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

Frederick Otu-Larbi,[1,2] Benjamin Neimark*,[3] Patrick Bigger,[4] Linsey Cottrell,[5] Reuben Larbi[6]

1. University of Energy and Natural Resources, P.O. Box 214, Sunyani, Ghana
2. Lancaster Environment Centre, Lancaster University, LA1 4YQ, Lancaster, UK
3. School of Business Management, Queen Mary, University of London, Mil End, E1 4NS, UK – Corresponding author, b.neimark@qmul.ac.uk
4. Climate and Community Project, 1014 Torney Ave., San Francisco, CA, 94129, US
5. Conflict and Environment Observatory, The Chapel, Scout Rd, West Yorkshire, UK. HX7 5HZ
6. Division of Health Research, Lancaster University, LA1 4YQ, Lancaster, UK

***Corresponding author**

Highlights

❖ The projected emissions from the first 120 days of the Israel-Gaza conflict were greater than the annual emissions of 26 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 36 individual countries and territories.

❖ The carbon costs of reconstructing Gaza are huge. Rebuilding Gaza will entail total emissions figure higher than the annual emissions of over 135 countries, putting on them par with that of Sweden and Portugal.

❖ Our upper estimate on all pre-/post-war activities are comparable to the burning of 31,000 kilo tonnes of coal– the amount of which can power about 15.8 coal-fired power plants in one year.[1]

❖ 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).

Keywords: Climate Change, Global Militaries, Greenhouse Gas Emissions, Israel-Gaza

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[a] This manuscript represents an update covering the first 120 days, plus associated infrastructure emissions, and post-conflict reconstruction. In our previous work, we examined the first 60 days, see, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4684768

Abstract

Israel and Hamas have been engaged in a conflict in the Gaza strip since October 7, 2023, when Hamas launched a surprise incursion into Israel killing more than one thousand people and taking hundreds more hostage. Since then, the world's attention has been on the horrific humanitarian crises brought by the war - about 30,000 Palestinian deaths and millions displaced while Gaza is reduced to rubble. One aspect of this war, and indeed of any war, which is less discussed is the environmental impact of the conflict, including the greenhouse gas emissions associated with the use of materials and resources by the warring factions. In this article, we estimate the carbon emissions of the war in Gaza for three distinct periods; construction and fortification activities prior to the latest conflict, emissions from the first 120 days of the war (October 2023 – February 2024) based on openly available data from media reports, and emissions from future reconstruction needs of damaged and destroyed buildings and infrastructure. We estimate the total carbon emissions due to direct war activities in the first 120 days to be between 420,265 and 652,552 tonnes of carbon dioxide equivalent (tCO2e). This figure rises to 47,669,097 and 61,443,739 tCO2e when we consider prewar and postwar construction activities. This is more than 135 individual nations annual emissions, highlighting the significant climate footprint of armed conflicts and the pressing need to account for carbon emissions during war.

Introduction: 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, and after months of unprecedented bombardment the human costs of the conflict are reaching scales previously unseen in the region. The numbers are staggering; as of February 2024, over 35,000 in Palestine and 1,139 in Israel have died, and over 100 Israelis and foreign nationals still held hostage by Hamas.[2,3] Estimates place 54-66% of Gaza's buildings — homes, schools, mosques, hospitals — as destroyed or damaged.[4] The Bank of Israel, initial forecasts of the future financial cost to Israel expected to reach up to $50 billion,[5] including rebuilding Gaza.[6] The World Bank has placed an estimated $18.5 billion price on the damages to physical structure alone.[7]

While the Israel-Gaza conflict was closely monitored at the UN Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) 28 meetings in Dubai by delegates and civil society organisations, its climate dimensions were barely acknowledged.[8] [b] Prompted by the hosts, the links between conflict and climate change were included on the UNFCCC

[b] Although there was a 'Peace Day' and declaration, there were no other UNFCCC outcome documents which mentioned the contribution that military activities or warfighting makes to the climate crisis. The COP28 Declaration on climate, relief, recovery and peace highlights the vulnerabilities of fragile and conflict-affected states to climate change, as well as the need for environmental peacebuilding, it fails to acknowledge the contribution from wars and the military, see: https://www.cop28.com/en/cop28-declaration-on-climate-relief-recovery-and-peace.

agenda for the first time.[9] It is important to build on this post-COP momentum to highlight gaps in current military emissions reporting,[10] while pushing for immediate cuts to military emissions as an economic sector where governments have direct authority to manage operations.[11] According to the United Nations Environmental Programme's most recent Emission Gap report,[12] military emissions are 'insufficiently accounted for' by the UNFCCC, but even with incomplete data, researchers have found that militaries *still* account for almost 5.5% of global emissions.[13] The data gaps clearly complicate estimations for key climate indicators.[c] The global climate change indicators for 2023 show significant changes in just the three years since the IPPC 6th Assessment Report came out. Total annual global emissions were up to 54 G tonnes CO_2e, yet the method of estimating GHG emissions change did not take into consideration emissions due to military actions.[14]

Within the turmoil of the current conflict are the less discussed, but vitally important, climate and wider environmental effects of the war. This omission is understandable as the world remains focused on the acute death and suffering. However, military operations remain an under-analysed dimension of the climate crisis that will worsen suffering on vulnerable communities and the wider region as the impacts of global warming intensify.[15] Difficulty in monitoring and accessing information about combat operations is one of the major reasons for the limited literature on the climate impacts of war, a second, being the lack of rigorous methodologies to track them. In the following article, we seek to fill this gap in knowledge surrounding military emissions, and particularly emissions during war.

As far as we are aware, the Israeli military (IDF) has never reported emissions figures.[d] No specific data on military fuel combustion emissions has been provided in Israel's annual National Greenhouse Gas (GHG) Inventory to the UNFCCC, although requested under the reporting category 1A5, which should cover emissions from military fuel use. [16] Therefore, to get some understanding of the baseline military emissions from the IDF, which we understand to be significant, we created a rough heuristic to provide some context to our analysis. To create this proxy figure, we take GHG emissions from militaries as a function of total defence spending based on an average carbon intensity for each defence dollar spent in 2019 for the top

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[c] The Global Climate Change indicators for 2023 show significant changes in just the three years since the IPPC 6th Assessment Report came out. Total annual global emissions were up to 54 G tonnes CO2e, yet the method of estimating GHG emissions change did not take into consideration emissions due to military actions (Foster et al. 2023).

[d] Military GHG emission data reported by governments can be reviewed by clicking on the map available at: https://militaryemissions.org/

five European defence budgets - France, Germany, Italy, Spain, and the Netherlands. The average military carbon emissions are estimated to be 0.14 kg of CO_2e per dollar in 2019.[17] Using this baseline, we estimate that Israel's 2023 military budget of US $27.5 billion would result in a total emissions figure of 3.85 million of CO_2 – about 5% of Israel's annual emissions and roughly the same emissions as the entire nation of Bahamas or Mauritius in 2022. [18,19] Palestine's defence-specific emissions are also unreported, however, given the more ad hoc nature of Hamas's offensive capabilities and the lack of data on expenditure by Hamas, we are not confident a similar proxy approach would deliver a meaningful figure.

