

A Multitemporal Snapshot of Greenhouse Gas Emissions from the Israel-Gaza Conflict

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Highlights:

- ❖ The projected emissions from the first 60 days of the Israel-Gaza war were greater than the annual emissions of 20 individual countries and territories.
- ❖ If we include war infrastructure built by both Israel and Hamas, including the Hamas' tunnel network and Israel's protective fence or 'Iron Wall,' the total emissions increase to more than over 33 individual countries and territories.³
- ❖ The carbon costs of reconstructing Gaza are enormous. Rebuilding Gaza will entail total annual emissions figure higher than over 130 countries, putting on them par with that of New Zealand.
- ❖ The ad-hoc nature of these calculations point to the urgent need for mandatory military emissions reporting for both war and peacetime through the UN Framework Convention on Climate Change (UNFCCC).

The Carbon Costs of Conflict

The decades-old conflict in Israel and Palestine has reached an inflection point. Israel's ground invasion of Gaza, following the horrific attacks by Hamas on October 7, 2023, shows no sign of letting up,⁴ and after two months of unprecedented bombardment, the human costs of the conflict are reaching scales previously unseen in the region. The numbers are staggering; as of December 30, 2023, over 21,600 Palestinians and up to 1,200 Israeli deaths, 50 thousand injured, roughly 80 percent of Gaza's population—1.8 million people—have

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² We are grateful for the helpful comments and suggestions from two anonymous reviewers of this brief.

³ This figure includes the first 60 days of the war (Immediate costs) and Hamas' tunnel network and Israel's 'Iron Wall' (Intermediate costs), but not reconstruction (see below). For country figures see: Emissions Database for Global Atmospheric Research (EDGAR): <https://edgar.jrc.ec.europa.eu/>. (02/01/23).

⁴ NYT, 2023. Where Israel has invaded central Gaza: <https://www.nytimes.com/interactive/2023/10/07/world/middleeast/israel-gaza-maps.html?smid=url-share#central-gaza-advance> 28 Dec. 2023. (28/12/23).

been displaced.⁵ Roughly 110 hostages remain captive in Gaza and hundreds of Israeli Defence Forces (IDF) soldiers have been killed.⁶ Estimates place 36-45% of Gaza's buildings — homes, schools, mosques, hospitals — as destroyed or damaged.⁷ According to the Bank of Israel, initial forecasts of the financial cost to Israel is expected to reach up to \$50 billion,⁸ including rebuilding Gaza.⁹

Within this turmoil are the less discussed, but vitally important, climate and other environmental effects of the conflict. This omission is understandable as the world remains focused on the acute death and suffering in Gaza. However, military operations remain an under-analysed dimension of the climate crisis that will intensify suffering on vulnerable communities as the impacts of global warming intensify.¹⁰ **In this research brief, we offer snapshots of carbon emissions of the Israel-Gaza war to address the gap in reporting the climate costs of war.** This analysis is meant to be used as an entry point for a more comprehensive picture of the effects of militaries' long war on the climate – an issue rarely examined by climate researchers.¹¹ In conclusion, we provide a list of factors not included in this analysis that, if data were available, would further provide a more comprehensive picture of carbon emissions of the conflict.

The Israel-Gaza conflict, and its climate dimensions, were closely monitored at the recent UN Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) 28

⁵ Harrison, E., 2023. As Gaza death toll mounts, Israelis look in vain for any sign of victory: <https://www.theguardian.com/world/2023/dec/30/gaza-death-toll-israelis-idf-refugee-camps-famine-lebanon-border-gaza-war> *The Guardian*, 30 Dec. 2023. (31/12/2023).

⁶ Aderet, O., 2023. Two Israeli Soldiers Killed in Gaza Combat: <https://www.haaretz.com/israel-news/2023-12-31/ty-article/two-israeli-soldiers-killed-in-gaza-combat/0000018c-bfd2-d4e1-ad8f-bff360880000>. *Haaretz*. 31 Dec. 2023. (31/12/2023).

⁷ Leffer, L., 2023. Inside the Satellite Tech Revealing Gaza's Destruction: <https://www.scientificamerican.com/article/inside-the-satellite-tech-revealing-gazas-destruction/>, *Scientific American*, 1 Dec. 2023. (22/12/23).

⁸ Reuters, 2023. War with Hamas to cost Israel above \$50 billion, *Calcalist* reports: <https://www.reuters.com/world/middle-east/war-with-hamas-cost-israel-above-50-bln-newspaper-2023-11-05/> 5 Nov. 2023. (18/12/23).

⁹ Schaer, C., 2023. Israel conflict: Who will pay for Gaza reconstruction?: <https://www.dw.com/en/israel-conflict-who-will-pay-for-gaza-reconstruction/a-67714098>, *DW*, 13 Dec. 2023. (19/12/23).

