REMOTE ASSESSMENT *of* BOMBARDMENT *of* UKRAINE'S POWER GENERATION *and* TRANSMISSION INFRASTRUCTURE, 1 OCTOBER 2022 *to* 30 APRIL 2023

A CONFLICT OBSERVATORY REPORT

29 FEBRUARY 2024

Yale SCHOOL OF PUBLIC HEALTH
Humanitarian Research Lab

Maps utilize the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA) Field Information Services Section subnational administrative boundary data. The naming conventions for oblasts, Crimea, and cities with special status are the short form Anglicized Variant (AV) names of the U.S. Board on Geographic Names Geographic Names Server.

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EXECUTIVE SUMMARY

The Yale School of Public Health's (YSPH) Humanitarian Research Lab (HRL), with research support from the Ukraine Digital Verification Lab (UDVL) at the Fletcher School of Law and Diplomacy, has verified 66 high confidence instances of conflict-related damage to Ukraine's power generation and transmission infrastructure according to the methodology in this report. This report identifies a further 157 incidents of damage for a total of 223 identified incidents across 23 oblasts from 1 October 2022 to 30 April 2023. These verified damage incidents span 17 oblasts across Ukraine with nearly 53 percent occurring in just five: Kyiv, Kharkiv, Dnipropetrovsk, Lviv, and Kherson oblasts.
Over 53 percent of the total verified incidents (35 of 66) occurred in October and November 2022. Kyiv oblast sustained the most verified incidents of conflict-related damage in this period, with 11 instances of damage out of 66 total verified incidents, 8 of which occurred during the months of October and November. This report finds that 128 identified incidents of damage occurred in oblasts that did not overlap with the frontline between 1 October 2022 and 30 April 2023.

This assessment focuses on the time period of 1 October 2022 to 30 April 2023 for two primary reasons: (1) Russia's officials' claims that the massive wave of attacks on energy infrastructure was a response to the 8 October 2022 explosion at the Kerch Bridge in Russia-occupied Crimea; and (2) the humanitarian impact to civilians resulting from damage to energy infrastructure in winter months, the season when heating needs are highest in Ukraine.

The geospatial and temporal distributions of these incidents, in conjunction with statements on attacks from public officials and state-sponsored media in Russia, appear consistent with a widespread and systematic effort to cripple vital power generation and transmission infrastructure across Ukraine. Incidents are distributed across an overwhelming majority of Ukraine's oblasts, including areas well removed from the frontlines of fighting. This wide geospatial distribution is suggestive of an effort to cripple Ukraine's energy infrastructure in a manner that is not clearly intended to achieve a direct and concrete military advantage in every instance. The wide geospatial distribution points to possible violations of the international humanitarian principles of distinction and proportionality, as well as the obligation to take all feasible precaution to minimize injury to civilians and damage to civilian objects.

Russia's officials, including President Vladimir Putin, have stated on multiple occasions that Russia is deliberately targeting Ukraine's energy infrastructure. Officials have at various points justified targeting Ukraine's power infrastructure as advancing Russia's military objectives, as retaliating for purported action by Ukraine, and as intentionally inflicting harm on civilians for the purpose of compelling Ukraine to submit to negotiations in terms favorable to Russia's interests (*See Section III. Possible Violations of International Law*). While Yale HRL does not make any definitive determinations on the legality of the individual incidents of damage logged in this analysis, these statements, together with the aggregate data, indicate that Russia's attacks on Ukraine's power generation and transmission infrastructure may constitute deliberate targeting that is inconsistent with international humanitarian law.

METHODOLOGY

This assessment remotely evaluated indicators consistent with conflict-related damage to power generation and transmission infrastructure through Yale HRL's fusion methodology, which combines open source data analysis and commercially available, very high resolution (VHR) satellite imagery and geospatial data analysis. For this analysis, "power generation and transmission infrastructure" is defined as facilities that generate electric

CONFLICT-RELATED DAMAGE TO UKRAINE'S ENERGY INFRASTRUCTURE

1 Oct 2022 - 30 Apr 2023

223 incidents of damage across 23 oblasts identified in open source reporting and satellite imagery

128 of 216 spatially located incidents of damage occurred in oblasts that did not have a frontline running through them during the analysis timeframe

66 incidents of damage verified to HRL open source and/or imagery verification standards

17 oblasts had verified incidents of damage to energy infrastructure occurring during the analysis timeframe

power from primary energy sources, including coal, geothermal, water (hydropower), wind, nuclear, solar, oil, natural gas, and biomass, or facilities such as power substations that transform or transmit energy from a power generation site. In this report, analysis of the transmission network between stations and substations (such as transmission lines not located within station or substation grounds) is not conducted due to the large number of such lines, the minimum visibility required for such an analysis, and the speed of repairs to such objects.

This report documents two categories of alleged incidents of damage to power generation and transmission infrastructure: (1) identified incidents and (2) verified incidents. Identified incidents are defined as all reported incidents of damage due to strikes damaging power generation and transmission sites identified by open source researchers.[i] Verified incidents are defined as incidents due to strikes with sufficient open source and/or imagery data to verify an identified incident with high confidence. Researchers analyzed open source information for reported strike incidents damaging power generation or transmission sites in Ukraine across Telegram, Twitter, and Facebook posts, official statements, news reports, and other publicly available sources to identify and verify incidents. Researchers performed additional geolocation of identified incidents as per the Berkeley Protocol on Digital Open Source Investigations.[1] Imagery analysts evaluated available VHR satellite imagery for visual indicators of damage consistent with damage resulting from munition effects. Researchers also assessed thermal detection data for temporal correlations of thermal anomalies with reported strikes on energy infrastructure.

LIMITATIONS

This report does not assess the number of civilians affected by power outages due to strikes, the quantitative scope of the potential humanitarian impact on affected populations, or the lost operational capacity of energy infrastructure damaged by strikes.[ii] Yale HRL determined that it was not possible to perform this analysis to a high standard given critical data gaps, most notably the absence of publicly available meter data from the power generation and transmission plants themselves, as well as the absence of specific power grid maps of facilities and their service areas. Additional types of analysis, particularly of whether parties to the conflict conducted so-called "double-tap" attacks or exercised precautions such as striking at night or in time periods that would otherwise limit civilian harm, were also not possible due to limited open source data and limited temporal resolution of satellite imagery data.

This report was not able to assess the status or potential damage to every electrical power generation or transmission facility or component in Ukraine. The number of facilities assessed in this report is likely significantly lower than the total number of facilities damaged. This is due to the number of power generation and transmission stations and substations in Ukraine and limitations on information published publicly on critical infrastructure damage. This study was performed with particular care for the operational security implications for documenting attacks. It is important to note that several officials of Ukraine directed the public not to share information about these attacks publicly due to concern that it would improve Russia's accuracy and targeting, which may have reduced the availability of open source information. The research team coordinated with relevant counterparts in Ukraine and the international community to take appropriate steps to ensure that this report would not cause additional risk to power generation and transmission capabilities (*See Section IV. Methodology*).

PURPOSE

This report is intended to complement the efforts of international organizations, government agencies, civil society organizations, human rights investigators, and legal mechanisms to document conflict-inflicted damage to critical civilian infrastructure in Ukraine and consequent violations of applicable international humanitarian law (IHL) and international human rights law (IHRL). Many of these reports have estimated the cost of damage and losses to the energy sector due to bombardment, verified occurrences of Russia's strikes on Ukraine's energy infrastructure, and assessed health, environmental, and livelihood impacts of damage to Ukraine's energy infrastructure, among other aims (*See Section I. Background*).

Yale HRL's assessment seeks to build upon these efforts and, for as many incidents as possible, preserve data that is (1) of use to accountability mechanisms and (2) usable by other entities and organizations engaging in present and future data collection and damage assessment. Though information on specific incidents is limited in this public report for protection reasons, data is archived in a format usable for present and future legal accountability mechanisms and is available upon request to credible organizations.

i. There are three incidents that are defined as identified incidents that do not meet the criteria of having been identified by open source researchers. Three additional incidents were identified and verified through satellite imagery and no open source reporting. The addition of these three imagery-identified incidents result in a total of 223 identified incidents.

ii. While Yale HRL and UDVL did not quantify civilian impact, they did log open source reporting that referenced power outages, impacts on water and sanitation, areas with impacted civilian populations, and impacts on internet connectivity where such information in the open source was available.

I. BACKGROUND

While Ukraine's government makes efforts to publicize the fact of attacks on civilian energy infrastructure, authorities frequently omit specific data on damaged or destroyed sites to protect site locations and their operational status and to minimize actionability of information in future possible targeting efforts.[2] This report builds on multiple ongoing and past independent efforts to assess the war's impact on Ukraine's power generation and transmission infrastructure as a potential violation of IHL. Yale HRL's assessment complements these previous reports to document damage to Ukraine's energy infrastructure and build a foundation of digitally verified information for accountability purposes.