We offer snapshots of direct GHG emissions of the Israel-Gaza conflict 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.[20] Methodologically, this work answers recent calls to move beyond the more limited, albeit frequently applied, Scope 1 or direct 'tailpipe' emissions and in-direct or Scope 2 emissions. Following Cottrell (2022), we advocate for a separate scope that includes wartime emissions, called 'Scope 3+.' [21] These wartime emissions categories, we argue, are vital to better understand the intricacies of conflicts, including intensive fuel consumption due to fighter and cargo aircraft and ships, rapid deployment of troops, as well as damage to local environments including fires, emissions from infrastructure debris, displacement of people, aid, and ultimately post-war reconstruction.[21] [e] These categories will provide researchers and policy makers an applied tool to begin comprehensively quantifying many aspects of war usually left out of carbon calculations even by militaries that do report some aspects of their overall environmental impact. Other significant indirect emissions may also apply due to disruptions and reverberating effects on the economy, which are not addressed under Scope 3+.

In our analysis, we use open-source data on combat operations and military installations to estimate the carbon footprint from both Israel and Hamas, including the emissions found in related combat and post-combat activities, such as aid delivery and reconstruction. In doing so, our analysis covers three-time horizons, including the **immediate, intermediate, and long-term** carbon cost of the conflict.

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[e] While our snapshot calculations below do not cover all the needed supply chain emissions found in Scope 3+, we do include several of the wartime fighting activities unique to conflict emissions.

To understand the **immediate** climate ramifications of Israel's invasion of Gaza over the first 120 days of the war, we calculate mainly Scope 1 'tailpipe emissions,' and some, but very limited, Scope 2 and 3 (manufacturing of bombs and other munitions) of the hundreds of Israeli bombing raids and reconnaissance flights (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. Within this same timeframe of 120 days, we also quantify the climate impacts of Qassam rockets sent into Israel by Hamas during the initial stages of the war.

The second time horizon covers the **intermediate** carbon emissions found in the preparations and fortifications prior to the latest conflict over the past 16 years. Over this time horizon, we consider emissions from the construction of security-related concrete infrastructure in both Israel and Gaza over this 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. [22] On the Israeli side, we include emissions for the 'Iron' or 'Smart Wall' separating Gaza from Israeli controlled territory - both above and below ground. The wall, planned since 2016 and finished in 2021, was built with the intention of protecting Israel form any Hamas attack from the Gaza strip.[23] We specifically include these to draw attention to how such carbon-intensive infrastructure and its centrality in the offensive and defensive dynamics of the conflict.

Finally, we analyse the carbon costs of future long-term reconstruction needs in Gaza given the scale of the destruction wrought by Israeli bombardment and future **long-term** emissions resulting from reconstruction of housing and other infrastructure. This final temporal dimension we calculate is forward-looking the carbon costs of rebuilding Gaza, even to its previous precarious state. In sum, these three temporal dimensions only partly cover the totality of the carbon emissions found across all dimensions the invasion and war in Gaza. If anything, this work demonstrates the challenges of analysing distinct activities found in wartime - leading to calls for an expanded Scope 3+, or separate categories covering conflict emissions.

Expanding the Scope 3+ wartime emissions, and why it matters

Recent work has drawn attention to the pressing need to account for large institutional and operational emissions from militaries and conflicts.[24] There are huge data gaps. The global estimate of 5.5% for military emissions includes key military technology industry and supply chains but excludes emissions from conflict and warfighting activities. The current UNFCCC reporting obligations do not set out requirements to cover conflict emissions, and there is no common agreed methodology or scope. To address this omission, Cottrell (2022)[21], proposed a framework outlining the Scope 3+ categories to be covered (see Figure 1, Table 1), as well as the standard Scope 1, Scope 2 and Scope 3 emissions – as set out by the GHG Protocol.[21]

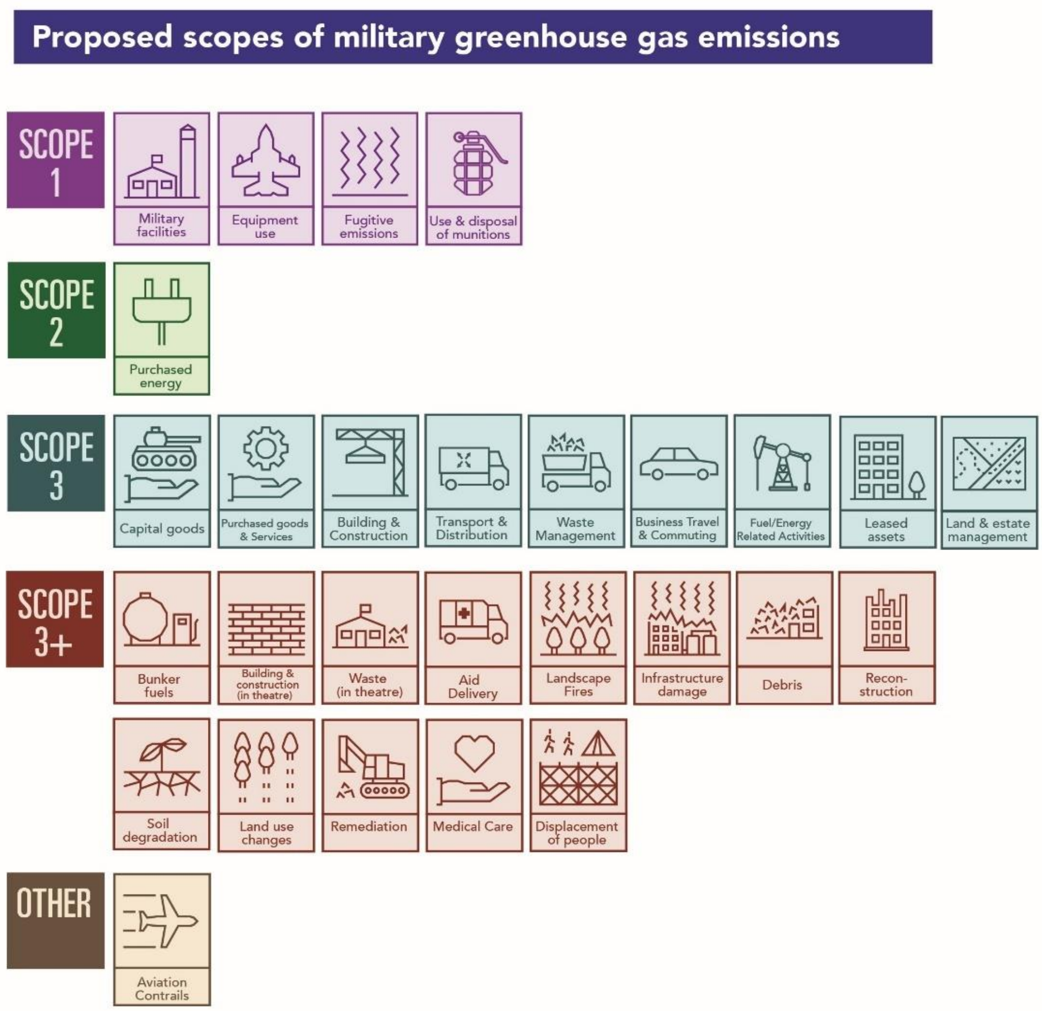

Figure 1: Schematic showing proposed scopes of greenhouse gas emissions from military and defense industry.