¹⁰ Neimark, B., Belcher, O., Ashworth, K., & Larbi, R. (2023). Concrete Impacts: Blast Walls, Wartime Emissions, and the US Occupation of Iraq. *Antipode*. <https://doi.org/10.1111/anti.13006>; Crawford, N. C. (2022). *The pentagon, climate change, and war: Charting the rise and fall of US military emissions*. Cambridge, Mass.: MIT Press.

¹¹ Rajaeifar, M.A., Belcher, O., Parkinson, S., Neimark, B., Weir, D., Ashworth, K., Larbi, R. and Heidrich, O., 2022. Decarbonize the military—mandate emissions reporting. *Nature*, 611(7934), pp. 29-32.

meetings in Dubai by delegates and civil society organisations.¹² Prompted by the hosts, the links between conflict and climate change were included on the UNFCCC agenda for the first time.¹³ It is important to build on this post-COP momentum to highlight gaps in current military emissions reporting,¹⁴ while pushing for immediate cuts to military emissions as an economic sector where governments have direct authority to manage operations.¹⁵ According to the UN Environmental Programme's most recent Emission Gap report,¹⁶ military emissions are '*insufficiently accounted*' for by the UNFCCC, but even with incomplete data, researchers have found that militaries account for almost 5.5% of global emissions.¹⁷

Indeed, as far as we are aware, the Israeli military (IDF) has never reported emissions figures. Therefore, to understand baseline military emissions from the IDF, which we understand to be significant, we created a rough heuristic to provide some context to our analysis below. To create this proxy figure, we take climate pollution from militaries as a function of total defence spending based on an average carbon intensity. For each defence dollar spent in 2019 by the top five European defence spenders, we estimate that Israel's 2019 military budget of US \$20.34 billion would result in a total emissions figure of 6.99 megatonnes of CO₂ - roughly the same emissions as the entire nation of Uruguay in 2019.¹⁸ This figure is significantly more than the total 2019 emissions figures from all of Palestine (4.8

¹² Cornwell, A. 2023. COP28 a rare chance in UAE for protests on Palestinians, climate action: <https://www.reuters.com/world/middle-east/cop28-rare-chance-uae-protests-palestinians-climate-action-2023-12-03/> (22/12/23). See also: Panel on War, Carbon and Infrastructure Whole Supply Chains and the Military Emissions Gap, [Concrete Impacts, ESRC-UKRI](#) 02 Dec. 2023 COP28, Dubai, UEA at: <https://www.youtube.com/watch?v=k1cWvZMhbco>

¹³ Bigger, P., Hassan, B., Elmallah, S., Prins, S., Cha, J., Ranganathan, M., Hanna, T., Cohen, D., and Bozuwa, J., 2023. Ceasefire now, ceasefire forever: No climate justice without Palestinian freedom and self-determination, Climate and Community Project. 13 Dec. 2023: <https://www.climateandcommunity.org/ceasefire-now>. (20/12/23).

¹⁴ See Kinney and Cottrell, 2023, "Always money for war", reflecting on COP28, <https://ceobs.org/always-money-for-war-reflecting-on-cop28/> (22/12/23). For further discussion and advocacy around gaps in military emissions reporting, see <https://militaryemissions.org/>.

¹⁵ Bigger, P., and Neimark, B. 2018. Weaponizing nature: The geopolitical ecology of the US Navy's biofuel program. *Political Geography*, 60, 13-22.

¹⁶ Lamb, W., Chancel, L., Crippa, M., Grassi, G., Guizzardi, D., Meng, J., Peters, G., and Pongratz, J. 2023. Broken Record Temperatures hit new highs, yet world fails to cut emissions (again). UNEP, Emissions Gap Report 2023, pg.6.

¹⁷ Parkinson and Cottrell 2022; <https://explore.globalcarbonbudgetdata.org/timeseries.html>

¹⁸ To get to this rough estimate, we took an average emissions intensity per dollar of the five largest defence European budgets - France, Germany, Italy, Spain, and the Netherlands - which averages to 0.14 kg of CO₂e per dollar in 2019. Military emissions figures drawn from <https://ceobs.org/the-eu-military-sectors-carbon-footprint/>; military spending drawn from the World Bank: <https://data.worldbank.org/indicator/MS.MIL.XPND.CD?end=2019&start=2019>

MTCO_{2e}).¹⁹ Palestine's defence-specific emissions are also unreported, however, given the more ad hoc nature of Hamas's offensive capabilities, we are not confident a similar proxy approach would deliver a meaningful figure.

