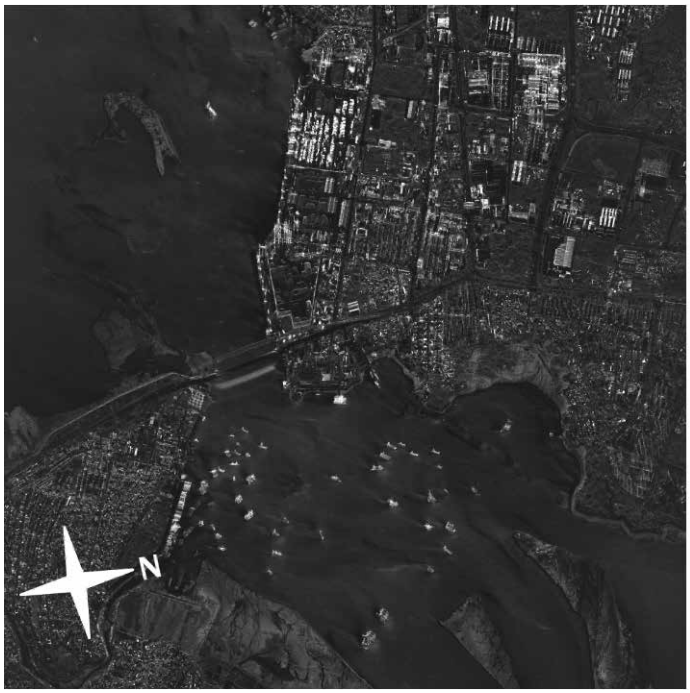
The case study of the Yangpu EDZ leveraged geospatial intelligence to directly link identified hazards, human security stakeholders, and environmental vulnerabilities to observable industrial infrastructure. Using satellite imagery from the National Geospatial-Intelligence Agency's (NGA) Unclassified Data Lake (NUDL), primarily from the ICEYE collection, we mapped the locations of the three largest petrochemical stakeholders (Sinopec Hainan Petrochemical, Sinopec's Yangpu Oil Terminal, and Hainan Jinhai Pulp & Paper Co.), and analyzed their proximity to residential areas, schools, hospitals, tourism zones, and environmental resources.l29l Imagery analysis included identification of storage tanks, pipelines, shipping berths, and ancillary structures, which were cross referenced against hazard maps showing fault lines, volcanic activity, lightning prevalence, and coastal/ groundwater contamination.

Supplementary Google Earth Imagery filled spatial and temporal gaps in the NUDL collection and provided additional context for visual confirmation of land use, zoning, and environmental features. By overlaying these GEOINT-derived infrastructure maps with hazard and exposure layers, we could more precisely assess potential human and ecological risks like pathways for chemical spills, population exposure following industrial accidents, and the vulnerability of natural resources. Figure 11 contains the final selected NUDL image and its unique S3 URL code. Visual bounding boxes of the image are also provided below, which served as the analytic basemap for this GEOINT-informed assessment.

Policy Analysis

Policymakers in the Yangpu EDZ will likely face significant challenges in the decade ahead as they balance economic expansion with adherence to sustainability commitments made by Hainan. The Chinese Air Pollution Prevention and Control Law imposes strict emission limits upon industrial plants and requires them to employ air filtration systems, submit emissions reports, and comply with national clean air targets, though public access to this data is restricted and punishments are often low with fines that are less expensive than the investments required to be compliant with green technologies. The national Dual Carbon policy seeks to promote carbon neutrality and renewable energy transmissions, and while petrochemical firms are encouraged to adopt green technologies and participate in China's Emissions Trading System (ETS), participation is voluntary and green programs see minimal engagement.

Petrochemical plants in the Yangpu EDZ frequently exceed permitted pollution levels despite the fact that the EDZ has a Water Pollution Preventions and Control Law that mandates strict wastewater treatment processes for petrochemical plants near coastal ecosystems. The Marine Ecological Red Line policy further restricts industrial discharge into sensitive marine habitats to protect Hainan's fisheries and tourism-driven economy, while the Hazardous Waste Control Law dictates strict containment, labeling, and disposal of toxic petrochemical refinement byproducts. The detail figures above includes a visual example of two possible violations: wastewater disposal into the ocean, and the runoff retention pond south of the plant.



ORIGINAL IMAGE: *ICEYE Collection*

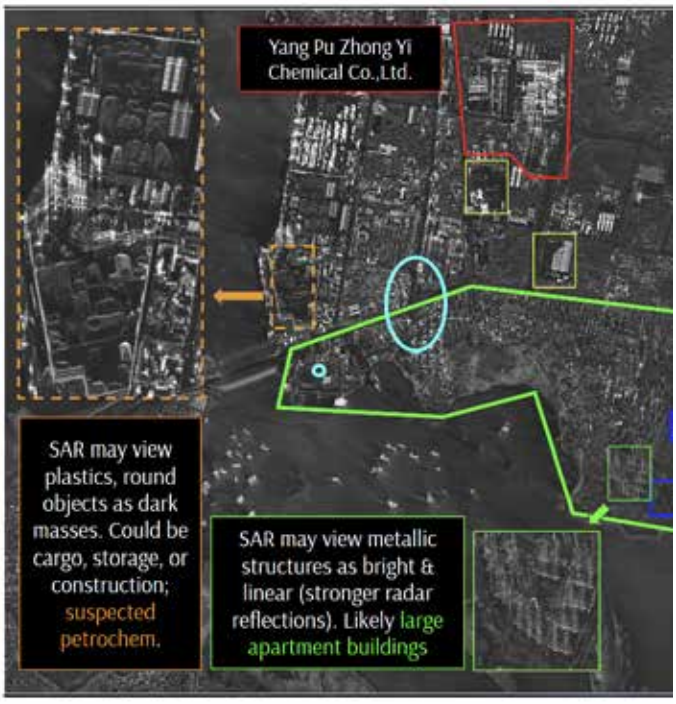
Image Date/Time: *20250129 / 0657Z*

Image ID: *20250129t065749_iceye_x37_slf_950375461*

Centroid: *109.211031, 19.730269*

Figure 11. Original NUDL Imagery of Yangpu EDZ, 2025 ICEYE US

Figure 12. Analysis of Yangpu EDZ, © 2025 ICEYE US



RED: Petrochemical industry
Likely petrochemical tanks and manufacturing zone layout

ORANGE: Possible Petrochemical element
Industrial nature; possible construction; proximity to port

YELLOW: Solar Farms
Push for reduced emissions

GREEN: Residential District
Family homes; parks; sports venues; restaurants & dining; continues south (beyond the image)

CYAN: Hotels & Tourist Centers
International hotel hubs, also found to the south

BLUE: Hospital & Courthouse/ Government Center
Large, modernized structures

Image information: *ID: 202501291065749 _iceye_x37 _slf_950375461*
Date/Time: 20250129 // 0657Z
Center: 19.730269, 109.211031

A closer look at the above images finds they may be storage areas for oil or other petrochemical precursors due to their proximity to port. We suspect images are of construction of an oil terminal and tank farm. The right image bounds ran (tank farm) and yellow (terminal) boxes based on analysis from Marine Insight's Guide to Oil Terminals.

Figure 13. Analysis of Yangpu EDZ (Detail 1), © 2025 GoogleEarth & 2025 ICEYE US

Although the Department of Ecology and Environmental Protection of Hainan Province is responsible for approving Environmental Impact Assessments for all new petrochemical projects, the process favors economic growth over environmental protection even in the face of strong local opposition of petrochemical projects. Despite challenges with protest and freedom of speech in China, protests against the petrochemical industry have occurred across the country. The "Free Trade Zone" status of the Yangpu EDZ provides foreign investors with reduced tariffs, tax exemptions, and streamlined regulatory procedures that can weaken environmental oversight and limit intervention. As state-owned enterprises dominate the petrochemical sector in Yangpu and across China, corporate transparency and accountability may be reduced. Despite the findings from our analysis of GEOINT from NUDL and Google Earth positioning lower-income housing next to petrochemical plants, the Yangpu Industrial Park Expansion Plan mandates petrochemical projects must be constructed away from residential areas to reduce public health risks. Moreover, instances of illegal hazardous waste dumping have been reported that suggest insufficient oversight and inadequate water tracking mechanisms.

Ultimately, regulatory bias favoring economic growth might be alleviated by independent oversight and the establishment of third-party environment auditing agencies. The effectiveness of policies compromised by weak monitoring infrastructure, inconsistent enforcement, and corporate lobbying could be improved by strengthening penalty structures and revoking operating licenses for repeat offenders that would deter systematic non-compliance. Introducing formal grievance mechanisms that allow citizen-led environmental reviews could also improve public trust and policy responsiveness. One of the primary challenges is the lack of real-time environmental monitoring systems, which limits the government's ability to track pollution levels and detect violations. Expanding public transparency through open-access pollution databases could enhance accountability and citizen engagement in environmental policy.

CONCLUSION

We found a wide variety of regulations and policies dictating careful state and manufacturer control over the petrochemical industry. However, combining geospatial analysis with open-source information, our findings painted a vastly different picture: pollution and development violations exposed weak enforcement of these policies, and vulnerable populations and ecosystems in the EDZ appear to be at increased risk of disaster.

Combining environmental hazards with apparent disregard for developmental layout plans, the EDZ's industrial ecosystem presents serious concerns for the coming years. Considering the Yangpu EDZ was the first to open to foreign businesses and is a Free Trade Zone, the opportunities for environmental and safety collaboration between China and the United States may be highest in these areas and serve to bolster strategic partnerships towards a mutually beneficial human security goal. Safety and emissions partnerships, particularly those seeking to prevent accidents or develop contingency plans in the case of disaster, may benefit both China and the United States as well as other regions around the world handling petrochemical industries.

With access to a greater number of higher-resolution images and the ability to track changes over time, future research would benefit from pairing images of ecosystem degradation and the expansion of human security areas and petrochemical infrastructure to establish direct associations between development; to check visual compliance with enacted policies to protect human and environmental security; and to establish the degree of risk faced by stakeholders based on distance from petrochemical manufacturing plants. Moreover, we would propose a future project pairing GEOINT with existing data on water and air quality, fish and marine wildlife health, or even population data may allow researchers to track changes in the local systems over time and highlight the most relevant policies targeting areas of concern.

While China, Hainan, and the Yangpu EDZ have enacted a series of preventative measures and policies to mitigate the environmental risks associated with petrochemical production, enforcement challenges and economic pressures undermine their effectiveness and are coupled with weak penalty enforcement and regulatory loopholes allowing firms to bypass compliance requirements with minimal repercussions. Increased monitoring efforts- a meaningful step towards environmental protections- have raised concerns that wastewater treatment facilities are failing to meet government standards. If these trends continue, Hainan's marine and wildlife biodiversity, as well as the island's human population, may face irreversible damage in the span of a few years, undermining the sustainability commitments made by the Yangpu EDZ.

LOOK AHEAD

As China continues to grow and diversify their economy, the government will be faced with challenges balancing competing priorities including the growth of profitable sectors, environmental preservation, and protecting their population. Hainan Island and the Yangpu EDZ represent a microcosm of those national decisions and the lasting effects they have on all stakeholders. Continued monitoring of the development of the Yangpu EDZ could provide insight into how the Chinese government is choosing to balance those priorities nationwide. ■

Russia's Arctic LNG Infrastructure: Development and Operational Analysis

Jennifer Jun from Johns Hopkins University

July 7, 2025

SUMMARY

The Arctic plays a pivotal role in Russia's liquified natural gas (LNG) ambitions, leveraging its vast natural gas reserves and strategic geographic advantages. In 2022, LNG accounted for approximately 52% of Russia's energy portfolio, and despite global sanctions, production is projected to grow by 11% annually through 2035. With gas exports dropping by 55% since 2021, Russia has shifted focus to LNG via the Northern Sea Route that connects the Arctic Ocean to the Pacific and Atlantic Oceans.

The oil and gas industry comprises three key segments: upstream, midstream, and downstream. Public attention on sanctioned LNG exports tends to focus on the final stages of the midstream and downstream sectors-from transporting extracted resources to refining and processing. This research addresses gaps in the understanding of earlier phases by examining the history and current operational status of upstream infrastructure at two operational Russian Arctic LNG facilities.

ACTIVITY

Recent satellite imagery reveals ongoing construction at Yamal LNG Facility, including additional storage tanks, and the operational deployment of Arctic LNG 2 Facility's Train 1 (T1), with preparations underway for Train 2 (T2). Vessel traffic at both facilities highlights sustained activity, though export logistics are facing seasonal and geopolitical constraints.

METHODOLOGY

This research project examines the two operational LNG terminals in the Russian Arctic along with their supporting infrastructure, including airports and ports. The study first established a timeline of activities using open-source information on the history, development, and current status of the terminals. To validate and refine this timeline, 58 publicly available multispectral and synthetic aperture radar (SAR) images from Maxar, Sentinel, and Landsat from 2003 to 2024 were processed and analyzed manually, providing a more detailed understanding of the terminals' construction and operational history. The analysis focused on the development of physical infrastructure at the facilities and surrounding areas that contributed to increased operational capabilities. Finally, the images were annotated to visually represent key findings from the analysis.

ARCTIC LNG TERMINALS & SUPPORTING INFRASTRUCTURE

The article provides a comprehensive overview of Russia's two currently operational Arctic LNG facilities-Yamal LNG and Arctic LNG 2-detailing their development history, construction timelines, and present-day operational status from 2003 through 2024. It also includes a status assessment of three additional proposed Arctic LNG sites, examining their evolving planning stages, projected timelines, and the broader implications of geopolitical and logistical constraints on their development.

YAMAL LNG FACILITY

Background & Facility Overview

The Yamal LNG facility (71.267087, 72.072118), one of Russia's two operational Arctic LNG plants, is located in Yamal-Nenets Autonomous Okrug, the world's largest natural gas producing region that accounts for approximately 80% of Russia's gas production and approximately 15% of global gas production. The Yamal LNG facility started as and remains a joint venture between Russia's Novatek (50.1%), France's Total (20%), China's National Petroleum Corporation (20%), and China's Silk Road Fund (9.9%), despite Western sanctions against Russia for the invasion of Ukraine. While Novatek operates the facility, the presence of major foreign stakeholders may also influence the midstream and downstream processes.

LNG trains are central to an LNG plant. Also known as liquefaction plants, LNG trains convert the natural gas extracted from the ground into liquid by removing impurities and cooling it to approximately -162°C. This change in form, from gas to liquid, decreases the volume to 11600th of its original gaseous state. The Yamal LNG facility itself consists of three 5.5 million metric tons per annum (Mmtpa) trains and one 0.9 MMtpa train, the plant has a nameplate capacity of 17.4 MMtpa. In 2020, the plant produced 18.8 million tons-larger than the anticipated capacity due to the cold climate- and accounted for more than 5% of the global LNG market. Tens of wells at the nearby Yuzhno-Tambeyskoye gas field supply the plant.

Additional to the LNG trains, the Yamal LNG facility consists of a high pressure (HP) flare, fractionation facilities, refrigerant, three condensate storage tanks, a boil-off gas (BOG) flare, four LNG storage tanks (with two new tanks under construction), a power generation facility, utilities, inlet gas area, a probable sanitary wastewater facility, and administration.

As seen in the latest accessible cloud-free high-resolution satellite imagery from Maxar taken on July 14, 2024, the Yamal LNG facility is supported by Sabetta port and a marine offloading facility to the east, Sabetta International Airport approximately five kilometers to the southwest, and a number of open-air storage yards and support facilities such as worker housing surround the facility.

History & Development

Prior to the construction of the Yamal LNG facility, Sabetta port, and the Sabetta International Airport, the area hosted minimal infrastructure for early exploration of gas fields after Russia's interest in increasing LNG output grew in the 1990s.

The Yamal LNG facility project was officially approved by the Russian government in 2010 and officially licensed three years later in 2013, when facility construction started. The facility's two supporting infrastructures, the Sabetta port and Sabetta International Airport, were also operational around this time, with the port's berths operational since November 2013 and the airport's first landing occurring in December 2014. A medium-resolution Landsat-8 image from June 10, 2013 shows the development of a breakwater at what would later become the port, and the airport runway visible. It also shows the completion of the main roads throughout the facility and its surrounding areas, as well as the beginning of construction of the plant grounds.

Figure 1: Overview of Yamal LNG facility and its supporting facilities, July 14, 2024. Maxar Technologies.

Figure 2: Overview of Sabetta International Airport, with a runway approximately 2.7 kilometers Jong, located approximately 5 kilometers southwest of the Yamal LNG Facility, July 17, 2024. Maxar Technologies.

Figure 3: Overview of Sabetta port and its marine offloading facility west of the Yamal LNG Facility, July 17, 2024. Maxar Technologies.

Another Landsat-8 image taken 14 months later, on August 3, 2014, shows considerable progress at the facility, port, and airport. The port's jetty is now under development, and several structures are visible at the airport next to its apron. Blue-roofed support facilities, probably housing for construction workers, are seen to the northwest and southeast of the main plant area. Groundwork throughout the plant's premises is also visible.

The construction process at the facility is better observed in the next available feasible high-resolution Maxar image, taken two years later, on July 6, 2016. Given the harsh Arctic conditions, the speed of the construction is notable and indicates the high priority of the development of the Yamal LNG facility. Because the Arctic's permafrost makes construction challenging, 122 modules for the Yamal LNG facility had been fabricated and shipped by 10 different yards from China and Indonesia.

The area is seen bustling with activity, especially at Sabetta port's marine offloading facility, where several cargo vessels and cargo barges are seen unloading material and equipment. Also at the jetty, mooring dolphins fixed structures used to secure vessels via ropes-are seen under construction.

At the central area of the Yamal LNG facility, storage tanks for both condensate and LNG were under construction, with all roofs raised but external work ongoing. East of the tanks, LNG transfer pipelines used to connect the facility to the jetty were also being installed. Temporary construction support facilities were seen throughout the area, as well as materials, equipment, and trucks. Sites for the first three train sites are observed to be at various stages, with the site for Train 1 showing the most progress with some modules and structures partially placed. The site for Train 2 shows most of the foundations for its modules and structures installed, whereas the site for Train 3 mostly shows ground razing and partial placement of building foundations in place. To the west of the train sites, additional facilities such as power generation, utilities, and inlet gas areas are also under construction.

Northeast of the central section, an operation camp and housing for construction workers were observed, along with temporary housing and open-air storage for materials in a round paved area. A fuel and lubricant storage site is under construction, and the waste landfill site to the north is observed near completion.

In addition to the construction of the Yamal LNG facility and the jetty at Sabetta port, tens of well pads for LNG extraction were observed under construction in the surrounding Yuzhno-Tambeyskoye gas field.

The first gas-in of Train 1 of the Yamal LNG facility started on September 10, 2017, signifying the commencement of the final commissioning phase and marking a pivotal milestone in the development of the project as it prepared to produce its first batch of liquefied natural gas later that year. Facility operations officially started on December 8, 2017, when Vladimir Putin attended the opening ceremony. Concurrently with these developments, the Yamal LNG project also included the building of a new class of ship. Christophe de Margeris, the first of these Yamalmax-class tankers with the highest commercial ice classification of Arc7 was completed in August 2017.

Figure 12: Well pads for extracting gas to be processed at the Yamal LNG Facility under construction, July 6, 2016. Maxar Technologies via Google Earth Pro.

Figure 15: Central section of the Yamal LNG Facility, July 17, 2024. Maxar Technologies.

Figure 16: Western section of the Yamal LNG Facility, July 17, 2024. Maxar Technologies.

By August 2018, the Russian government and Novatek announced that the Yamal LNG plant's second train was operational six months ahead of schedule. Its first shipment was announced, adding an additional 5.5 MMtpa of LNG capability, leading to a total of 11 million tons per year from the Yamal LNG facility in less than a year of the first train's gas-in. Its third train started operations later in November 2018, twelve months ahead of the original schedule.

A year later, in November 2019, Russia's Novatek announced that in that year the plant produced more than 16.5 million tons of LNG, exceeding its annual nameplate production capacity with the three trains in operation. Its high output levels were supported by ship-to-ship LNG transshipment by LNG tankers such as Vladimir Rusanov, Vladimir Voronin, and Nikolay Yegenov. These tankers allowed for the successful loading of LNG cargo from the Yamal LNG facility to lower ice-class tankers, then ultimately to customers in Europe.

Maxar imagery taken during this period of elevated output, specifically on August 20, 2020, shows indicators of significant levels of activity. At the jetty, an unidentified LNG carrier-potentially a Yamalmax class- which measures approximately 299 meters by 52 meters, is berthed, presumably to load LNG for transfer. North of the jetty and immediately north of the four LNG storage tanks, the foundation for what would later become two new storage tanks is being placed. Although it is yet unclear whether the tanks will store LNG or other materials such as condensate or fuel, the Yamal LNG facility's production exceeding its expected nameplate capacity suggests the tanks will likely be used to store LNG to support the increased output.

Another observed sign of activity is the flare flame observed at the HP flare, indicating the controlled burning of excess gases released from the processing or storage systems.

In June 2021, the Yamal plant's fourth and smallest LNG train came online after delays set the operation of the liquefaction unit back by three years. Two months later, Train 1 underwent maintenance and halted operations temporarily from August 1 to August 19, 2021. Such temporary halts for maintenance are part of standard practice for operational safety, performance optimization, and management.

Recent Developments & Operational Status

In May 2023, Novatek announced that Yamal LNG achieved a remarkable milestone of producing its billionth cubic meter of gas, indicating sustained successful operations at the plant. A month later, Train 2 underwent a temporary shutdown for scheduled maintenance. In August 2023, train 3 also underwent a similar maintenance halt in operation, and it was announced that no halt for repair was anticipated in 2024.

An analysis of 58 satellite images, including multispectral and synthetic aperture radar (SAR) data, from May 2023 to November 2024 show recent developments and the operational status of the Yamal LNG facility.