Table 1: Proposed Scopes 1, 2, 3 and 3+ emissions reporting categories for militaries[f]

Scope 1: Direct GHG emissions	**From sources that are owned or controlled by the organisation**
Military facilities	Fuel combustion in static units including solid, liquid or gaseous fuel use for heating, cooling or generators.
Equipment use	Fuel combustion from mobile equipment use, including aircraft, land vehicles, marine vessels and spacecraft (Within the troposphere and stratosphere only).
Fugitive emissions	Fugitive emissions, e.g. methane, arising from treatment and disposal of solid, liquid and gaseous waste and wastewater, in facilities owned or controlled by the military. Also, other fugitive emissions mainly from use of HFCs, PFCs or SF_6 in refrigeration, air conditioning, radar and electrical equipment and from other chemical use (such as de-icers) or losses.
Use and disposal of munitions	Detonation of munitions in training and active combat, including the incineration, detonation, open burning or treatment of end-of-life and obsolete explosive ordnance, in facilities owned or controlled by the military.

Scope 2: Indirect GHG emissions	**From purchased or acquired energy not owned or controlled by the organisation**
Purchased energy	Includes electricity, steam, heat and cooling for use at, e.g. military bases and buildings.

Scope 3: Other indirect GHG emissions	**From other sources resulting from activities of an organisation, but occur from sources not owned or controlled by that organisation**
Capital goods	Includes the raw material extraction, manufacture and transportation of all major military equipment (for land, sea, air, space), civilian equipment (including business transport fleet) and IT systems.
Purchased goods and service	Includes the raw material extraction, manufacture and transportation of other purchased military and civilian goods (such as weapons, combat gear, clothing, IT, office equipment and perishables). Also includes services such as the provision of private military and security companies, logistics, maintenance, IT and telecommunication support, catering etc.
Building and construction	Includes the construction and renovation of buildings and similar assets.
Transport and distribution	Includes the transportation and distribution of products and services purchased not included above, in vehicles not owned or controlled by the military.

[f] Adopted from *Cottrell, L.* 2022. A framework for military greenhouse gas emissions reporting https://ceobs.org/report-a-framework-for-military-greenhouse-gas-emissions-reporting/

Waste management	Disposal and treatment of solid, liquid and gaseous waste and wastewater in facilities not owned or controlled by the military. This includes fugitive emissions (e.g. methane) and emissions from the incineration, detonation, open burning or treatment of end-of-life and obsolete explosive ordnance.
Business travel and commuting	Transportation of military or civilian staff for business-related activities in vehicles not owned or operated by the military. Also includes transportation of military or civilian staff between their homes and place of work in vehicles not owned or operated by the military.
Fuel/energy related activities	Includes the raw material extraction, manufacture and transportation of fuels and energy, not already included in Scope 1 and 2.
Leased assets	Operation of assets leased by the military and not included in Scope 1 and 2 and operation of assets owned by the military and leased to other entities.
Land and estate management	Includes damage to natural ecosystems, deforestation, impacts on agricultural areas, wetlands and fires caused by training and land use practices.

Scope 3+: Other indirect GHG emissions linked to the military	**From other sources resulting from military activities and warfighting**
Bunker fuels	Combustion of fuels used for international aviation, spacecraft launches, land-based and maritime transport, and not reported under Scope 1 or Scope 2.
Building and construction (in theatre)	Includes the construction of bases, buildings and similar assets in theatre.
Waste (in theatre)	Incineration, disposal, haulage and treatment of military-derived solid waste and wastewater, from military deployment overseas and not included above.
Aid delivery	Includes the production, delivery, and distribution of equipment, food, water, shelter and/or services, to people or organizations directly in~~to~~ the theater of war or to displaced populations.
Landscape fires	Includes accidental fires caused by military training exercises and fires caused during active combat. Includes fires in natural forests, plantations, shrub, grassland, pasture, peatlands, agricultural land and peri-urban areas.
Infrastructure damage	Includes fires and damage to infrastructure, as well as any fugitive emissions due to leaks or losses from infrastructure (such as methane).
Debris	Includes the building debris generated from the use of explosive weapons during warfighting, haulage and waste management.
Reconstruction	Includes the raw material extraction, manufacture and transportation of construction materials, as well as emissions from the construction activities.
Soil degradation	Includes soil erosion, disturbance and desertification, which can accelerate the loss of carbon from soils and reduce their potential to be effective carbon sinks.

Land use changes	Includes damage to natural ecosystems, deforestation, impacts on agricultural areas, wetlands and fires caused by changes in land-use practices.
Remediation	Includes the raw material extraction, manufacture and transportation of restoration materials, as well as emissions from the remediation/restoration activities and disposal or treatment of any contamination or hazardous waste.
Medical care	Includes military and civilian causalities, and the logistics and provision of medical equipment and facilities, medical staff and management of medical waste.
Displacement of people and humanitarian support	Includes internally displaced people and transboundary refugees, and the logistics and provision of food, shelter, welfare management. Liaison with external humanitarian aid agencies or national governments required.

Other non-CO2 effects	**Description**
Aviation contrails and non-CO2 effects	Aircraft and spacecraft flying in the stratosphere can cause non-CO_2 climate change contributions and a CO_2 emissions weighting factor can be used to approximate these non-CO_2 climate change contributions.

The Scope 3+ framework was adapted and applied for the initial and follow-on conflict emission estimates from Russia's invasion of Ukraine,[25] and draws attention to the primary emission sources, highlights the scale of otherwise hidden emissions and could be used to hold Russia accountable for the climate damage caused. The process also highlights the inadequacy of the current reporting obligations to the UNFCCC, and failure of the UNFCCC's structure to enable accounting of conflict emissions. Under the current reporting obligations, military emission data is provided on a voluntary basis only and limited to military fuel use.[g] Unfortunately, data on military emissions is either left out or embedded within a country's overall emissions reported to the UNFCCC, and there is no consideration of the contribution from other wartime activities such as fires and reconstruction needs.

The distribution of emissions across these Scope 3+ categories will vary depending on the conflict setting, duration, nature of warfare, type of weapon systems used, and post-conflict recovery. For Ukraine, researchers also identified additional indirect emissions resulting from closure of international airspace and the need to reroute flights, plus from the wider impact on Ukraine's economy and on the European energy sector. Similarly, the Israel-Gaza conflict and

[g] Military use of other GHGs (SF_6 and perfluorocarbons under category 2.G.2.a) is also requested by the UNFCCC but only reported by the UK and Japan.

wider unrest in the Middle East has disrupted international shipping through the Red Sea and caused significant indirect emissions. Estimates suggest that emissions by shipping from the Far East to the Mediterranean increased by 63%, when compared to the same period before the conflict. [26] This was due to a combination of longer shipping routes, faster sailing speeds needed, and use of older, less efficient vessels. Such indirect emissions are excluded in estimates for this paper. The outline framework and Scope 3+ categories are vital to help better understand the climate damage caused by conflict, and drive needed action to reduce harm. There is already abundant guidance on GHG accounting, and whilst the framework does not replicate quantification methods, it sets out the key categories for consideration and focus. Acquiring datasets relating to a conflict remains challenging, including Scope 3 emissions linked to military procurement and other civil equipment and supply chains.