Approach: Carbon snapshots of a long, explosive conflict

In this research brief, we provide 'snapshots' of carbon emissions from the Israel/Gaza conflict across three distinct time horizons. First, we calculate limited direct emissions figures for the first 60 days of combat following Hamas's dreadful attack on October 7. To understand the immediate climate ramifications of Israel's invasion of Gaza, we calculate mainly Scope 1 'tailpipe emissions,' and some, but very limited, Scope 2 and 3 (manufacturing of bombs and rockets) of the hundreds of Israeli bombing raids (primarily conducted by F-16s), tanks and other vehicles, cargo flights, and patrol flights by other aircraft, including F-35s, and the emissions of the estimated munitions used by Israel on Gaza.²⁰ Within this same timeframe of 60 days, we also quantify the climate impacts of Qassam rockets sent into Israel by Hamas during the initial stages of the war.

In the second time horizon, we consider emissions from the construction of security-related concrete infrastructure in both Israel and Gaza over a 16-year period. This calculation stretches back to 2007 to gain insight into the climate impacts of an underappreciated facet of military emissions, the use of concrete in security infrastructure. We include built concrete infrastructure used by Hamas' Gaza tunnel construction which was ramped up to circumvent the Egyptian-Israel blockade put in place in 2007.²¹ On the Israeli side, we include emissions for the 'Iron' or 'Smart Wall' separating Gaza from Israeli controlled territory- both above and below ground. This wall has been planned since 2016 and was reportedly finished in 2021 with the intention of protecting Israel from any Hamas attack from the Gaza strip.²²

¹⁹ Palestine Central Bureau of Statistics

https://www.pcbs.gov.ps/Portals/Rainbow/Documents/Emissions_2021_04.htm. (12/31/23).

²⁰ This figure is almost certainly a significant underestimate as it does not account for the significant military aid Israel receives from the US and European countries which has its own climate costs. See Euro-Med Human Rights Monitor, 2023. Israel hits Gaza Strip with the equivalent of two nuclear bombs: <https://euromedmonitor.org/en/article/5908/Israel-hits-Gaza-Strip-with-the-equivalent-of-two-nuclear-bombs> 2 Nov. 2023. (28/12/23).

²¹ The Guardian. 2023. Israeli army says it has uncovered biggest Hamas tunnel yet: <https://www.theguardian.com/world/2023/dec/17/israeli-army-says-it-has-uncovered-biggest-hamas-tunnel-yet> 17 Dec. 2023. (28/12/23).

²² Grandos, S., Mellen, R., Tierney, L., Galocha, A., Brown, C., and Steckelberg, A., How Hamas breached Israel's 'Iron Wall' <https://www.washingtonpost.com/world/2023/10/10/how-hamas-entered-israel/>. *The Washington Post*, 10 Oct. 2023. (28/12/23).

Finally, we offer a somewhat speculative figure on the carbon costs of future reconstruction in Gaza given the scale of the destruction wrought by Israeli bombardment.²³ This final temporal dimension we calculate is forward-looking – the carbon costs of rebuilding Gaza, even to its previous precarious state. This number is somewhat lower confidence given that dimensions and material composition of the nearly 100,000 Gazan structures²⁴ destroyed by Israel are not precisely known nor are the contents of those buildings that will need to be replaced; however, this figure begins to demonstrate the astonishing environmental costs of Israel’s unrelenting campaign in Gaza.

Results of Carbon Analysis

The figures presented below are all snapshots across different types of emitting activities and time scales – which we have categorised as: immediate, intermediate and long-term. Again, immediate emissions consider a limited sample of different polluting activities during the first 2 months, of fighting, from Oct 7 to Dec 4, 2023; intermediate emissions consider the embedded carbon footprint of concrete used in construction of defence-related tunnels, walls, and barriers built by Hamas and Israel on the Gaza border since 2007; long-term emissions project the embedded carbon, from contemporary building practices, for reconstructing Palestinian buildings that have been destroyed by Israel. Due to the speed of the conflict and the challenge of documenting carbon analysis of war in real time, much of the data we rely on are from investigative journalist reports from the front lines of the conflict, and methods based on previous studies we, alongside colleagues, have conducted on the accounting of greenhouse gas emission during war.²⁵ Each of the figures we provide below should be

²³ Zwijnenburg, W., 2023. Uninhabitable? The reverberating public health and environmental risks from the war in Gaza: [PAX Report Gaza Uninhabitable FIN.pdf \(paxforpeace.nl\)](#) (24/12/23).

²⁴ Bailey, D., Rivault, E., and Palumbo, D. 2023. Nearly 100,000 Gaza buildings may be damaged, satellite images show: <https://www.bbc.co.uk/news/world-middle-east-67565872> 1 Dec. 2023. (22/12/23). This includes the first two months of fighting.

Visualizing Damage Estimation in Gaza, <https://datapartnership.org/gaza-israel-conflict-impact-analysis/notebooks/damage-assessment/damage-assessment.html> (20/12/23).; Malsin, J., and Shah, S., 2023 The Ruined Landscape of Gaza After Nearly Three Months of Bombing: <https://www.wsj.com/world/middle-east/gaza-destruction-bombing-israel-aa528542> *The Wall Street Journal*. 30 Dec. 2023. (22/12/23).