According to CNN, Ukraine's Prosecutor General's Office (OPG) documented 255 Russian attacks on Ukraine's energy infrastructure across 24 of Ukraine's 27 administrative regions in the first year since the full-scale invasion began.[3] Based on data from Ukraine's OPG, a subsequent CNN analysis reported that Ukraine's energy facilities were struck 82 times in October 2022, more than all previous months since the full-scale invasion combined.[4] CNN also cited data from the Ukrainian think tank DiXi Group, which counted 1,350 Russian rockets and drones aimed at Ukraine's energy infrastructure between October 2022 and late January 2023 based on records from Ukraine's armed forces as well as public and private Ukrainian energy companies.[5] DiXi Group stated that 255 strikes had hit 112 energy facilities in the year since the full-scale invasion, with 77% occurring between October 2022 and February 2023.[6]

In August 2023, the United Nations Independent International Commission of Inquiry on Ukraine (COI) reported to the United Nations Human Rights Council that Russia's armed forces significantly expanded attacks on energy infrastructure beginning on 10 October 2022.[7] It also noted a change in the types of facilities struck: prior to 10 October 2022, attacks by Russia's armed forces largely impacted oil refineries and electric substations related to railways; after 10 October 2022, electric substations and power plants, including thermal power plants producing both electricity and heat, became the focus of attacks across 20 of Ukraine's 24 oblasts.[8] The Commission concluded that "the large-scale attacks launched between 10 October 2022 and 26 January 2023… were widespread and systematic."[9] The Commission also stated that Ukraine's authorities shared a list of 159 attacks that damaged or destroyed 79 energy-related installations between 10 October 2022 and 12 January 2023.[10]

The Dutch peace organization PAX, in association with the Centre for Information Resilience (CIR), produced a report in December 2022 that identified 213 reported incidents resulting from military action to Ukraine's energy infrastructure between February and November 2022, 63 of which were subsequently verified through a combination of open source reporting and high-resolution satellite imagery.[11] According to the PAX report, attacks launched by Russian forces in October 2022 damaged 40% of the country's generation and transmission facilities.[12]

"The large-scale attacks launched between 10 October 2022 and 26 January 2023… were widespread and systematic"

- UN Independent International Commision of Inquiry on Ukraine

Other publicly available damage assessments have estimated the cost, overall scale, and specific typologies of damage to power infrastructure. The PAX analysis found that the verified incidents occurred across 17 of Ukraine's 24 oblasts and that most verified incidents involved 330 kV transformer substations, many of which were the primary substations for their respective cities.[13] The Kyiv School of Economics (KSE) Institute calculated in May 2023 that Ukraine had sustained 8.3 billion USD in direct damage to energy facilities as of April 2023, an increase of 200 million USD since February 2023.[14] The damage to energy infrastructure accounted for 5.6% of the total estimated 147.5 billion USD in direct damages to residential and non-residential infrastructure in Ukraine.[15] Strikes caused large blackouts across multiple regions of Ukraine around 23 November 2022, plus several other blackouts for cities across Ukraine in autumn 2022 and winter 2023.[16]

Actual damages are expected to be much higher due to both currently incomplete information about occupied territories and recommendations by Ukraine's authorities to limit the release of detailed information regarding energy infrastructure facilities.[17] In addition, Ukraine's air defense forces' increased effectiveness over the course of the conflict has very likely reduced the number of strikes inflicting damage on energy infrastructure. Personnel operating power sites also placed sandbag barriers and similar objects around key equipment at power generation and transmission sites,

namely transformers, to minimize damage to those structures, as observed in Yale HRL's imagery analysis. Consequently, these assessments of damage incurred likely constitute only a fraction of total attempts to strike Ukraine's energy infrastructure.

Meanwhile, Ukraine's "increased experience with emergency stabilization" and "high rates of emergency restoration" have shortened lengths of time for which many of these facilities are rendered inoperable or damaged.[18] While Ukraine's President Volodymyr Zelensky warned on July 2023 that Russia would likely ramp up its attacks on energy infrastructure again during the winter of 2023-2024, Ukraine's Energy Minister German Galushchenko expressed confidence in the ability Ukraine's authorities to execute repairs and ensure reliable energy supplies.[19] Ukraine's infrastructure minister also stated that nearly all thermal power stations damaged in late 2022 and early 2023 by Russia's attacks had been repaired 30 July 2023.[20]

Many damage assessments have utilized open source data methodologies similar to Yale HRL's open source data fusion methodology. PAX's report combined both open source reporting and high resolution satellite imagery in its analysis. A model developed by *The Economist* to analyze locations and intensity of conflict combined data from NASA's Fire Information for Resource Management System (FIRMS) and Synthetic Aperture Radar (SAR).[21] The KSE Institute Report utilized digital tools to collect and analyze information from government officials, agencies, local authorities, residents, and others, as well as ortho-rectified drone images taken in liberated areas and satellite, aerial, and street-level imagery analyzed by Polish-U.S. company Tensorflight to assess damage to infrastructure, including via machine learning models.[22] Yale HRL's fusion methodology, detailed later in this report, utilizes many of these accepted data collection and analysis techniques and implements rigorous data preservation to support replicability of analysis and digital evidence transfer for present and future accountability mechanisms.

II. DETAILED FINDINGS

Yale HRL and UDVL identified 223 unique incidents of damage to Ukraine's power generation and transmission infrastructure, of which researchers located 216 incidents geographically (spatially located incidents) and located 217 to a specific date or time period (temporally located incidents).[iii] These identified incidents were located across 23 oblasts, including oblasts comparatively distant from frontlines of fighting. Yale HRL was able to verify 66 incidents of conflict-related damage across 17 oblasts out of the 223 total identified incidents of damage to this report's high confidence standard (*see Section IV, Assessment Methodology*).

IDENTIFIED INCIDENTS OF DAMAGE

Identified incidents are defined as all reported incidents of conflict-related damage allegedly damaging power generation and transmission sites identified by open source researchers.[iv] Among the 223 identified incidents, 217 could be temporally located and 216 could be spatially located to at least an oblast. Almost half (about 47%, or 101 of 217 incidents) of temporally located incidents occurred during the months of October and November 2022. More than half (about 52%, or 113 of 216 incidents) of spatially located incidents occurred in Kharkiv, Kherson, Dnipropetrovsk, Zaporizhzhia, and Kyiv oblasts. Among identified incidents logged by Yale HRL and UDVL:

OBLAST	IDENTIFIED INCIDENTS	VERIFIED INCIDENTS
Kharkiv	25	9
Kherson	25	4
Dnipropetrovsk	23	6
Zaporizhzhia	21	5
Kyiv	19	11
Donetsk	14	1
Mykolaiv	10	0
Odesa	10	4
Lviv	9	5
Vinnytsia	9	2
Sumy	7	2
Kirovohrad	7	2
Chernihiv	6	0
Zhytomyr	6	4
Poltava	5	4
Ivano-Frankivsk	4	3
Khmelnytskyi	4	2
Luhansk	3	1
Volyn	3	0
Cherkasy	2	0
Rivne	2	1
Chernivtsi	1	0
Ternopil	1	0
TOTAL	**216**	**66**

Figure 1. Geographically identified incidents of damage and verified incidents of damage per oblast

220 incidents of damage on Ukraine's energy infrastructure identified through open source reporting;

3 incidents identified through satellite imagery analysis;

11 of 19 identified incidents of damage in Kyiv oblast and Kyiv city occurred during **October and November** 2022;

128 incidents of damage occurred in oblasts that did not overlap with the frontline at any point according to ISW data on frontline locations from 1 October 2022 through 30 April 2023; and

4 identified incidents occurred on sites containing "**dangerous forces**" — namely dams, dykes, and nuclear electrical generating stations — as defined in Article 56 of Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts (AP I).

iii. Temporal location is referred to in the Berkeley Protocol as chronolocation. Chronolocation is "the corroboration of the dates and times of events depicted in a piece of information, usually visual imagery" (page 65), UN OHCHR and the Human Rights Center at the UC Berkeley School of Law, Berkeley Protocol.

iv. There are three incidents that are defined as identified incidents that do not meet the criteria of having been identified by open source researchers. Three additional incidents were identified and verified through satellite imagery and no open source reporting. The addition of these three imagery-identified incidents result in a total of 223 identified incidents.