Scope 3 accounting follows a life cycle approach, evaluating the full emissions associated with raw material extraction, manufacturing or processing, transportation, use, and end-of-life management of goods or services. The GHG Protocol provides clear and transparent methods on accounting.[27] However, most organisations reporting on their GHG emissions fail to fully include Scope 3 emissions, including the military and the defence sector. The CO_2 AI + BCG Carbon Emissions Survey 2023 reported that just 10% of companies surveyed were comprehensively measuring all their emissions.[28] Scope 3 emissions can be a significant proportion of an organisation's total emissions, meaning that the total carbon footprint for the military can be to 5 to 6 times higher than from the operational Scope 1 and 2 GHG emissions alone.[21]

The framework sets out for the minimum requirements that militaries should use to account for their GHG emissions - including in times of war - and is a useful starting point given the lack of agreed measurements tools. In 2023, NATO published its own GHG reporting methodology although this explicitly excludes emissions from NATO-led operations and missions, and other activities such as training and exercises. There is also no mention of warfighting emissions or how these may need to address in the future.[29] Clearly, Scope 3+ would be a significant step forward in our ability to understand and analyse the climate impacts of war, however, as we demonstrate in this article, there are many challenges to calculating such 'real-time' carbon assessments. We discuss these limitations of data gaps in our discussions section.

Carbon snapshots of a long, explosive conflict

The figures presented in Table 2 below are all snapshots across diverse types of emitting activities and time scales – which we have categorised as: immediate, intermediate, and long-term. Due to the nature of conflicts, timeframes 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 used to account for greenhouse gas emission during war. The projected emissions from the first 120 days of the Israel-Gaza conflict were greater than the annual emissions of 26 individual countries and territories. For each activity, we provide a lower and upper estimate of the total greenhouse gas emissions (Figure 2 and Figure 3). The basis for these estimates is explained in the methodological section.

Table 2: Immediate Estimations of Conflict Activities for the first 120 days (07 October 2023 – 07 February 2024) in tonnes CO_2 equivalent (tCO_2e)

Emission Activity	***Brief description***	***Lower estimate (tCO_2e)***	***Mean Estimate (tCO_2e)***	***Upper estimate (tCO_2e)***
Cargo Flight	244 carrying around10,000 tonnes of goods in total.	134,629	159,107	183,586
Bombing and Reconnaissance Flights	Israeli F-16 & limited F-35 flights - 300 flight hours each day	125,928	157,410	188,892
Tanks and Vehicles	We assume a total of five hundred vehicles involved in ground operations in Gaza; 1250 tanks and 2250 Infantry Fighting Vehicles (IFVs).	61,333	91,999	122,666
Israeli Bombs and Artillery	100,000 ground artillery items, totalling about 8000 tonnes of steel and explosives used. About 45,000 air-dropped bombs us ed on Gaza. Sizes range between 150kg and 1000kg.	70,165	78,236	86,306
Hamas Rockets	9,500 Qassam rockets fired into Israel.	713	927	1140
Gaza Electricity Production	Between 60,000 and 180,000 litres of fuel delivered daily to Gaza. A total of 7.2 to	19,440	38,880	58,320

	22million litres over the 120-day period.			
Hamas Bunker Fuels	Hamas is estimated to have stored between 0.5 and 1 million litres of fuel prior to the latest conflict.	1,350	2025	2,700
Gaza Aid Delivery (Trucks)	14,000 trucks a 600 km return journey between Egypt and Gaza to deliver aid. 2.5-3.3 million litres of fuel used in aid delivery.	6707	7825	8942
Total Immediate Emissions		**420,265**	**536,410**	**652,552**

Fighter Jets and Cargo Flights

In the first 120 days, we calculated emissions based on 244 cargo flights carrying 10,000 tonnes of supplies from the US to Israel.[30] In these calculations, we assumed that flight time from US to Israel is 11 to 15 hours one way. A variety of aircraft have been used in these cargo shipments. However, we assumed these flights are Boeing 777-200s based on media reports[31] with an average fuel consumption of 11,400 litres/per hour.[32] That gives a total of 61.2 to 83.4 million litres of fuel used for delivery of cargo based on 22- and 30-hours return flight time, respectively. The other key aspect under this category is the jet fuel Israel burned running aerial bombardment of Gaza. The bombing and reconnaissance campaign has been conducted primarily with F-16s, while F-35s have been flying patrol missions.[33] The over 200 airframes the Israeli military has used in this conflict logged around 15,900 flight hours in the initial 120-day period.[33] For the F-16, each flight hour would burn 3,600 – 5,400 litres of jet fuel. Although the F-35 burns 40% more fuel than the F-16, the lower fuel consumption for the F-16 has been used as a conservative estimate. This amounts to an estimated 57.8 - 85.9 million litres of JP-8 jet fuel used. The combined emissions from fighter jets and cargo flight fuel use is estimated to range between a lower and upper limit of 261,800 tCO_2e and 372,480 tCO_2e respectively. This is based on an emission factor of 2.2 kgCO2e/litre of jet fuel used (Table 5).[34 h]

[h] In our estimation based on available evidence, total crude oil imports since October 2023 until February 2024 were 3,802,420 tonnes, which, if consumed, equates to 11,288,054 tCO2e. Total jet fuel delivery since October 2023 until February 2024 were roughly 977,127 barrels or 125,072 tonnes, which equates to 343,949 tCO2e. Please note that the estimated emission value includes production, refining, transportation and consumption (Scope 3).

Bombs, Artillery and Rockets

Following de Klerk and colleagues,[25] we adopt the emissions intensity of 1.5 tonnes of CO_2 of embodied carbon from steel casing and explosives production for each ton of artillery and rocket fired by Hamas of IDF in this conflict. In the initial assault on October 7 and for several weeks following the start of Israel reprisals, Hamas fired around 9,500 Qasam rockets.[35] These rockets are estimated to weigh between 50 and 80kg each. Therefore, the estimated total weight of these rockets is 475-760 tonnes with an estimated carbon emission of 713 – 1140 tCO2e. Meanwhile, Israel fired approximately 100,000 shells with a weight of 80 kg/round since the war began on 7th October 2023. We estimate the total weight of artillery shells used to be 80,000 tonnes, giving a lower estimate of emissions from artillery and rockets to be 12,000 tCO2e. However, if all artillery used by IDF are 155mm shells, the embodied carbon could be as high as 136kg CO2e for each artillery.[25] This is based on an emission factor of 60.35kgCO2e for the manufacturing of composition B explosive and 75.62 kgCO2e for the manufacturing of steel casing. Our higher estimate for artillery used by IDF is 13,600 tonnes of CO_2. Israel has also reportedly used 45,000 air-dropped bombs on Gaza through sorties from fighter jets since the conflict began in October 2023. 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.[36] The most used bombs by the IDF are MK-82 containing ~90kg of TNT and 140kg of metal casing and other components.[37] The IDF are also widely reported to have used larger MK-85 bombs weighing about 1000kgs each.[37] Five thousand of these bombs were supplied to Israel by the US at the start of the conflict in October 2023. Media reports indicate that between 20,000 and 25,000 tonnes of bombs have been dropped from the air over Gaza during the conflict.[33] We therefore estimate these values as the lower and upper limits for our calculations of emissions due to bombing raids. Carbon emissions from bombs dropped on Gaza by the IDF is estimated to be between 58,165 and 72,706 tCO_2e. The total carbon emissions from the production of artillery and air-dropped bombs used by the IDF since the war began is estimated between 70,165 and 86,306 tCO_2e. This figure is based on the amount of steel and explosives used in the manufacture of the bombs.