The latest high-resolution image, taken by Maxar on July 17, 2024, shows detailed changes to the LNG facility since the latest publicly available image from August 2020 on Google Earth Pro
The most notable changes to the facility include the continued construction of two new storage tanks north of the four pre-existing LNG storage tanks at the facility, likely to support the increased output capacity of the plant.

West of these two new tanks, a wide road and round perimeter has been razed. The purpose of this unidentified work is yet unclear. However, the shape of this construction is similar to the ground area of what had previously been temporary housing for construction support to the west, next to the permanent operation camp and housing. Future monitoring will be required to identify the purpose of this groundwork.

Further southeast of the Yamal LNG facility in July 2024 is the support area, serving as an open-air storage yard filled with containers and materials, six helipads, construction camp, and temporary production base for contractors. Three helicopters were observed on helipads.

The Sabetta International Airport, approximately five kilometers southwest of the Yalam LNG facility, is operational, with an actively maintained runway and two helicopters and one aircraft observed on the apron. Its active maintenance and consistent presence of aircraft indicate its ongoing support of operations at the Facility.

Throughout the study period, the continued presence of vessels on Maxar imagery at Sabetta port indicated high levels of activity at the Yamal LNG facility. Forty-nine of the 58 analyzed images show one or two vessels, consistent in size with that of an Arc7 tanker, moored at the jetty. This pattern of activity indicates sustained high levels of LNG processing and export from Yamal, despite increased Western pressure such as the EU sanctions package in response to the Russian invasion of Ukraine. It also supports the open source reports that Yamal LNG has resumed ship-to-ship cargo transfers as the direct Northern Sea Route to Asia becomes more challenging to navigate in the winter. Ship-to-ship transfers are expected to become more frequent in the coming year due to the aforementioned EU sanctions package and ban on transshipment.

Two more recent images studied- one a medium-resolution Landsat-8 image taken on October 15, 2024, and another a Sentinel-1 SAR image taken on October 21, 2024-show the presence of vessels, likely LNG carriers, moored at the jetty. In the Sentinel image, the vessel shows strong backscatter and stands out against the low to no backscatter of the water. In addition, in the Landsat-8 image-the latest multispectral image analyzed-one of the two storage tanks is now externally complete, with white roofing. Visible HP flare flame also indicates operation at the facility.

Insights & Future Analysis

The Yamal LNG facility exemplifies the scale and ambition of Russia's Arctic energy strategy. Imagery analysis shows the development of the facility and its high production capacity. The facility's support infrastructure and activity observed at these sites also show that the plant will continue to maintain a critical, if not growing, role in Russia's energy production despite external pressures such as sanctions or seasonal navigation barriers. Future monitoring of the facility's ongoing expansions, particularly the new tank sites and evolving logistics at Sabetta port, will be essential to understand Yamal LNG's operational trajectory, as well as Russia's Arctic resource management and energy security.

ARCTIC LNG 2 FACILITY

Background & Facility Overview

The second of Russia's two operational LNG plants in the Arctic is the Arctic LNG 2 facility (71.009482, 73.806917). It is located approximately 68 kilometers to the southwest across the Ob River from the Yamal LNG facility and in the Gydan Peninsula. The facility is owned by 000 Arctic LNG. This is a joint company formed by Russia's Novatek (60%), France's Total (10%), China National Petroleum Corporation (10%), China National Offshore Oil Corporation (10%), and the Japan Arctic LNG (10%). Arctic LNG 2 exports gas from the nearby Salmanovskoye (Utrenneye) oil and gas condensate field, which was discovered in 1979. While Novatek operates the facility, the presence of major foreign stakeholders may also influence the midstream and downstream processes.

Figure 18: Close-up view of the support area southeast of the Yamat LNG Facility, July 17, 2024. Maxar Technologies.

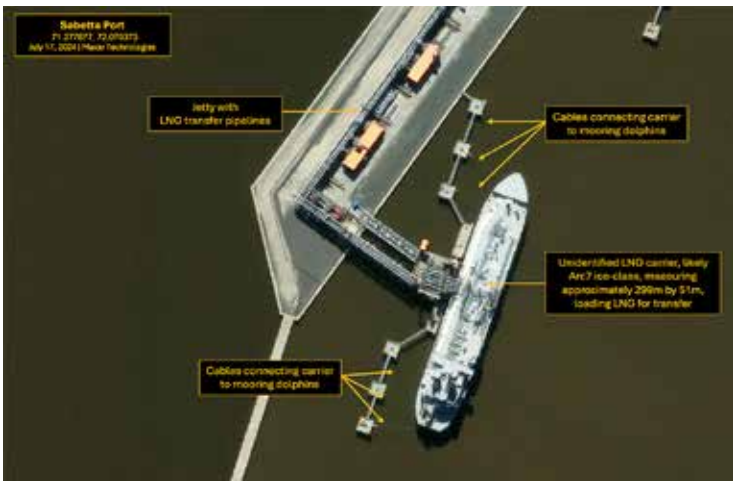


Figure 20: Overview of Yamal LNG Facility and Sabetta port, October 15, 2024. Landsat-8 Courtesy of the U.S. Geological Survey.

Module #	Module Description	Module #	Module Description
TMP-001	Dehydration & Mercury Removal	TMR-003	Pipe-Rack
TMP-002	Fractionation & NGL Recovery	TMR-004	Pipe-Rack
TMP-003	Liquefaction	TMR-005	Pipe-Rack
TMP-004	Boil-off Gas, Fuel Gas & Hot Oil	TMS-001	Inlet Stabilizer & AGRU
TMP-005	Utilities	TMS-003	Refrigerant Compressors
TMR-001	Pipe-Rack	TMS-004	Refrigerant Compressors
TMR-002	Pipe-Rack	TMS-005	Power Generation

Diagram showing the arrangement of the fourteen modules on the GBS. *(Source: Novatek pre-commissioning, commissioning & start-up execution plan)*

Figure 22: Gravity-based structure to be used at the Arctic LNG 2 Facility.

The Arctic LNG 2 facility is notable for its use of gravity-based structures (GBS). This platform is designed to rest on the seabed and therefore does not require construction into the Arctic terrain which can be susceptible to permafrost thawing. The GBS terminals, which consist of processing (liquefaction) equipment and LNG storage tanks, reduce the need to develop additional infrastructure in the harsh conditions of the Arctic. Although only two GBS are at the site now, a total of three are planned for the Arctic LNG 2 facility. The GBS are built at another shipyard in the dry dock of the NOVATEK-Murmansk LLC shipyard and taken to the facility site. Although Arctic LNG 2 is Novatek's first facility with GBS, it plans to build additional LNG facilities with them in the future.

In addition to the LNG trains, the Arctic LNG 2 facility consists of a flare system, operations control administration, utilities, well pads, power generation, waste treatment and disposal facility, helipads, and more.

The latest accessible cloud-free high-resolution multispectral image from Maxar taken on July 4, 2024, shows the Arctic LNG 2 facility is supported by Utrenny Airport, approximately 15 kilometers to the east, and the Utrenny Terminal, where the GBS are located. Additionally, a number of open-air storage yards and support facilities such as worker housing surround the facility.

History & Development

In March 2017, Russia's Novatek announced plans to build Arctic LNG 2, following the successful start of construction of the Yamal LNG facility. Arctic LNG 2 was originally planned to be completed by 2023, as "the Gydan and Yamal peninsulas have a vast resource base that allows the production of over 70 million tonnes [per annum]…comparable to the LNG production in Qatar."

Landsat-8 images taken on July 14, 2018, show the site prior to the start of the facility construction. It shows minimal infrastructure, including a probable early exploratory well pad as well as a small pier located at what would later become the Utrenny Terminal.

By March 2020, the construction site had received 20,000 tons of construction material, delivered by nuclear-powered ice-breaking cargo vessels. Open source reporting indicated that the vessel, Sevmorput, had made two similar deliveries in the summer of 2019 and several more were planned in 2020. During this time period, a Landsat-8 image from March 2020 shows the harsh Arctic conditions at the construction site, with most of the Ob River shore frozen and covered in ice and snow. In the river, what seems to be a trail made by the aforementioned icebreaker is observed.

Construction at the facility, terminal, and the airport continued the following years, with the Utrenny Airport landing its first plane in June 2024. Two years later, a Maxar image taken on August 6, 2023, shows the facility still under construction but several structures complete. Most notably, this image is the last accessible high-resolution image of the Utrenny terminal before T1 was seen at its intended site, as shown in the next accessible image taken on August 13, 2023. Prior to T1's arrival, August 6, 2023, Maxar imagery shows several tugboats and deck cargo bringing in construction material to the Terminal.

Figure 23: Overview of the Arctic LNG 2 Facility, July 4, 2024. Maxar Technologies.

Figure 24: Overview of the Utrenny Airport, July 4, 2024. Maxar Technologies.

Figure 28: Arctic LNG 2 Facility and Utrenny Terminal, August 13, 2023. The Tl gravity-based structure (GBS) was delivered sometime between August 6 and 13, 2023. Maxar Technologies.

Figure 29: Arctic LNG 2 Facility and Utrenny Terminal, April 19, 2024. Maxar Technologies.

Figure 30: View of the Arctic LNG 2 Facility and Utrenny Terminal, July 4, 2024. Maxar Technologies.

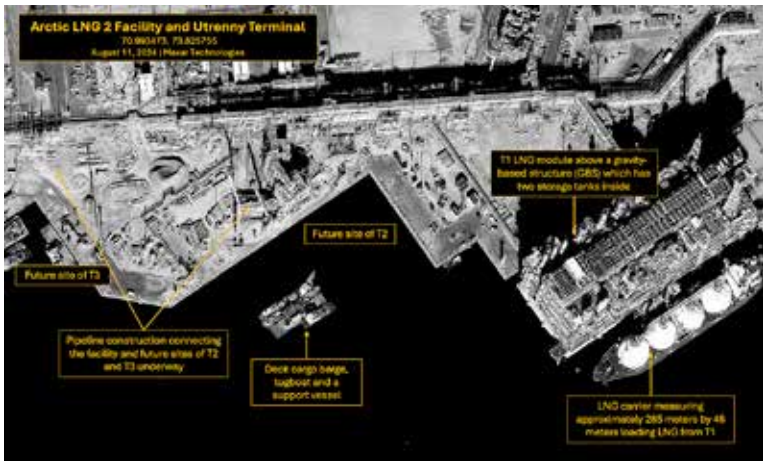


Figure 32: Arctic LNG 2 Facility and Utrenny Terminal, August 11, 2024. Maxar Technologies.

Figure 33: Arctic LNG 2 Facility and Utrenny Terminal, October 1, 2024. Landsat-8 Courtesy of the U.S. Geological SurveyJ

With T1 in place, the train was commissioned four months later in December 2023, when operations and production at the facility officially started. Although cloud-free and feasible satellite images are rare in the winter and early spring months, an image taken on April 19, 2024, show active flares at the onshore facility as well as at the flame stack on T1, indicating operation.

The latest available multispectral image of the facility at the time of analysis, captured on July 4, 2024, shows the progress of the construction and operational status of the site. The image shows the T1 module in operation, with an active flare observed at its flame stack. Additionally, pipeline construction connecting the onshore facility and the future sites of T2 and T3 is underway.

Surrounding the terminal, structures are seen still under construction, with roofing underway. Further south onshore are various open-air storage sites, three helipads, administration buildings, and worker housing. Inland to the east is additional facility support, including a wastewater site, several open-air storage sites, probable power generation, as well as worker housing and support buildings.

A few months later, in December 2023, Novatek had faced significant delays in the construction of the plant due to Western sanctions over Russia's invasion of Ukraine. Novatek issued force majeures to warn that it will not be able to honor contractual obligations due to the pressure. Western sanctions have singled out the Arctic LNG 2 project as a priority, with the U.S. Assistant Secretary for Energy Resources explaining to the U.S. Senate Foreign Relations Committee that "our objective is to kill that [Arctic LNG 2] project."

However, despite these challenges, Novatek announced its plan to start delivering the foundations of T2-the second GBS-in late July 2024. Other sources also stated that the delivery would start between July 22 to July 25 of that year and additional reports suggested that the Arctic LNG 2 plant was ramping up its production as it entered summer and the handful of months when the Arctic warms up enough for easier vessel access. Export by vessel was reported to have started, and volumes reached "the highest so far this year." A Maxar image-the latest accessible high-resolution image of the facility during the study period taken on August 11, 2024, supports such reporting. An LNG carrier, measuring approximately 285 meters by 46 meters, is observed berthed alongside T1, likely loading LNG processed by the T1 module. Additionally, a deck cargo barge, tugboat, and a support vessel were seen nearby transporting construction material.

Recent Developments & Operational Status

October 2024 was eventful for the Arctic LNG plant. Moscow's Kommersant published the Russian Energy Ministry's gas production data, which shows that the facility had produced 1.54 billion cubic meters of gas between January and September of 2024, a notable level considering that the facility is not yet complete and only relies on 1 train module. However, later in the month, on October 11, 2024, T1 was reportedly shut down, and the facility halted commercial operations without any plans to restart during the winter. The stated reasons were a "lack of appetite from buyers [as a result of Western sanctions] and a lack of Arc7 ice-class vessels needed to lift LNG during the winter months." Additional sources confirmed this reporting later in the month, as commercial liquefaction at the facilities was paused due to high inventories and lack of available export methods.

A rare partially cloud-free Landsat image taken on October 1, 2024, shows a sliver of the second module-T2-at its dedicated site next to T1, indicating that the train was still put into place sometime between mid August and late September despite the halt in operation of T1, suggesting ongoing efforts for long-term production capabilities.

The Arctic LNG 2 facility is assessed to still be at a halt in operation, with no clear plans for restarting until the ice thaws during summer 2025, or when export challenges are mitigated. Although lack of cloud-free medium and high-resolution satellite imagery over the Arctic area make it challenging to view the facility and assess its most current state, a Sentinel-1 SAR image supports reporting of the operation's halt.

Compared to October 2023, the SAR image shows a comparatively lower vessel presence at the same time of the year. 42 subsequent Sentinel-1 SAR images taken between October 1, 2024, and December 1, 2024 show a persistent lack of vessel presence at the port.

Insights & Future Analysis

The facility's progress-including the commissioning of Train 1 and the installation of Train 2-demonstrates Novatek's resilience and commitment to maintaining Russia's position as a major LNG exporter despite delays caused by Western sanctions and logistical hurdles.

However, recent operational halts due to high inventories and limited export capacity highlight vulnerabilities in Arctic LNG 2's operational framework, particularly under intensified geopolitical pressures. These challenges, coupled with the plant's reliance on Arc7 ice-class tankers and the sensitivity of Arctic navigation, further complicate year-round export capabilities, especially during the winter, suggest that sustained monitoring of its logistical adaptations and infrastructure expansion will be crucial in the analysis of the facility.

Future analysis of the Arctic LNG 2 Facility should focus on the integration and functionality of subsequent GBS units, particularly T3, and the resolution of export constraints. Tracking developments in vessel traffic, storage capacity, and supporting infrastructure, such as Utrenny Airport, will provide insights into Arctic LNG 2's recovery trajectory and operational capabilities.

ADDITIONAL FACILITIES

Russia's Arctic energy ambitions do not stop with the two construction facilities. In 2020, Novatek published plans for three additional plants: Obskiy LNG, Arctic LNG 1, and another as yet unnamed prospective project. However, these projects have seen major challenges or replanning.

Novatek originally proposed another LNG terminal just south of the Yamal LNG facility, called the Obsky LNG Terminal. However, this plan was reconfigured in June 2021 to the Obsky Gas Chemistry, dedicated to producing other types of fuel such as ammonia, hydrogen, and methanol. The decision is likely to have been a combination of technical and financial feasibility, shifting market demands, and long-term Arctic resource optimization plans. The planned Arctic LNG 1 project, also in the Gydan Peninsula but further south of the Arctic LNG 2 facility, is currently in the investment decision making stage, with construction expected to start in 2026 or 2027. Even earlier in the planning stage is the Arctic LNG 3 project, only in its early exploration drilling phase. Given the halt in operations and delays with the Arctic LNG 2 facility, it is highly likely that the timelines for the Arctic LNG 1 and Arctic LNG 3 projects have also been affected. These delays highlight the increasing challenges that sanctions and logistical constraints present Russian development of Arctic energy infrastructure. Russia's ability to advance these projects will depend heavily on its capacity to navigate these barriers.

Concluding Analysis

The Yamal LNG and Arctic LNG 2 facilities exemplify Russia's Arctic energy strategy, underscoring the region's vast natural gas reserves and Russian ambitions to sustain its position as a global LNG exporter.

With its robust support infrastructure and operational consistency, the Yamal LNG facility continues to solidify its position as a cornerstone of Russia's LNG production. Meanwhile, though operationally constrained, the Arctic LNG 2 facility, with its use of GBS, represents a significant technological leap. It is a testament to Russia's efforts to innovate and overcome challenges posed by the harsh conditions of the Arctic as an investment to support future Arctic facilities.

The analysis has highlighted several notable insights. For the Yamal LNG facility, sustained export activities via Arc7 tankers and ongoing construction of additional storage tanks provide evidence of Russia's efforts to expand production and logistics capacity. At the Arctic LNG 2 facility, its recent halt in operations underscores the regional vulnerabilities associated with limited transport infrastructure and reliance on seasonal navigation. Monitoring these facilities will remain crucial to understanding their operational trajectories and broader implications for Arctic resource management. The analysis will also benefit significantly from additional imagery access and other data sources. Although this project utilized thermal imagery and nighttime NASA Suomi imagery in an effort to supplement the lack of cloud-free multispectral imagery due to the harsh conditions of the Arctic, the analysis and the limited feasibility of these images at the publicly accessible level did not provide notable insights.

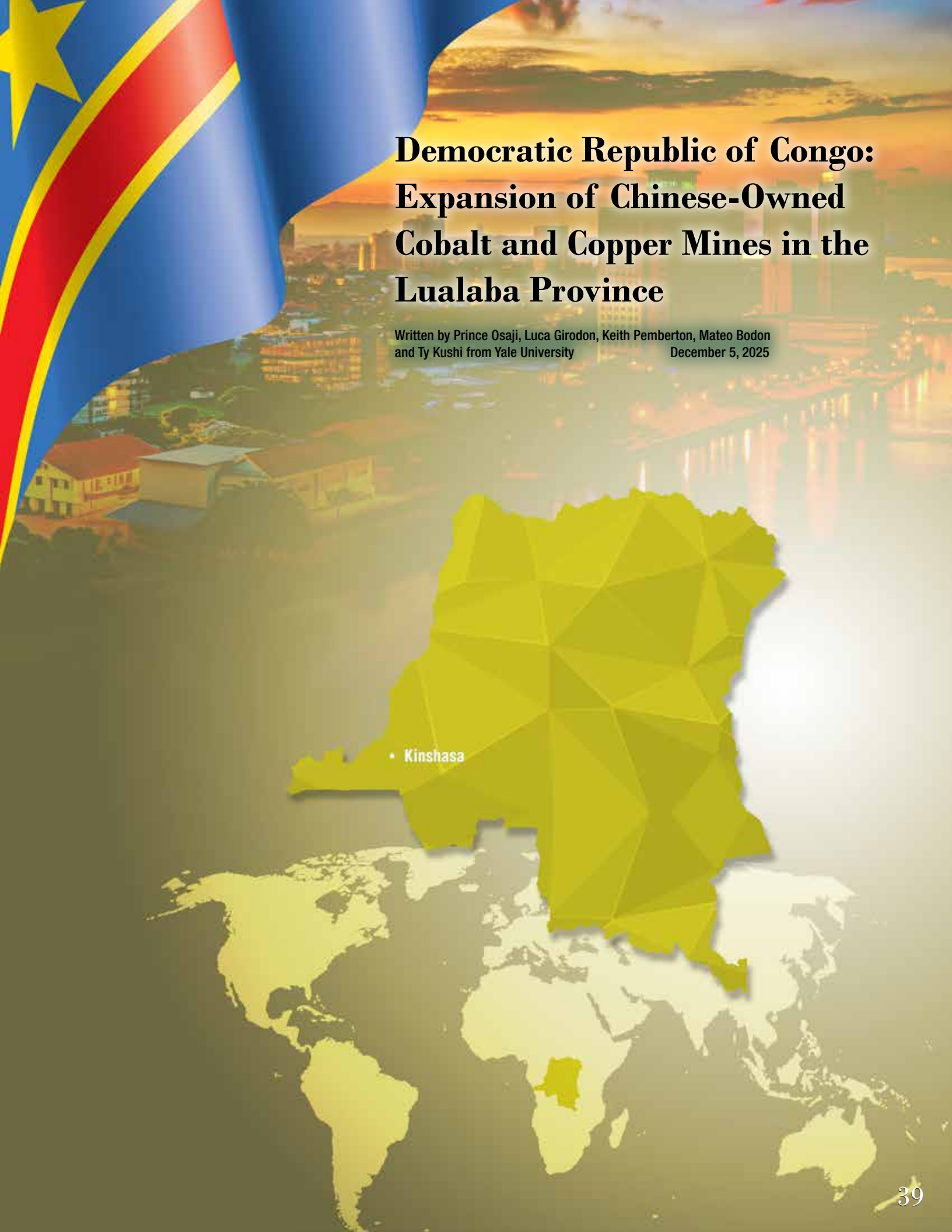
LOOK AHEAD

Future Russian LNG projects, such as the proposed Arctic LNG 1 and Arctic LNG 3, remain in early planning or investment stages, with timelines likely affected by the challenges faced by Arctic LNG 2. However, given the operational capabilities and progress both Yamal and Arctic LNG 2 projects had in recent years, careful and continued monitoring is necessary for the proposed projects. This report provides a baseline for understanding Russia's Arctic energy strategy as well as a foundation for future geospatial analyses of similar infrastructure in other regions. While this paper primarily focuses on upstream infrastructure, broader sanction circumvention tactics must also be understood in the context of midstream and downstream activity. To do so, it is first necessary to acknowledge the complexities of the task. Given the international equity structure of the Yamal LNG facility including stakes by France's Total and China's CNPC and the Silk Road Fund, some LNG shipments may be delivered through entities affiliated with these foreign stakeholders. This equity structure complicates efforts to track sanctioned cargo and raises the possibility that exports may flow to destinations outside Russia's direct control. Further complicating the matter is Russia's increasing reliance on Floating Storage Units (FSUs) to facilitate transshipment from ice-class LNG carriers to conventional tankers. These structures enable Russia to reduce its dependency on the scarce Arc7 tankers, allow continued LNG flows during the winter months, and further challenges sanctions enforcement. Understanding the dynamics of ownership, vessel contracting, and delivery routes beyond the LNG facilities will also be critical to evaluating the efficacy of sanctions and identifying potential pathways for circumvention. ■

Democratic Republic of Congo: Expansion of Chinese-Owned Cobalt and Copper Mines in the Lualaba Province

Written by Prince Osaji, Luca Girodon, Keith Pemberton, Mateo Bodon and Ty Kushi from Yale University

December 5, 2025



SUMMARY

Chinese companies control 72% of the cobalt and copper mines in the Democratic Republic of Congo (DRC), a country that produces over 70% of the world's cobalt and approximately 10% of its copper, according to Canadian estimates and foreign relations research councils.