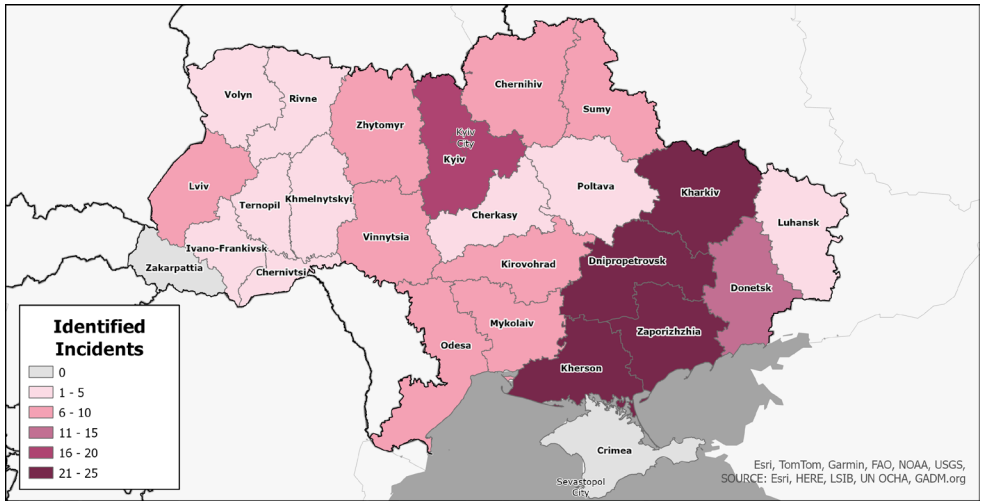

Fig.2 Identified incidents of damage, 1 October 2022 - 30 April 2023

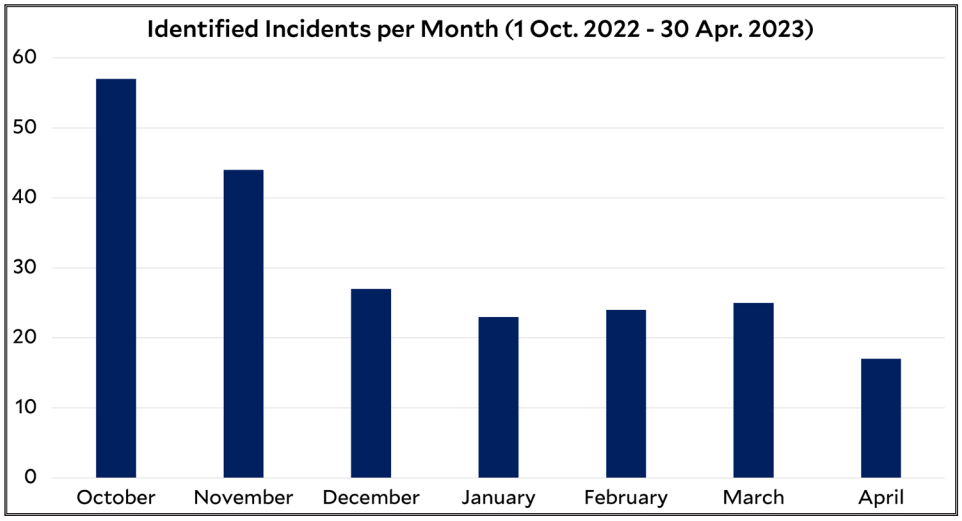

Fig.3 Identified incidents per month, 1 October 2022 - 30 April 2023

VERIFIED INCIDENTS OF DAMAGE

Verified incidents are defined as incidents damage due to alleged strikes with sufficient open source and/or satellite imagery data to verify an identified incident with high confidence. Of the 223 identified incidents of damage, Yale HRL and UDVL researchers were able to verify and locate 66 incidents across 17 oblasts during the specified time period. Of these 66 verified incidents, 61 incidents were verified by open source reporting, 9 were verified by very high resolution (VHR) imagery, and 4 were verified by both open source reporting and VHR imagery according to the Open Source and Imagery Verification Standards described in the Methodology. Yale HRL identified and verified three incidents of damage via VHR imagery without prior open source reporting identification.

In 9 of the 66 verified incidents of damage, imagery analysts observed damage including but not limited to charred or damaged transformers, charred or damaged pipelines, and cratering consistent with munitions effects to facility roofs, among other visual indicators. The nature of structures at generation and transmission sites (particularly the presence of dark-colored and vertical structures rather than structures with roofed profiles), limited imagery availability, and limited imagery resolution are likely contributors to the relatively small proportion of imagery-verified incidents of damage.

