CLIMATE DAMAGE CAUSED BY RUSSIA'S WAR IN UKRAINE

by Initiative on GHG accounting of war

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EXECUTIVE SUMMARY

Months of the military conflict caused by Russia's full-scale invasion of Ukraine have caused significant damage and led to the unfolding of a humanitarian crisis. Civilian infrastructure has been destroyed and damage has been done to the environment. This war adversely affects the global climate causing significant carbon dioxide and other greenhouse gas emissions into the atmosphere.

This interim assessment, which is focused on four activity areas directly affected by the war, concludes that greenhouse gas emissions for seven months of the full-scale war totals at least 100 million tCO_2e. This is the equivalent of the total GHG emissions over the same period in a country like The Netherlands. As a number of impacts of this war have not yet been taken into consideration, there figures are likely to underestimate the true level of emissions. The longer Russia's war continues, the higher final figures will be.

The post-war reconstruction of civilian infrastructure accounts for half of the GHG emissions, followed by fires. Emissions from warfare account for a smaller share although limited information was available to make a comprehensive analysis.
Transport emissions from refugees and IDPs are relatively low.

1. INTRODUCTION

On 24 February, the Russian Federation launched an unprovoked, large-scale invasion of Ukraine. The war has been dragging on for months, causing a humanitarian crisis with many people perishing, getting injured or having to flee their homes. The military conflict has also damaged or destroyed civilian infrastructure including buildings, factories, and roads. The impact on the local environment has significantly worsened people's quality of life, destroyed natural ecosystems and polluted the environment. Each explosion of a missile or projectile causes pollution of air, water, and land with toxic substances. Many industrial installations have been hit, which leads to uncontrolled chemical releases.

Initiatives have been started to keep track of environmental damage. The Ministry of Environmental Protection and Natural Resources of Ukraine has launched a website[1] aggregating damage to the environment based on reports from local and regional governments. The Conflict and Environment Observatory and the Zoï Environment Network released briefings to assess different environmental types of damages like radiations risk and water pollution, with a most recent focused on the industry[2]. Data about local pollution incidents is collected by the Center for Environmental Initiatives Ecoaction using an interactive map[3].

On top of local pollution, this war causes significant greenhouse gas (GHG) emissions into the atmosphere. While the world is struggling to drastically reduce GHG emissions to limit the average global temperature increase to 1.5 °C, these extra emissions caused by the war make it even more difficult to reach the goals of the Paris Agreement.

In the past, GHG emissions related to the military and conflicts were often overlooked, omitted or underreported as described in a recent publication[4]. The Conflict and Environment Observatory has proposed a framework[5] for the military to report their emissions in a transparent way. The Expert Group of the International Military Council on Climate and Security also addresses the challenges the military faces in order to decarbonise[6]. This report as such will not address the issues raised in the above reports but will rather provide an assessment of GHG emissions caused by this conflict.

In this interim assessment, we focus on those sources of emissions that can directly be attributed to the war. First, we look at the emissions due to millions of Ukrainians fleeing their homes either within the country as Internally Displaced Persons (IDPs) or abroad. Second, we look at the emissions caused by the warfare as a result of both the Russian army attacking Ukraine and the Ukrainian army defending the country in response. Third, an assessment is made of the emissions due to fires caused by fighting in the conflict zone. Last but not least, an assessment is made of the future emissions from the reconstruction of destroyed or damaged civilian infrastructure.

Given the significant leakage of methane into the atmosphere, the deliberate damage caused to the Nord Stream 1 and 2 gas pipelines is included in the totals as well.

The war has a significant impact on other sources of emissions as well. The economy of Ukraine is expected to shrink significantly, which will lead to decreased emissions.
On the other hand, increased emissions will occur outside Ukraine due to Ukrainians picking up their lives in the places where they are seeking temporary shelter. Industrial production, like the production of steel or fertilisers for export, will be taken over by industries elsewhere. The outage of the Zaporizhzhia Nuclear Power Plant, which supplied 25% of electricity demand, will lead to more coal-fired power production. All these effects are very much in flux and it is too early to quantify at this stage.