Like many other critical and near-critical minerals-which are minerals or rare earth elements used in "critical" technologies like renewable energy- a large portion of cobalt and copper the West receives originates from Chinese extraction or refinery sites, making these supply chains dangerously insecure.

ACTIVITY

This paper aims to understand how Chinese mining companies are solidifying their dominance of the DRC's cobalt and copper supply chains by analyzing the development of three mines: Sicomines, Tenke Fungurume, and Kisanfu. As major producers that have undergone recent transformations, such as physical expansions and increases in vehicles and equipment, these mines can provide insight into current and future trends in the China-DRC mineral relationship and how they impact potential opportunities for the United States to secure critical mineral supply chains. This research uses satellite imagery to reveal that the mines have increased ore production, maximized on-site processing power and capacity, and implemented other tactics to continue scaling up their production and processing capacity.

BACKGROUND

As the great power competition between the US and China intensifies, attention has increasingly shifted to China's dominance of the supply chain for critical and near-critical minerals, defined in the Energy Act of 2020 as minerals "essential to the economic or national security of the United States." China is estimated to control the global production of around 58 percent of light rare earths-rare earth elements of a lower or "lighter" atomic weight-and 90 percent of heavy rare earths. In fact, more than half of the critical minerals the US currently imports are originally sourced from Chinese producers or refiners. The geopolitical ramifications of such an arrangement pose strategic risks to the US and its allies, especially if China were to restrict access to these minerals. In April 2025, China imposed export controls on seven rare earth elements in response to US tariff increases. And in October 2025, China expanded its export controls to deny exports of its rare earth elements for use by foreign militaries. If diplomatic disputes were to intensify, the access of the US and its allies to critical and near-critical minerals would be put in jeopardy.

The past two decades have witnessed a surge in DRC-based Chinese owned mining operations, fundamentally altering both the country's mineral economy and its role in the global supply chain for critical minerals. Driven by soaring demand, especially for copper and cobalt, China's expansion in the Congolese mining sector has reconfigured not only local extraction and export patterns but also international geopolitical dynamics.

The rise of these Chinese-owned mines in the DRC can be traced back to the early 2000s. As China's economic ascent accelerated, its government encouraged state-owned and private firms to invest abroad in pursuit of resource security. The African Copperbelt, which passes through southern DRC and contains some of the world's richest reserves of copper and cobalt, became a focal point of this effort. By 2007, landmark deals were struck, such as a $9 billion Sicomines agreement between the DRC and a consortium of Chinese companies, including Sinohydro and China Railway Engineering Corporation. These deals traded long-term mining access in exchange for investments in local infrastructure, although delivery on these promises has fallen short, according to the Council on Foreign Relations. An agreement announced in January 2024 commits the Chinese businesses to a $7 billion investment in the DRC's mining infrastructure, underscoring the continuing evolution of these arrangements.

Unfortunately, the risks of human rights violations in these mines are extremely high. Much of the mining at these industrial mines is performed by "artisanal miners," freelance workers who perform the mining using shovels or pickaxes in chemically toxic environments for the equivalent of a few US dollars per day. Artisanal mining is prohibited by law, but is still present at most mines in the DRC. Miners are often physically abused, sexually harassed, and discriminated against based on their race or gender.Studies have revealed that many of these labor rights violations have been committed in several Chinese-owned mines, including the Kamoto Mine, the Tenke Fungurume Mine, Sicomines, Metalkol Roan Tialings Reclamation (RTR) Mine, and Dewiza Mine.

The significance of the expansion of these mines is far-reaching. Chinese firms control or hold majority stakes in almost three-fourths of cobalt and copper mines in the DRC, including the Sicomines Copper-Cobalt Mine, the Tenke Fungurume Mine, and the Kisanfu Mine. The consolidated Chinese presence now accounts for an estimated 70% of the DRC's cobalt exports and a substantial share of its copper production, effectively shaping global market prices and supply reliability.The DRC itself produces more than 70% of the world's cobalt and about 10% of its copper, making the country indispensable to the global economy.

The development and expansion of these mining projects have dramatically increased mineral output. For instance, Sicomines' annual copper production more than doubled between 2017 and 2023, rising from 115,000 to over 206,000 metric tons, while cobalt output has also grown sharply. Similar trends are evident in the China Molybdenum Co. Ltd (CMOC)-owned Tenke Fungurume and Kisanfu mines, which now rank among the world's largest producers of copper and cobalt.

US economic and national security depend on the secure supply of cobalt and copper. However, since the late 20th century, the US has been import dependent, both on Chinese direct imports and imports from other countries originating from Chinese production or refinery sites.

Cobalt is an important material in the production of lithium-ion batteries. The omnipresence of these batteries is felt in everyday life, powering phones, laptops, tablets, and electric vehicles (EVs). Lithium-ion technology is a crucial component of America's expanding EV market and clean energy implementation more broadly. Moreover, cobalt alloys are unique in their resistance to extreme heat, which enables their use in military-grade technology, aircraft engines, and space technology.

Copper is also critical for its ability to conduct electricity, a capacity that has become increasingly important with the development of energy intensive technologies like artificial intelligence (AI). A modern electric grid, with the capacity for AI data centers, will be possible only with a secure supply of copper. Copper's conductivity, ductility, efficiency, and recyclability position it as integral to alternative energy sources, notably solar and wind. To meet rising energy demands and provide the infrastructure for their delivery, the US relies on copper.

FACILITY BACKGROUND

Sicomines

Sicomines is a copper and cobalt mine located in the Mutshatsha Territory of the Kolwezi District, within the Lualaba Province in southeastern DRC. It is a joint venture between Chinese companies that retain a 68% stake, and Congo's state mining company. The mine was created in 2007 after the DRC, under President Kabila, signed an agreement valued at around $9 billion US that gave the companies exploitation licenses to extract the minerals; in return, the companies were expected to invest about $3 billion into infrastructure.

By 2016, however, China had only spent about $750 million on infrastructure development, significantly below its initial promise of $3 billion. Moreover, a state auditor from the DRC claimed that the mines, now estimated to be worth at least $93 billion, had been significantly undervalued at the signing of the 2008 agreement. This was in no small part due to the initial agreement's lack of a formal estimation of the reserves and the DRC's limited negotiating power given their need for the funds. As a result, by January 2024, DRC President Tshisekedi had secured a new agreement with several amendments, including an increased infrastructure development fund of $7 billion. Though the agreement failed to increase the government's equity stake in Sicomines, it included that China would be responsible for royalty payments to the government.

Sicomines has 8.1 million metric tons of copper reserves and 0.5 million metric tons of reserves, and has consistently grown in its annual production. In the first half of 2016, Sicomines produced 28,000 metric tons of copper, on track to produce 82,000 metric tons by the end of the year. By 2023, the mine's annual output was 206,612 metric tons of copper and 5,951 metric tons of cobalt, contributing to the $3.83 million in direct cobalt imports from China that the US received that year, as well as the likely tens of millions in indirect imports that ultimately originated from Chinese-owned mines.

Tenke Fungurume Mine

Tenke Fungurume (TFM) is one of the world's largest copper-cobalt mines, located in the Lualaba Province of the DRC on a concession spanning 1,500 square kilometers. Considered the world's fifth-largest copper mine and second-largest cobalt mine, TFM is a cornerstone of the global supply chain for critical minerals essential for clean energy technologies. Its reserves are estimated at 176.8 million metric tons, with high-grade ore grading 2.1% copper and 0.30% cobalt.

The mine's ownership transitioned decisively to Chinese control between 2016 and 2019. China Molybdenum Co. Ltd (CMOC) acquired a 56% stake from US-based Freeport-McMoRan in 2016 and consolidated its control by purchasing the remaining private shares in 2019, achieving an 80% ownership stake. The remaining 20% is held by the DRC's state-owned mining company, Gecamines. This acquisition placed a strategically vital asset under the control of a leading Chinese company, aligning with Beijing's goal of securing upstream resources for its dominant electric vehicle and battery manufacturing industries.

Under CMOC's control, TFM has undergone aggressive expansion. After an initial expansion phase from 2011-2013, CMOC launched a third expansion in 2021 with a $2.51 billion investment aimed at doubling production capacity. This investment boosted output to 280,297 metric tons of copper and 21,592 metric tons of cobalt by 2023. CMOC has set an ambitious target to raise the combined annual output from TFM and the nearby Kisanfu mine to between 800,000 and 1,000,000 metric tons of copper by 2028, which would solidify its position as a top global producer.

However, this expansion has been accompanied by significant political and social challenges. A major dispute over royalty payments erupted in 2022, leading the DRC government to halt TFM's exports for nearly a year. The dispute was resolved in April 2023 after CMOC agreed to pay Gecamines $800 million. Additionally, TFM has faced scrutiny over environmental practices, though it became the first mine in Africa to receive "The Copper Mark" ESG certification in 2024, signaling a commitment to responsible mining practices.

Kisanfu Mine

The Kisanfu Mine (KFM) stands as one of the world's largest and highest producing copper and cobalt mines, playing a pivotal role in both local and global supply chains. The mine is located in the African Copperbelt, the largest and most productive sediment-hosted copper province in the world, which contains over 5 billion metric tons of copper ore and significant cobalt concentrations, accounting for nearly half of all copper in sedimentary deposits globally. And as of 2024, the mine was producing 136,000 metric tons of copper.

The Kisanfu Mine is operated by China Molybdenum Co. Ltd (CMOC) Kisanfu Mining SARL, which is 95% owned by KFM Holding and 5% owned by the government of the DRC. KFM Holding itself is 75% owned by CMOC Group Ltd. and 25% by Contemporary Amperex Technology Co., Ltd (CATL). In other words, CMOC Group has a 71.25% stake in the mine, Contemporary Amperex has a 23.75% stake, and the DRC maintains a 5% stake. In addition to the Kisanfu Mine, CMOC-the world's leading producer of copper and cobalt-has an 80% stake in Tenke Fungurume Mining SA.

METHODOLOGY

This project started with a comprehensive overview of the African critical mineral supply chain, studying the role that China played in both the production and refining of critical minerals such as graphite, cobalt, and copper in ten of the top African producers by country. Based on the especially large proportion of copper and cobalt output controlled by Chinese companies in the DRC, this study was narrowed to the country and then further to the Lualaba Province, which is where the majority of the cobalt and copper production is located within the country.

This project will analyze the recent physical developments in three DRC mines: the Kisanfu Mine, the Tenke Fungurume Mine, and the Sicomines. These mines were chosen because they produce high levels of cobalt and copper in the DRC, and all had Chinese-owned companies as the majority stakeholders. This is why other large mines like the Frontier Mine-which is owned by the Luxembourg-based Eurasian Resources Group- or low producing Chinese mines-like Miniere de Kalumbwe Myunga (MKM) were not included. Moreover, each of the selected mines also underwent significant recent on-the-ground developments, which could potentially be indicative of current or future changes in other similar mines.

To maximize the amount of usable data, this research combines open source Google Earth satellite imagery with commercially available Maxar Technologies imagery. The analysis gives an overview of the types of equipment, infrastructure, and activity that exist in the mine. In addition, this investigation tracks the developments over time, including physical expansions, signs of construction, and varying levels of activity to determine if the mine is expanding operations and ramping up output. This analysis also examines past indicators of expansion, such as the clearing of forestry, to predict whether an expansion is planned in the future.

The satellite data analysis is then complemented by background research. Using verified sources, this research examines the mine's recent production outputs, any relevant political developments or legislation, the major stakeholders (including Chinese-owned companies), and any other pertinent factors. The background research helps to contextualize the satellite data analysis and provide a more comprehensive understanding of the causes for the developments within a particular mine.

DRC MINE ANALYSIS

Sicomines

Description and General Trends

The Sicomines campus covers an area of around 11.5 square kilometers, divided into several sections. The westmost section contains the tailing storage facilities (TSF), which are structures designed to contain the residue produced from the extraction and processing of the cobalt and copper minerals. To the east and southeast of the TSF are two waste dumps where waste rock, or rock without valuable minerals, is placed.

The power station, worker facilities, and ore processing facilities are located in the northern area of the mine. In the central and western part of the mine, there are two mining extraction sites: the Dikuluwu Open Pit and the Mashamba West Open Pit. These are the primary spots for the extraction of the copper and cobalt minerals. Finally, in the southeastern part of the mine, there is a freshwater reservoir.

Figure 2. Overview of Packaging Sites and Trucking Plot, © 2025 Maxar.

The ore processing facility has at least four sites with packaged cobalt and copper. Two of the sites are located on the western sides of the ore processing facility, with Packaging Site #1 located at the westmost side and Packaging Site #2 located approximately 200 meters eastward. Packaging Site #3 is located on the northeastern side of the mine, close to the worker facilities.

Packaging Site #4 is located south of the third site, near the access gate, as shown in Figure 2. This is likely the final station before the packaged cobalt and copper are shipped, given the dozens of transport trucks, high level of car activity, and the location right next to the exit out of the mine. Moreover, between August 21, 2024, and April 30, 2025, a new trucking plot was paved, which would allow for more transport trucks to reside. It is likely this was an attempt to increase their ability to transport packaged copper and cobalt quickly.

Finally, there were several other markers of high levels of activity across the campus. The worker dormitories section consists of 100+ buildings, which, combined with additional reports, means that approximately 3,000 individuals were employed at this mine. There

Figure 8. Leaching Tank, May 2024-April 2025, © 2024 Maxar, © 2025 Google Earth

are multiple mining drainage pools distributed throughout the campus, which show there had to be a large level of mining production, given that these pools are formed from the interaction of mining activity with water. There are also several haul and regular roads connecting the different sections of the mine, which points to a need to accommodate a high level of intra-mine traffic.

Notable Developments

Leaching is the process of extracting minerals from ore by dissolving them to separate useful minerals from the insoluble ore. Stirred leaching is the kind of leaching that typically occurs in a leaching tank, using a stirring leaching device. Between August 21, 2024, and April 30, 2025, a probable leaching tank was added to the Sicomines campus Because stirred leaching is often used for high-grade copper ores, the addition of this structure would likely mean the mine is moving towards more strongly prioritizing high-grade copper production.

Additionally, three probable fuel tanks or liquid containers were added. A conveyor belt was also added, connecting the leaching tank and the building to the other structures in the mine, likely to move the ore and minerals to the different processing sites within the mine. Finally, there is a newly paved road that did not exist on May 28, 2024, but construction likely started by August 21, 2024, and was finalized by April 30, 2025.

Figure 9. Additional Equipment, May-August 2024, © 2024 Google Earth

Figure 10. Fence and Haul Road Construction, May-July 2024, © 2024-2025 Maxar.

Between May 8, 2023, and August 21, 2024, several buildings, vehicles, and pieces of equipment appeared on a piece of land-approximately 7,000 square meters in size-that was previously not in use In the southwestern area of the newly used land, there was a line of thirteen probable passenger trucks and cars. Throughout this plot, there were also three buildings constructed: one small one in the southwestern area to the west of the passenger cars, one large rectangular building around the center of this plot, and one small building approximately 20 meters north of the central rectangular building. Around the center of the added plot, there are about three mining trucks and two large containers. Finally, in the northern area, there were several pieces of equipment. In short, the usage of this previously unused land demonstrates an expansion in the operations of the mine.

Between May 28, 2024, and July 26, 2025, a probable fence was constructed, as demonstrated by the defined line encircling this compound and the shadow that can be observed when the image is closely examined. There are also cars present on recently constructed haul roads, and approximately ten mining trucks are parked in the southeast area of this compound. The haul roads connect to the larger roads connecting the mine, but due to the lack of construction, this compound will likely be used simply as additional space to park cars and equipment for the immediate future. Ultimately, this development is another example of how this mining campus is expanding and increasing operations.

Another key development to note is the growth of the mining drainage pools, the water that comes into contact with, and drains from, active or inactive mining operations. For most of 2023, the mining drainage areas in this area had been relatively minimal, with the general amount of water produced remaining relatively constant up through May 28, 2024. By August 21, 2024, these pools seemed to have dried up, but by April 30, 2025, not only had the pools returned, but they had expanded into a full river.

Changes in mining pool volume raise the question of whether precipitation played a role in compounding the effects of these mine pools, especially given that June to August are the dry seasons in the DRC. However, it's important to note that the southern region of the DRC, including the Lualaba Province, experiences less precipitation than other parts of the country. Moreover, even if one assumes that the lack of mining drainage in August 2024 is the result of a lack of precipitation, there is still a massive increase in mining pool volume before April 30, 2025, in relation to previous years. As a result, our team assesses that there was likely a spike in operations in the months preceding April 30, 2025.

In total, Sicomines is showing signs of several developments. First, there has very likely been a substantial increase in operations. An increase in mining pool area, the increase in equipment on previously unused land, and the construction of intra-mine infrastructure all show that Sicomines is scaling up operations. Finally, the addition of leaching tanks means they are likely also increasing their on-site processing capacity, specifically for high-grade ores.

Tenke Fungurume Mine

Description and General Trends

The TFM campus is a vast industrial complex comprising multiple open pit mines, extensive processing facilities, and logistical support areas. The primary extraction sites include the Kwatebala and Mwadinkomba pits, which are connected by a dense network of haul roads.

The heart of the operation is the modern Solvent Extraction Electro-winning (SX-EW) facility, where ore is processed into 99.99% pure copper cathodes and cobalt hydroxide. Key components of this facility, visible in satellite imagery, include a grinding and milling circuit, massive circular thickeners for separating ore concentrate from waste liquid, and a long EW tankhouse for final metal plating. The site is also characterized by sprawling waste rock dumps and tailings storage facilities (TSFs) that have expanded in tandem with production increases.

Figure 12. Tenke Fungurume Campus Overview, AidData, March 2023.

Notable Developments

Satellite imagery confirms a period of intense and continuous expansion across the TFM site, aligning with CMOC's publicly stated investment goals. Analysis of the TFM Equipment Management Department reveals a significant increase in logistical operations. Imagery from mid-2024 shows a heightened presence of haul trucks and other vehicles compared to previous years. This area expanded spatially by over 1.2 square kilometers between July 2022 and June 2023 alone, which signifies a major scale-up of mining and transport activity needed to feed the expanded processing plants.

The mine's ancillary and logistics hub saw significant development between November 16, 2023, and June 25, 2025. The most prominent change is the construction of a large, white-roofed building, likely a new workshop or warehouse, which is absent in the November 2023 and June 2024 imagery. Additionally, the ground throughout the site appears more developed and graded in the June 2024 and June 2025 images, and stockpiles of materials like heavy-duty tires seem to have increased. This activity points to an investment in the mine's support infrastructure, which is essential for sustaining the higher operational tempo required by the ongoing production expansion.

Another key detail to note is the dynamic activity within the secondary tailings and sedimentation pond. This area is actively used to manage the site's water balance and for cyclical tailings deposition and drying. Satellite imagery clearly captures these fluctuations. In November 2023, the pond showed a large, bright, and mostly dry "beach" of deposited tailings. By June 2024, after a period where the area was largely submerged in murky brown water in late 2023, the pond had receded again. This cyclical activity reveals that the pond is a critical component of the mine's water and waste circuit, adapting to the needs of expanded processing operations.

Overall, the developments demonstrate that TFM experienced a period of significant growth between 2022 to 2025. Between 2022 and 2023 alone, there was a substantial increase in equipment, infrastructure, and facilities, showing that the mine was increasing its operations. This trend continued with the construction of at least one building and other pieces of equipment at the logistics hub of the campus between 2023 and 2024. Finally, the activity of the secondary tailings pond gave additional evidence of a considerable expansion in the past few years.

Figure 13. TFM Equipment Management, June 2022-2024, © 2024 Maxar.

Figure 14. Expansion of the Logistics and Maintenance Hub, November 2023-June 2025, © 2023 BlackSky Global LLC & © 2024 & 2025 Maxar.

Figure 15 Overview of Packaging Sites and Trucking Plot, © 2025 Maxar.

Figure 16. Overview of Kisanfu Mine, June 2025 © 2025 Maxar.

Kisanfu Mine

Description and General Trends

The Kisanfu mine, operated by CMOC, spans over 20 square kilometers. The mine is divided into at least six main functional areas: an extraction site, a mineral processing plant, two sets of waste rock dumps, and two tailings storage facilities (TSF).

The extraction site is located in the middle of the mine, surrounded by haul roads to allow for the easy transportation of raw mined materials to the other stations within the mine. One of these roads goes to the mineral processing plant, which is located on the eastern side of the campus. Next to the processing plant is one of the two TSF; the other is located on the southwestern side of the mining campus. Finally, there are two sets of waste rock dumps located on the northwestern side and the south-central side of the mine.