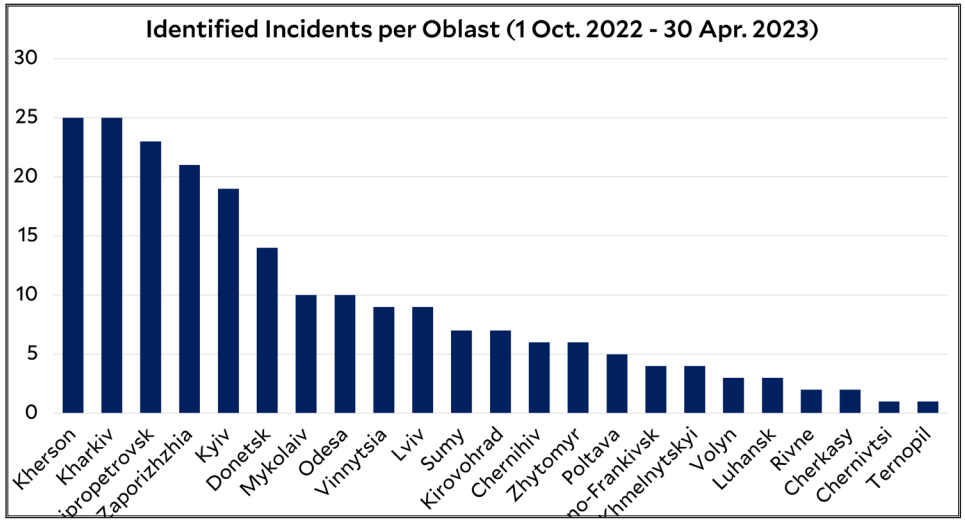

Fig.4 Identified incidents per oblast, 1 October 2022 - 30 April 2023

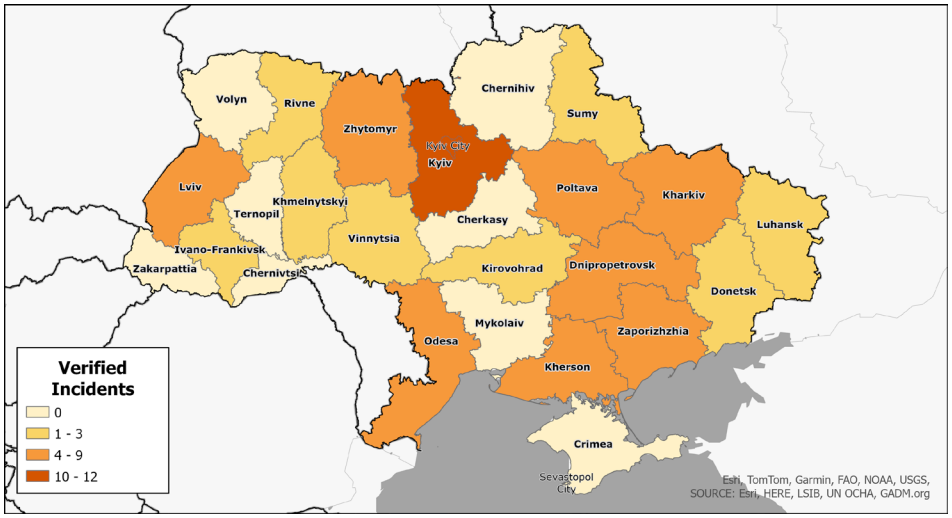

Fig 5. Verified incidents of damage, 1 October 2022 – 30 April 2023, by oblast

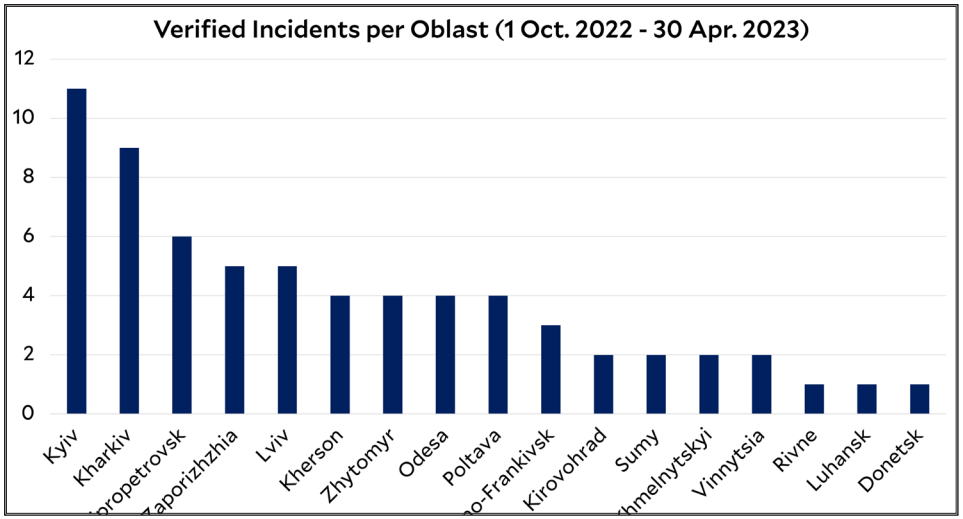

Fig. 6 Verified incidents of damage by oblast, 1 October 2022 – 30 April 2023

Most verified incidents (53%, or 35 out of 66) occurred in five of Ukraine's 24 oblasts: Kyiv, Kharkiv, Dnipropetrovsk, Lviv, and Kherson. At least 53% of the total verified incidents (35 of the 66) occurred during October and November 2022. Kyiv oblast and Kyiv city sustained the most verified incidents of conflict-related damage with 11 instances of damage out of 66 total verified incidents, with 8 of these instances occurring in October and November. Dnipropetrovsk oblast sustained 4 verified incidents of damage during October and November 2022. Over time, media reporting on incidents was less detailed, which contributed to a smaller proportion of identified incidents being verified.

Yale HRL assesses that there was likely significantly more damage to Ukraine's power generation and transmission infrastructure during the 1 October 2022 – 30 April 2023 period than researchers were able to verify to a high confidence standard. The limitations on temporal and spatial resolution of satellite imagery, underreporting of detail in open source data, and limited timely data vis-a-vis repair rates limited the ability for Yale HRL and UDVL analysts to both identify and verify incidents to this assessment's Verification Standards. This assessment has the benefit of using only data which is publicly and commercially available, and thus providing an open source account of conflict-related damage to Ukraine's power generation and transmission infrastructure.

III. POSSIBLE VIOLATIONS OF INTERNATIONAL LAW

This research presents possible *a priori* evidence of international law violations. First, the geospatial distribution of damage to the power generation and transmission infrastructure across an overwhelming majority of Ukraine's oblasts appears consistent with a widespread and systematic effort to cripple Ukraine's energy infrastructure. The widespread impact of strikes on energy infrastructure that serves civilians may violate the international humanitarian law principles of distinction and proportionality.

Second, Russia's officials have provided a variety of public statements that a) directly admit Russia is targeting Ukraine's energy infrastructure, and b) provide contradicting rationales for those attacks. These officials have at various points justified targeting Ukraine's power infrastructure in three main ways: (1) as advancing Russia's military objectives; (2) as retaliation for purported action by Ukraine; or (3) as the intentional infliction of harm on civilians for the purpose of compelling Ukraine to submit to negotiations in terms favorable to Russia's interests. The latter two justifications potentially demonstrate Russia's intent to violate international humanitarian law, particularly Additional Protocol I (*Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts (Protocol I), adopted 8 June 1977*). Both Russia and Ukraine are Parties to Additional Protocol I and are therefore subject to its obligations.

CAVEATS AND LIMITATIONS

This assessment is bound by several limitations. Yale HRL does not assess whether Parties to the conflict did "take all feasible precautions in the choice of means and methods of attack with a view to avoiding, and in any event to minimizing, incidental loss of civilian life, injury to civilians and damage to civilian objects" in accordance with Article 57(2)(a)(ii) of Additional Protocol I.[23] Yale HRL also does not assess whether the power generation and transmission infrastructure sites in its datasets service any military operations. Yale HRL did observe the presence of visual indicators consistent with trench-work and/or checkpointing in the vicinity of a small number of damaged sites, including one installation containing dangerous forces as defined in Article 56(1) of Additional Protocol I. Yale HRL analysts mapped the sites at which they observed potential indicators of proximate presence of military operations. They then compared the approximate temporal incidence of these indicators against Ukraine's and Russia's areas of control around the same period.

This comparison did not yield definitive conclusions as to whether Parties to the conflict constructed, occupied, or used these objects to support military operations.[v] Yale HRL did not discern whether the objects that are potentially consistent with past or present military usage located near these installations containing dangerous forces (or other power generation and transmission installations) were erected for the sole purpose of defending the protected works or installations from attack, which could implicate Article 56(5) of Additional Protocol I. Yale HRL has limited detail on individual incidents. As a result, Yale HRL is currently unable to make a complete assessment of whether individual incidents meet the international humanitarian law requirements of distinction and proportionality. Yale HRL does not conduct attribution of responsibility for individual incidents of damage.

WIDESPREAD TARGETING OF ENERGY SITES AND RELEVANT INTERNATIONAL HUMANITARIAN LAW

Part IV of Additional Protocol I establishes general protections for civilian populations and civilian objects against the effects of hostilities, including certain infrastructure. It establishes the threshold conditions that must be met to legally target objects such as power generation and transmission infrastructure.

Article 52 lays out the legal principles for general protection of civilian objects:

1. That civilian objects (i.e., all objects which are not military objectives) shall not be the object of attack or reprisals;[24]
2. That attacks shall be limited strictly to military objectives, which are "limited to those objects which by their nature, location, purpose or use make an effective contribution to military action and whose total or partial destruction, capture or neutralization, in the circumstances ruling at the time, offers a definite military advantage." All other objects are civilian objects and cannot be the subject of a lawful attack; and
3. That in case of doubt of whether a normally civilian object is being used to make an effective contribution to military action, civilian nature is presumed.[25]

Even when an energy infrastructure site can be appropriately described as a military objective, international humanitarian law maintains that these attacks remain subject to the principle of proportionality

v. Yale HRL used data archived by the Conflict Observatory from the Institute for the Study of War (ISW). This data is derived from: George Barros, Kateryna Stepanenko, Thomas Bergeron, Noel Mikkelsen, Daniel Mealie, and Mitchell Belcher, "Interactive Map: Russia's Invasion of Ukraine," Institute for the Study of War and AEI's Critical Threats Project, accessed 24 January 2024, https://perma.cc/TLE7-ESS9, https://storymaps.arcgis.com/stories/36a7f6a6f5a9448496de641cf64bd375.

and distinction. International humanitarian law emphasizes that the expected military advantage from an attack on a military objective must be concrete and direct.[26] Broad attempts to affect civilian morale do not meet these criteria. In addition, "an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive to the concrete and direct military advantage anticipated" is a prohibited indiscriminate attack per Article 51(5)(b) of Additional Protocol I.[27] The Russian Federation may claim that its attacks on power generation and transmission infrastructure are lawful because such facilities produce power used at least in part for military operations. Nevertheless, per Article 57 of Additional Protocol I, Parties are obligated to "do everything feasible to verify that the objectives to be attacked are neither civilians nor civilian objects and are not subject to special protection, but are military objectives."[28] Additionally, Parties are obligated to take "constant care" to "spare the civilian population, civilians and civilian objects."[29]

With regard specifically to energy infrastructure, Article 56 affords special protection to works or installations containing "dangerous forces, namely dams, dykes and nuclear electrical generating stations."[30] These "works or installations containing dangerous forces… shall not be made the object of attack, even where these objects are military objectives, if such attack may cause the release of dangerous forces and consequent severe losses among the civilian population."[31] Similarly, military objectives located at or near these works or installations "shall not be made the object of attack if such attack may cause the release of dangerous forces… and consequent severe losses among the civilian population."[32]

This special legal protection for works and installations containing dangerous forces only ceases:

> a) for a dam or a dyke only if it is used for other than its normal function and in regular, significant and direct support of military operations and if such attack is the only feasible way to terminate such support;
>
> b) for a nuclear electrical generating station only if it provides electric power in regular, significant and direct support of military operations and if such attack is the only feasible way to terminate such support;
>
> c) for other military objectives located at or in the vicinity of these works or installations only if they are used in regular, significant and direct support of military operations and if such attack is the only feasible way to terminate such support.[33]

Of the 223 identified incidents in Yale HRL's dataset, four of the incidents damaged works or installations containing dangerous forces. Three of these incidents involved damage to hydroelectric plants, and one incident involved damage to a substation located at a nuclear power plant. Of this specific category of incidents, imagery analysts observed visual indicators potentially consistent with objects of past or present military activity at only one hydroelectric site.[vi] Even in this instance, it is not clear that the objects were in use by military actors at the time of strike or that they were being used for any role beyond defense of the facility.