The impact of this war extends beyond the borders of Ukraine. Supplies of natural gas from Russia to Europe through pipelines have been interrupted or significantly reduced, forcing Europe to look for alternative sources of energy supply. For example, the life-time of some nuclear power plants has been extended in Belgium and Germany, dormant coal-fired power plants have been reactivated and Liquefied Natural Gas (LNG) supplies have been increased and will increase in the coming years. In August, it was reported that Russia was flaring substantial amounts of natural gas close to the border with Finland as it was not able or willing to supply it to Europe. Similarly to the situation in Ukraine, these effects are very much in flux so far and it will only be possible to have them quantified after winter.

GHG emissions are described for each of the fours sectors in the chapters below.

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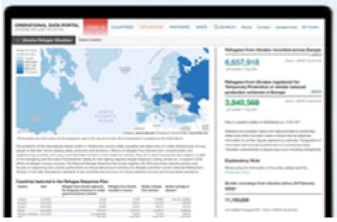
1. https://ecozagroza.gov.ua/en
2. Ukraine conflict environmental briefing: Industry https://ceobs.org/ukraine-conflict-environmental-briefing-industry/
3. https://en.ecoaction.org.ua/warmap.html
4. Military and conflict-related emissions: Kyoto to Glasgow and Beyond https://www.perspectives.cc/public/fileadmin/user_upload/military-emissions_final.pdf
5. A framework for military greenhouse gas emissions reporting https://ceobs.org/report-a-framework-for-military-greenhouse-gas-emissions-reporting/
6. The World Climate and Security Report 2022: Decarbonised Defence - Combating Climate Change and Increasing Operational Effectiveness with Clean Military Power, The Need for Clean Military Power in the Age of Climate Change. https://www.clingendael.org/publication/world-climate-and-security report-2022

2. REFUGEES AND IDPs

Immediately after the invasion on 24 February 2022, many Ukrainians decided to leave their homes. The majority of the people fled westwards staying in Ukraine as Internally Displaced Persons (IDPs) or went abroad to other European countries or even further.

7,710,924
refugees from Ukraine recorded across Europe



4,386,102
refugees from Ukraine registered for Temporary Protection or similar national protection schemes in Europe

More details: Operational Data Portal
Ukraine Refugee Situation

6,243,000
estimated number of IDPs in Ukraine
Source: Internal Displacement Report

Table 1: Key figures on refugees and IDPs[7]

In order to assess GHG emissions from refugees flying abroad and internally displaced persons (IDPs), we have considered three factors:

A) The number of people travelled; their departures and destinations
B) Transport modes
C) GHG emissions per person kilometre for each of those transport modes

Some of the refugees and IDPs came back after the Russian forces had to retreat or ceased posing an immediate threat to the population. It was estimated that approximately 40% of the refugees and IDPs went back to their homes.