Notable Developments

Circular thickeners play a critical role in mineral processing by separating ore concentrate from waste liquid, thereby producing a more refined material for further treatment. Between May 29, 2023, and June 25, 2025, satellite imagery reveals that six large circular thickeners were constructed. The intermediary photos showing the thickeners without lids and the surrounding construction vehicles further provide evidence of ongoing work, and the building of the thickeners demonstrates the mine's push to scale up processing.

Figure 17. Circular Thickeners, May 2023-July 2025, © 2023 Google Earth, © 2025 Maxar.

Another significant addition between May and July 2024 was a rectangular structure whose highly reflective surface, as captured in imagery, demonstrates it may have been constructed from metal. While its exact function remains uncertain due to limited image clarity, its design and placement reveal that it is likely a conveyor belt system. Such equipment is essential for transporting raw ore from extraction zones to processing facilities, further pointing toward an effort to streamline and accelerate ore processing.

Satellite imagery from the same May-July 2024 period shows the emergence of a blue-roofed facility. This structure was not present in 2023 and appears to have been completed with the addition of a roof by mid-2024. Based on its design, particularly the white circular features resembling fans, it is likely an industrial mine cooling system, which would imply an expansion of underground mining operations, as coolers are critical to maintaining safe temperatures in subterranean shafts. The addition of such infrastructure highlights CMOC's commitment to deeper extraction, expanding the scale and depth of Kisanfu's mining activity.

Figure 18. Conveyor Belt System, May 2024-June 2025, © 2024-2025 Maxar

Another development occurred where satellite comparisons between May and July 2024 revealed a transition from dry land to water-filled basins (see Figure 20, Water Basin). These changes are consistent with increased mine drainage, which typically results from expanded mining activity that exposes and interacts with groundwater sources. Drainage accumulation provides indirect evidence of heightened operations, as intensified extraction often leads to elevated water management challenges. As a result, this further demonstrates a significant increase in mining operations throughout this period.

Figure 20. Water Basin, May-June2024, © 2024 Maxar.

Figure 21. Tailings Storage Facility, May 2023-July 2024, © 2023 Google Earth © 2024 Maxar.

Figure 22. Land Clearing, May-July 2024, © 2024 Maxar.

The expansion of waste storage facilities is also visible. A new TSF was established between 2023 and 2024, reflecting the mine's rising output (see Figure 21, Tailings Storage Facility). Because tailings storage is essential for managing the residue from ore processing, the creation of another TSF underscores both the scale of recent production and the environmental demands of accommodating larger volumes of waste.

The clearing of land and vegetation was observed between May and July 2024 (see uyr 22, Land Clearing). Although uneven and somewhat irregular, this clearing may indicate preparation for future mine expansion, whether through additional infrastructure or extended extraction zones. Such preemptive land-use change is often a precursor to large-scale construction or operational shifts.

Similarly, imagery shows the waste rock dump expanding in two stages: first between May and July 2024, and again by June 25, 2025. Waste rock, which lacks economically valuable minerals, inevitably grows in volume alongside productive extraction. Its expansion, therefore, mirrors the overall increase in mining intensity.

Taken together, these developments illustrate a period of rapid expansion at Kisanfu between 2023 and 2025. The addition of processing capacity through new thickeners, the likely installation of a conveyor system, the possible construction of underground cooling infrastructure, the creation of new tailings storage, the accumulation of mine drainage, and the steady growth of waste rock deposits all point toward one conclusion: CMOC is not only sustaining but actively scaling up its operations at Kisanfu. These physical changes reflect both immediate increases in production and preparation for continued long-term growth, further entrenching Kisanfu's role as one of the most important copper-cobalt mines in the world.

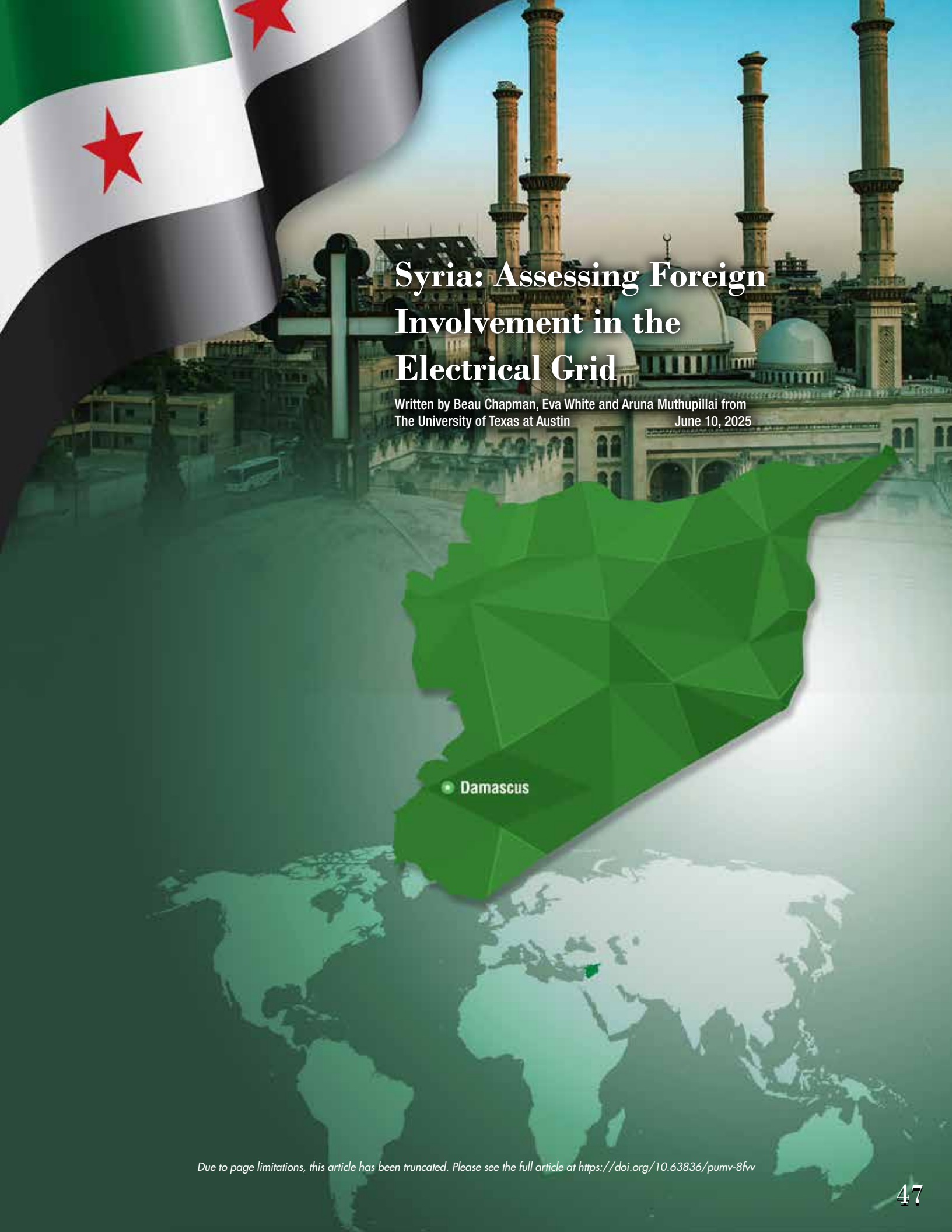
CONCLUSION

Satellite imagery of the three mines shows that Chinese companies are rapidly increasing ore production on each of their campuses. Each of the mining facilities is adding intra-mine infrastructure, equipment, and vehicles that will allow them to rapidly scale up operations in the coming years. Increase in the volume of water basins and mining drainage pools, as well as expansions of waste rock dumps, provide further evidence that the production levels of the mines are increasing at a notable rate.

In addition to increasing raw production levels, Chinese-owned mines in the DRC seem to be significantly expanding their on-site processing capacity. Imagery has tracked the construction of circular thickeners, conveyor belt systems, and other similar processing equipment.Moreover, the construction of additional tailings storage facilities and leaching tanks provides additional evidence that these mines are looking to maximize their processing power.

Finally, Chinese-owned mines in the DRC are looking to the future. Historically, the clearing of forestry has served as an accurate indicator of a future expansion of operations. There have been several instances of forestry clearance across mines, which means that mines likely have future expansion plans on the way.

It is important to note that more information is needed to determine whether these patterns of expansion are unique to Chinese-owned mines or are being witnessed at other major mines as well. Either way, based on these visual indicators for increased ore production, greater on-site processing capacity, and integration of renewable imagery, these mines could help China solidify its dominance in the cobalt and copper supply chains. ■



Syria: Assessing Foreign Involvement in the Electrical Grid

Written by Beau Chapman, Eva White and Aruna Muthupillai from
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SUMMARY

This study analyzes the impact of the Syrian Civil War and the fall of the Assad government on Syria's energy infrastructure and foreign investment in the energy sector. Using satellite imagery and open source intelligence, this report finds with moderate confidence that Iran's role in the energy sector has decreased; that alternate regional powers have explored investment opportunities with limited progress; and that electricity availability in major cities has seen no observable improvement.

The report outlines two potential futures: Future 1 envisions increased foreign investment driven by eased sanctions and government stability, with countries pursuing projects like gas pipelines and oil field development. Future 2 predicts continued instability due to groups like ISIS and ongoing factional conflicts that deter foreign investment. Key indicators to monitor include power plant construction, initiation of proposed projects, electric grid improvements, and government stability.

ACTIVITY

This report uses satellite imagery and open-source intelligence (OSINT) to assess countries' involvement in the Syrian energy sector. When possible, satellite imagery is obtained from publicly accessible sources like Copernicus Hub or Google Earth. In some instances, commercial Maxar imagery provided the most recent data or data for a date/time not available through public imagery. OSINT collected from think tanks; local, regional, and international news outlets; and social media sites, like X, Facebook, and Instagram, provided valuable information on projects that have not begun construction and are therefore not visible on satellite imagery.

BACKGROUND

The Syrian Civil War that began in 2011 devastated the country's critical energy infrastructure. Militant groups consistently targeted power plants, and in 2021, power consumption levels were 15% of those measured in 2010, according to Reuters and the United Nations Development Programme. In a May 2024 interview with Chinese state news, Syria's Minister of Electricity Ghassan Al-Zamel reported that the cost of war on the electricity grid was around USD $40 billion, and that more than half of the electric infrastructure was destroyed.

To repair the power grid, Assad's government opened the door for foreign countries to aid in the reconstruction process. Russia invested in Syria's oil and gas fields and signed a contract for the rehabilitation of key Syrian power plants, according to think tanks, regional news, and Syrian state news. Iran also heavily invested in the energy sector. Iran was a main source of oil and gas for Assad's government, and signed Memorandums of Understanding (MoU) with Syria for the repair of the Aleppo, Al-Taim, Jandar, and Tartus Power Plants, as well as the construction of a new power plant near Latakia as reported by the European University Institute and Reuters.

However, in late November 2024, a rebel offensive was launched in Syria. By December 8, 2024, resistance groups had swept through the country and overthrown the government, causing President Assad to flee to Russia. As a result, Iranian shipments of oil and gas were stopped, leading the oil refinery in Baniyas to halt operations. Iran's decreased presence in the country created an opportunity for other countries to increase their investment as the new government sets the goal of 24-hour electricity availability.

METHODOLOGY

In addition to satellite imagery and open-source intelligence (OSINT) as outlined in the Activity Intro, this report also uses nighttime light imagery obtained from NASA to assess the current state of Syria's electricity grid. We charted average levels of nighttime light brightness from Damascus and Aleppo, Syria's two biggest cities, from September 2024 to March 2025. A line of best fit was then generated to clearly visualize the overall trend. One point was excluded from the graph and the line of best fit calculation where data for more than half the defined area of interest was missing.

DISCUSSION

We assess with moderate confidence that:

- The fall of the Assad government has decreased Iran's involvement in Syrian energy projects.

- Jordan, Turkey, Qatar, Russia, and Saudi Arabia seek investments in Syrian energy projects, but, so far, have made little concrete progress.

- Electricity availability for the people of Syria has not improved since September 2024.

Decrease of Current Iranian Involvement

Iran worked on numerous power plants in Syria, but only power plant projects in the cities of Latakia and Aleppo were ongoing up until the fall of the Assad government on December 8, 2024.

Latakia

On September 12, 2017, Syria's then-Minister of Electricity, Muhammad Zuhair Kharboutli, and Iran's Ministry of Energy signed an MoU to bring Iranian expertise and investment to the country. The MoU included the construction of a 540-megawatt (MW) gas-fired power plant on the outskirts of the port city of Latakia. According to state media, Iran's MAPNA Group, a conglomerate of Iranian manufacturing, power, and engineering companies, obtained the contract to build the power plant from the Syrian General Electrical Generating Corporation (PEEG) on October 2, 2018.

After over five years of construction, MAPNA Group announced on November 5, 2024, that they had "provisionally handed over" the second gas unit to Syria's PEEG. A provisional handover refers to completed construction that fulfills the requirements of a contract. Rebel groups took over Latakia province on December 9, 2024, and it is unclear if MAPNA Group remains present on site.

Since the fall of the Assad government on December 8, 2024, the latest available imagery from January 14, 2025, shows no significant changes at the site, indicating that the construction process has been paused.

Figures 1 and 2 show the construction progress made from 2019-2024.

Aleppo

The 2017 MoU between Minister Kharboutli and Iran's Ministry of Energy also included an agreement to repair two turbines at the Aleppo Thermal Power Plant. According to Iranian state media, in June 2022, engineers from the MAPNA Group repaired the plant's fifth unit, and in October 2023, they repaired two additional units. Commercial satellite imagery seen in Figure 3 shows steam appearing from two of the stacks at the Aleppo Thermal Power Plant after the date of the repairs, indicating that the units are likely in operation.

Prior to November 2024, Iranian state media claimed that Iran had reaffirmed their commitment to rehabilitate the remaining three units of the Aleppo Thermal Power Plant. However, since rebel groups took over Aleppo Province on November 30, 2024 there has been no further reporting to indicate whether MAPNA Group has continued their work at the plant. On December 17, 2024, a Lebanese news source reported that the Iranian Foreign Ministry spokesman Esmail Baghaei urged the new Syrian government to abide by the previously signed agreements, treaties, and MoUs. The spokesperson for the National Security and Foreign Policy Commission at the Iranian Parliament stated on May 27, 2025, that Syrians are demanding Iranian contractors return to the region, according to Iranian reporting. No official response from the Syrian government has been reported at this time.

Increase in Alternative Foreign Involvement

As Iran's presence has diminished, additional countries have sought to increase their regional influence. Jordan, Turkey, Qatar, Russia, and Saudi Arabia have sought investments in Syrian energy projects, but we assess with moderate confidence that they have made little concrete progress so far.

Jordan

On January 7, 2025, Syrian news sources and Attaqa reported on a bilateral meeting held between the Jordanian Minister of Energy Saleh Al Kharabsheh, Syrian Minister of Mineral Resources Ghiyath Diab, and then Syrian Minister of Electricity Omar Shaqruoq. Kharabsheh stated that Jordan was ready to supply Syria with around 250 MW of electricity daily through the 400-kilovolt(kV) transmission line connecting the two countries, but according to the Middle East Monitor, the line has been out of operation since 2012 and Syria is not able to receive electricity. In January 2025, a technical team from Jordan was preparing to inspect the Syrian power line to determine how long the proper repairs would take, though until repairs occur the electricity will not be transmitted. The process is expected to take up to six months.

The Jordan-Syria transmission line connection is located at the Nasib Border Crossing. Lines stretch from the Deir Ali Power Plant near Damascus, through Nasib, and connect to the Jordanian electricity grid at the North Amman Power Station.

Media on social networks and news outlets show workers from the Jordanian "Irbid District Electricity Company" working on energy infrastructure in Syria.

Figure 1: Annotated imagery of the preparations for construction of the Latakia Power Plant.

Figure 2: Annotated imagery of the progress made on Latakia Power Plant over five years.

Figure 3: Sentinel imagery showing the restoration of units at the Aleppo Thermal Power Plant.

Figure 4: Annotated imagery showing no visible changes at the Aleppo Thermal Power Plant in 2025.

Figure 5: Mapped electricity lines connecting Jordan and Syria through the Nasib Border Crossing.

Figure 6: A screenshot from a video taken of repairs at the Nasib Border Crossing. Key features marked. Source: Facebook user @Khaled Iskef

Figure 7: Geolocated coordinates of the video. Key features marked.

According to an interview with the Syrian Minister of Electricity Ghassan al-Zamel, and a news site focused on Syrian energy, Syria has struggled to obtain enough fuel to operate their power plants. Al-Zamel claimed that only 28% of the required gas and 45% of the required fuel were being provided dail. In another interview with Interior Minister Al-Faraya on February 7, 2025, it was stated that the Nasib border crossing was being used to supply gas to Syria. Additionally, the CEO of Jordan Petroleum Refinery Company, Hassan al-Hayari said that 500 tons of gas were exported to Syria every day, according to independent Syrian reporting.

Qatar

In January 2025, the Jordanian Minister of Energy proposed using the Floating Storage Regasification Unit (FSRU) in Aqaba, connected with the Arab Gas Pipeline, to supply Syria with the gas required to fuel their power plants, according to an announcement reported by Arab news outlets. Figure 8 shows the FSRU in Aqaba, Jordan.

Figure 8: Floating Storage Regasification Unit (FSRU) in Aqaba, Jordan. April 29, 2023

On March 13, 2025, it was announced that Qatar would fund the provision of gas to Syria through the Arab Gas Pipeline from the Aqaba port in Jordan, to the Deir Ali Power Plant near Damascus. The fuel would increase the plant's output by 400 MW, and the Syrian Minister of Electricity confirmed the deal, estimating that it would allow for 2-4 more hours of electricity per day, doubling the previously allotted 2 hours, according to various news sources and the UNDP We have found no evidence that these shipments have started or have resulted in an increase in hours of electricity per day.

On January 16, 2025, Qatar's Prime Minister, Mohammed bin Abdulrahman bin Jassim Al Thani, met with Syria's president, Ahmed al Sharaa, to discuss efforts to reactivate damaged energy infrastructure in Syria. Qatar committed to supplying Syria with an initial 200 MW of electricity as part of the agreement, with plans to gradually expand the capacity across more than ten regions, according to Qatar's Ministry of Foreign Affairs.

In March 2025, Reuters reported that Qatar is also working with Turkey to provide electricity to Syria through two floating power ships. In total, the two ships will provide 800 MW of electricity according to the Syrian director general of the General Establishment for Electricity Transmission and Distribution. He did not specify over what time period the ships would be operating. The decision to send the energy ships came only after the U.S. granted sanction waivers for energy sales with Syrian state institutions for six months.

As of March 13, 2025, the ships have not been sent, and no timeline has been set for their use in Syria, according to social media. The Syrian Minister of Electricity has claimed that the ships may never arrive because of financial and logistical challenges, an independent Syrian news source reported. They are not visible in any of Syria's major ports in the most recent available imagery.

On May 29, 2025, news sites reported that Syria signed an MoU valued at USD $7 billion with several international companies led by Qatar's UCC Holding. This agreement aims at developing major power generation projects, including four combined-cycle gas turbine power plants in eastern and central Syria and a solar power plant in the south. These projects are anticipated to be completed in three years and are expected to provide over half of Syria's electricity needs.

Figure 10: An image of a tanker matching the dimensions of the Aquatica. March 22, 2023.

Figure 9: An image of a tanker matching the design and dimensions of the Sakina near Baniyas.

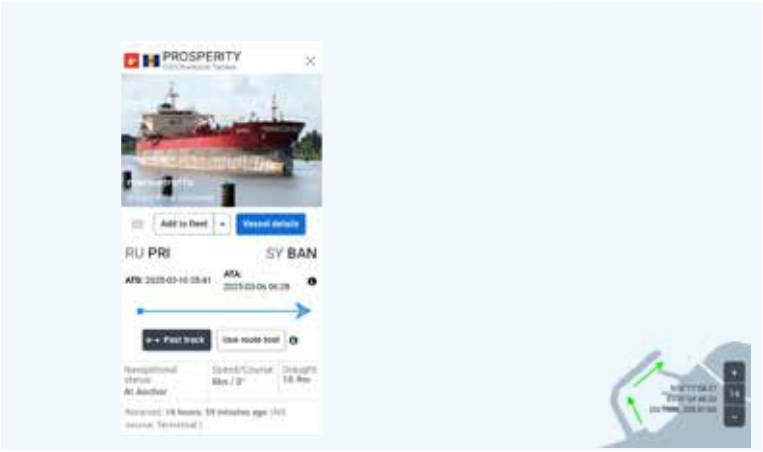


Figure 11: AIS data of the Prosperity's location near Baniyas on March 5, 2025. Source: Daraj Media

Russia

In March 2025, U.S.-sanctioned Russian crude oil tankers Aquatica and Sakina reportedly provided Syria with around 200,000 tons of oil, according to independent Syrian reporting and Reuters. Satellite imagery in Figure 9 shows a ship with the same dimensions and design as the Sakina anchored near Baniyas around the date of the reported delivery, though we are unable to confirm this is the Sakina. Baniyas is home to the Baniyas Oil Refinery, the largest oil refinery in Syria.

Sentinel imagery in Figure 10 from March 22, 2025, also shows a ship matching the dimensions of the Aquatica's near Baniyas around the date of the reported delivery. However, imagery lacks enough resolution to determine if the design of the deck aligns with publicly available images of the Aquatica.

On March 6, 2025, the U.S.-sanctioned Russian tanker Prosperity arrived at Baniyas carrying 37,000 tons of diesel, according to Reuters. There is no available imagery of the anchored ship, but Automatic Identification System (AIS) data shared on a regional news outlet places it near Baniyas a day before the Reuters report.

According to the International Energy Agency, over 99% of Syria's total energy supply in 2022 came from oil and natural gas. This increase in oil and gas imports has the potential to increase output for Syria's power plants requiring additional fuel.