²⁵ See: Cottrell, L. 2023. A framework for military greenhouse gas emissions reporting, CEOBS, <https://ceobs.org/report-a-framework-for-military-greenhouse-gas-emissions-reporting/>; de Klerk, L., Shlapak, M., Shmurak, A., Mykhaleenko, O., Gassan-Zade, O., Korthuis, A., and Zasiadko, Y. 2023. Climate damage caused by Russia’s war in Ukraine, 24 February 2022–23 February 2023.” Initiative on GHG Accounting of War; Euro-Med Human Rights Monitor, 2023. Israel hits Gaza Strip (0/11/23); Crawford, 2022, The pentagon, climate change, and war.

interpreted as lower-bound estimates. We have taken a conservative approach to quantifying the carbon impacts of each category of emissions, as described in each brief section (see Table 1).

Table 1: Figures of CO₂ Emissions Equivalent²⁶

<i>Emission source</i>	<i>Primary data</i>	<i>Detailed information</i>	<i>Total CO₂ equivalent emissions in tonnes (tCO₂e)</i>
Immediate emissions			
Aircraft missions (Israeli F-16 & limited F-35 flights)	300 flight hours each day ²⁷	16,000 flight hours 57.8 million litres of JP8 fuel used. Emission factor (Ef) for JP-8 is 2.2 kgCO ₂ e per litre. ²⁸	121,000
US supply flights	200 flights carrying 10,000 tonnes of goods, mostly from USA ²⁹	Based on fuel consumption of Boeing 777-200 or similar aircraft. Average flight time is 11 hours. Fuel consumption is 11,400 litres per hour. Total flight time is 4400 hours. Total fuel consumed is 49.5 million litres tonnes with an emissions factor of 2.7 kgCO ₂ e per litre of fuel.	133,650
Flights subtotal			254,650
Israeli Artillery	100,000 ground artillery	About 8000 tonnes of steel and explosives used. ³⁰	13,600

²⁶ This table is just a snapshot of some of the major contributing factors of the war's carbon emissions. In the conclusion, we provide a list that would provide a more comprehensive picture of the conflict.

²⁷ Zusovac, Z. 2023. Analysis: Israel's Gaza bombing campaign is proving costly, for Israel <https://www.aljazeera.com/news/2023/11/3/analysis-israels-gaza-bombing-campaign-is-proving-costly-for-israel>, 3 Nov. 2023, Al Jazeera (20/12/23).

²⁸ Although F-35s burn fuel at a higher rate, since we do not know the exact number of the flight hours used by F-35s compared to F-16s, we've taken a conservative estimate based on JP-8 used by F-16s with an emission factor of 2.2 kgCO₂e per litre. https://www.epa.gov/sites/default/files/2015-07/documents/emission-factors_2014.pdf

²⁹ Arnaout, A. Israel receives 10,000 tons of US military equipment since start of Gaza war: <https://www.aa.com.tr/en/middle-east/israel-receives-10-000-tons-of-us-military-equipment-since-start-of-gaza-war/3075027>, *Anadolu Ajansı*, Dec. 06, 2023.; The Times of Israel, 2023. 244 US cargo planes, 20 ships deliver over 10,000 tons of military equipment to Israel — report, https://www.timesofisrael.com/liveblog_entry/244-us-cargo-planes-20-ships-deliver-over-10000-tons-of-military-equipment-to-israel-report/ 29 Dec. 2023. (22/12/23).

³⁰ Duggal, H., Hussein, M., and Shakeeb, A. 2023. Israel's attacks on Gaza: The weapons and scale of destruction: <https://www.aljazeera.com/news/longform/2023/11/9/israel-attacks-on-gaza-weapons->

Israeli Bombs	About 10,000 bombs dropped on Gaza. Sizes range between 150kg and 1000kg. ³¹	We use an average value of 230kg per bomb for the calculation. This is the weight of MK-82 bomb, the most common used by Israel. A total of 2300 tonnes. ³²	6,689
<i>Munitions subtotal</i>			20,289
Israeli Tanks and Vehicles	We assume a total of 500 vehicles involved in ground operations in Gaza; 300 tanks and 200 Infantry Fighting Vehicles (IFVs). ³³	A tank and IFV are assumed to use 2.4 and 0.77 litres of standard diesel per kilometre, respectively. ³⁴ A total of 1.85million litres has been used by frontline and supply vehicles. 2.7kgCO ₂ per litre of fuel used.	5,663
Hamas Rockets	9,500 Qassam rockets fired into Israel.	475 tonnes of rockets	713
Immediate emissions (first 60 days total):			281,315

[and-scale-of-destruction](#), Nov 9, 2023, *Al Jazeera* (20/12/23); Euro-Med Human Rights Monitor, 2023. Israel hits Gaza Strip (30/11/23).