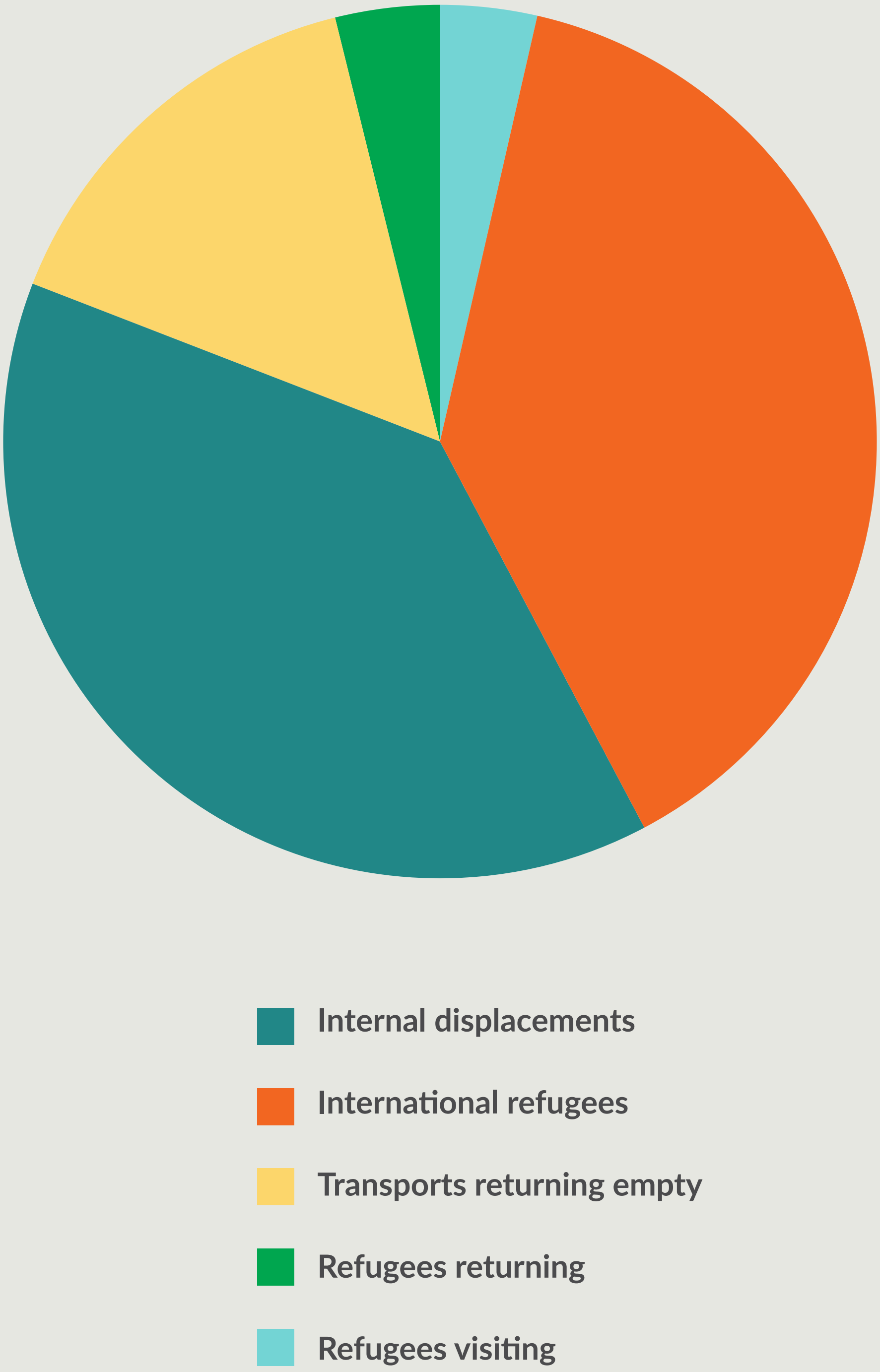
Please see the Annex for more detail regarding the calculation methodology.

	Emissions, th. tCO_2e	Emissions, %
Internal displacements	50	3.6
International refugees	539	38.6
Transports returning empty	539	38.6
Refugees returning	215	15.4
Refugees visiting	54	3.7
TOTAL	**1,397**	**100.0**

Table 2. Overview of GHG emissions from refugees and IDPs

https://data.unhcr.org/en/situations/ukraine, accessed 22 October 2022

Distribution of GHG emissions from refugees and IDPs



3. WARFARE

Fossil fuels

Fossil fuels are an essential component of military operations as they are used by tanks and armoured vehicles, aircrafts, other military vehicles, as well as by logistics vehicles carrying munitions, soldiers, foods and other general cargoes. Fuel is used during the mobilisation of forces, operational movements, relocations, and even stand-by time. For instance, old tanks and armoured fighting vehicle (AFV's) do not have auxiliary power units to run for recharging their batteries and main engines have to run periodically to recharge the batteries. Apart from military vehicles and trucks, fuel is also used by civilian vehicles involved in war-related activities—emergency services, medical vehicles, movements related to evacuation, rebuilding supply chains, the use of tractors to recover abandoned and damaged vehicles, etc. Fuel storage facilities are also often targeted by missile or drone attacks to undermine the ability to sustain military operations.