Turkey

After the fall of Assad's government in December 2024, a delegation from Turkey's energy ministry was set to visit Syria to address energy challenges, according to a Turkish news agency. On January 10, 2025, Energy Minister Bayraktar stated that Turkey was developing business models to integrate the private sector in supporting Syrian electricity, and that natural gas could be provided to assist in electricity generation.

As of January 2025, Turkey plans to export 500 MW of electricity to Syria, according to Arab news outlets reporting on statements Bayraktar made during the 15th session of the General Assembly of the International Renewable Energy Agency (IRENA). At the same event, Bayraktar also stated that Turkey already supplies 210 MW to Syria daily, distributed through seven different points with plans to increase it to 300 MW by February 2026.

Additionally, Reuters reported that Turkey is the supplier for the previously mentioned plan to provide two floating power plants Syria with 800 MW of electricity. Turkish company "Karpowership", which has 40 power ships in their fleet, according to their website, would supply the ships. There is no reporting or imagery indicating that these ships have arrived or are on their way to Syrian ports.

In a news conference on January 30, 2025, Alparslan Bayraktar announced plans to build a 50-60 km gas pipeline to Aleppo to provide energy to power plants, increasing electricity supply by 50%.

The pipeline was slated to take 12-15 months to construct. Turkish officials also suggested the pipeline could eventually operate in reverse, enabling Syrian gas to flow north into Turkey, according to an Arab satellite news site.

According to Turkish state media, Turkey's Energy and Natural Resources Minister Alparslan Bayraktar announced that as of May 21, 2025, a natural gas pipeline between Kilis and Aleppo (distance 50-60km) was completed. However, testing and installation of equipment are ongoing, and natural gas will not be exported until June According to Syrian state media, this pipeline will connect to the Aleppo Thermal Power Plant. Turkish state media reports that six million cubic meters of gas will be supplied daily to fuel Syrian power plants, adding an estimated 1200-1300 MW to the grid. This project is part of the Arab Gas Pipeline Project, which is located underground, making it difficult to observe construction on satellite imagery.

According to Syrian state media, on May 22, 2025, an agreement was signed to connect Syria and Turkey with a 400-kV transmission line capable of sending 80 MW of electricity. The Syrian energy sector's chief Mohammed al-Bashir stated in a joint press conference that the transmission line is expected to be in operation by the end of 2025. According to independent Syrian news, the transmission line would link Turkey's Reyhanli District to the Syrian Harim region in the Idlib countryside.

Two Turkish companies are represented in the aforementioned USD $7 billion MoU signed between Syria and Qatar's UCC Holding, Turkey's Kalyon GES Enerji Yatirimlari and Cengiz Enerji.

Saudi Arabia

According to the Atlantic Council, during a meeting between a Saudi delegation led by an adviser to the royal court and the new Syrian president in early January, Saudi Arabia pledged to supply fuel to Syria and replace Iran as Syria's primary oil supplier. A Saudi oil tanker was reportedly on its way to Baniyas as of late December 2024, however we have been unable to confirm this claim with OSINT or satellite imagery. These imports could fuel the Syrian power plants that operate on oil.

Assessment of the Current State of Syria's Grid

Before the fall of Assad's government, the damaged Syrian electricity grid struggled to keep up with demand. Under the new government, Aleppo and Damascus show no signs of increased electricity availability. Figure 12 shows analysis of nighttime light data from September 2024 to March 2025. The data shows no increase in brightness following the collapse of Assad's government.

Nighttime light radiance declined on average in Aleppo and Damascus from September 2024 to March 2025. Additionally, American news reported Syria's persistent energy crisis following the fall of Assad's government, and on April 1, 2025, a nationwide power outage affected the grid. Syria's new government plans to incorporate a three-phase plan to address the problem originating from low access to fuel and maintenance equipment, according to news reports. This approach includes urgent emergency maintenance to provide rationed electricity to the entire population, repairs of power plants and transmission lines, and development of a sustainable "24-hour power supply". No further details were provided on the logistics of this plan.

On February 27, the new government announced plans for a 100 MW solar investment project to be built near Damascus, according to a news report. The project has not yet attracted any investors.

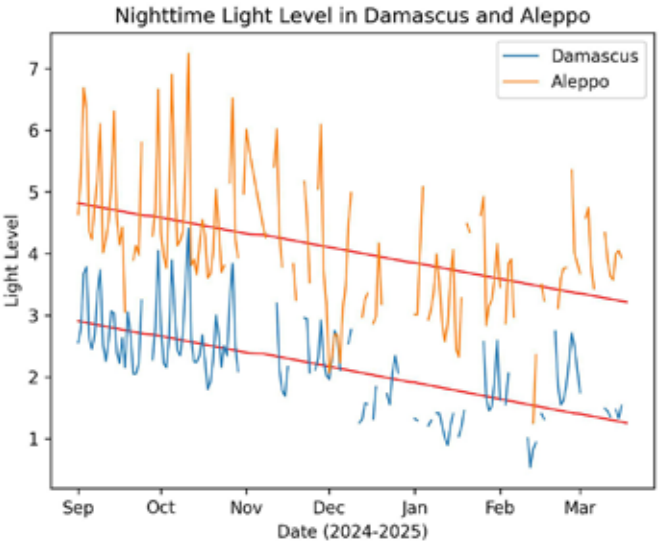


Figure 12: A graph of nighttime light imagery in Damascus and Aleppo from September 2024 to March 2025. Source: NASA Nighttime Lights Data

Possible Futures

With a new government struggling to meet demands, we assess two likely futures for the trajectory of foreign involvement in Syria's energy infrastructure.

Future 1: As sanctions decrease and the new Syrian government remains stable, more countries plan for longer term investment in energy projects.

On May 13, 2025, the President of the United States announced that a plan to lift sanctions against Syria. On April 24, 2025, the U.K. lifted sanctions on services related to energy production, hoping to "facilitate essential investment in Syria's energy infrastructure." Additionally, on May 20, 2025, the European Union (EU) decided to lift sanctions on Syria to aid in the country's rebuilding process.

Turkey-Qatar Gas Pipeline Project

According to Azerbaijani state media, on April 2, 2025, Turkey and Syria reached an agreement to resume construction of a pipeline linking Qatar's North Field gas reserves to Turkey's Trans Anatolian Pipeline (TANAP), which would pass through Syria, Saudi Arabia, and Jordan. A map of this plan is shown in Figure 13. These renewed ambitions for a gas pipeline would provide the EU with cheaper and more reliable imports, according to Turkish state news. The project would potentially provide Syria with easier access to sources of gas, an important source of fuel for their power plants.

However, Turkey's Energy Minister previously confirmed in December 2024 that the project remains dependent on Syria achieving stability, according to a Turkish news agency. As of May 2025, no timeline, capacity estimates, or funding agreements have been finalized.

Figure 13: A map of the proposed Turkey-Qatar gas pipeline. Source: Turkiye Today

Integration into the Arab Energy Network

According to a report from the staff of the International Bank for Reconstruction and Development, Turkey could try to continue integrating Syria's electric grid into the currently stalled "EIJLLPST Interconnection," a broader Arab-Asian-European electricity network. This would connect Egypt, Iraq, Jordan, Lebanon, Libya, Palestine, and Syria to Turkey's electricity grid, positioning Turkey as a regional hub for electricity transmission between the Middle East, Asia, and Europe. For Syria specifically, this would allow increased access to electricity through the new cross-border connections.

Arab Gas Pipeline Revival

The Arab Gas Pipeline, currently links Egypt, Jordan, and Syria. It was originally intended to extend to Turkey, allowing Egyptian and potentially Israeli gas to flow into European markets through Turkey, as seen in Figure 14. According to an Israeli think tank, extension plans were abandoned in 2009 due to financial disputes and Egypt's declining gas exports. International think tanks have speculated that this pipeline could be a part of Turkey's broader energy transit strategy.

Re-establishing the oil pipeline from Syria to Iraq

In the past, Iraq has considered revitalizing the currently defunct Kirkuk Baniyas pipeline to Syria as an alternative to the Kirkuk-Ceyhan pipeline. In October 2023, Iraqi officials claimed that discussions regarding the reconstruction of the 850-kilometer pipeline took place during a two-day meeting between the state-owned North Oil Company in Kirkuk and several local oil companies, according to a London-based news platform. A spokesperson for the Iraqi prime minister claimed that the pipeline would require continued negotiations between the two countries. According to business news, on April 25, 2025, an Iraqi delegation met with the Syrian president. They discussed the technical, financial, and security implications of working to restore the Kirkus-Baniyas pipeline.

This project would provide Iraq with access to the Mediterranean through Syria, avoiding reliance on the current connection to Turkey's Ceyhan port, but costs might exceed USD $8 billion.

Integration with this pipeline would further increase Syria's access to oil, allowing them to fuel their power plants.

Azerbaijan's interest in gas and oil fields

In January 2025, the CEO of SOCAR Turkey publicly signaled the company's interest in Syria, citing the possibility of increased energy demand with stability growth, as reported by Azerbaijani national news. SOCAR (State Oil Company of the Azerbaijan Republic) is

Azerbaijan's state-owned oil and gas company, and SOCAR Turkey is its wholly owned subsidiary based in Turkey, according to regional news and the company's 2022 Annual Report. In April 2025, a meeting between the presidents of Azerbaijan and Syria discussed the possibility of increased involvement in Syria's northeastern oil and gas fields. SOCAR would carry out the development, according to regional news.

Increased Saudi investment

On February 25, 2025, Saudi Arabia announced that it would begin a new shipping service between Jeddah and Latakia, signaling increasing commercial shipping activity under the new Syrian government as well as increased cooperation between the two countries, according to independent Syrian reporting. Additional oil imports could increase the capacity for Syria's oil-fueled power plants to produce electricity.

According to Syrian state media, on April 28, 2025, Syria's Minister of Energy, Mohammed al Bashir met with the Saudi Arabian Ambassador to Syria, Dr. Faisal al-Muifel, in Damascus. Discussion revolved around increasing cooperation in the energy sector and investing in projects that supported the reconstruction of Syria's electricity infrastructure.

Future 2: Decreases in the new government's stability hinder power grid progress and foreign investment opportunities.

Syria's energy infrastructure requires intensive repairs, and a stable government committed to the cause. Failure to achieve full internal sovereignty may further degrade the state of Syria's grid.

Threat of ISIS

ISIS is currently reorganizing in Syria's eastern desert, making use of weapons caches left behind by pro-Assad forces, according to VOA. In the 2025 Annual Threat Assessment, the U.S. Intelligence Community assessed that the fall of Assad's government could lead to ISIS regrouping and taking advantage of instability in Syria. During the overthrow of Assad's government, experienced ISIS fighters also reportedly escaped from Syrian camps, according to the UN.

The group has previously seized oil fields and power plants in Syria and Iraq, using illicit energy sales to finance operations. ISIS has a history of destroying energy infrastructure. In 2021, VOA reported that they bombed a pipeline that supplied gas to Deir Ali and Tishreen power plants.

CONCLUSION

Iran's decreased presence in Syria allows other countries to step in and increase their regional leverage. Since the fall of the Assad government, progress on Iranian-backed energy infrastructure projects in Syria have halted. Satellite imagery shows no progress made in construction or repairs at the Latakia and Aleppo power plants, and the flow of Iranian oil into Syria has stopped. It is important to note that satellite imagery alone cannot completely rule out the presence of Iranian engineers. More substantial OSINT reporting on current events at both the Latakia and Aleppo power plants would provide higher confidence in this assessment.

Tracking foreign involvement offers an early indicator of which countries are aligning with the new government. Jordan, Turkey, Qatar, Russia, and Saudi Arabia have signaled interest to increase their involvement in Syria's energy sector. While Jordan has contributed to infrastructure repairs at the Nasib Border Crossing, many of the proposed projects from Qatar and Turkey have yet to commence. More detailed reporting on planned locations and timelines for proposed projects would allow for closer monitoring with satellite imagery and higher confidence on their status.

The condition of Syria's electricity grid is an important measure of the new government's ability to provide basic services essential for government stability. Charted nighttime light imagery shows an overall decrease in average radiance in Damascus and Aleppo following the government takeover, suggesting the grid has not yet improved. It is important to acknowledge that this imagery is subject to missing data, spans only a seven-month period, and covers just two of Syria's cities. More complete data, comparisons to imagery from previous years, and analysis of additional areas throughout the country would increase confidence.

Disclaimer: This topic is rapidly developing.

CONTINUED FRAGMENTATION

If the new government fails to quell violence and unrest from resistance groups, delays could occur in key energy infrastructure repairs, and the potential for further damage would increase. For instance, according to various news sources, Assad loyalists launched an attack on Syria's coast on March 9, 2025 that targeted the Tartus power plant. Electricity in Latakia was cut as a result of damage to a 230-kV transmission line.

Contributor's Note

This project was made possible through contributions from undergraduate researchers (listed alphabetically): Jack Chrismon, Alayna Parlevliet, Andrew Paumen, Isabella Sherwood, Alexander Suster, David Tran, and Catherine Word.

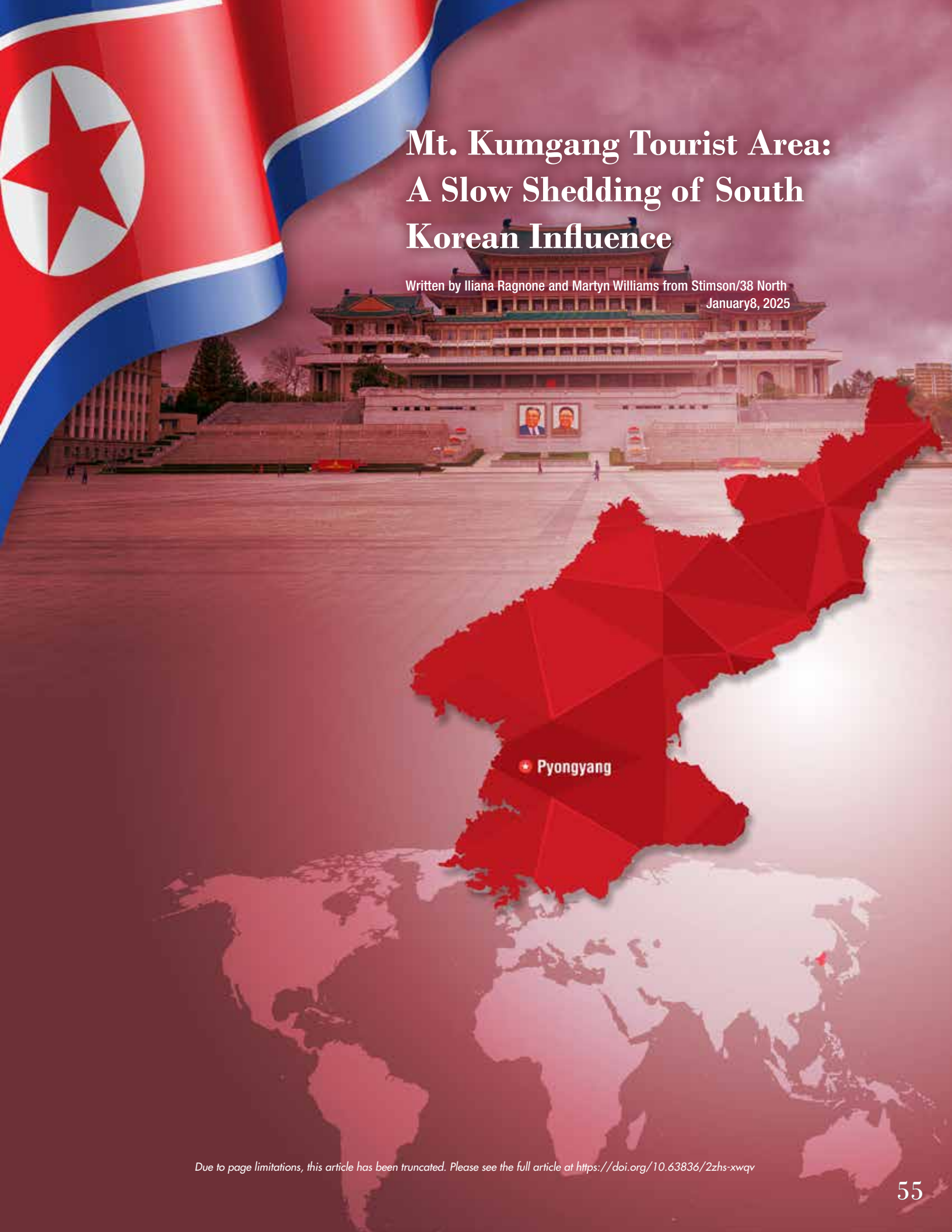
LOOK AHEAD

Over time, events may contribute to the likelihood of the alternative futures. Future 1: Look for countries continuing to ease their sanctions, the commencement of construction for proposed projects, and announcements for new foreign investment in Syria's energy sector. These events would indicate international confidence in Syria's stability and an increased willingness to partner with the new government. Future 2: Look for increases in terror attacks, an intensifying of conflict between Syria's factions, or growing unrest from Syria's citizens. These events would cause countries to hesitate in continuing or beginning investment in Syria's energy sector. ■

Mt. Kumgang Tourist Area: A Slow Shedding of South Korean Influence

Written by Iliana Ragnone and Martyn Williams from Stimson/38 North

January8, 2025



SUMMARY

The Mt. Kumgang Tourist Region was a popular South Korean tourist destination until a security incident led to its closure in 2008. Despite optimism after the 2018 Panmunjom Summit that long-stalled inter- Korean economic projects would resume, no progress was made before the summit process fell apart. In late 2019, Kim Jong Un visited Mt. Kumgang, denouncing South Korean claims on the resort and instructing it be rebuilt according to North Korean standards and tastes.

Progress on renovating the site has been slow, and initial plans were likely impacted by the pandemic. Activity picked up in 2022 to finish razing the majority of South Korean-built facilities, but it is unclear when serious construction may begin, especially with renewed emphasis on finishing the Wonsan-Kalma Beach Resort. Given North Korea's separation of ties with South Korea, it is also unclear who the target audience for the renovated resort will be.

ACTIVITY

Satellite imagery and North Korean state media indicate that from Mt. Kumgang Tourist Region's closure in 2008 until Kim Jong Un's visit in 2019, little significant activity was observed. Since, efforts to renovate the site have progressed slowly. It remains to be seen the audience for these updates, particularly given recent developments in the inter-Korean relationship.

Introduction

The Mt. Kumgang Tourist Region—a special administrative region carved out of North Korea's Kangwon Province in 2002—was initially opened to foreign tourists, including those from South Korea, in 1998. It began under the umbrella of the Wonsan-Mt. Kumgang International Tourist Zone, which includes sites such as Wonsan, Masikryong Ski Resort, and Mt. Kumgang, among others. The project quickly became a beacon of hope in inter-Korean economic cooperation, with South Korea's Hyundai Asan—the conglomerate also part of the Kaesong Industrial Complex joint venture—receiving a decades-long contract to build-out the area's infrastructure.

In its years of operation, Mt. Kumgang was filled with hotels, ski and golf resorts, and other facilities, and brought in around 400,000 visitors each year. Specifically, Mt. Kumgang was frequented by tourists from the South. By the time of its closing in 2008, Mt. Kumgang had been visited by over 1.9 million South Koreans.

However, not unlike other inter-Korean cooperative projects, the stability and longevity of the area ebbed and flowed with the political tides of North-South relations. In 2008, a South Korean tourist was shot by a North Korean guard, resulting in Seoul banning its citizens from visiting Mt. Kumgang until Pyongyang agreed to a joint investigation of the incident and safety guarantees for future tourists. North Korea never agreed to these terms—and the site has remained closed to South Korean tourists. It is unlikely tours of any form have taken place since.

Beginning of the End

Despite optimism that inter-Korean economic projects, including the Mt. Kumgang Tourist Area, would resume after the signing of the Panmunjom Declaration in 2018, no progress was made before both the inter-Korean and US-DPRK summit processes fell apart. As a result, Kim Jong Un visited the Mt. Kumgang Tourist Area in October 2019, asserting that the buildings around the site were a "hotchpotch" devoid of national character, and "built like makeshift tents in a disaster-stricken area." He went on to dispel any notions that Mt. Kumgang was a common property of both North and South Korea, and that an improvement in inter-Korean ties would lead to a resumption of tourism in the area. He ordered the removal and/or remodel of existing facilities that were relics of the inter-Korean initiative that Mt. Kumgang once was.

In December 2020, Premier Kim Tok Hun, a member of the Central Committee of the Workers' Party of Korea, visited Mt. Kumgang, calling for work to turn the site into a "modern and all-inclusive international tourist and cultural area" to push forward with a phased approach.

Significant activity was not observed until 2022, when several prominent sites were demolished. The cycle repeated again in 2023.

In July 2023, South Korean media reported the chairwoman of Hyundai Asan sent—and consequently withdrew after the North's refusal to acknowledge it—an application to visit Mt. Kumgang. In response, the DPRK Foreign Ministry issued a statement indicating Pyongyang had no intention to allow the visit to take place and reaffirmed that the Mt. Kumgang Tourist Area is solely a part of North Korea's territory.

The 30th Plenary Meeting of the 14th SPA Standing Committee of DPRK— held in February 2024—adopted a decree abolishing any formal agreement on North-South economic cooperation, formally cementing the end of the Mt. Kumgang Tourist Area as a cooperative project.

North Korea has since severed additional ties to its southern neighbor— both in law and in practice—meaning the future of Mt. Kumgang International Tourist Zone is unlikely to bear resemblance to the inter- Korean project of the past. North Korea's demolition of border links on both the west coast highway (Asian Highway-1, or AH-1) connecting South Korea with the Kaesong Industrial Complex and the east coast highway (Asian Highway-6, or AH-6) connecting to the Wonsan-Mt.

Kumgang Tourist Zone in October 2024 now physically prohibits access to Mt. Kumgang from the South by road. Rail lines connecting the two countries have also been severed.

While North Korea's vision for Mt. Kumgang as solely its own initiative has not been announced in state media, imagery around the complex reveals that much of the structures from the inter-Korean cooperative era has been demolished, and little has been done to revitalize and rebuild the area.