Many expert legal analyses support the conclusion that it is unlikely that Russia's attacks on energy infrastructure comply with IHL. The Independent International Commission of Inquiry on Ukraine (COI) assessed that "[t]he intensity, geographical scope, and type of installations targeted lead the Commission to conclude that the objective of the large scale attacks was not just to damage or destroy individual energy installations, which could serve a military purpose, but also to disrupt and destabilize the entire energy system in Ukraine" such that "[t]he scale of the disruption is of a nature to inflict significant harm to the civilian population."[34] On this basis, the Commission found "reasonable grounds" to conclude that the waves of attacks after 10 October 2022 by Russia's armed forces on Ukraine's energy-related infrastructure were "disproportionate and a violation of international humanitarian law."[35] Reflecting on the likelihood of IHL violations stemming from Russia's targeting of Ukraine's energy infrastructure, U.S. Naval War College professor emeritus Michael Schmitt stated to the BBC in December 2022, "We're at a point now where they're hitting so many targets that I can't imagine they're picking power infrastructure that qualifies as a military objective in every case."[36] Other investigative organizations have come to similar conclusions: a recent Bellingcat report on Russia's command and control apparatus identified that Russia used cruise missiles, which are supposedly 'high-precision' munitions, to target Ukraine's electrical infrastructure in the aftermath of Ukraine's destruction of the Kerch Bridge. Bellingcat noted that "[a]ttribution of the programming of the flight-path of these allegedly high-precision weapons is relevant as the deliberate or indiscriminate targeting of Ukrainian civilians and civilian infrastructure could constitute potential war crimes."[37]

vi. Yale HRL does not assess whether the power generation and transmission infrastructure sites in its datasets service any military operations, and whether the sites could therefore constitute military objectives under Article 56 of Additional Protocol I. ICRC, Additional Protocol I, Article 56.

THE RUSSIAN FEDERATION'S JUSTIFICATIONS FOR TARGETING UKRAINE'S POWER GENERATION AND TRANSMISSION INFRASTRUCTURE

Russia's officials have stated that Russia deliberately targets Ukraine's power generation & transmission infrastructure.

An important aspect of the legal analysis of Russia's bombardment of Ukraine's energy infrastructure is the comments by Russia's senior government officials and influential commentators in Russia's media and civil society. Russia's officials, including President Vladimir Putin, have stated on multiple occasions that Russia is deliberately targeting Ukraine's power generation and transmission infrastructure. Russia's state-sponsored news outlet *Russia Today* (RT) posted an analysis on Telegram identifying exact coordinates of transformers within key facilities and the types of sites Russia's attacks should target, including switch gears at several nuclear power plants, at least some of which have sustained damage.[38]

While deliberate targeting of energy infrastructure is not per se unlawful, statements from Russian Federation officials have provided various justifications for these attacks, several of which potentially demonstrate an intent to commit these attacks in violation of IHL. These comments by government and non-government officials, while providing important context, do not alone indicate an intent to inflict intentional harm on civilians, cause collective punishment, or deny civilians the means of the sustainment of life. However, these comments may be relevant to any pursuit of accountability for these alleged attacks, as they are indicative of intent.

Russia's justifications for targeting Ukraine's power generation & transmission infrastructure:

- **Advancing Russia's military objectives**
- **Retaliation for purported action by Ukraine**
- **Intentional infliction of harm on civilians to compel Ukraine to submit to negotiations in terms favorable to Russia's interests**

Russia's officials have primarily justified attacks in three main ways: (1) as advancing Russia's military objectives; (2) as retaliation for purported action by Ukraine; or (3) as the intentional infliction of harm on civilians for the purpose of compelling Ukraine to submit to negotiations in terms favorable to Russia's interests. Attacks for the first of these purposes may be lawful under certain circumstances; attacks for the second two purposes would likely violate IHL.

MILITARY OBJECTIVES

First, many of Russia's officials have attempted to justify strikes using the language of Additional Protocol I, framing these attacks as intended to advance military objectives. Russia's Minister of Defense Sergei Shoigu has claimed that Russia's armed forces are striking at "объекты военной инфраструктуры, а также объекты, влияющие на снижение военного потенциала Украины" ("objects of military infrastructure as well as objects that effectively reduce Ukrainian military potential") using high-precision weaponry.[39]

A February statement from Russia's Ministry of Defense claimed that the critical energy infrastructure in Ukraine it targeted in one set of attacks "обеспечивающим функционирование предприятий оборонно-промышленного комплекса Украины" ("support the functioning of enterprises of the Ukrainian military-industrial complex").[40] Non-military officials of the Russian Federation have also claimed the strikes are aimed at military objectives. These include Minister of Foreign Affairs Sergei Lavrov, who has stated that strikes are intended to prevent NATO from providing weaponry to Ukraine.[41] State Duma Member Andrei Gurulyov described Russia's campaign against Ukraine's energy infrastructure as an attack against Ukraine's "все энергетические системы" ("whole energy system") to cripple Ukraine's productive capacity.[42]

RETALIATION

While Russian Federation officials have claimed that the attacks are lawful and directed at legitimate military objectives, officials have also described strikes as reprisals or efforts to inflict civilian suffering. The latter are not lawful justifications for the use of military force. The use of these justifications suggests that many of Russia's attacks were not initiated with the intent that the attacks would lead to a definite military advantage and thus may be in contravention of IHL.

Russia's officials have claimed that deliberate attacks on Ukraine's energy infrastructure are retaliation: Russia's President Vladimir Putin himself stated that attacks on Ukraine's critical infrastructure in October 2022 were legitimate retaliation for attacks on Russian infrastructure, including Ukraine's 8 October 2022 strike, which Putin referred to as a "террористический акт" ("terrorist attack").[43]

“За это они там и будут сидеть и без газа и без электричества и без всего. Потому что если киевский режим выбрал путь военных преступников, они должны там и замерзнуть, и сгнить”

“[F]or that they will sit there without gas and without electricity and without everything. Because if the Kyiv regime has chosen the path of war criminals, they must both freeze and rot there”

- Deputy Speaker of the State Duma Boris Chernyshov

Other Russian Federation officials who have claimed that strikes are intended as retaliation include Russia State Duma Defense Committee member Viktor Sobolev, who described strikes as a politically motivated response to purported Ukrainian shelling of Donetsk.[44] These justifications of the attacks as general retribution measures do not claim that these strikes are directly relevant and necessary for achieving concrete military objectives of Russia and Russia-aligned forces. Russia’s officials’ statements indicating that attacks are reprisals aimed at inducing political cooperation from Ukraine likely contravene the principles articulated in Article 52. Article 33 of the Fourth Geneva Convention states that “no protected person may be punished for an offense he or she has not personally committed” and prohibits collective punishment as well as “all measures of intimidation or of terrorism.”[45] Article 51(6) of Additional Protocol I similarly prohibits “attacks against the civilian population or civilians by way of reprisals.”[46]

INTENTIONAL INFLICTION OF HARM ON CIVILIANS

Russia’s officials have also used language indicating a disregard for the extent of civilian suffering, in apparent contravention of Additional Protocol I, particularly Article 57’s obligation for Parties to take “constant care” to “spare the civilian population, civilians, and civilian objects.”[47] Beyond expressing a disregard for civilian suffering, officials have implied that that they are exploiting civilian suffering as a useful tool to compel Ukraine to negotiate on terms favorable to Russia.[48] Deputy Chairman of the Security Council of Russia (and former President and Prime Minister) Dmitriy Medvedev wrote on Telegram in October 2022 that in order for Ukraine to stabilize its energy supply it was “Надо признать правомерность требований России в рамках СВО и её результаты” (“necessary to recognize Russia’s legitimate demands in the context of the SMO [special military operation] and its results”) and implied that upon Ukraine’s recognition of Russia’s demands, “И тогда со светом наладится” (“then the lights will work again”).[49]

Press Secretary of the President of the Russian Federation Dmitri Peskov stated in November 2022 that there was every opportunity for Ukraine’s leaders “чтобы выполнить требования российской стороны и прекратить все возможные страдания местного населения” (“to fulfill the demands of the Russian side and end all possible suffering of the local population”).[50] Deputy Speaker of the State Duma Boris Chernyshov stated on the political talk show “Svoya Pravda” that strikes on Ukraine’s infrastructure were a response to purported and unspecified Ukrainian war crimes, describing them explicitly as “удары возмездие” (“strikes of retribution”) and concluding, “За это они там и будут сидеть и без газа и без электричества и без всего. Потому что если киевский режим выбрал путь военных преступников, они должны там и замерзнуть, и сгнить” (“[F]or that they will sit there without gas and without electricity and without everything. Because if the Kyiv regime has chosen the path of war criminals, they must both freeze and rot there”).[51]

IV. METHODOLOGY, CHALLENGES, AND LIMITATIONS

The investigative methodology for this report relies on the fusion of open source data analysis and commercially available very high resolution (VHR) satellite imagery analysis. It aggregates and verifies multiple data sources on the time, location, and reported descriptions of attacks affecting power generation or transmission stations. The units analyzed were incidents of damage to generation or transmission stations or substations that open source researchers identified as having occurred due to conflict. This analysis does not include damage to power lines due to the limited ability to observe damage to these thinner infrastructural elements in even VHR satellite imagery, the sheer number of power lines in the country, and the limited ability to identify and verify open source data available on power lines in the country. Frontline assessments of identified incidents were conducted at the oblast level based on ISW Russia-occupied territory data between 1 October 2022 through 30 April 2023. Oblasts that contained Russia-occupied territory during that timeframe include Kharkiv, Zaporizhzhia, Luhansk, Donetsk, and Kherson.