Consuming large quantities of fuel leads to significant greenhouse gases emissions and climate change impacts related to the war. The quantification of fossil fuel consumption is very complicated though due to limited data availability and high uncertainty about the level of such impacts. A bottom-up approach to quantification requires numerous data and assumptions about the number of vehicles involved in military operations and logistics, operating specifications of various types of vehicles, transportation distance and distance during operational movement of troops, supply chain structure, etc. Such military-related data are rarely available in peace time and almost impossible to obtain during the war. A top-down approach could rely on high level estimates of fuel consumption by the Armed Forces and, though being also associated with limited data availability and high uncertainty, could provide an indication of the level of fuel consumption.

SUPPLIES OF GASOLINE, DIESEL & JET FUELS

to the Russian Defence Ministry's units in six regions bordering Ukraine & the temporary occupied Donetsk & Luhansk Regions

According to Bloomberg's calculations based on an analysis of railway data

8. Calculated based on the data reported by Bloomberg: Russia Sends More Fuel to Army In Ukraine Amid Mobilisation, https://www.bloomberg.com/news/articles/2022-10-12/russia-sends-more-fuel-to-army-in-ukraine-amid-mobilization

Therefore, additional fuel consumption by this supply route alone could be estimated at approximately **1 million tonnes**. Actual fuel consumption is likely to be significantly higher since additional supply routes used during the seven months of the Russian invasion included supplies from Belarus to the Northern Ukraine and supplies from temporarily occupied Crimea to the Southern Ukraine. Total fuel consumption could reach up to at least **1.5 million tonnes**.

In the national GHG emission reports under the UNFCCC, military related emissions are included in category 1.A.5 OTHER (Not elsewhere specified) of the common reporting framework. This category includes all remaining emissions from non-specified fuel combustion, including emissions from military fuel use (1.A.5.a – stationary combustion, 1.A.5.b – mobile combustion).

According to the most recent data available for Ukraine for the year 2020

CO^2

448.03

kilotonnes

1.A.5 OTHER

(all from the mobile combustion of liquid fuel – 6,159.43 TJ of fuel)[9]

=

140

kilotonnes

FUEL

Though this category could include additional emission sources, this is the most reliable data source to assess the scale of military-related emissions in Ukraine before the Russian invasion.

Since the beginning of the war in February 2022, the consumption of fuel for military purposes in Ukraine has also increased significantly. A conservative assumption is that the consumption has increased at least threefold, corresponding to the annual consumption of 420 kilotonnes of fuel or 315 kilotonnes of fuel for the nine months of 2022. Combined with the consumption of fuel by various civilian vehicles supporting military activities (e.g. thousands of volunteers transporting vehicles and other supplies to the frontlines), the estimated fuel consumption could reach up to 0.5 million tonnes of fuel for the nine months of 2022.

Russia's significantly higher consumption of fuel (1.5 million tonnes compared to 0.5 million tonnes based on the assumptions made) is explained by the consumption

9. Ukraine. 2022 National Inventory Report (NIR), https://unfccc.int/documents/476868

for the mobilisation of forces and movements during the invasion, dominant positions of Ukraine's interior defence lines and the Ukrainian Armed Forces' reliance on lighter equipment and vehicles, and longer supply-chain distances for the attacking country.

Total fuel consumption is estimated at 2 million tonnes and total emissions are estimated at 6.37 million tonnes CO_2e.