Floating Hotel and Pier

Without a doubt, the most recognizable location in the tourist zone was the floating Hotel Haegumgang. Originally built in Singapore, the 200 room-hotel was first a Four Seasons hotel near the Great Barrier Reef in Australia. It was later sold and moved to Vietnam before its purchase by Hyundai Asan in 1998 and consequent move to Kosong port.

Throughout its time in Kosong, the hotel was moored with large cables to a dock. A sea wall and two adjacent piers kept the structure relatively protected from the open water.

Close to the dock on land was an additional residential area. In 2005, the area had 34 chalets and sometime between then and 2010, a neighboring plot was developed that could house up to 20 caravans. Several support buildings were also added and ground work at the site hinted that more had been planned.

By 2010, satellite imagery showed the resort and the floating hotel, chalets and caravans sat unchanged until 2022.

In October 2019, the hotel served as a backdrop in state media images of Kim Jong Un during his visit, upon which he instructed South Korean-owned structures to be removed—including the Haegumgang Hotel.

However, it was not until the spring of 2022 that work to dismantle the hotel and neighboring caravans and chalets commenced. By the end of that year, they were gone.

Currently, the site remains clear of any new construction, but activity at the piers picked up during 2024. Several vessels visited during the year for short periods of time, including a cargo ship and at least one North Korean Navy vessel, likely from Kosong Naval Base located across the bay.

Ananti Golf Resort and Spa
(Diamond Mountain Golf Resort and Spa)

For a few weeks, one of the major attractions in the tourist zone was the Ananti Golf and Spa Resort, located near Diamond Mountain. The facility sat on hills overlooking the bay area and was only about a kilometer from the water's edge, but its opening was spectacularly poorly timed. It opened its doors in May 2008, less than two months before the site was shut down.

Like other structures at the site, it sat vacant for much of the following years, although between April 9 and 10, 2022, about a month after workers began tearing down the floating Hotel Haegumgang, satellite imagery showed the lodging buildings were destroyed. State media reported their destruction as a result of a forest fire, though the validity of these claims is unclear based on commercial satellite imagery. However, imagery does show that the resort apartments or condos were razed between April 8 and 10, 2022.

The main club and spa building remained in tact at the time, but satellite imagery from October 23, 2024 captured work to dismantle the structure underway.

Figure 1. No construction activity observed at former site of Haegumgang Hotel on imagery from October 31, 2024.

Figure 2. Imagery from November 2023 shows the base of Haegumgang Hotel was removed from the pier area.

Figure 3. Imagery from December 2022 shows caravan and residential areas have been razed. Debris is observed on the foundation of the Haegumgang Hotel, but the structure no longer is in the port.

Figure 4. Imagery from December 2021 shows the Haegumgang Hotel and the surrounding area prior to demolition. A cargo vessel is also seen at one of the piers.

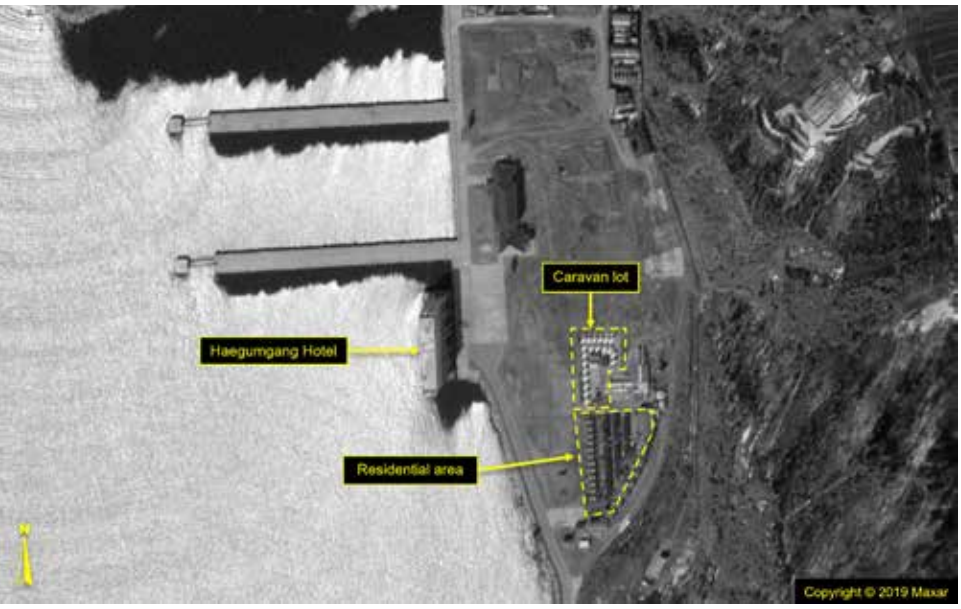


Figure 5. The pier area at Mt. Kumgang before Kim Jong Un's visit in October 2019.

Figure 6. Imagery from October 2024 shows demolition of the main club and spa building at Ananti Golf Resort and Spa.

Bay Area

In addition to the main facilities at the site, numerous smaller buildings have been removed or are being removed across the tourism zone to leave no reminders of the original project.

In late August 2022, the Kosong Bay Sushi Restaurant was demolished. The building sat alongside the bay and had once served as the inter- Korean transit office, but later became a restaurant.

The sushi restaurant was near a large, paved area that housed logistical offices and units and a South Korean-run gas station. The logistics area was largely cleared of structures in 2016. Additional demolition work was carried out in the summer of 2023.

The canopy of the gas station still stands, making it one of the last remaining structures in the area. However, it was shown in a state of decay in on-the-ground photos taken in 2017 so the integrity of it today is likely poor.

For several years, more than 40 buses that had been used to ferry tourists around the region were parked on the paved area, but they were eventually repurposed for domestic purposes and observed sporadically throughout other areas of the site.

Other Hotel & Resort Area

Sometime between September 2 and 7, 2022, the Kumgang Cultural Center was destroyed. The distinct domed building previously served as the meeting point during the 2018 North-South family reunion. The family reunions—held only once since 2015—occurred mere months after the inter-Korean Panmunjom Declaration was signed, representing a time of peace and hope in relations between Pyongyang and Seoul. The House of Culture was among the sites included in Kim's 2019 declaration that Mt. Kumgang's facilities lacked national identity and needed an overhaul.

This structure differed from the Kumgang Family Reunion Center, a 12- story hotel initially constructed in 2008 that hosted participants in family reunions in 2009, 2010, and 2014. Through May 2022, the complex surrounding the Family Reunion Center was left largely untouched.

However, by October the same year, furnishings and materials from inside the hotel were removed and piled up in the parking lot. Debris remained in the area until early 2024. Possible cargo containers lining portions of the complex perimeter appeared around the time demolition began, and are still observed on imagery from October 2024. The hotel's exterior appears to be unchanged.

In mid-2022, a tourist building opposite the Kumgang Cultural Center site was razed, and the logistics area was cleared. The logistics area had housed over 100 cargo containers but they were removed when the building was razed.

A year later, a South Korean-built fire station in front of the Kumgang Family Reunion Center was demolished.

Access and Future of the Sites

When Kim Jong Un visited the site in 2019, he spoke of the need to modernize the facility, removing South Korean buildings and replacing them with a number of new projects including a passenger port, an airport and a new train service to connect the airport with the resort. As the removal of South Korean buildings approaches its end, none of the new projects appear to have been started.

Given Kim's instructions and the devolving state of North-South relations, this tourist zone, when rebuilt, will not depend on South Korean tourists or investments. North Korea's push to eliminate any special relations with the South and the recent removal of road and rail links between the two Koreas means the only feasible way into the Mt. Kumgang region at present by way of South Korea is via road or rail from the north. It is possible that should South Korean tourists be allowed to visit again in the future, they could fly into Wonsan Kalma Airport, about 60 kilometers to the north, or come from other areas within the country by car or train. Based on Kim's 2019 guidance, it appears that a direct air route is preferred.

With party resources focused on opening the Wonsan-Kalma Tourist Zone next year, some six years late, it seems unrealistic that serious work on revitalizing the Mt. Kumgang area will start anytime soon. It is also unclear who the target audience for such a resort might be. ■

Figure 7. Razed apartment or condo buildings observed on imagery from late 2022. The main club and spa building remains in tact.

Figure 8. Imagery from December 2021 shows the Ananti Golf Resort and Spa prior to demolition.

Figure 9. Kosong Bay Sushi Restaurant and nearby area demolished on imagery from December 5, 2022.

Figure 10. Kosong Bay Sushi Restaurant prior to razing. Cargo containers or caravans seen nearby with rust on their roofs.

Figure 11. Imagery from October 2024 shows the canopy atop the South Korean gas station remains in tact, while other nearby facilities have been razed or are not in use.

Figure 12. Storage and vehicles observed in lot adjacent to South Korean-owned gas station on imagery from December 2021.

Figure 13. Prior to any demolition to Mt. Kumgang, logistics lot and transport depot were positioned near a gas station.

Figure 14. Kumgang Cultural Center, nearby support facilities, and other buildings meant to support tourism razed on imagery from December 2022.

Figure 15. Original layout of tourism area surrounding Kumgang Cultural Center.

Russia's Civil Aviation Industry: Impact of COVID-19 and Ukraine Conflict-Related Sanctions Following February 24th, 2022

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Due to page limitations, this article has been truncated. Please see the full article at https://doi.org/10.63836/0cbc-whr7

SUMMARY

This product demonstrates increased activity in Russia's civil aviation industry since 2017, despite the effects of the COVID-19 pandemic and ongoing international sanctions implemented following Russia's 2022 escalation of armed conflict in Ukraine. The author's analysis provide imagery-driven insight into the impact of those sanctions and the global pandemic by assessing the development patterns of Russian airports from 2017 to present day (2024).

Observations of the Russian civil aviation industry suggest an aggregate increase in activity, despite health concerns from COVID-19 and strategic sanctions intended to negatively impact civilian aviation infrastructure. Imagery and open-source information analysis show construction projects increased in all Russian military districts between 2017 and 2024 except for the Western district. Demolition, deconstruction, and project infrequency decreased in this same period.

ACTIVITY

In recent years, the Russian Civil Aviation Industry (RCAI) has faced challenges due to a combination of factors, including the Coronavirus Disease 2019 (COVID-19) pandemic and economic sanctions imposed by western countries. Russian operations within Ukraine and the escalation of that conflict in 2022 led to economic sanctions against Russia. These sanctions have created financial constraints, market isolation, and access to technology and components for the RCAI. Without the effects of the COVID-19 pandemic or the ongoing issues stemming from the invasion of Ukraine, the primary challenges to the RCAI would be maneuvering foreign aircraft purchases, maintaining civilian aircraft manufacturing, and expanding international flights to new markets. Although sanctions against the RCAI were discussed in 2014 following Russia's annexation of Crimea, only one state-owned and low-cost airline (Dobrolyot) actually faced EU sanctions. Though Dobrolyot was dissolved shortly after, the Russian government established a new low-cost airline, known as Pobeda, which still exists as of November 2024. However, the ongoing challenges due to sanctions hinder the RCAI for several reasons. First, there is currently a widespread ban on Russian flights landing at US, UK, Canadian, and EU airports, international Russian flights are largely relegated to Turkey, Serbia, Belarus, and China. Second, upon request of the Russian government, the RCAI retained aircraft leased from Western states after their legal owners requested their plans be returned. As of February 2022, 97% of passenger air traffic occurred via Western manufactured aircraft. Third, the RCAI is currently adapting to sanctions on imported aircraft parts from Western manufacturers, which impact Russia's majority-imported aircraft fleet. To navigate this issue, Russian airlines are cannibalizing parts and sourcing illicitly made aftermarket parts from unauthorized manufacturers. For example, S7 Airways sourced parts from Turboshaft, a company based in the United Arab Emirates, accounting for USD 1.5 million in parts between February 2022 and May 2024. However, this only accounts for part of S7's pre-invasion part imports of around USD 100 million per month, which fell to under USD 25 million per month as of April 2022. Specifically, US sanctions prevent the importation of the following parts: engines and engine components, navigation systems, cabin pressure valves, cockpit displays, and landing gear. S7 Airlines has stated its technicians have learned to repair Boeing 737 and Airbus A320 engines, as well as Honeywell auxiliary power units, allowing them to circumvent parts shortages. Other aircraft components manufactured by US companies (such as Northrop Grumman) are procured by Russia through the use of intermediary states (China, the UAE, Turkey, Tajikistan, Kyrgyzstan).

METHODS

Editor's note: As of March 2024, Russian Military Districts have been reorganized. For the purpose of this report, the Northern Military District should be read as the current Leningrad Military district, and the Western Military District is now the Moscow Military District.

PLANNING

For the purposes of this product, 227 airports were chosen for review. These airports were recorded in 2018 as registered with Russia's civil aviation authority Rosaviatsiya, or the Federal Air Transport Agency (FAVT). The Federal Air Transport Agency is responsible for funds allocations from the Russian government, adherence to industry and international standardizations, creation of relevant laws, as well as the United Air Traffic Management System of the Russian Federation. Sampling was limited to locations most likely to be impacted by federal policy changes. The 2018 list is the earliest available in the 2017-2024 analysis time frame. 55 additional commercial airports not registered with the FAVT were added to the sample to represent geographic gaps and provide representation of a wider range of the Russian population. 34 personal and/or military use airports without commercial airline activity were filtered out of collection for a final sample size consists of 248 locations.

The 2017-2024 time frame allowed analysts to establish a baseline of activity levels within the sample (2017 - Quarter 1 of 2020), account for potential effects of the COVID-19 pandemic (Quarter 2 of 2020 - Quarter 4 of 2021), and assess for potential effects of western sanctions following an increase in war efforts against Ukraine after February 24th, 2022 (Quarter 1 of 2021 - 2024).

COLLECTION

Airports were geolocated and categorized by Russian military districts for workload distribution and grouping purposes only - there is no known correlation between the RCAI and Russian military districts. The terms district and region are used interchangeably throughout the product.

Analysts collected, annotated, and analyzed imagery of each airport using the open-source imagery portals Google Earth, Maxar, and ESRI Imagery Wayback. A target goal of one image per quarter per airport (28 images per location) allows for a consistent read on the status of ongoing projects. Analysts collected supplementary open-source information to provide additional measurables for trend analysis. These measurables include purpose (commercial-only or mixed (commercial and military/personal craft)), scope (international or domestic-flights only), size (large, intermediate, or small - based on qualitative observations of overall property area, runway length, number of runways, runway apron, facilities present, etc.), and present-day activity level (steady, steady growing, inconsistent, or closed - based on qualitative observations of flight data, imagery, and open-source information).

Data Processing and Exploitation

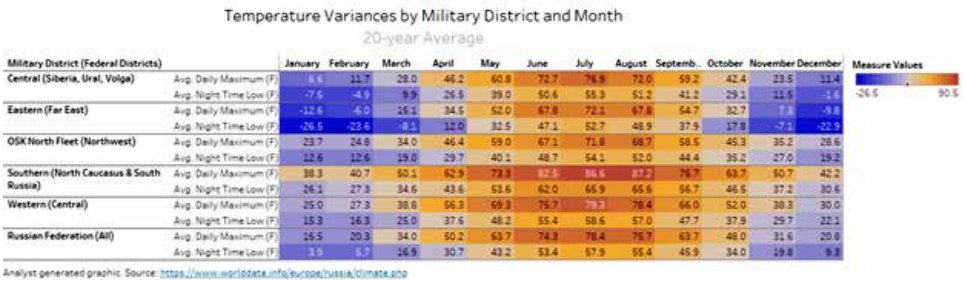
Qualitative observations made during imagery analysis were codified as indicators for storage into a data matrix. Examples of positive indicators include building, runway, and miscellaneous project classifications.

Negative indicators include demolition and degradation classifications. Each category has subclassifications including when the event was first noticed, if it appears ongoing, completed, was completed within one quarter, or showed no apparent progress. The full list of indicators can be found in the structured data file.

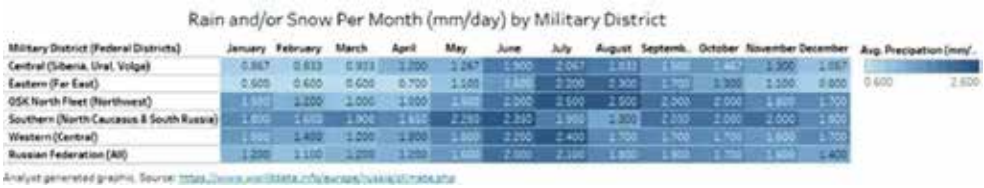
To account for imagery gaps, inferences were made in some cases as to whether a project was put on hold or no project occurred (there is no observable change between the two available images), a project was advanced (there is observable change, but the project does not appear to be finished), further degradation occurred (there is further decay in integrity), and so on. All instances of project start or completion are notated when they are first noticed and are never inferred.

Potential imagery for all quarters totaled 7,936. Analysts collected and annotated 1,801 images during this project. Out of those images, 2,399 total indicators were observable. An additional 2,105 indicators are inferable, totaling the instance count to 4,504.

Tableau and ArcGIS visualization software were utilized to trim and exploit data for trend analysis. Measurable trends in data tables and charts were compared with Tableau. Maps for geospatial analysis were generated with Tableau and ArcGIS.



High and low temperatures differences between military districts and months, averaged over a 20-year span. Analyst generated graphic. Source: https://www.worlddata.info/ europe/russia/clima



Precipitation (millimeter/day) differences between military districts and months, averaged over a 20-year span. Analyst generated graphic. Source: https://www.worlddata.info/ europe/russia/clima

Difference in days per month that have rain/snow between military districts, averaged over a 20-year span. Analyst generated graphic. Source: https://www.worlddata.info/europe/russia/clima

DISCUSSION

Trend One: Climate Impacts on Projects

This project assessed climate data for variances between military districts that would impact project status and/or airliner activity. No significant differences were found to support climate as a key driver behind regional disparities in project status and/or airliner activity. Qualitative observations suggest that in areas with extreme cold climates, Russia relies on specialized airframes, including helicopters, to maintain operations without impact on activity.

On average, Russia experiences mild spring and summer seasons, with much colder autumn and winter seasons. Indicators, collected by calendar year quarter, allows for rough similarity with seasons: Q1 with winter (January, February, March), Q2 with spring (April, May, June), Q3 with summer (July, August, September), and Q4 with winter (October, November, December). The terms season and quarter are thus used interchangeably in this section.

The temperature variances by military district are based on the average of their constituent Russian federal districts. Because some military districts do not overlap exactly with federal districts, weather data may be affected by the different distribution of measurements.

In reference to precipitation, the average snowfall has a 12:1 ratio with rainfall. For example, 12 inches of snow is equivalent to one inch of rain. For simplicity, analysts assume that in months with average temperatures below freezing, precipitation is snow.

Rain / Snowfall Metrics by Military District

Western conditions: Moderately cold winters, mild summers. Precipitation is mostly steady year-round, but it increases in spring and early summer; however, the authors feel this is not enough to realistically affect airport activity.

• Winter: The large number of ongoing projects is likely due to less precipitation as compared to other seasons, despite colder temperatures. The lack of progress on those ongoing projects is likely due to said cold temperatures. Projects first being noticed and project completion are most likely smaller projects, or those that are not climate sensitive.

• Spring: Like winter, this quarter has one-third of projects showing no progress, likely because of lingering winter weather conditions. Most projects were first noticed in spring, coinciding with warming temperatures.

• Summer: Ongoing projects and project completion increased from springtime, likely because of warm temperatures. Over one-fourth of projects were first seen in the summer, again because of weather conditions. This increase is despite higher rainfall in the early and middle months of the season.

• Autumn: As with winter, the number of ongoing projects is steady due to a decrease in precipitation from earlier seasons. Cold temperatures may contribute to the single project not showing any progress.

Eastern conditions: Coldest average temperatures, especially in winter. Contrasted with mild summers. Low rainfall between winter and spring, slightly wetter in summer and fall.

• Winter: Over a fifth of ongoing projects occurred in wintertime, despite sub-zero average temperatures; this is likely due to the low amount of precipitation in the region. However, almost a fifth of total projects showing no progress were in this quarter (not ongoing), likely because of the sub-zero temperatures themselves.

• Spring: Over half of the projects were completed in springtime, coinciding with warmer weather. Likewise, almost half of projects were first noticed in spring, with construction restarting after cold winters. Spring also had a roughly equal distribution of projects completed within one quarter, projects with no progress, and ongoing projects.

• Summer: Like spring, summer saw over two-fifths of projects first noticed, again likely due to warm weather. Summer also had over half of projects completed in one quarter, most likely because of warmer temperatures.

• Autumn: As with winter, autumn saw over a fifth of ongoing project instances, again likely because of low precipitation. Similar to winter, freezing temperatures likely caused projects to show no progress. However, it also included almost a fifth of project completion within one quarter, likely to finish minor projects in preparation for winter.

Overall, the distribution of projects with no apparent progress remained relatively consistent across all quarters but for different reasons: colder temperatures in winter and autumn likely slowed activity, while smaller projects were often deferred to spring and summer. Similarly, the distribution of ongoing projects showed a steady pattern throughout the year. This consistency was likely due to the need to maintain construction schedules regardless of weather conditions to ensure airport operations remained uninterrupted.

OSK North Fleet conditions: Cold winters and mild summers. There is more precipitation than all other regions, especially between July and January- this means snow in the wintertime. Analysts did not incorporate any airports from Russia's northern islands, such as the Novaya Zemlya and Franz Josef Land archipelagos, as they have little to no commercial activity or importance. This slightly affects the regional weather averages, as these northern islands were also excluded from regional weather averages.

• Winter: There were only ongoing projects. Sub-freezing temperatures and snowfall do not appear to halt construction but may slow progress down.

• Spring: Most project starts (three-fourths) were first noticed in this season, coinciding with warming temperatures. Similarly, springtime included two-thirds of project completion. This season also had the only instance of a project not showing any progress, likely a holdover from wintertime. Also, it had the only instance of project completion within one quarter; construction was likely held off until snow thawed.