Tanks and Vehicles

The Israeli Defense Force is estimated to have 2,500 tanks and over 5,000 Infantry Fighting Vehicles (IFVs) in total.[38] Israel has lost several tanks and vehicles while others have been immobilised by Hamas fighters.[39] Assuming half of pre-war vehicles were used in the conflict between October 2023 and February 2024, we estimate that about 1250 tanks and 2250 Infantry Fighting Vehicles (IFVs) have been involved in the ground operations in Gaza. Considering the small size of the frontline, each vehicle is assumed to travel between 10 and 20km each day. Based on estimates used by de Klerk and colleagues (2023) in their carbon accounting of the ongoing Ukraine war we assume that each tank and IFV uses 2.4 and 0.77 litres per kilometre travelled, respectively. Therefore, for the first 120 days of the war, 5.7 –11.4 million litres of fuel were consumed by frontline vehicles. We adopt the assumption from Klerk et al., 2023[25] 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 22.7- 45.4 million litres. The use of vehicles is estimated to have contributed between 61,333 and 122,666 tCO2e based on an emission factor of 2.7 kgCO2e/litre of diesel and petrol (Table 5)[34]. Although Hamas has also used vehicles in its initial assault on October 7, 2023, and subsequently during the war, it is difficult to estimate the total number of vehicles involved. However, we expect the total emissions from this activity to be negligible compared to other activities. We have also accounted for total fuel used by Hamas which will include the fuel used for these vehicles and therefore we do not provide a separate estimate.

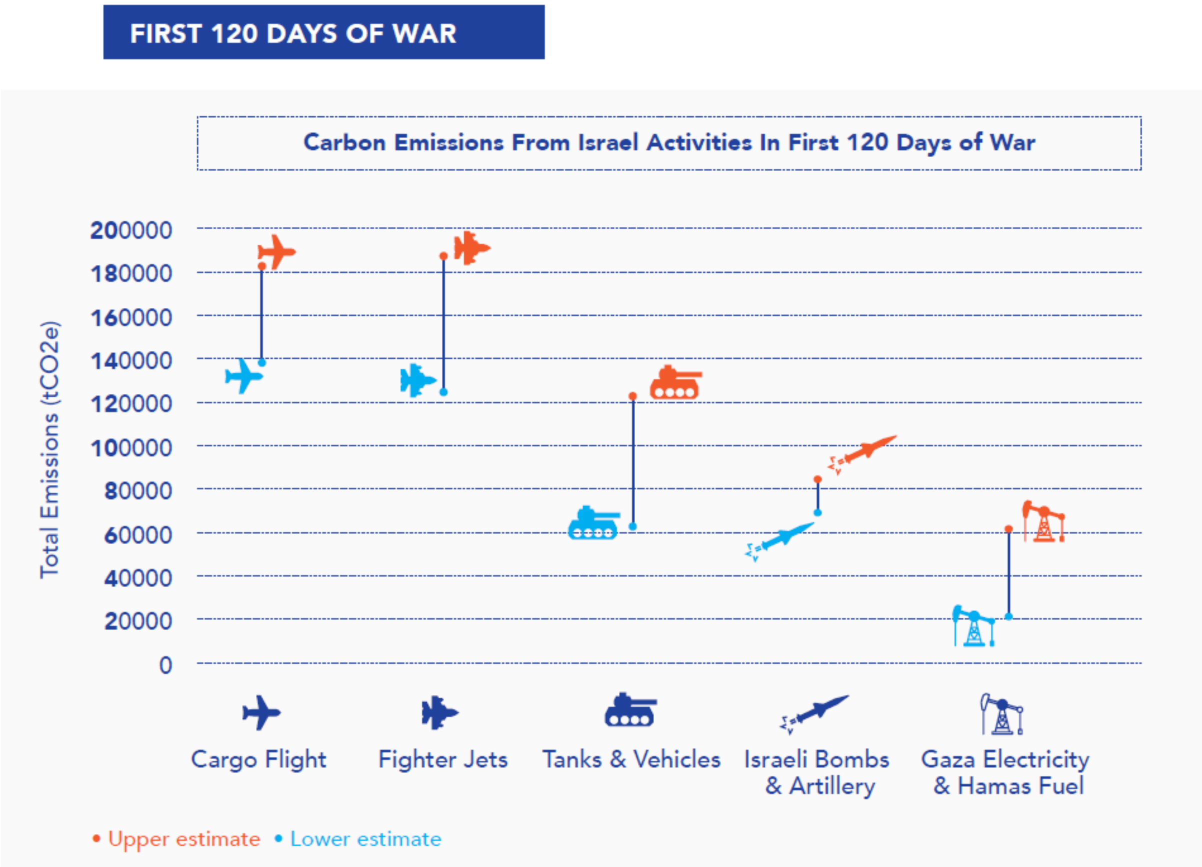

Figure 2: Estimated carbon emissions from Israeli Defense Forces (IDF) war activities from October 07, 2023 – February 07, 2024. Blue indicates lower bound of estimates while orange indicates upper limits of estimates.

Gaza Electricity Production and Fuel Consumption by Hamas

Prior to the conflict, about half of Gaza's electricity supply came from Israel. The rest of Gaza's energy was supplied by a 65MW diesel-fuelled power plant and a wide array of rooftop solar photovoltaic (PV) panels.[40,41] Up to 25% of Gaza's electricity was generated through PV panels prior to the war, representing one of the world's highest shares.[40,42] With most of the solar PV's and the sole power plant destroyed, electricity supply in Gaza now largely depends on diesel-powered generators. At the start of the latest conflict on October 7, 2023, fuel delivery into Gaza was severely restricted by the IDF. However, these restrictions were eased in November 2023 following pressure from the international community, allowing between 60,000 and 180,000 litres of fuel to be delivered daily. We estimate that between November 2023 and February 2024, 7.2 -21.6 million litres of fuel have been into Gaza with total carbon emissions of 19,440 – 58,320 tCO2e. We assume that this fuel was used for electricity generation as well as running essential services including ambulances. Hamas reportedly had between 500,000 and 1 million litres of fuel stored prior to the conflict. The carbon emissions from burning this fuel is estimated between 1,350 and 2,700 tCO_2e. These estimates of carbon emissions from fuel usage is based on an emission factor of 2.7kgCO2e per litre of diesel or petrol (Table 5)[34].

Aid Delivery

Food, medicines and other essential goods have been delivered to Gaza by various organisations including the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA) and the World Food Program (WFP). These organisations coordinate the deliveries of supplies to Egypt from where trucks carry the goods on a 600km return journey for delivery to Gaza. Aid delivery has faced various obstacles and thus have not been consistent. However, various reports indicate that about 13,800 trucks have delivered aid to Gaza between October 2023 when the conflict began and February 2024 which is the period under study.[43] These trucks consume ~30 to 40 litres of fuel per 100km travelled. We estimate total fuel used by these trucks in delivering aid to Gaza between 2.5 and 3.3 million litres. The lower and upper estimates of carbon emissions from fuel used in delivering aid to Gaza are estimated at 6,707 and 8,942 tCO_2e, respectively. We have not included emissions from flights that deliver these supplies to neighbouring countries for onward deliveries to Gaza because we have not been able to obtain accurate data on these flights.