Some additional components of the overall emissions from fuel consumption were also assessed using the bottom up approach:

- **1,035,509 tCO_2e** – emissions from the use of military aviation;
- **136,193 tCO_2e** – the pre-February emissions during preparation for the invasion; these emissions include emissions from the movement of vehicles from their permanent bases to train stations and from the train stations to the temporary bases, emissions from training activities, emissions associated with the supply and maintenance of temporary bases, troops and equipment movements by train, and the relocation of navy ships[10] ;
- **73,525 tCO_2e** – emissions from the Russian troops' movements during the invasion and the first operational movements;
- **18,131 tCO_2** – emissions from the transportation of munitions (please see below).

GHG emissions from the use of munitions

Artillery weapons in both 152 mm (used by Russia and Ukraine) and 155 mm calibres (used by Ukraine) can deliver a projectile of approximately 40 kg to ranges of 17 to 40 km and are used during the war on a massive scale.
Significant GHG emissions are caused by the manufacture, transportation and use of artillery munitions. In particular, GHG emissions occur during the following operations:

- manufacture of raw materials used for the production of munitions;
- transportation of munitions to the battle field;
- combustion of propellant during the firing of munitions;
- warhead detonation at the point of impact.

Artillery munitions used during the war are likely to be refurbished to replenish the stocks. Therefore, the emissions associated with the manufacture of munitions are taken into account for the purposes of assessment of climate impacts of the war.

The estimated number of artillery rounds shelled varies significantly within a wide range of 5,000 to 60,000 rounds per day. It also varies over time depending on the intensity of shelling at different sections of the frontline.

10. According to the assessment by KT-Energy LLC; please see for more detail the presentation titled "GHG emissions of Russian military preparations across borders of Ukraine" prepared by Kateryna Levyk and Kyryl Tomliak, which is available at https://kt-energy.com.ua/en/projects/ghg-emissions-of-russian-military-preparations-across-borders-of-ukraine/

The assumed level of artillery use is 0.9 million of artillery rounds per month (30,000 rounds per day) or 5.4 million per six months of the war for Russia and additionally 0.2 million rounds per month (7,500 rounds per day) or 1.35 million per six months of the war for Ukraine. The estimates could be considered conservative under the conditions of limited information available and high levels of uncertainty[11]. Moreover, there was also large quantity of munitions destroyed due to strikes at munitions depots and storage sites, which caused the detonation and explosion of munitions. In particular, there were more than 400 HIMARS strikes with more than 50 Russian warehouses destroyed. According to the assumed level of artillery use, the number of rounds actually used could be higher but includes 122 mm rounds, which are approximately twice lighter and therefore have a lower global warming impact.

The assumed weight of an artillery round together with its container is 80 kg. The total weight of artillery rounds that need to be transported to the battle field is 432,000 tonnes for Russia and 108,000 tonnes for Ukraine (540,000 tonnes in total).

Although Russian logistics is reliant on railway infrastructure, the last kilometres can only be supplied with trucks. The assumptions used in the assessment of emissions from munitions transportation are as follows:

- assumed transportation distance for artillery rounds is 100 km (a 200 km round trip);
- the amount of artillery rounds transported by one truck is approximately 6.4 tonnes (80 boxes per truck);
- assumed fuel consumption is 40 litres of diesel fuel per 100 km.

The emissions from the use of artillery munitions include the following:

- 918,000 tonnes CO_2e from the manufacture of munitions (steel casing and explosives);
- 19,778 tonnes CO_2e due to emissions at the point of firing and at the point of impact;
- 1,283 tonnes CO_2e from detonation at the point of impact; and
- 18,131 tonnes CO_2e from the transportation of munitions.

Total emissions due to munitions use would be approximately 1 million tonnes CO_2e.