Much open source reporting (particularly after October 2022) provides limited detail on damage caused by attacks on civilian infrastructure for protection reasons, minimizing actionability of information in potential future attacks.[52] Open source researchers were sometimes able to obtain only limited detail on the location and extent of damage to facilities.[53] This data gap introduced challenges to geolocation and subsequent open source and imagery verification.

As a result, this report defines all reported incidents of damage due to alleged strikes on power generation and transmission sites identified by open source researchers as identified incidents. There were three separate incidents of damage identified in satellite imagery when seeking to verify other identified incidents at a given site; for the purpose of clarity, these are also included under identified incidents even though they were not identified by open source researchers. Verified incidents are defined as incidents due to strikes with sufficient open source and/or imagery data to verify an identified incident with a requisite degree of confidence as verified incidents. Therefore, verified incidents are the subset of identified incidents that Yale HRL and UDVL have been able to verify through open source and/or VHR satellite imagery verification to the verification standards described below.

The diagram below illustrates this workflow (Figure 7). Even with limited additional information, identified incidents that did not meet Yale HRL's verification standards were appropriately documented as they still retain value for accountability efforts when combined with other sources, methodologies, and investigations.

OPEN SOURCE METHODOLOGY

Analysts conducted verification of all claims made in this report according to the protocols developed by Amnesty International and the Berkeley Protocol on Digital Open Source Investigations.[54]

a. Identification and Collection of Incidents of Damage to Power Generation and Transmission Locations: Yale HRL partnered with open source researchers at the Ukraine Digital Verification Lab (UDVL) at Tufts University to collect open source data on incidents of strikes between 1 October 2022 and 30 April 2023 inflicting damage on power generation and transmission facilities. Researchers collected and analyzed open source reports of strikes on power stations and substations, identifying their location, date and time, and reported impacts on power capacity and livelihoods based on available information in open source. Data included posts on Telegram, Facebook, and other social media, statements by governmental officials and representatives, and media reports. In addition, information compiled by Ukraine-based think tank DiXi Group on energy infrastructure attacks was analyzed and archived by Yale HRL and UDVL open source researchers. Researchers attempted to verify visual media such as photographs and videos; however, because significant metadata of this media is frequently stripped when posted online, the array of tools for verification of visual media were limited in some cases.

b. Geolocation: Yale HRL and UDVL researchers conducted geolocation in order to verify the location of damaged stations and substations. If sufficient images or videos accompanied reported incidents, researchers could precisely locate where these images or videos were taken by identifying unique physical features, such as surrounding buildings, vegetation, and physical landscape. Because of limited specific geographic information in some public reports, geolocation to an exact location was not possible for all strike/damage incidents.

c. Verification: Researchers assigned an overall rating to each incident based on an assessment of the underlying data credibility and reliability. This value rating was comprised of two assessments: (1) source analysis and (2) content analysis. Both analyses were adapted from the verification principles outlined in the Berkeley Protocol.[55] Additionally, Yale HRL

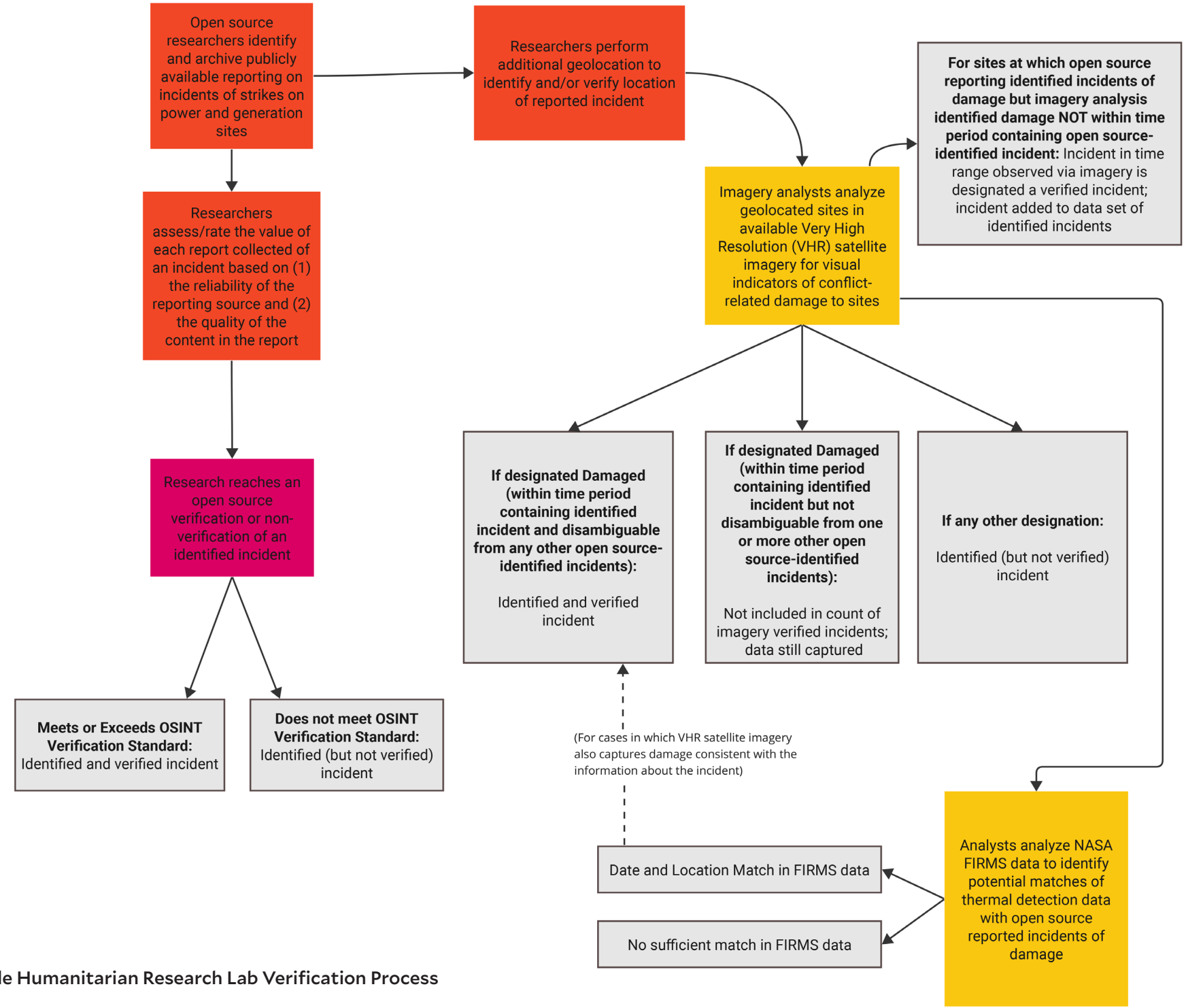

Fig.7 Yale Humanitarian Research Lab Verification Process

language analysts studied source materials in Russian to provide translations where necessary. All Russian sources quoted directly in this report were cross-checked by multiple language analysts, who conferred to reach consensus in instances of diverging translations.

Source analysis was based on:

1. **position**: the credibility of primary sources' claimed access to events in question and/or video and photo evidence or credibility of secondary sources' access to firsthand information and ethical use of primary accounts, including identification of source of information (though the withholding of specific names does not affect the evaluation of this credibility);
2. **motivation:** the possibility of a source's potential motivation to falsify or misrepresent information, the efforts a source undertakes to make its underlying data available, the relevant bias or lack thereof of language used in the reporting, the source's fact-checking efforts, and the favorability of information reported to one party relative to others; and
3. **historic accuracy**: the source's history of making inaccurate claims or misrepresenting observations and the source's history of making accurate claims.