• Summer: Over a third of ongoing projects occurred in this quarter; like spring, construction is not obstructed by warm temperatures. Summer also accounted for the last third of project completion, again aided by warm temperatures. It also accounted for a quarter of projects first noticed, primarily those that could be continued into cooler months.

• Autumn: Like winter, there were only ongoing projects, showing that colder temperatures and higher precipitation amounts likely do not halt construction.

Southern conditions: Hot summers. Mild autumns and winters, where the average daytime temperature does not drop below freezing. Precipitation is also higher than average, especially in spring and summer. Being the southernmost region, all average seasonal temperatures here are higher than other regions.

• Winter: This season accounted for nearly one quarter of ongoing projects, as opposed to other regions, where the number of ongoing projects tended to be lower in winter. This is likely due to milder temperatures. The same can be inferred for the higher-than-average number of projects completed in one quarter, project completion, and projects first being noticed.

• Spring: Almost half of all projects were first noticed in spring, coinciding with warming temperatures. Nearly two-thirds of projects were completed in this quarter, likely for the same reason; warm temperatures allowed them to carry over from winter. Likewise, this season accounted for one-third of projects completed in one quarter and nearly a quarter of ongoing projects.

• Summer: Unlike other regions, summer accounted for the only instance of a project showing no progress; this could be due to hot temperatures. Summer accounted for less than a quarter of projects first noticed, also likely due to hot temperatures. Conversely, half of projects completed

in one quarter occurred in summertime, likely due to the warmer temperatures.

• Autumn: Over a fifth of ongoing projects occurred in autumn, along with the same percentages of project completion and projects first noticed as winter, likely due to the similar weather conditions between the two seasons.

Overall, the number of ongoing projects in each quarter remained relatively consistent, likely due to the warmer temperatures in the south, allowing for continued progress through autumn and winter.

Central conditions: Warmer summers than average, along with spring and autumn. Winter is moderately cold. Precipitation remains relatively steady throughout the year, increasing in spring and summer, then decreasing from autumn into winter.

• Winter: This quarter consisted entirely of ongoing projects, likely because of cold temperatures halting other project phases until after winter.

• Spring: Nearly two-thirds of projects were first noticed in this quarter, most likely due to warming temperatures following wintertime. The same can be inferred for project completion, where spring encompassed over half of these, as well as over half of project completion within one quarter. Spring encompasses over a third of projects with no progress, likely as a holdover from winter.

• Summer: This quarter accounted for almost half of all projects showing no progress; increased rainfall might affect this statistic. However, summer also accounted for over a third of ongoing projects and project completion, as well as 30 percent of projects first being noticed. It also accounted for nearly half of projects completed in one quarter; like spring, warm weather allows for quicker progress.

• Autumn: This season mostly consisted of ongoing projects, likely carrying over from summer and including those that continue into winter. The number of projects with no progress in this quarter may be due to halts carrying over from summer, or because of increased precipitation after a drier summer. These conditions could also affect the small percentages of project completion and projects first noticed in this season.

Trend Two: Geographic Distribution of Projects

This project assessed demographic data for variances between military districts that would impact project status and/or airliner activity. Analysts found that while population and density scaled with the designed capabilities of the airport as well as the concentration of higher capability airports, the projects were tailored to the needs of specific airports. Therefore, region-based trend analysis using demographics would require data outside the scope of this product.

This project assessed geographic proximity to Ukraine for trend variations between regions after the February 24th, 2022, upscaling in the Russo Ukraine conflict. Analysts found that airports in immediate proximity to Russia are at potential risk for direct impact, such as Princess Olga International Airport (Western Military District), which is a mixed military and commercial location, and was the target of Ukrainian drone attacks on September 29th, 2023. There are additional reports of attacks targeting other airports and manufacturing plants in relative proximity that have been either successful or intercepted. However, the Ukrainian military has increased its long-range strike capability into Russia as the war has progressed, suggesting that RCAI locations that share space with military assets are at higher risk than those within closest proximity.

Airport flight frequency by military district and airport size

Overall, the Eastern district led the whole of Russia in construction projects across all types. The authors view is this is likely due to its distance from the effects of the war. Its rurality also aids in having more room to expand. Within this district, the plurality of projects was miscellaneous, but not by much more than runway or building projects. However, this does not mean that these miscellaneous projects were necessarily expensive or major. The close ratio between steady and inconsistent airport activity levels could mean that current air traffic levels do not necessitate larger projects in general, and the authors determine this is likely on a location-by-location basis.

The Central district had the second highest average percentages of projects across all types; like the Eastern district, it is the authors' view its physical distance from the effects of the war may aid in this. Within the region, most projects were miscellaneous, followed by building and runway projects, respectively. As with the Eastern region, the close ratio between steady and inconsistent airport activity levels may explain that across the region, airports do not have enough activity to warrant larger projects with buildings and runways.

Following this was the Western district, which accounted for the second highest number of miscellaneous projects. With this, over half of the projects in the region were miscellaneous, followed by building and runway projects. This may be explained by the higher population density in the region relative to other regions, making for higher air traffic that limits the amount of building and runway projects possible during commercial activities. Conversely, it could also be due to the close ratio between steady and inconsistent airport activity levels, as the latter account for less major projects because they do not warrant them, as per the analysts' view.

The Southern district had the second-to-last average percentage of projects, despite its high population density; this is likely because of the Russo-Ukrainian war, as the district borders Ukraine. Building projects were the majority of projects in this district; as most airports in the region are at steady activity levels, the analysts feel this may be due to construction focusing on buildings as other projects are completed.

Finally, the OSK North Fleet district made up the least number of total projects. This is primarily due to the low number of airports in the region, thus reducing the number of projects possible. Within the district, miscellaneous and runway projects were roughly equivalent, but building projects made up only 14.29 percent of total projects. The authors believe this is likely due to miscellaneous and runway infrastructure requiring more work due to higher precipitation and sub-freezing temperatures.

Examples of each type of projects encountered follows:

Building projects: These include construction of new buildings and add ons to existing buildings, including refurbishment of roofs.

Spichenkovo Airport, Central Military District. Between 2022 and 2023, the airport constructed a new terminal in front of the original one.

Runway projects: These include construction of new runways, refurbishment or repaving of existing runways, and extension of existing runways.

Okha Airport, Eastern Military District Between 2020 and 2022, the airport built a completely new runway parallel to the existing one.

Vorkuta Airport, OSK North Fleet: Between 2022 and 2024, the airport repainted the threshold markings and designation numbers, but did not repave the end of the runway

Miscellaneous projects: These include all non-building and non-runway construction projects, including

- Infrastructure (signal equipment, roads, parking lots)
- Non-runway tarmac (including repaving)
- Storage facilities (materials and aircraft)
- Aesthetics (monuments, parks)

Kaluga International Airport, Western Military District: Between 2021 and 2022, the airport expanded one of its existing parking lots.

Balandino Airport (also known as Chelyabinsk Airport), Central Military District: Between 20 77 and 2024, the airport expanded its tarmac, to include the apron and taxiway.

Irkutsk International Airport, Central Military District. Between 2020 and 2021, the airport constructed a small hangar.

Lensk Airport, Eastern Military District: Between Q2 and Q3 of 2021, the airport built an airplane installation/monument (gate guardian) at the front of the airport.

TREND THREE: DEGRADATION AND DEMOLITION

Degradation refers to biogenic and anthropogenic decline in infrastructure quality over time. For example, this includes runway deterioration over time due to aircraft usage.

Demolition is defined as the purposeful destruction of buildings and other infrastructure. For simplicity, the terms demolition and deconstruction are used interchangeably.

Across all of Russia, analysts found 70 indicators of demolition or degradation. The majority of these happened in the Central district, likely because the upkeep of a large number of airports inherently includes cycles of construction and demolition. Furthermore, most degradation occurred in 2020 and 2021, likely a result of the COVID-19 pandemic slowing or halting airport activity, including construction projects. OSK North Fleet saw the least degradation or demolition, with only one indicator for the whole region during the period. However, the authors feel this was likely due to the small number of airports seeing less traffic compared to other regions, and therefore experiencing less wear on infrastructure.

Initially, analysts marked certain indicators of runway degradation, such as grass growing on the runway (known as foreign object debris, or FOD). However, many locations had grass or other foliage on the runway but still had flight activity, and degradation was never resolved between the first appearance of FOO and the last collected image. This suggests that this FOO is a non-factor for airport operations and may be a way for the RCAI to save money for other projects.

In some cases, demolition followed by construction on the same location, replacing the previous structure. Select examples are represented below.

Uray Airport, Central Military District: Between 2022 and 2023, the airport demolished structures that were most likely storage containers.

Sheremetyevo International Airport, Western Military District: Between 2078 and 2020, the airport demolished a previously standing terminal building and replaced it with a new terminal section.

ANALYTIC CONFIDENCE:

The analytic confidence was moderate. Structured analytic techniques were used internally to vet assessments. Overall source reliability was moderate to high, with very little conflict amongst sources. Analysts had a moderate level of expertise with the topic and collaborated in a team environment. The task was moderately complex and challenging, with a moderate deadline.

GRAPHS

Observed Construction Project Totals by Timeframes and Military Districts

Construction projects are broken down into three categories: building, miscellaneous, and runway. Building projects include renovations to existing buildings and construction of new buildings. Miscellaneous projects include infrastructure such as signal towers, roadways, and parking lots; storage facilities (aircraft and resources); and aesthetic complementary such as gate guardians and gardens/parks.

Source: analyst-generated graphic.

Observed Degradation and Demolition Project Totals by Timeframes and Military Districts

Degradation instances are marked when there are indicators of natural decay such as an unaddressed roof collapse or structural integrity visibly worsens over time. Demolition projects are marked when there are indicators of manmade destruction, such as presence of construction equipment, organized piles of debris/resources, and/or structured removal over time. A lack of projects is marked when the airport is in observable operation (planes, cars, etc. shift between images) yet there is no change of infrastructure.

Source: analyst-generated graphic.

GEOGRAPHIC DISTRIBUTION OF AIRPORTS BY SIZE AND FLIGHT FREQUENCY

Size and Flight Frequency classifications are a qualitative assessment based on available open-source information (flight data, business websites, and reports) and observations made during imagery analysis.

Source: analyst-generated graphic.

Lipetsk Airport, Western Military District Between 2021 and 2022, a hangar began to degrade; by Q2 of 2022, the airport removed the hangar debris.

Magan Airport, Eastern Military District: Between 202 7 and 2024, the airport demolished a building and constructed a new building on the same plot. It saw additional deconstruction in 2024.

LOOK AHEAD

The data collection time frame included an ongoing year (2024) at the time of analysis. As such, data for 2024 is incomplete; sources have not entered the most recent imagery yet. Furthermore, analysts did not collect images from before Q1 2017, so if a project was in progress or just completed before this period, then it was not reflected in the data and outside the scope of this project.

Concurrently, in Q1 2017, almost all locations did not have imagery (96.7 percent). For future research to avoid imagery gaps, analysts should adjust the timeframe's start date to account for earlier data for a holistic trend analysis and adjust the end date to not include a time frame concurrent with the collection phase. Due to time constraints, analysts did not collect imagery and open-source information on manufacturing plants and scrapyards, two metrics that were identified as key components of the RCAI. Future research should include these locations to enhance the report's accuracy and provide a comprehensive assessment of the RCAI. These sites are integral to understanding Russia's sanction circumvention strategies, such as domestic parts sourcing and parts cannibalization. Financial data on airlines, manufacturers, and airports would help fill information gaps, as still imagery does not provide complete information on project statuses. White papers on financial distribution and policy changes from the Federal Air Transport Agency would provide insight on the funding and monitoring of state-funded projects. Analysts encountered limited supply chain information on aircraft parts imported by Russia; part lists for commercial airframes are open-source information available for further research. ■

Russia-China Land Infrastructure: Changes to Cross-Border Road and Rail Infrastructure Between 2020 and 2024

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SUMMARY

Latest: In accordance with planned infrastructure construction and improvement, both China and Russia increased land transportation capabilities across all border crossings, creating a net positive change in road and rail capacity.

Impact: The improvements to cross-border infrastructure and increased border traffic demonstrate Chinese-Russian commitments to increase economy ties. However, the full economic impact on both countries is unknown. Furthermore, Russian economic and foreign policy continue to favor expanded trade with China due to negative impacts from the ongoing Russo-Ukrainian war.

ACTIVITY

Economic activity likely increased along the China-Russia border at nine established crossings from January 2020 to December 2024, based on significant development of road-based infrastructure. China demonstrated steady development pace overall, with three crossings- Dongning, Manzhouli, and Suifenhe- showing an average of a 231% increase in truck traffic, with an additional two crossings, Heihe and Hunchun, expanding their facilities to accommodate growing trade. Russian development was more gradual, with a 156% change in traffic at two locations, Poltavka and Blagoveshchensk. Rail infrastructure remained mostly unchanged, except for the expansion at the Russian municipality of Nizhneleninskoye. Future border developments will likely depend on shifting geopolitical and economic factors, as proposed additions to existing crossings and the creation of new crossings are uncertain.

BACKGROUND

China-Russia Land Border Crossings

Between China and Russia, there are only nine border crossings, all of which are located between northeastern China and southeastern Russia; this is despite the China-Russia border spanning over 2,600 miles. Though there are mountain passes between northwestern China and south-central Russia, these are impossible to cross with vehicles.

Five of the border crossings solely incorporate roads, while the remaining four crossings have both roads and railroads, providing two mechanisms for both passengers and cargo to cross at. There are no border crossings that are solely via rail. All nine border crossings were identified using the Chinese government's website listing ports of entry.

Land Border Crossings

Location Name	Road/Road & Rail Status
Dongning, China - Poltavka, Russia	Road
Heihe, China - Blagoveshchensk, Russia	Road
Hulin, China - Markovo, Russia	Road
Hunchun, China - Kraskino, Russia	Road & Rail
Manzhouli, China - Zabaykalsk, Russia	Road & Rail
Mishan, China - Turiy Rog, Russia	Road
Shiwei, China - Olochi, Russia	Road
Suifenhe, China - Pogranichny, Russia	Road & Rail
Tongjiang, China - Nizhneleninskoye, Russia	Road & Rail

Rail Gauge Interoperability

China uses a 1435 mm standard gauge, whereas Russia uses a 1520 mm broad gauge. On the Chinese side of the Sino-Russian rail border crossing are large transshipment or bogie exchange facilities. The purpose of these facilities is to handle conversion of rail cars to overcome the gauge differences. The presence of these facilities indicate China has invested significantly in infrastructure to handle the gauge disparity, while Russia appears to lack many of the same facilities and infrastructure at the same border crossings. Thus, Chinese goods crossing into Russia must change tracks upon crossing the border, whereas Russian goods imported into China can travel further without changing tracks. This creates a disadvantage for Russia, as transporters must spend more time moving cargo from one train to another at internal exchange facilities, delaying travel, and ultimately hindering the cross-border supply chain.

However, it is worth noting that Russian territorial governments as well as Moscow have come forward with announcements to modernize the main lines, spurs, and border crossings to keep up with growing trade demand in the east, particularly from China. This includes the modernization and reconstruction of stations at its various rail crossings at the Chinese Russian border.

Eastern Polygon Rail Infrastructures' Current Capacity

Russia's eastern rail infrastructure, particularly the Baikal-Amur Mainline (BAM) and the Trans-Siberian Mainline (TSM), is struggling to handle growing freight demand driven by increased trade with Asia-Pacific countries. This surge stems from Russia's pivot to eastern markets amid Western sanctions and rising Chinese demand for resources like coal, natural gas, and crops. However, limited transport capacity, border crossing delays, and infrastructure bottlenecks continue to hinder trade flow.

However, past, current, and proposed projects aim to minimize bottlenecks (such as the reconstruction of the Skovorodino-Reinovo railway and the Dzhalinda-Mohe rail bridge) and resolve issues with operating limits on existing mainlines and infrastructure such as the BAM, TSM, and lines connecting the main lines to China.16l Additionally, it is important to note that "calculations show that the growing capacity will still not keep up with the growth in demand," with Yakutia officials calling for a "radical solution to the problem."

In December of 2022, the Russian government directed Russian Railways to prioritize container trains for coal exports to the Far Eastern Federal District, adding three container trains per day. However, the addition of trains was insufficient to add enough capacity to fulfill coal export contracts, thus, checkpoint delays mainly impacted imports from China. According to Surana Radnaeva of Sinoruss (a Russian financial company primarily doing business with China), Russia's infrastructure was unprepared for the current surge in trade with China. Radnaeva stated that the strain not only affects border crossings, but also internal Russian infrastructure.

The Russian government plans to boost freight capacity on the BAM and TSM from 150 million tons in 2023 to 270 million tons by 2032. However, financial estimates suggest that modernization efforts will likely fall short in the near term, leaving Russia ill-equipped to fully support rising Eastern trade demands.

It is important to note that as of 2 July 2023, "Almost half of the transport capacity of Russian railways is occupied with the export of coal, which makes it difficult to export goods with higher added value." There are still obstacles on alternative routes from Russia to China - border crossings for trucks. The time period for exiting to China through some checkpoints in the Far Eastern Federal District is 20-25 days.

Ongoing and Future Projects

Regarding cross-border infrastructure, China and Russia publicly announce their larger-scale projects, with a broad focus on solidifying existing economic and political ties. The following projects involve ongoing development of existing crossings, propositions to develop said crossings, or propositions to create new crossings.

• Manzhouli, China - Zabaykalsk, Russia: In May 2024, China Railway and Russian Railways (both state-owned enterprises) signed a strategic cooperation agreement.1771Under the broader scope of China's Belt and Road Initiative (BRI), this agreement aims to improve existing border crossings, including the Manzhouli-Zabaykalsk location. Proposed plans include the construction of a new 1435mm-gauge rail track across the border, as well as a significant increase in road capacity from 18 lanes to 28 lanes, potentially making the crossing the largest and busiest border crossing. Furthermore, this agreement aims to boost mail, e-commerce, and agricultural shipments (including meat and grain) via regular container trains. Both nations are prepared to handle increased rail traffic while continuing to use existing infrastructure, such as warehouses and terminals. The Russian clearance post's boundaries were expanded to allow customs and tax benefits, with local authorities supporting investment and cost reimbursement. Additionally, in 2022, Trans-Container, a subsidiary of Delo Group (Russia's largest transport company), upgraded the Zabaykalsk terminal, increasing capacity to 555,000 containers (in twenty-foot equivalent units, or TEU) annually.

• Tongjiang, China - Nizhneleninskoye, Russia: As of September 2023, Russian intermodal company FESCO and Chinese transport company Margin Group are collaborating on a container terminal near the rail border crossing, with a planned capacity of at least 340,000 TEU per year. Additional projects expected by 2030 include storage facilities for stable gas condensate, petroleum products (including liquefied petroleum gas, or LPG), hazardous cargo handling, and other general imported goods.

• Hunchun, China - Kraskino, Russia: As of July 2023, a new international logistics terminal is under construction at the Hunchun border crossing, to include an amalgamation of warehouses and workshops. Also, as of September 2023, Russian and Chinese state transport officials discussed the laying of 1435mm track (which is the Chinese standard gauge) in near Kraskino to reduce delays in transferring cargo between trains and causing storage constraints at the border.

• Mohe, China - Dzhalinda, Russia (proposed): In July 2023, the Chinese government and the Sakha Republic federal subject government agreed to construct a railway connecting the respective cities of Mohe and Dzhalinda. A second railway connecting the two countries over the Amur River is also slated to connect the same municipalities. Although no starting date has been given, the Republic of Sakha Railway Company signed a memorandum of understanding with the China Industry Overseas Development Association to begin construction.

This new railway can allow Russia to export up to 10 million tons of natural resources, including coal and timber, without relying on Vladivostok's seaport. China will primarily fund and construct the project under a concession agreement, broadly granting it long-term access to the region's resources in exchange for financing the project.

METHODS

Planning

In order to answer the research question of, "From January 2020 to December 2024, what changes, additions, or upgrades have been made to land-based transport infrastructure connecting Russia to China?" the team determined that change in China-Russia land transport infrastructure would be measured by chronologically cataloging activity and construction project status at each border crossing. The following factors formed the basis for this analysis:

• Changes in road-based infrastructure regarding: major highways, entry and exit ramps, interchanges, cargo depots, fuel stations, and border infrastructure. Regarding the latter, this includes inspection points and holding areas for semi-trucks and passenger vehicles.

• Changes in railway-based infrastructure regarding: railway lines and networks, railroad crossings (such as bridges or tunnels), and rail yards, to include cargo depots and fueling stations. Furthermore, this also includes intermodal terminals, where rail transport transitions to road-based transport (primarily semi-trucks), and vice versa. Finally, as with road-based changes, this includes border infrastructure, with inspection points and holding areas for train cars.

Locations were determined based on open-source information on border crossings between China and Russia and confirmed via geospatial analysis. This includes both road and railroad connections, focused on southeastern Russia/northeastern China.

Collection

All available satellite imagery of Russian-Chinese border crossings from Q1 2020 to Q4 2024 was collected from the following sources:

• Google Earth Pro: The team utilized this program as the primary imagery source, given its high-quality and comprehensive temporal collection of imagery. Google Earth Pro is an application that provides historical imagery to the present day; by using the time slider function, one can shift between all available dates. This program compiles imagery from multiple sources, such as US government entities (e.g. NGA, the US Navy, NOAA, NASA) and private entities like Airbus.

• ESRI Wayback: The team utilized this program as a secondary imagery source. Like Google Earth Pro, ESRI Wayback provides historical imagery. One benefit is that using its "Swipe Mode," one can select two dates and switch back and forth from them in a swiping motion, thus seeing change simultaneously, rather than selecting back and forth. However, unlike Google's program, it compiles various dates into certain broad time categories, sometimes adding sections of imagery beyond a certain scope.