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11. According to the Royal United Services Institute for Defence and Security Studies report, Russia was firing approximately 20,000 152-mm artillery shells per day compared with Ukraine's 6,000, with an even greater proportional disparity in multiple rocket launchers and missiles fired, Source: Ukraine at War Paving the Road from Survival to Victory, https://static.rusi.org/special-report-202207-ukraine-final-web_0.pdf. According to other analysts, the firing rate was 1-1.5 million rounds per month (30,000 – 50,000 per day) from May 2022 onwards, https://twitter.com/Volodymyr_D_/status/1560350883929620481. Representatives of the MoD of Ukraine reported the use of 40,000-60,000 rounds per day by Russia during the period of intense fighting, https://telegraf.com.ua/ukr/ukraina/2022-09-06/5715744-godovoe-proizvodstvo-snaryadov-raskhoduetsya-za-mesyats-okkupanty-istoshchayut-svoi-arsenaly-pomozhet-li-kndr. As of 15 September, the US alone has committed to supply 126 155 mm Howitzers and up to 806,000 155mm artillery rounds and 2,000 precision-guided 155 mm artillery rounds, https://media.defense.gov/2022/Sep/16/2003078831/-1/-1/1/UKRAINE%20FACT%20SHEET%20%E2%80%93%20SEP.%2015.PDF . There were estimates that during six months of the war Russia alone could have used seven million of artillery rounds excluding losses due to destruction of warehouses, https://theins.ru/politika/254514

Since the estimates cover artillery rounds only, it is assumed that at least additional 30% of the emissions estimated could be associated with the use of other explosives and munitions, such as small calibre rounds, medium and heavy mortar projectiles, land mines, hand and drone grenades, munitions for tank guns, artillery rockets and air missiles, etc (including various munitions exploded during the destruction of armour and vehicles).

Overall emissions associated with the use of munitions and explosives would be at least 1.2 million tonnes CO_2e.

Total Warfare Emissions

	th. tCO_2e	%
Emissions from fuel consumption by the Russian Army	4,779	
Emissions from fuel consumption by the Ukrainian Army	1,593	
Emissions from Air Force	1,036	
Pre-invasion force accumulation	136	
Invasion and Russian troops' operational movement	74	
Delivery of artillery munitions from temporary warehouses to the battlefield	18	
Subtotal fuel consumption	**7,636**	**86,2**
Emissions from the use of artillery munitions	20	
Emissions from the manufacture of artillery munitions	918,000	
Emissions from the use of other munitions	5,933	
Emissions from the manufacture of other munitions	275	
Subtotal ammunitions	**1,219**	**13,8**
TOTAL	**8,855**	**100**

Table 3. Total GHG emissions from the warfare

Distribution of GHG emissions for Warfare

4. FIRES

Due to intense fighting during the war, the number of fires caused by shelling, bombing and mine-laying operations increased within a large part of Ukraine's territory. As access to burned areas is limited, especially in the occupied territories and the war zone, the most accurate and reliable tool to monitor fires is satellite-based remote monitoring.

The number of fire incidents, fire start and end time, the details of fire boundaries, the area and land category of each fire and other data used for the purposes of assessment of fires was obtained from open source fire information systems—the US-based Fire Information for Resource Management System[12] (FIRMS) and the European Forest Fire Information System[13] (EFFIS). This assessment covers a seven-month period from 24 February 2022 to 24 September 2022 and involves a comparison with the same period in 2021. It was limited to fires with an area of more than 1 ha.

To assess the impact of military operations on fires, the territory of Ukraine was divided into three zones (Please see Figure 1).

1. Zone 1 covers 66.5% of the territory of Ukraine, where no ground warfare were conducted;
2. Zone 2 — zone of active warfare (ground warfare were conducted for more than 24 hours, the frontlines from OSINT source[14]), covering 19.5% of the territory of Ukraine. To form Zone 2, a 12-mile zone on both sides of the (moving) front lines was applied;
3. Zone 3 — temporarily occupied territories (14.0% of the territory of Ukraine), where ground warfare were conducted for not more than 24 hours or did not take place at all.