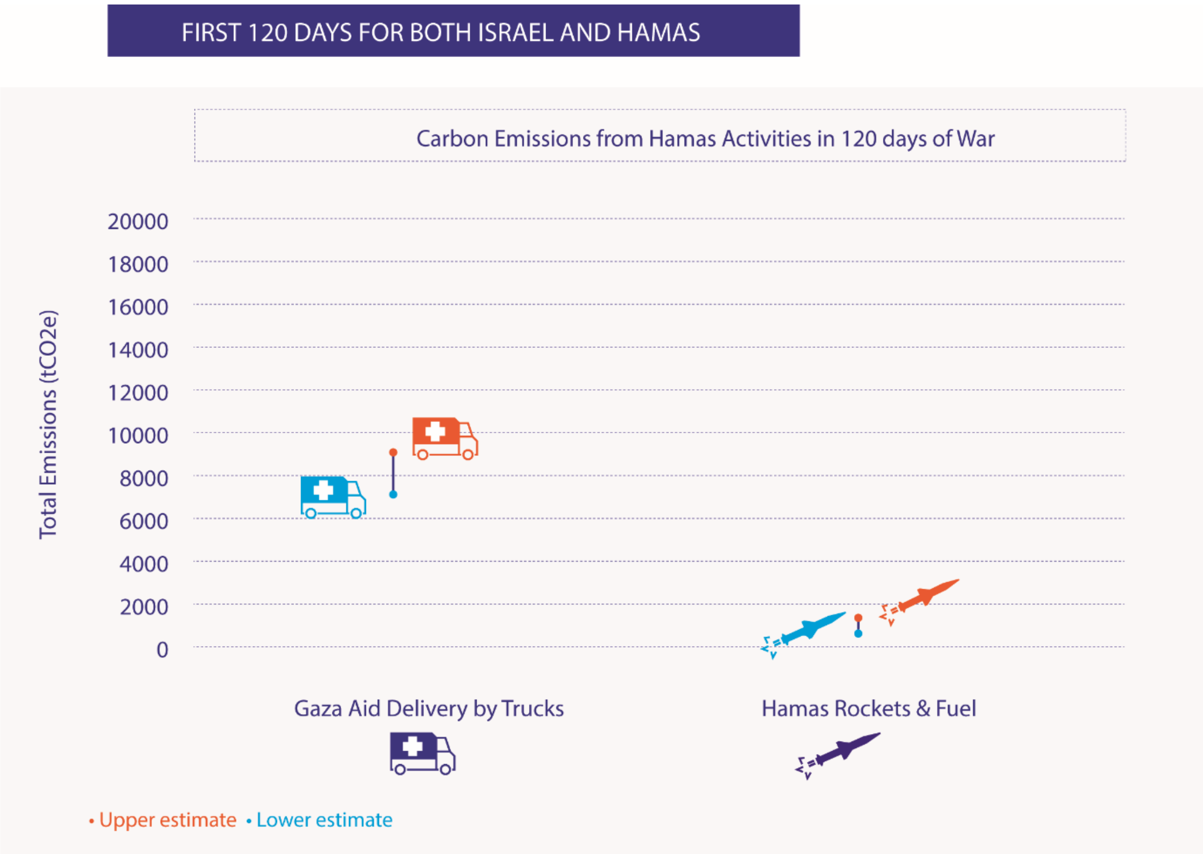

Figure 3: Estimated carbon emissions from Hamas and Palestinian war activities from October 07, 2023 – February 07, 2024. Blue indicates lower bound of estimates while orange indicates upper limits of estimates.

Intermediate Estimations

The figures presented in Table 3 are again a snapshot of the intermediate costs associated with mainly two activities – the massive use of concrete and iron used in fortifications prior and during the conflict. The immediate and intermediate time frames increase total emissions to more than over 36 individual countries and territories. Again, for each activity, we provide a lower and upper estimate of the total greenhouse gas emissions (Figure 4). The basis for these estimates is explained in the methodological section.

Table 3: Intermediate Estimations of Conflict Activities in tonnes CO_2 equivalent (tCO_2e)

Emissions Activity	*Brief description*	*Lower estimate (tCO_2e)*	*Mean Estimate (tCO_2e)*	*Upper estimate (tCO_2e)*
Hamas' Tunnel Network	500km of tunnels. 10cm/20cm thick,	174,600	326,700	478,800

	2m tall and 1m wide			
Israel's 'Iron Wall'	65km long, 6m tall, 3meter concrete below ground	274,232	293,310	312,387
Total Intermediate Emissions		**448,832**	**620,010**	**791,187**

Hamas Tunnels

We have assumed, based on detailed descriptions of the network, that the tunnels are two meters tall, 1 meter wide and have a thickness of between 10 and 20 centimetres.[44,45,46,47,48] Thus for the four sides of the tunnels, we estimate that a total of 300,000 to 600,000 cubic meters of concrete was used in constructing the tunnels. Assuming that there are 100kgs of steel in each cubic meter of concrete, we obtain between 30,000 and 60,000 tonnes of steel used in the tunnels. We have calculated the total amount of concrete and steel used and applied the emission factor of concrete (180kgCO2e/ton)[49] and steel (1.55tCO2e/tonne)[15], respectively, to obtain 174,000 - 478,800 tCO2e emissions resulting from the Gaza Metro/tunnel construction.

Israel's '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 6-meter-high metal fence, and large concrete barriers. It runs along most of the border between Israel and Gaza for about 65km. In calculating emissions due to Israel's Iron Wall, we used a methodology like that observed above for Gaza's tunnels. Emissions from above ground features were calculated based on 140,000 tonnes of steel used in the construction of the wall.[50] Based on an emission factor of 1.55 tCO2e/tonne of steel, we estimate 217,000 tCO_2e as the emissions due to the construction of the above-ground component of the Iron Wall. 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 width is assumed to be 0.5 meters. We use a lower and upper estimate of 3m and 5m respectively for the depth of the below-ground concrete component of the iron wall. We obtain a total of 97,500 to 162,500 cubic meters of concrete work. We apply a factor of 2.4 tonnes/m3 to obtain the weight of concrete used to be between 234,000 and 390,000 tonnes. We estimate that 9,750 – 16,250 tonnes of steel reinforcement was used in the below-ground component of the Iron Wall based on 100kg of steel per cubic meter of concrete work. The below-ground component of the Iron Wall is estimated to have a carbon footprint of 57,232 – 95,387 tCO2e. The lower and upper carbon emissions due to the construction of Iron Wall are estimated to be between 274,232 and 312,387.