Content detail was evaluated based on:

1. **geolocation:** whether content was able to be geolocated by Yale HRL or UDVL researchers or by a different high-reliability source such as an international news or human rights organization; the presence or absence of reasons to doubt the report of an alleged location of damage;
2. **temporal location:** the extent to which the information reported aligns with the time of day, date, season, and/or year alleged and the presence or absence of incongruities; and
3. **manipulation:** the presence or absence of indications that the content has been manipulated, as checked against forensic verification tools.[vii]

Detailed definitions of source and content value are provided in the figures that follow.

FIG.13 SOURCE ANALYSIS MATRIX

	HIGH VALUE	MEDIUM VALUE	LOW VALUE*
POSITION	**PRIMARY:** Credible access to events in question and/or video and photo evidence. **SECONDARY:** Credible access to firsthand information and ethical use of primary accounts, including identification of source of information (specific names may be withheld).	**PRIMARY:** Source is not definitively known to have access to events in question and does not show evidence. **SECONDARY:** Source is not definitively known to have access to reliable primary information. Primary sources used by this source are not always identified.	**PRIMARY:** Source is known to not have access to or expertise with events in question and does not show evidence. **SECONDARY:** Source is known not to have access to reliable primary information.
MOTIVATION	There is no reason to suspect a motivation to falsify or misrepresent information in this type of reporting from this source. The source makes a reasonable effort to make underlying data available.	Neutral information sharing is not the source's primary motivation. Source does not provide information that allows researchers to confirm. The source uses biased language or the source shares information primarily, though not exclusively, favorable to one party.	The source shares information primarily favorable to one party and does not appear to engage in any fact checking. Neutral information sharing is not the source's motivation. There is no way to evaluate the underlying source of information.
HISTORIC ACCURACY	**PRIMARY:** No history of providing inaccurate information. **SECONDARY:** Highly reputable journalist and source (e.g., Kyiv Post, Guardian, Deutsche Welle) with rigorous fact-checking and journalistic standards, and appropriate protocols for issuing corrections.	**PRIMARY:** Source has a history of making accurate but one-sided claims. **SECONDARY:** This source has a limited history of sharing inaccurate or misleading information, especially in withholding information unfavorable to its position.	**PRIMARY:** Source has routinely misrepresented their observations. **SECONDARY:** Source has been routinely contradicted by other sources or fabricated primary evidence.

*A low value source can be made "medium" if content it shares passes checks for manipulation. See content matrix below.

vii. As per the Berkeley Protocol, chronolocation is "the corroboration of the dates and times of events depicted in a piece of information, usually visual imagery" (page 65), UN OHCHR and the Human Rights Center at the UC Berkeley School of Law, Berkeley Protocol.

FIG.14 CONTENT ANALYSIS MATRIX			
	HIGH VALUE	MEDIUM VALUE	LOW VALUE
GEOLOCATION	Relevant content has been geolocated by Yale HRL or a different high-value source (such as an international news or human rights organization).	Relevant content has not been geolocated and there are no reasons to doubt the alleged location.	Content shows a different location than alleged or content has not been geolocated and there are reasons to doubt the alleged location (e.g., image has been used with reference to other locations). Information referring to a different context must be excluded, even if it is from a high-value source.
TEMPORAL LOCATION	Information appears to match the time of day, season and year alleged.	Information matches the time alleged, but there are minor incongruities (e.g., slight differences in time of event).	Information does not appear to match the time alleged. Information referring to an irrelevant time must be excluded, even if it is from a high-value source.
MANIPULATION	There is no reason to believe that content has been manipulated. Content can be checked against forensic verification tools	Manipulation cannot be ruled out, but no positive evidence of it has been established (e.g., on DBKF or forensic verification tools).	Content has been assessed as manipulated, either through forensic analysis or external reporting (e.g., on DBKF). Manipulated information must be excluded, even if from a high-value source.

Rating counts and comparison of incidents against verification standard: After individual reports are rated for their source value and content value, these reports are aggregated for each incident. Each incident is then given an overall Open Source rating. For an incident to be deemed verified based on the open source data, it must meet the criteria outlined in Open Source Verification Standard Matrix (Figure 15).

FIG.15 OPEN SOURCE VERIFICATION STANDARD	
OPEN SOURCE RATING	VERIFICATION REQUIREMENT
Highest rating of any source is "High"	1 item
Highest rating of any source is "Medium"	3 items *or* 2 medium items, if at least one includes a photo, video or piece of audio that has been checked for manipulation
Highest rating of any source is "Low"	No number of low-value sources is sufficient. *However, a low-value source can provide medium or high value content but must be rigorously checked.*

LIMITATIONS

The open source methodology used in this report utilizes data collected from social media, statements from officials, and news reporting, among other sources. This methodology does pose some limitations. Yale HRL does not conduct interviews with witnesses or victims; only the specific information available in the open source is collected. Yale HRL does not conduct any site visits, relying instead on remotely collected data.

Relative to many earlier reports of incidents, open source reporting on later incidents provided less information about damage and attacks on civilian infrastructure, both in terms of volume and specificity. This was likely due to protection-related reasons, namely minimizing the potential actionability of information for future attacks. Several of Ukraine's officials advised against posting detailed information about strikes. On October 12, the head of the Kyiv region military administration Oleksii Kuleba implored residents not to film locations, stating, "Do not specify locations and places of incoming hits. Be responsible, because our safety depends on it."[56] Additionally, the governor of Chernivtsi oblast advised witnesses against photographing sites and urged that people wait for official information in response to an attack on critical infrastructure in the oblast.[57]

Consequently, in many of these cases, researchers were only able to discern location at a raion or even oblast level, making further open source and imagery verification difficult. As a result, the number of identified incidents is larger than the number of verified incidents (that is, verified by Yale HRL and UDVL researchers via imagery or to the Open Source Verification Standard outlined above). Nonetheless, all identified incident data retains value for accountability efforts in combination with other similar investigative efforts undertaken by other organizations and researchers on civilian infrastructure damage in Ukraine and has been

archived for long-term preservation of data in accordance with legal evidentiary standards as outlined in the Berkeley Protocol.

IMAGERY ANALYSIS METHODOLOGY

Analytic geospatial methods employed for this report include:

1. **multi-temporal change detection**, which involves the comparison of two or more satellite images of the same area captured at different times to detect or "subtract" differences in coloration, visual properties, and presence, absence, or positional change of objects across the images;[58]

2. **non-remote sensing data cross-referencing**, which involves cross-referencing open source narrative reports, photographs, video, and other media or details describing visually observable phenomena with available satellite imagery; and

3. additional verification of VHR imagery findings via **cross-referencing of VHR imagery and open source findings with data from NASA's Fire Information for Resource Management System (FIRMS),** a publicly available online database that collects near-real time active fire data based on satellite observation from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS).[59]

VHR satellite imagery played an important role in the verification of reported incidents of damage to stations and substations through analysis of visual indicators of damage. The imagery averages a spatial resolution between 38 and 50 cm, which allows analysts to identify changes to natural and manmade landscape features including individual buildings, vehicles, trees and more.

Yale HRL analysts assessed all available VHR satellite imagery for each power station or substation identified as damaged in the open source data collection. Of the incidents for which there was sufficient geolocation to conduct satellite imagery analysis, the analysts classified the evidence of damage to power generation and transmission facilities into one of three damage assessment categories: (1) "damaged"; (3) "not visibly damaged"; and (4) where inconclusive, "possibly damaged."[viii] In this report, "possibly damaged" and "damaged" imagery findings are not designated in their own count or category as they do not meet the Imagery Verification Standard to be deemed verified incidents unless they otherwise meet the Open Source Verification Standard.

For identified incidents, at least two analysts examined all available VHR satellite imagery at that site. For these sites, the first analyst noted where and on what date they observed any visual indicators of damage in satellite imagery and described in detail the damage they observed; the second analyst analyzed the same imagery and noted any additional or differentiating observations from the first analysis. Each analyst then assigned a damage assessment for the incident based on the above damage assessment scale. Any identified incident for which imagery analysts concurred on a "damaged" assessment attributable to a time window in which only one identified incident occurred is deemed verified. A "no visible damage" finding in available VHR imagery of an identified incident is not taken as refutation of an incident having occurred. That said, a "damaged" finding in VHR imagery can verify an identified incident alone without an independent open source verification. If two or more analysts differed in their assessments for a given incident, the analysts convened to re-analyze the imagery concurrently and discuss their findings in an attempt to reach agreement on the assessment. At least two analysts assessed imagery for sites of each identified incident to double verify and reduce the potential for inaccurate observation.