³¹ Qiblawi, T., Goodwin, A., Mezzofiore, G., and Elbagir, N. 2023. 'Not seen since Vietnam': Israel dropped hundreds of 2,000-pound bombs on Gaza, analysis shows: <https://edition.cnn.com/gaza-israel-big-bombs/index.html> Dec. 22, 2023. (24/12/23). Handicap International. 2023. Occupied Palestinian Territories - Israel: 12,000 bombs dropped on Gaza, one of the most intense bombing campaigns in modern war: <https://www.hi.org/en/news/occupied-palestinian-territories---israel--12-000-bombs-dropped-on-gaza--one-of-the-most-intense-bombing-campaigns-in-modern-war> 7 Dec. 2023. (24/12/23).

³² Duggal, H., Hussein, M., and Shakeeb, A. 2023. Israel's attacks on Gaza.

³³ Roblin, S., 2023. How many armored vehicles has Israel lost fighting Hamas? <https://www.popularmechanics.com/military/weapons/a45783283/how-many-armored-vehicles-has-israel-lost-fighting-hamas-gaza/> *Popular Mechanics*. Nov 13, 2023., (22/12/23).

³⁴ de Klerk et al., 2023, Climate damage caused by Russia's war in Ukraine.

Intermediate emissions			
Hamas tunnels	500km of tunnels. 10cm thick, 2m tall and 1m wide ³⁵	720,000 tonnes of concrete and 30,000 tonnes of steel	176,000
Israeli Iron Wall	65km long, 6m tall, 3meter concrete below ground (assumed) ³⁶	140,000 tonnes of steel and iron for above ground fence. 234,000 tonnes of concrete and 9,750 tonnes of steel for belowground wall.	274,000
Intermediate total:			450,000

Long term emissions			
Reconstruction totals	100,000 buildings destroyed	Assuming 3 to 5 story buildings have an average of 300 tonnes of embodied carbon emissions ³⁷	30,000,000

Jets, bombs and rockets

In the first two months of the war, the total emissions from the activities we calculate here run to **281,315 tCO₂e**. This includes combined emissions of bombs, rockets and artillery, flight time for bomb raids, and the delivery of materiel (for Israel) via cargo jet. This is roughly the equivalent of 75 coal-fired power plants operating for a year.³⁸ However, these numbers also demonstrate the asymmetry of offensive weaponry in Israel’s assault on Gaza. In the initial assault on October 7 and for several weeks following the start of Israel reprisals, Hamas fired around 9,500 Qasam rockets; the total carbon pollution from those rockets is at least 713 tonnes of CO₂e. Meanwhile, over the first sixty days of combat (53 combat days plus 7 days of ceasefire), Israeli fired around 2,000 artillery rounds per day, summing to approximately 100,000 shells. Assuming a weight of 80 kg/round, and an emissions intensity

³⁵ Joffe, T. 2023. Hamas's Sinwar: We have 500 km of tunnels in Gaza, only 5% were damaged: <https://www.jpost.com/breaking-news/hamass-sinwar-we-have-10000-terrorists-within-israel-669265> 27 May 2021. (20/12/23).

³⁶ Popoviciu, A., and Masarwa, L. 2023. Gaza: What the iron wall built by Israel means for besieged Palestinians. <https://www.middleeasteye.net/news/israel-iron-wall-gaza-palestinians-siege> 11 Dec. 2021. (19/12/23).

³⁷ Tamimi, M., Shehadeh, A., and Otoom, M. 2023. Gaza conflict's environmental toll: A surge in carbon emissions: <https://jordantimes.com/opinion/mohammad-firas-tamimi-ali-shehadeh-and-mwaffaq-otoom/gaza-conflicts-environmental-toll-surge>. 18 Nov 2023. (22/12/23).

³⁸ Greenhouse Gas Equivalencies Calculator: <https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results> (30/12/23).

of 1.5 tonnes of emissions for each ton of artillery, the total emissions associated with the munitions of Israel's bombardment are 12,000 tonnes. This figure could rise to 13,600 tonnes of CO₂ based on an emission factor of 136kgCO₂e for each artillery fired as estimated by de Klerk et al. (2023).³⁹

Israel has also reportedly dropped 10,000 bombs on Gaza through sorties from fighter jets. It is difficult to know the types of bombs used with certainty. However, information available indicates that these bombs weigh between 150 and 1000kg each.⁴⁰ For ease of calculation, we assume that each of these bombs is an MK-82,⁴¹ containing ~90kg of trinitrotoluene (TNT) and 140kg of metal casing and other components.⁴² The total weight of all bombs dropped from the air is therefore estimated at 2300 tonnes, in keeping with our conservative estimation. The total CO₂ emissions from TNT and steel used in making these bombs is estimated at 7,000 tCO₂e.