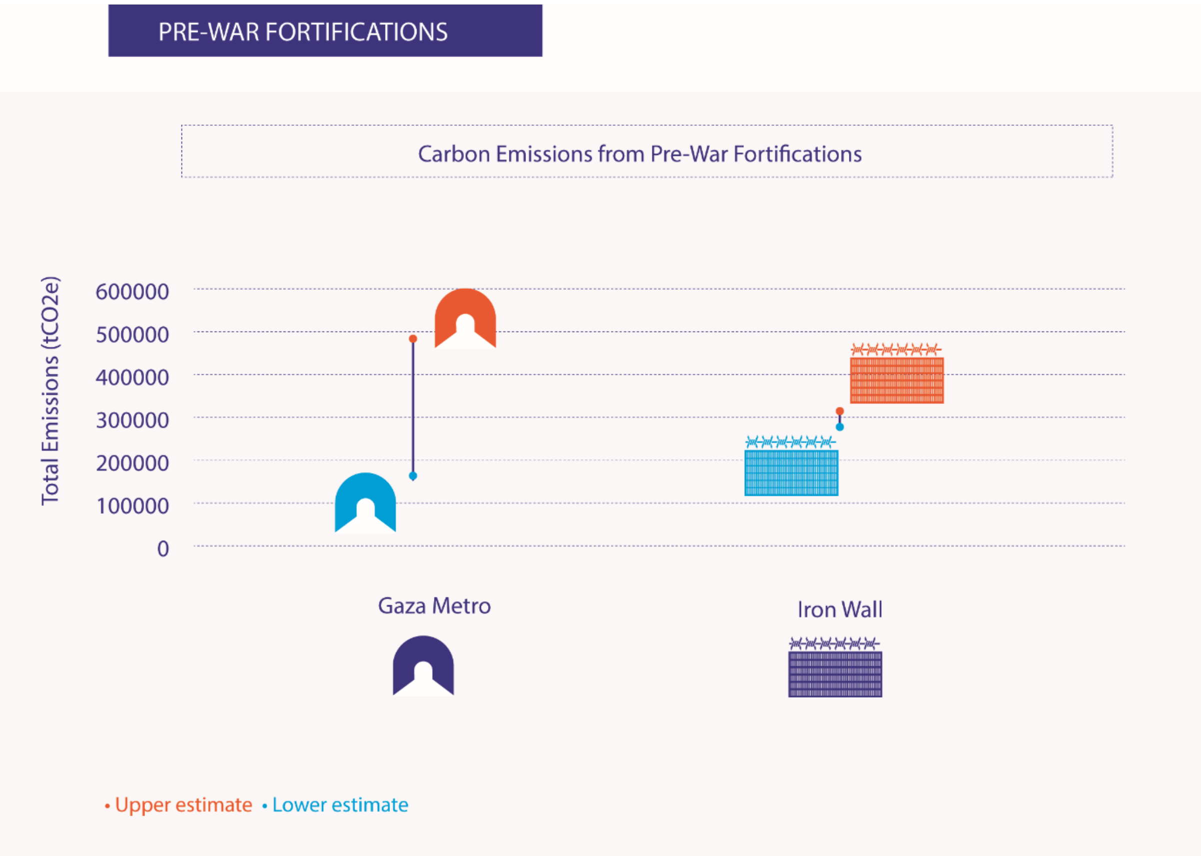

Figure 4: Estimated carbon emissions from pre-war fortifications and tunnels constructed by the Israeli Defense Forces (IDF) and Hamas prior to the lasts conflict on October 07, 2023. Blue indicates lower bound of estimates while orange indicates upper limits of estimates.

Long Term Reconstruction Emissions

By far the largest carbon emission output comes from the reconstruction needs of Gaza. Intense bombing of Gaza has significantly damaged infrastructure, including hospitals, apartment buildings, roads, water and wastewater treatment plants, sewer networks, schools and universities, and water wells.

Table 4: Long Term Carbon Costs of Rebuilding Gaza in tonnes CO_2 equivalent (tCO_2e)

Emissions Activity	*Brief description*	*Lower estimate (tCO_2e)*	*Mean Estimate (tCO_2e)*	*Upper estimate (tCO_2e)*

Long Term Reconstruction	Reconstruction of 156,000 to 200,000 buildings destroyed in Gaza	46,800,000	53,400,000	60,000,000

We estimate that the carbon cost of reconstruction the building damaged or destroyed in Gaza to be between 46.8 million and 60 million tonnes of carbon dioxide equivalent (see Table 4 and Figure 5). Our upper estimate on all pre-/post-war activities are comparable to the burning of 31,000 kilo tonnes of coal– the amount of which can power about 15.8 coal-fired power plants in one year.[51] The carbon costs of reconstructing Gaza are massive. Rebuilding Gaza will entail total emissions figure higher than the annual emissions of over 135 countries, putting on them par with that of Sweden and Portugal. It is estimated that roughly about 156,000 to 200,000 buildings have been destroyed or damaged in Gaza.[52,53,54] This includes residential, commercial, and industrial buildings.[55] Building storey height, construction type and floorplan area vary, and a review has not been undertaken for this estimate. However, taking a conservative estimate, we assume that each of the building needing to be rebuilt or restored, has embodied emissions of 300 tonnes of CO_2. This estimate is based on the amount of steel and concrete to be used in reconstructing these building as well as their transportation to Gaza. The assumed embodied carbon of each building is consistent with benchmark values used in estimating carbon footprints of building in other countries[56].