Visual indicators of damage included: discoloration to the analyzed structure, including indicators of possible burning or charring; observable difference in structural texture compared to pre-conflict dates; total or partial collapse or serious failure of the walls, roofs, or pipelines of the analyzed structure, to include black spots on the rooftop suggesting tiles' lack or displacement, and collapse of chimneys; and presence of damage proxies like large debris/rubble or sand deposit around the building clearly not attributable to construction, to dilapidation of an analyzed structure over time, or to normal activity at the facility.[60] "No visible damage" was assessed in satellite imagery when an identified incident did not have any or sufficient visual indicators of damage at the corresponding site and date of the incident. An assessment of "no visible damage" does not conclude that damage is not present at the site; it acknowledges that potential damage was not observed by analysts at this time.

This damage assessment scale is an adaptation of the scale outlined in the Building Damage Assessment chapter of the Emergency Mapping Guidelines developed by the International Working Group on Satellite-based Emergency Mapping (IWG-SEM).[61] IWG-SEM, a voluntary group of organizations formed to improve cooperation, communication, and professional standards

viii. For cases of damage observed in imagery within a time frame that included more than one identified incident in Yale HRL's dataset (damage not disambiguated to a single identified incident in Yale HRL's dataset), those identified incidents were not deemed verified by imagery. However, that designation is provided in the underlying data to assist further investigations.

for satellite-based emergency mapping, produced a working paper in 2018 that proposed "a simple but standard building damage classification that can be internationally adopted, especially to increase consistency of the thematic information provided by different SEM entities for the same event."[62] The IWG-SEM's proposed building damage assessment scale defines four damage categories: no visible damage, possibly damaged, damaged, and destroyed.[63] However, because the IWG-SEM damage classification definitions center heavily on structures with roofed profiles, and because energy infrastructure sites have a diverse range of vertical imagery profiles due to varying types of equipment, materials, and structures, Yale HRL has condensed IWG-SEM's "destroyed" and "damaged" categories into one "damaged" category for this report.

After VHR imagery analysis, imagery analysts cross-referenced the location and date of each identified incident with thermal detection data from NASA's FIRMS. A thermal detection signal on NASA's FIRMS on the same date as the reported date of the incident and occurring within 500 meters from the reported or geolocated site of the incident adds further verification of an incident already verified by VHR imagery. However, a thermal detection data point matching the incident date and located within 500 meters from the location of the incident without VHR imagery is not sufficient to definitively determine that the thermal detection in the FIRMS data is conflict-related. Therefore, a thermal detection without VHR imagery availability was not considered sufficient to positively verify an incident of conflict-related damage due to the high rate of false positives in FIRMS data, especially for energy infrastructure sites that may emit thermal detections as part of their normal operations. Nonetheless, findings from FIRMS data analysis were logged for all incidents that contained sufficiently specific location information to search the point or area in FIRMS.

If imagery analysts observed damage at a site in which at least two incidents occurred and there was not clear and available imagery in between the dates of the two incidents, then the count of verified incidents via imagery was not changed because it is not sufficiently clear to which identified incident the damage observed in imagery is attributable.[ix] In the underlying data, however, the damage assessment is included in the notes of both incidents for preservation of data and analytical findings for further investigation by accountability mechanisms.

At a small number of identified incident sites, imagery analysts observed damage consistent with conflict-related impacts that did not correspond to the temporal scope of the open source-identified incident. These phenomena were added to the total incident count, although where open source reporting corresponding to the relevant period identified in imagery analysis does not exist, only an approximate time range in which the incident occurred may be provided.

If open source research during or after the imagery analysis process revealed additional information about an incident, imagery analysts re-analyzed the site appropriately in accordance with Yale HRL's fusion approach of open source and imagery analysis.

All assessment team analysts followed a common and consistent process to identify potential damage at each power station or substation. If damage was identified on any given facility site, and this damage was not visible prior to the date of the identified incident, it was then determined whether the apparent sustained damage could be attributed to conflict. The availability of pre-incident imagery (as well as pre-invasion imagery for baseline images of the facility's pre-invasion physical appearance) and patterns of visible damage to an analyzed structure were required for a site to be classified as damage resulting from armed conflict.

Availability of pre-incident imagery: Baseline imagery prior to the date of the identified incident as logged by open source researchers was used to determine the general condition of the facility's infrastructure and enabled analysts to establish with greater certainty whether instances of damage were the result of the incident identified in open source data.

Pattern of visible damage: Visible locus of apparent direct impact (on a roof or on the ground) with indications of damage spreading beyond that single point is observed. This may include, but is not limited to, gradually smaller markings and/or perforations in roofing, or a perimeter of rubble consistent with damage caused by artillery and/or missile fire. The visual profile of unforced structural dilapidation is not consistent with this pattern of damage.

Further, the exterior condition of the analyzed structure and visible surrounding damage were also considered throughout site analysis.

Assessment of structural condition: Analysts assessed the general condition of the facility's exterior structure as seen through VHR imagery. Any indications of disrepair or heavy wear may suggest that some apparent instances of post-incident damage were not conflict-related.

Potential charring and smoke: Instances where darkened patches of land and/or infrastructure can be seen around areas of apparent damage can be indicative of the incendiary effects of explosive artillery/missile fire, as can smoke visibly emanating directly from

ix. However, if the first clear available imagery captured after an identified incident is from after the 30 April 2023 end of this report's analysis period, there is open source reporting indicating the incident occurred prior to 30 April 2023, and the analysis indicates damage to a site, the incident is considered verified as "damaged" even though the damage could plausibly have occurred after 30 April 2023.

areas of supposed damage. In addition to the analysis of VHR imagery, research was conducted to determine whether any fires or other notable non-conflict-related events took place at any given facility.

LIMITATIONS

The ability of satellite imagery analysis alone to detect or verify sites is limited by the volume, frequency and quality of imagery captured at a given location. Probabilistically, if a satellite passes over a given location with low frequency, the likelihood of capturing damage that is quickly repaired and the ability to establish a narrow time window in which the strike occurred is significantly reduced. Given how crucial energy infrastructure is to the well-being and needs of the population, repairs of damage to a power facility may be undertaken quickly, sometimes within hours of an incident. When rapid repairs occur, imagery is likely unavailable for the narrow time window during which the infrastructure was visibly damaged.

Constraints on satellite imagery availability can also make it impossible to disambiguate via imagery alone two separate reported incidents of damage to an energy infrastructure site if there is not clear imagery available between the two reported incident dates. In these instances when observation of conflict-related damage existed between two dates with imagery, but open source research identified at least two incidents between the two dates, neither identified incident could be counted as verified to be damaged via imagery assessment.

Given limitations on site and information access and many officials' recommendations to avoid sharing critical information about locations and damage inflicted, many incidents of damage inflicted on power generation and transmission sites may go unreported in open source venues and therefore be un-identifiable using open source methods and data. Because daily or near-daily satellite imagery was not available to researchers, it is possible that damage observed in available imagery could be attributable to one of these unreported incidents rather than the incident reported by Yale HRL and UDVL open source researchers. It is not currently possible to totally mitigate this limitation using the remote collection methods currently available to Yale HRL and UDVL researchers. Ultimately, the underlying imagery analysis observations and open source data are preserved and archived in accordance with digital archiving standards in the event additional information regarding incidents previously unidentifiable by remote collection methods becomes available.

Damage to non-roofed structures, especially to structures consisting of narrow or thin metal lines or pipes, can also be difficult to detect in satellite imagery, depending on an image's quality and spatial and spectral resolution. The continued operational status of many of the stations and substations also means that changes at the site must be disambiguated during analysis from normal activity at the site.

V. CONCLUSION

The data collected and published by Yale HRL in this report supports the finding of a widespread and systematic effort to damage Ukraine's power generation and transmission infrastructure. The large number and geospatial spread of incidents across an overwhelming majority of Ukraine's oblasts, including areas well removed from the frontlines of fighting, coupled with Yale HRL's assessment that the data in this report is likely an undercount, is suggestive of an effort to cripple Ukraine's energy infrastructure beyond that necessary to obtain a direct and concrete military advantage. These attacks may constitute violations of the international humanitarian law principles of distinction and proportionality, as well as the obligation to take all feasible precaution to minimize injury to civilians and damage to civilian objects.

Rationales provided by Russia's officials for conducting strikes on Ukraine's energy infrastructure also suggest that strikes may contravene international humanitarian law. While some of Russia's officials have stated that the strikes on Ukraine's energy infrastructure have military objectives and therefore accord with Russia's obligations under international law, other statements have identified political retaliation and infliction of widespread civilian suffering as motives. These rationales potentially contravene several provisions in the Fourth Geneva Convention against collective punishment as well as Additional Protocol I obligations of Parties to the conflict to take constant care to minimize civilian suffering.

Since September 2023, Russia has again resumed bombardment of energy infrastructure sites in Ukraine.[64] Additional open source evidence collection and monitoring efforts are required to support present and future accountability efforts.

VI. ENDNOTES

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