The other key aspect of this calculation is the jet fuel Israel has burned running aerial bombardment of Gaza. The bombing campaign has been conducted primarily with F-16s, while F-35s have been flying patrol missions.⁴³ Over the first 60 days following October 7 attacks, the 200+ airframes the Israel military has used in this conflict logged around 15,900 flight hours, and each flight hour burns 3600 litres of jet fuel per hour for the F-16, which is the figure we use in this calculation. The F-35 burns 40% more fuel than the F-16, but we have chosen to use a single, lower fuel consumption estimate to err on the conservative side. This amounts to 57.8 million litres of JP-8 jet fuel, with total carbon emissions of 120,840 tonnes; this is further a conservative estimate because as much as 60% of aircraft emissions accrue because of other emissions, particularly water vapor, that has a short-lived, but relatively stronger, climate warming effect than CO₂, which is weaker but stays in the atmosphere longer.

³⁹ Most of these emissions come from the manufacturing of the ammunition (see de Klerk et al. 2023)

⁴⁰ Qiblawi, T., Goodwin, A., Mezzofiore, G., and Elbagir, N. 2023. 'Not seen since Vietnam':

⁴¹ <https://www.aljazeera.com/news/longform/2023/11/9/israel-attacks-on-gaza-weapons-and-scale-of-destruction>

⁴² The Geneva International Centre for Humanitarian Demining, 2016. Characterisation of Explosive Weapons: <http://characterisationexplosiveweapons.org/studies/annex-e-mk82-aircraft-bombs/> (22/12/23).

⁴³ Zusovac, Z. 2023. Analysis: Israel's Gaza bombing campaign is proving costly, for Israel

Cargo Flights

Up to Dec 4th, there were around 200 cargo flight carrying 10,000 tonnes of supplies from the US to Israel.⁴⁴ Flight time from the US to Israel is about 11 hours one way. Therefore, total flight time for 200 flights is 4,400 hours. Assuming these flights are Boeing 777-200s or similar, the average fuel consumption is 11,400 litres/per hour.⁴⁵ That gives a total of 49.5 million litres of fuel used for delivery of cargo. The Intergovernmental Panel on Climate Change provides an emission factor of 2.7kg of CO₂ per litre of fuel⁴⁶ for aviation fuel. The total emissions for cargo flights are therefore estimated at 133,000 tCO₂e.

Tanks and Vehicles

We assume that about 300 tanks and 200 Infantry Fighting Vehicles (IFV) have been involved in the ground operations in Gaza. This is a very conservative estimates considering reported losses of equipment by the IDF.⁴⁷ Based on estimates used by de Klerk and colleagues (2023) in their carbon accounting of the Ukraine war, 2023, we assume that each tank and IFV uses 2.4 and 0.77 litres per kilometre travelled, respectively. Considering the small size of the frontline, each vehicle is assumed to travel 10km each day. Therefore, for the first 60 days of the war, 524,400 litres of fuel were consumed by frontline vehicles. We adopt the assumption from Klerk et al., 2023 that for each litre of fuel used on the frontlines, 3 litres are used by logistics and other supporting vehicles elsewhere, bringing the total fuel used by vehicles to 2,097,600 litres. At 2.7kgCO₂e per litre of diesel or petrol,⁴⁸ we estimate that a total of **5,600 tCO₂e** has been emitted from vehicles involved in the war from Israeli operations.

⁴⁴ Arnaout, A. Israel receives 10,000 tons of US military equipment since start of Gaza war. This number has increased since this reporting on Dec.7th, but we base our calculations on only the first 2 months of the conflict, so roughly 200 cargo flights. For updated information on military cargo aid to Israel, see: The Times of Israel, 2023. 244 US cargo planes, 20 ships deliver over 10,000 tons of military equipment to Israel — report: https://www.timesofisrael.com/liveblog_entry/244-us-cargo-planes-20-ships-deliver-over-10000-tons-of-military-equipment-to-israel-report/ 25 Dec. 2023. (31/12/23).

⁴⁵ IPCC. 2006. 'Mobile combustion' IPCC Guidelines for National Greenhouse Gas Inventories https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf. (30/12/23).

⁴⁶ ICAO, 2023. ICAO carbon emissions calculator methodology - air freighter https://applications.icao.int/icec/Freighter_Methodology_1.0.pdf. (28/12/23).

⁴⁷ Peck, M. 2023. Israel's war with Hamas shows why tanks are not invulnerable: <https://www.businessinsider.com/israels-war-with-hamas-shows-why-tanks-are-not-invulnerable-2023-12?r=US&IR=T>, *Business Insider*, 5 Nov. 2023. (30/12/23). Roblin, S., 2023. How many armored vehicles.

⁴⁸ EIA, 2023. US Energy Information Agency: <https://www.eia.gov/> (28/12/23).