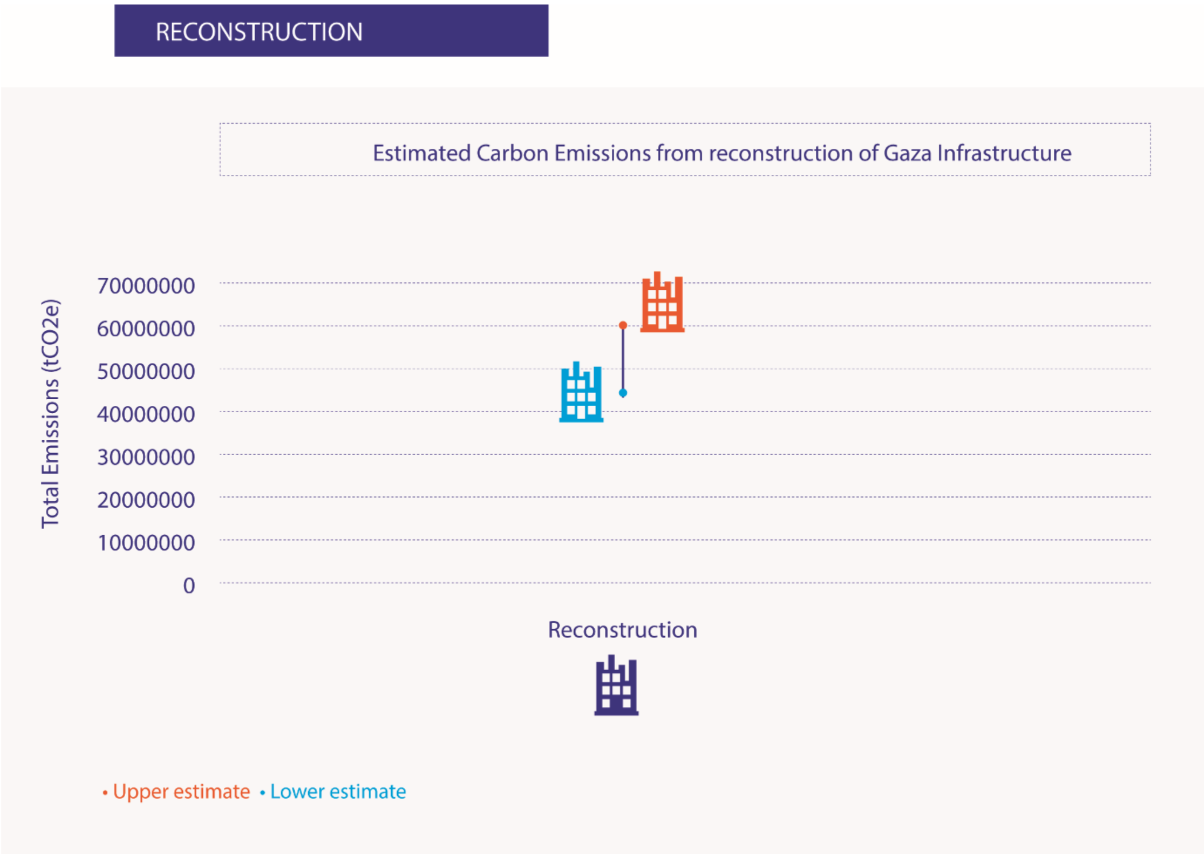

Figure 5: Estimated carbon emissions from reconstruction of destroyed buildings in Gaza. Blue indicates lower bound of estimates while orange indicates upper limits of estimates.

Discussion and Conclusion: Limits to our Analysis and Further Research Needs

Militaries are responsible for an estimated 5.5% of global carbon emissions – comparable to the combined contributions from civilian aviation (2%) and civilian shipping (3%) - yet the global military sector has largely remained understudied and unreported.[57] Our aim in this paper was to provide a broad estimate the carbon footprint of the war between Israel and Hamas for the first 120 days since the war began. We used openly available data from media reportage to estimate the carbon emissions from the ongoing conflict between Israel and Hamas for the period October 2023 to February 2024. 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. However, even this conservative snapshot shows the scale of carbon emissions is comparable to the emissions from running about 16 coal-powered plants for a year (see Figure 6). 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, skirmishes on the Israel-Lebanon border, and associated military operations in Yemen).

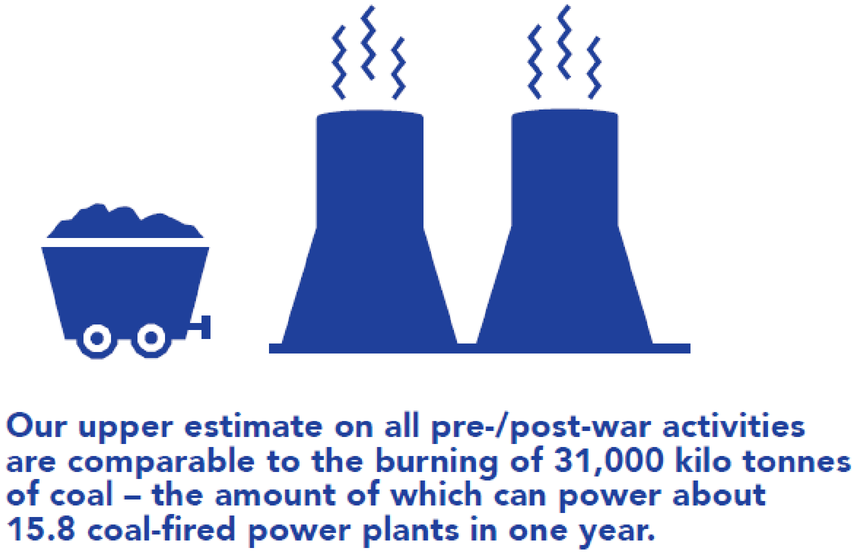

Figure 6: Comparison of total emissions estimated for the Israel-Hamas conflict to coal consumption in a typical power plant.

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(2022)[21] 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.[21] 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 vital, although still missing categories across the multiple Scopes 1-3+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) the emissions and reduced carbon sequestration potential created through land clearance, (4) future emissions costs of flights by the US and other Israeli allies to deliver material to the region, (5) fires from explosions, (6) rescue operations and transportation of the wounded, and (7) 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 personnel 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. Due to existing loopholes in reporting to the UNFCCC set during the Clinton and H.W. Bush administrations, and then reaffirmed by Obama in Paris, 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 just 4 countries in the 2023 reporting cycle provided military fuel emission data which aligned to UNFCCC reporting obligations.[21] 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 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.

Methodology and Sources of Data

This is an ongoing conflict. Therefore, it is difficult to obtain official data on numbers of equipment being used, sorties conducted, or resources used from either of the warring factions, and representatives from each party have offered explanations as to why. We rely on open-source information from media reportage, as well as reports from independent organization such as United Nations agencies working in Gaza and Israel. We have attempted to triangulate data about the same emission activity from multiple sources to ensure greater reliability of our calculations wherever possible.

Estimation of Carbon Emissions

For these different time horizons, we conduct scope one analysis of the emissions due to 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. This part of our analysis also considers the fuel used in generating electricity for essential services in Gaza as well as the delivery of aid using trucks. Scope 1 analysis relates to carbon emissions emanating directly from an activity. We also include a limited scope 2 and 3 analysis of electricity generation, and the manufacturing of bombs and rockets used by both Israeli Defense Forces (IDF) and Hamas. Scope 2 refers to the assessment of greenhouse gas emissions that result from the consumption of purchased energy such as electricity while scope 3 analysis deals with indirect carbon emissions from the production value-chain of equipment and ammunition production.

Uncertainty in Carbon Emission Estimates

We adopt a commonly used methodology for estimating carbon emissions from emissions from a discrete selection of war fighting activities and implied carbon costs from both military and civilian construction projects.[59,60] In this approach, emissions from an activity is estimated by multiplying the activity data by emission factors, yielding estimates at different temporal and spatial scales. This basic calculation is applied to the data obtained from media reports and other sources to obtain estimates of carbon dioxide equivalent emissions due to the ongoing war in Gaza. We calculate lower bound and upper bound carbon emissions for each activity to account for the uncertainty in data obtained from various sources. The activities and the data used in estimating carbon emissions are presented in Table 4 below.

Table 4: Sources of carbon emissions from Israel-Hamas war and correspondent lower and upper bounds of data

Emission Factors Used in Calculations

Our primary source of emission factors for calculations in this study is the Intergovernmental Panel on Climate Change (IPCC). We use alternative emission factors where a value could not be obtained from the IPCC as indicated in Table 5.

Table 5: Emission factors used in calculating carbon emissions from Israel-Gaza conflict

Emission Source	*Emission Factor Used*	*Reference*
Diesel	2.7 kgCO_2e/litre	IPCC, 2006[34]
Petrol	2.7 kgCO_2e/litre	IPCC, 2006[34]
Jet Fuel	2.2 kgCO_2e/litre	IPCC, 2006[34]
Concrete	180 kgCO_2e/tonne	ICE,2019[49]
Steel	1.55 kgCO_2e/kg	Neimark et al., 2023[15]
Cement	900 kgCO_2e/tonne	ICE, 2019[49]
Artillery and Rockets	1.5tCO_2e/tonne	De Klerk et al, 2023[25]
155mm artillery	136kgCO_2e/artillery	De Klerk et al, 2023[25]

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