• Maxar: The team utilized Maxar as a tertiary imagery source. While high-quality, certain locations are only partially photographed, while others have no historical imagery beyond a certain time period, thus not fully extended backwards into the project's scope. Also, some imagery does overlap with the previous two sources, as both Google and ESRI utilize Maxar imagery within their respective programs.

Supplemental open-source information was collected with a managed attribution platform (Authentic8 Silo) for sites/search engines that present topical/technical risks to systems. Some sources include:

• Baidu: Baidu is China's foremost search engine, equivalent to Google in the US. Using it as intended (as a search engine) provides access to Chinese government sites, as well as Chinese-language media, in their original published format. However, as content is largely censored or otherwise controlled by the Chinese government, the trustworthiness of search engine results is low.

• Yandex: As with Baidu, Yandex is Russia's foremost search engine. It provides access to original-language Russian government publications and media sources. Though less censored than Baidu, Yandex's search results are tailored towards government-positive articles and media, thus making its trustworthiness low.

• OpenRailwayMap: OpenRailwayMap is based on the Open-StreetMap geospatial platform. Though comprehensive in seemingly including every rail line around the world, its open-source nature makes its credibility moderate, as it is likely inaccurate at some portions (simply due to a lack of information on certain rail lines).

Data Processing and Preparation

An Excel sheet was created to catalog data for each border crossing. The Excel sheet included:

Data Processing Fields

Field	Description
Location Names	Names of the individual border crossings
Coordinates	X and Y, in decimal form
Crossing Type	Road or Road & Rail
Quarterly chage columns	Range from Q1 2020 to Q4 2024
Indicator Codes	Incorporate category (road/rail- letter codes), type (status of construction progress- numbers), country (C/R for China/Russia)

Afterwards, the data was cleaned for simplicity, converted into a comma separated value (CSV) file, and then imported into ArcGIS to visualize with a time slider.

DISCUSSION

From 2020 to 2024, infrastructure development at China-Russia border crossings likely followed economic and political drivers within each country more than weather conditions, with China maintaining year-round construction and Russia concentrating work in Q2-Q3. Road infrastructure saw more activity than rail, likely due to higher maintenance needs and strategic priorities with road-based travel. On the Chinese side, reduced traffic during COVID likely enabled steady progress, while seasonal traffic peaks possibly explain recurring infrastructure degradation. In contrast, Russian activity was more limited, likely due to economic constraints and seasonally-based construction cycles, where although there was construction in Q4 and Q1, work increased during the warmer months of Q2 and Q3.

Joint Trends

Despite harsh winters, infrastructure projects, especially roads, likely continued to progress due to economic and political drivers, while rail upgrades remain limited, possibly due to lower maintenance and cost needs.

First, the authors determined it is likely that weather conditions do not impede progress on infrastructure projects, with construction noted (either in progress or completed) in Q4 and Q1 of most years, despite the cold and sometimes snowy climate of northern China and southeastern Russia. As stated in the previous section on Russian trends, other factors, such as economic and political drivers, likely play a role in construction progression.

Second, although railways pass through four of the nine China-Russia border crossings, there was little change in rail infrastructure, apart from Russia's building of new tracks at Nizhneleninskoye. This could be due to railroads needing less upkeep as opposed to roadways, both in regard to physical maintenance and the financial expenditures behind such.

Chinese Side Trends

China's reduced traffic during COVID likely enabled steady infrastructure progress as projects could continue unhindered by vehicle transits through construction areas, while seasonal wear and increased traffic potentially explain higher rates of infrastructure degradation in Q2 and Q3 across all years.

First, most construction projects observed were completed between Q2 2020 and Q4 2021. This likely coincides with the lack of international travel during the COVID pandemic, allowing Chinese construction firms to continue progress unabated by passenger travel. Second, also likely coinciding with the pandemic, there was a decrease in commercial traffic between Q2 2020 and Q3 2023. Third, most infrastructure deconstruction or degradation occurred in Q2 and Q3 across all years, which could be due to increased passenger or commercial traffic. This can impede efforts to repair or improve infrastructure and can also warrant the removal of temporary structures for logistical or aesthetic purposes.

Russian Side Trends

Across 2020 to 2024, Russian locations showed less indicators of both construction and deconstruction, likely due to economic factors, as well as construction cycles culminating in the second and third quarters of each year, despite Chinese cycles continuing year-round.

First, there were comparatively fewer indicators of construction, as well as deconstruction, than on the Chinese side, especially during the COVID pandemic from Q1 onward, into Q2 and Q3 2021. Second, most construction projects were completed in Q2 and Q3 across all years (primarily from 2022 to 2024), likely indicating that these were the busiest construction seasons. Since China appeared to continue construction in the winter months, this further indicates that other conditions beyond weather play a factor in project cycles.

BY LOCATION

Dongning, China - Poltavka, Russia
(Road crossing only)

There have been few changes on the border crossing between Dongning, China and Poltavka, Russia from 2020 to 2024, likely contributing to increased economic trade between the two municipalities, through changes in traffic in China and parking infrastructure expansion in Russia.

Dongning, China

On the Chinese side of the border, the only development has been an increase in semi-truck traffic around a likely small coal depot, from 75 trucks in Q3 2021 to over 160 trucks in Q2 2022. This coincides with overall traffic remaining a constant across China's section of the border over the past five years. This demonstrates a continuation of road-based economic activity along the China-Russia border and indicates that it likely increasing.

Poltavka, Russia

The one notable change in the Russian side of the border is the relatively recent development of an isolated parking lot 2.5 miles from the border. Before the parking lot's completion in Q2 2024, the dirt plot preceding it was primarily populated with semi-trucks and some automobiles. The new parking lot remedies this issue despite an increase in overall traffic at the facility, as there were 81 trucks in Q3 2021 compared to 112 in Q2 of 2022. This indicates a development in road-based infrastructure to support growing economic activity in this section of the border. Given the fact that both the Chinese and Russian sides of the border are experiencing growing truck traffic, it is highly likely that economic activity between China and Russia is increasing along the Dongning-Poltavka border, potentially becoming an economic hub for the two countries in the near future.

Heihe, China - Blagoveshchensk, Russia
(Road crossing only)

The border crossing between Heihe, China, and Blagoveshchensk, Russia has shown a significant increase in road infrastructure from 2020 to 2024, primarily centered around the new highway bridge constructed in late 2019. These changes incorporated additional projects along the road on either side of the bridge, contributing to increased Chinese cargo inspection and storage capabilities; Russian construction projects in progress are of unknown purposes.

Heihe, China

On the Chinese side of the border, there has been a significant effort in developing road-based infrastructure near the highway bridge that connects Heihe and Blagoveshchensk; indicators of this type of development can be seen in both sections A and B. During Q2 2020, early stages of large-scale construction can be seen in section A, with the foundations set for multiple buildings. The completion of this construction was seen in Q1 2021; this site is very likely an inspection station, indicated by the presence of semi-trucks. The only development that occurred in section B during this period was the completed construction of the road that connects to the highway bridge. In Q2 2022, minor road-based infrastructure would be added near the entrance of the highway bridge.

Also on the Chinese side, over the course of 2022 and 2024, further construction of road-based infrastructure was seen in section A. In Q2 2022, minor developments can be seen near both entrances of this facility. In Q4 2024, the completed construction of a building that slightly resembles a warehouse can be seen near the northwestern corner of the facility. The same image also shows 26 semi-trucks parked side by side in the southwestern space of that area; this number is an increase from seven trucks in Q2 2024. It is likely that the facility is used to store and load cargo onto the freight trucks that are stationed there so that it can be transported directly to Russia.

Blagoveshchensk, Russia

On the Russian side of the border, there were rarely any indicators in section C alluding to the development of road-based infrastructure along that section of the road. In Q1 2021, a port that was in close proximity to the highway bridge was deconstructed. The port was likely removed due to its temporary nature of onloading and offloading construction material. In Q4 2022, there was evidence of construction taking place along the road, with four building foundations laid. As construction is still ongoing in that area as of Q3 2024, it is difficult to determine the type of infrastructure that is being built. Regarding road traffic, there were only three semi-trucks seen in line at the border in Q4 2022; by Q3 2024, this increased to 38 trucks seen.

A CNN article published in June 2022 describes the construction and opening of the Heihe-Blagoveshchensk highway bridge, which opened for use in that same month. Despite imagery showing completion before our scope (late 2019), this delay is attributed to the COVID pandemic. As of 2022, the bridge is known to only be used for cargo transport, but its proposed passenger capacity is around two million travelers per year; cargo is estimated for four million tons, totaling around USD 200 billion by 2024. Both China's Xi Jinping and Russia's Vladimir Putin expressed positivity about the bilateral political and economic effects of the bridge's construction.

Hulin, China - Markovo, Russia
(Road crossing only)

At the Hulin, China and Markovo, Russia border crossing, all infrastructure changes occurred on the Russian side, solely involving building construction along the cross-border road, likely indicating an increase in Russian interest of economic activity between Markovo and Hulin. The blue building just southeast of the bridge and river/border serves as a reference point.

Due to a lack of imagery between Q2 2021 and Q4 2023, it is unknown when the following construction began. Regardless, on the Russian side, road-based infrastructure construction was first seen in Q4 2023, where at least two confirmed buildings were under construction; this is possibly four separate buildings, but this is still unknown. The purpose is also unknown, but as the construction site incorporates both sides of the road and is about 0.5 miles from the border, it is likely related to border security or economic activity. This construction continued into Q1 2024.

Hunchun, China - Kraskino, Russia
(Both road and rail crossing)

The border crossing between Hunchun, China and Kraskino, Russia saw a gradual increase in road-based transport infrastructure between 2020 and 2024, aiming to better facilitate cargo transportation via lane additions, as well as new storage facility construction. Despite the presence of rail lines, all changes solely related to road-based infrastructure.

Hunchun, China

On the Chinese side of the border, there was expansion and widening of the road to allow larger vehicles to transport cargo. During Q3 2020, there were indicators of ongoing construction on the road towards the border crossing. There was also construction taking place near the west side of a warehouse facility residing near the border. Images collected during Q4 2023 and in Q1 and Q2 2024 further corroborate continuing construction, which showed the completion of nine large warehouse facilities in Q4 2023, along with the installation of a fueling station near the border crossing. The presence of these facilities indicates a greater focus on commercial truck-based logistics and transitory storage. This could prove beneficial for Hunchun, as it is a significant hub for e-commerce and other commercial activities in that region.

Kraskino, Russia

The Russian side of the border also showed indicators of road infrastructure development. Imagery collected from Q2 2024 shows large scale construction activity occurring on a large plot of land, comprising several small and large buildings. The roads that lead into the site were widened, most likely to allow larger freight and other types of cargo trucks to enter the area. Like the activity occurring on the Chinese side of the border, it is possible that the site is being used to develop a large-scale warehouse facility. The establishment of road infrastructure to the east of the site, along with two ongoing construction projects taking place near the road towards the border, further indicates this likelihood.

Manzhouli, China - Zabaykalsk, Russia
(Both road and rail crossing)

All changes observed occurred on the Chinese side of the Manzhouli, China and Zabaykalsk, Russia border crossing, and were entirely road based, primarily regarding changes in commercial traffic patterns, as well as tourist area construction. This indicates an increase in economic activity across the border at this location related to the importing of goods into China.

Beyond Q3 2021, imagery showed no apparent changes to infrastructure, but throughout the time scope, commercial traffic fluctuated. Coinciding with the COVID pandemic, the number of semi-trucks around the border significantly decreased within Q2 2020, and remained low (at 21 trucks present) until Q3 2021, where traffic increased to over 80 trucks present. However, between Q4 2021 and Q3 2023, traffic appeared to decrease from around 30 trucks to around 20 trucks present. From Q3 2023 to Q4 2024, the number of trucks significantly increased from 20 to over 80 trucks again, showing longer lines across the border and within holding areas.

In Q2 2020, two buildings were under construction near the main cross border road within the designated tourist/visitor area. Construction continued through Q3 2020, where a small building (separate from the two under construction) had its roof painted. By Q3 2021, both buildings were completed; one appears to be an observation tower for tourism, while the other's purpose is unknown.

Mishan, China -Turiy Rog, Russia
(Road crossing only)

The border crossing of Mishan, China and Turiy Rog, Russia has had minor increases in infrastructure between 2020 and 2024, where some small structures were constructed on both sides, possibly to contribute to the coal trade in northeastern China and southeastern Russia.

Mishan, China

Most of the structural increases belong to the Chinese side. 02 2021 was the first reported change in the construction of small structures. Similarly, there was also road infrastructure construction in 03 2024. One note is that because the Chinese side contains what appears to be an industrial site, there is a reoccurring black mound of what is highly likely to be coal deposits roughly every two years. In 03 of both 2022 and 2024, there were major coal deposits in Mishan. Though China does not export coal to Russia, Mishan's status as the key port of entry into the Heilongjiang province (a significant source of Chinese coal), providing access to Russia's Vladivostok port for other exporting activities.

Turiy Rog, Russia

On the other hand, there is little activity on the Russian side in Turiy Rog. There were small structures constructed in 03 2022. It is unclear as to what these structures are or their use. In 01 2023, it is noteworthy that the road traffic appears to be blocked. There was deconstruction in 04 2024, where the structures constructed in 03 2022 were removed by 04 2024.

Shiwei, China - Olochi, Russia
(Road crossing only)

The border crossing between Shiwei, China and Olochi, Russia saw minor road-based infrastructure development, largely around China's visitor area construction activities and Russia's road expansion and creation.

Shiwei, China

On the Chinese side, there was temporary road construction in that same quarter, which appears to be repaving; this was completed within that quarter. There was also pavement expansion in progress; however, this showed no apparent progress as of Q3 2024. It is important to note that this construction takes place near what appears to be a visitor center or border inspection station.

Olochi, Russia

On the Russia side, Q4 2023 showed some road construction in progress, with a lane addition on the main cross-border road, as well as some development of smaller frontage or spur roads. These smaller roads parallel the road that intersects with the main cross-border road at a T shaped intersection, traveling northeast/southwest within Russia.

Suifenhe, China - Pogranichny, Russia
(Both road and rail crossing)

The border crossing between Suifenhe, China and Pogranichny, Russia saw an increase in both road and rail infrastructure throughout the period of 2020 and 2024, primarily to increase material storage and transport capacity.

Suifenhe, China

On the Chinese side, most rail changes occurred in two adjacent sections. In Q2 2020, two warehouses were under construction. By Q4 2021, these warehouses were completed, with additional foundational construction of another warehouse in progress. In that same quarter, a smaller warehouse was demolished. As of Q3 2024, a larger warehouse was completed, with two others torn down. Despite the construction of new rail sections branching off from the main line for storage purposes, the amount of cargo cars present slightly decreased from Q4 2021, from around 350 to 300.

Pogranichny, Russia

Regarding Russian road infrastructure, imagery showed an increase in infrastructure to park, unload, and pass vehicles through at the border crossing. The first imagery of the aforementioned period is taken from Q2 2020. In this quarter, there was no observed traffic, and there were construction projects in progress. An additional parking lot was constructed by Q4 2021, with other minor road infrastructure deconstructed. By Q3 2024, a warehouse was constructed, and there was also a heightened amount of traffic in the area, from about 110 semi trucks in Q4 2021 to over 200 in Q3 2024.

Suifenhe Storage

Further west into the Chinese side of the border, imagery primarily shows deconstruction around what is very likely an industrial storage site (due to the presence of warehouses and construction materials), possibly due to a decrease in other construction activities nearby. Between Q4 2020 and Q4 2021, there was development of road infrastructure, namely parking lots, around storage facilities. This was accompanied by minor infrastructure removal in the same vicinity. However, as of Q2 2024, a section of infrastructure was undergoing deconstruction north of the main cross-border road. In Q3 2024, the aforementioned deconstruction was complete, and there was further degradation of smaller dirt roadways to the west of this site.

Pogranichny Road, Russia

Additionally, the Russian side of the border saw road-based building infrastructure, with a single site first noticed in Q2 2020. In all images collected beyond the first image (04 2020, Q4 2021, and Q3 2024), this construction expanded, with the original buildings accompanied by more foundations, and ultimately 13 confirmed buildings on the site by Q3 2024. The imagery appears to show this site still under construction as of that quarter. Though the purpose is unknown, these buildings' adjacency to the border and their foundations as nonresidential sites likely make them border inspection or customs offices, paralleling these existing counterparts on the Chinese side.

Pocgranichny Rail, Russia

Furthermore, the Russian side's rail section saw construction to likely increase the rail-based raw material transport capacity. In Q2 2021, construction was first seen at an existing construction material storage site adjacent to the rail lines. By Q2 2022, construction continued at the site, and two small supporting warehouses were under construction just south of the rail lines. As of Q2 2024, the two warehouses were completed, and at both the storage site and directly next to the tracks, additional construction materials were present.

Tongjiang, China - Nizhneleninskoye, Russia (Both road and rail crossing)

The border crossing between Tongjiang, China and Nizhneleninskoye, Russia significantly increased the development of rail-based infrastructure, and slightly increased development of road-based infrastructure between 2020 and 2024, likely increasing the ability to store train cars within Russia.

Tongjiang, Russia

All major developments occurred on the Russian side of the border. In Q2 2020, ongoing construction of a multi-track rail stop was seen and was completed by Q2 2022. By constructing eight rails diverging from the two main lines, Russia can now stage up to four times the original capacity of cargo cars at this stop. Further towards the border, a construction site and a small building near the highway bridge were found to be deconstructed in Q4 2023. Also, there was a small dock previously present beneath the bridge, and it was replaced with sand or a similar material filling the land.

Nizhneleninskoye, Russia

On the Russian side of the border, there was little activity that took place. The only change occurred between Q2 2020 and Q2 2022 with the deconstruction of small-scale road infrastructure located near the highway bridge.

Assessments Based on Open-Source Information

In using OpenRailwayMap, the team made certain assessments for the following locations that corroborated imagery:

• Hunchun, China - Kraskino, Russia: Data indicates the presence of dual gauge tracks at the border crossing with a bogie exchange or transshipment station at the Hunchun station.

• Manzhouli, China - Zabaykalsk, Russia: The Manzhouli-Zabaykalsk border crossing operates with independent 1435mm and 1520mm gauge tracks, suggesting largescale bogie exchange or transshipment operations. There is an absence of dual gauge tracks.

• Suifenhe, China - Pogranichny, Russia: Dual gauge tracks are present, beginning just after the Grodekovo-2 station and extending into China at the Suifenhe station. Additionally, single tracks of both 1435mm and 1520mm exist in the Suifenhe station. The presence of dual gauge tracks in several areas around the border crossing suggests that both Russian and Chinese trains can operate in certain sections without requiring immediate cargo transfer. However, both stations are largely comprised of their respective gauges, indicating rail freight must undergo bogie exchange or transshipment operations once it has reached either station.

• Tongjiang, China - Nizhneleninskoye, Russia: As previously stated, this border crossing largely consists of dual gauge tracks. Unlike other crossings, such as Manzhouli-Zabaykalsk, which has extensive bogie exchange and transshipment yards, the Tongjiang Nizhneleninskoye bridge appears to be designed to minimize these requirements. It appears that the largely dual gauge tracks allow for rail freight to be directly transferred or continue operation without the need for bogie exchanges, depending on locomotive compatibility. According to Rail Journal, the "bridge can carry trains operating on Russia's 1520mm-gauge and China's 1435mm-gauge tracks, with Russian-gauge trains able to travel 15km to a depot in China."

CONCLUSION

The long-term trajectory of Chinese-Russian trade will likely depend on how both countries address infrastructure concerns and expand border trade capacity amid shifting geopolitical and economic pressures. First, international geopolitical and economic situations influencing Chinese Russian trade remain extremely fluid. While Russia has largely turned to eastern markets for the export of natural resources, including timber and energy products, growing demand from Asian countries, particularly China, has so far outpaced what Russia can supply. Russian officials have consistently stated radical reforms to Russia's Eastern Polygon trade infrastructure must be made to properly accommodate growing demand in the east while coping with a lack of trade cooperation from the west.

While recent and ongoing projects have made notable improvements to border infrastructure and trade facilitation between the two countries, few significant impacts are expected in the near term of twelve to twenty-four months. Conversely, the most significant impacts are expected from current, future, and proposed initiatives aimed at addressing visible border bottlenecks and expanding trade capacity through the end of the decade.

To fully assess the long-term implications of border crossing infrastructure development between China and Russia, sustained monitoring of major checkpoints will be essential. Future research should prioritize imagery and open-source coverage of construction progress, changes in freight volume, and road and rail network upgrades on both sides of the border. Additionally, tracking new trade agreements, changes in customs procedures, and economic developments near border areas can provide insights into how both Russian and Chinese infrastructure investments translate into trade flows.

Limited transparency from both Chinese and Russian government and media sources significantly hinder assessments of border infrastructure development and trade trends, especially regarding project intent and pandemic-related disruptions. First, there is a lack of open-source information on Chinese and Russian public activities, given the nature of their governance as authoritarian states. Both China and Russia do not publicize most of their infrastructure project information regarding financial data or the exact nature of their public works projects. For example, local planning documents would help clarify the nature of what exactly both countries are constructed, and would reduce uncertainty in assessing whether buildings have border control, tourist, manufacturing, or other functions.

Second, the same lack of publication applies to data on COVID-19 and its effects on passenger and cargo travel between China and Russia. This information would provide more insight on past activities between the countries, such as tourist or visitor statistics, as well as shifts in trade actions; such as if medical products were traded more than raw materials from 2020 to 2021. Such information could explain why certain changes in construction cycles appeared (or did not) through fluctuations in the amounts of lumber, metals, and other material transported.

This analysis could be improved by a more thorough pre-2020 baseline, and more building-level identification. Though this is out of the project's scope, a greater amount of background information would help contextualize the reasoning behind some of the changes along the border, as well as why construction cycle or traffic fluctuations occurred.

Additionally, in collecting and analyzing imagery, taking the time to identify certain buildings near the border itself would help provide context for changes. ■

2025 YEARBOOK

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