Intermediate carbon costs: Concrete infrastructure

Gaza Metro

The Gaza Metro, or the subterranean tunnel network spanning Gaza, is made up of roughly 500 kilometres of concrete and iron.⁴⁹ The Gaza Metro was originally built to circumvent the Israel-Egypt blockade of Hamas in 2007-8, bring goods into Gaza and launch attacks into Israel.⁵⁰ It has since become a focal point in the war due to its importance in the October 7 attacks and hiding Hamas fighters and the captive hostages. We have assumed, based on detailed descriptions of the network, that the tunnels are 2 meters tall, 1 meter wide and have a thickness of 10 centimetres.⁵¹ That gives a total of 100k cubic meters for the floor and top of the tunnels, and 200k cubic meters of concrete for the sides. Assuming that there are 100kgs of steel in each cubic meter of concrete,⁵² we have calculated the total amount of concrete and steel used and applied the emission factor of concrete (180kgCO₂e/ton) and steel (1.55kgCO₂e/kg), respectively, to obtain the total of **176,000 tCO₂e** emissions resulting from tunnel construction.

Israel Iron Wall

Designed to monitor movement and deter Hamas fighters from entering Israel, the 'Iron Wall' features monitoring and surveillance cameras and underground sensors, along with basic materials such as razor wire, a 20-foot-high metal fence, and large concrete barriers. It runs along most of the border between Israel and Gaza for around 65km. In calculating Israel's Iron Wall, we used a methodology like that observed above for Gaza's tunnels.

⁴⁹ Joffee, T. 2023. Hamas's Sinwar: We have 500 km of tunnels; Cohen, R. S., Johnson, D. E., Thaler, D. E., Cahill, J., Allen, B., Bartels, E. M., and Efron, S. 2017. From Cast Lead to Protective Edge: Lessons from Israel's Wars in Gaza. Rand Corp. Leonhardt, D., and Jackson, L. 2023. Gaza's Vital Tunnels: <https://www.nytimes.com/2023/10/30/briefing/gaza-tunnels.html> *The New York Times*. October 30, 2023. (27/12/23); https://www.rand.org/pubs/research_reports/RR1888.html . (30/12/23).

⁵⁰ Arranz, A., Saul, J. Farrell, S., Scarr, S., and Trainor, C., 2023. Inside the tunnels of Gaza Dec. 31, 2023. <https://www.reuters.com/graphics/ISRAEL-PALESTINIANS/GAZA-TUNNELS/gkvldmzorvb/>. (30/12/23).

⁵¹ Harel, A., Cohen, G. 2014. Haaretz probe: IDF lacked training, equipment to tackle tunnels in Gaza war: <https://www.haaretz.com/2014-10-17/ty-article/.premium/idf-lacked-training-equipment-to-tackle-tunnels-in-gaza-war/0000017f-e0f7-d568-ad7f-f3ff0fbe0000> *Haaretz*, 17 Oct. 2014. (30/12/23); Berlinger, J. 2023. The 'Gaza metro': The mysterious subterranean tunnel network used by Hamas: <https://edition.cnn.com/2023/10/28/middleeast/hamas-tunnels-gaza-intl/index.html>. *CNN*. 28 October 2023. (27/12/23).

⁵² The value for steel per cubic meter of reinforced concrete is estimated to be more than 200. This is once again a conservative estimate given the lack of access to quality steel in Gaza. See: Average Quantities of Reinforcement in Concrete: <https://oneclicklca.zendesk.com/hc/en-us/articles/360020943800-Average-Quantities-of-Reinforcement-in-Concrete> . (26/12/23).

Emissions from above ground features calculated based on 140,000 tonnes of steel and iron used.⁵³ This is estimated at 217,000 tCO₂e based on an emission factor of 1.55 tonnes of CO₂ per ton of steel/iron. Although the underground component of the wall is said to be several meters below ground, the actual depth remains undisclosed. The total length is 65km. The depth and width are assumed to be 3m and 0.5 meters respectively, giving a total of 97,500 cubic meters of concrete work. We apply a factor of 2.4 tonnes/m³ to obtain the weight of concrete used. Then we apply an emission factor of 180kgCO₂e/ton to obtain total of 42,120 tCO₂e from the concrete. Similar analysis leads to 9,750 tonnes of steel reinforcement and emission of 15,112 tCO₂e. The total emissions attributable to the Iron Wall, including both the above and below ground components is estimated at 274,232 tonnes of CO₂ equivalent.

Long term carbon costs: Reconstruction of destroyed buildings

Intense bombing of Gaza has significantly damaged infrastructure, including apartment buildings, roads, water treatment plants, sewer networks and water wells, to list a few⁵⁴. It will take years to re-build much of this infrastructure and cost billions of dollars while incurring significant carbon costs. It is estimated that roughly about 100,000 buildings have been destroyed in Gaza.⁵⁵ This includes residential, commercial, and industrial buildings.⁵⁶ A visual inspection of building from various online sources shows that residential and commercial buildings in Gaza are mostly consist of 3 to 5 storeys. Schools, hospitals and industrial building are often shorter with one or two floors. Taking a conservative estimate, we assume that each of the building which have been rebuilt or restored, have embodied emission of 300 tonnes of CO₂. This number is about half of those estimates used elsewhere - between 550 and 600.⁵⁷ The total carbon emissions we calculate to be roughly **30 million tCO₂e from reconstruction, equivalent to the annual emissions of New Zealand**, were obtained by multiplying the number of buildings by the embodied emission in each building destroyed.

⁵³ Popoviciu A., and Masarwa, L. 2021. Gaza: What the iron wall built by Israel means for besieged Palestinians. <https://www.middleeasteye.net/news/israel-iron-wall-gaza-palestinians-siege> *Middle East Eye*. 11 Dec 2021.

⁵⁴ Zwijnenburg, W., 2023. Uninhabitable?

⁵⁵ Tamimi, M., Shehadeh, A., and Otoom M. 2023. Gaza conflict's environmental toll.

⁵⁶ Data Partnership 2023. Visualizing Damage Estimation in Gaza: <https://datapartnership.org/gaza-israel-conflict-impact-analysis/notebooks/damage-assessment/damage-assessment.html>. (01/01/24).

⁵⁷ Tamimi, M., Shehadeh, A., and Otoom, M. 2023. Gaza conflict's environmental toll.

Limits to analysis and further research needs

By no means do we believe that our analysis is comprehensive - or even adequate. It is, if anything, only a conservative snapshot of a few carbon intensive activities. Many were chosen due to our access of readily available data, and expertise of our team in calculating military-related concrete emissions.⁵⁸ There are, however, several significant categories of operations that will be important to quantify to gain a more complete picture of the climate ramifications of the Israel-Gaza conflict (as well as ongoing attacks in the West Bank, and skirmishes on the Israel-Lebanon boarder). Moving forward, we hope researchers build on this work to provide a more complete picture of the climate implications of the conflict, described by Cottrell as 'Scope 3+' emissions, due to the extended nature of conflict emissions, and to continue to push for transparent reporting of global military emissions to the UNFCCC.⁵⁹

This work will need to be picked up by civil society and academic researchers, given that there is no mandatory emissions reporting for military conflict. Such categories include: (1) Hamas and Israeli ground transportation beyond tanks and ground-based weapons systems, (2) replenishing of weapons stockpiles for both Israel and Hamas, (3) transport of aid deliveries to Gaza, (4) the emissions and reduced carbon sequestration potential created through land clearance, (5) future emissions costs of flights by the US and other Israeli allies to deliver material to the region, (6) fires from explosions, (7) rescue operations and transportation of the wounded, and (8) road reconstruction in Gaza and Israel and the clearing of debris. Other significant categories includes a full detailing of reconstruction of Gaza beyond only carbon analysis of concrete buildings, and finally, a Scope 2, 3 and 3+ reporting of material, troop deployment and even diplomatic and humanitarian assistance, including shuffling of trained personal and staff to assist in the ceasefire talks and aid delivery.

Outside of the black box of emissions from war, we know that the everyday operations of militaries around the world are significant emitters of greenhouse gas emissions but still lack comprehensive data. Around 5.5% of total global carbon emissions are attributable to

⁵⁸ Neimark, B., Belcher, O., Ashworth, K., & Larbi, R. (2023). Concrete Impacts; See also: <https://www.concreteimpacts.org/>

⁵⁹ See Cottell, L., 2022, A framework for military greenhouse gas emissions reporting, <https://ceobs.org/report-a-framework-for-military-greenhouse-gas-emissions-reporting/> Rajaeifar, M.A., Belcher, O., Parkinson, S., Neimark, B., Weir, D., Ashworth, K., Larbi, R. and Heidrich, O., 2022. Decarbonize the military.

militaries, more than double the proportion attributable to commercial airlines.⁶⁰ Due to existing loopholes in reporting to the UNFCCC set during George HW Bush administration and then reaffirmed in Paris in 2015, carbon accounting by militaries remains voluntary, and many do not report their emissions at all. In fact, research by the Military Emissions Gap suggests that only 4 countries currently supply some, albeit incomplete, emissions reporting to the UNFCCC.⁶¹

This work is meant to draw attention to the climate impacts of war and militarism – an underappreciated aspect of the climate crisis. By no means do we seek to divert attention away from the human suffering the war has caused, especially for millions living in fear of losing their lives in Gaza due to Israeli bombardment or those still being held hostage by Hamas- we echo calls from around the world for a durable ceasefire. But this exercise attempts to offer some glimpses of the wider environmental and climate effects of the conflict- effects that are not separable from the wider humanitarian costs of war.

⁶⁰ Parkinson, S., and Cottrell, L. 2022. Estimating the Military's Global Greenhouse Gas Emissions.

⁶¹ For an accounting of current gaps in military reporting, see the Military Emissions Gap at: <https://militaryemissions.org/>