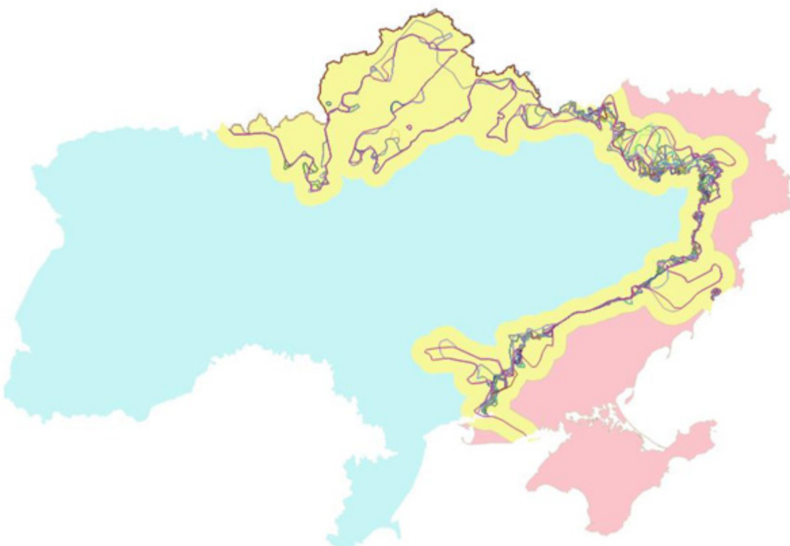


Figure 1. Frontlines and Zone 1 (blue), Zone 2 (yellow) and Zone 3 (red)

12. https://firms.modaps.eosdis.nasa.gov
13. https://effis.jrc.ec.europa.eu
14. https://liveuamap.com/uk

The two maps below reflect fires for the seven months (214 days) of the war in Ukraine against the background of the above zones, according to the data from the satellite system EFFIS for the periods 24 February 2021 to 24 September 2021 and 24 February 2022 to 24 September 2022.

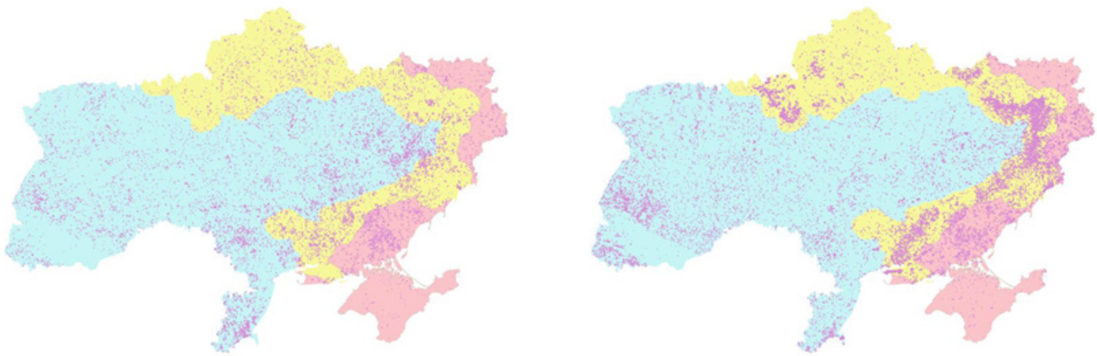


Figure 2. Fires according to EFFIS

Distribution of fires	Number of fires	Total fire area, ha	Area of forest fires, ha	Area of farm fires, ha	Area of other natural component fires, ha	Area of fires in built-up areas, ha	Area of other fires, ha
Zone 1	2,066	122,693	7,618	94,656	19,342	471	604
Zone 2	3,724	315,046	47,443	234,002	29,302	2,747	1,546
Zone 3	425	48,423	2,164	43,057	2,965	146	92
Total	6,215	486,162	57,225	371,715	51,609	3,364	2,242

Table 4. Fires in Ukraine for 214 days of the war (with an area of more than 1 ha)

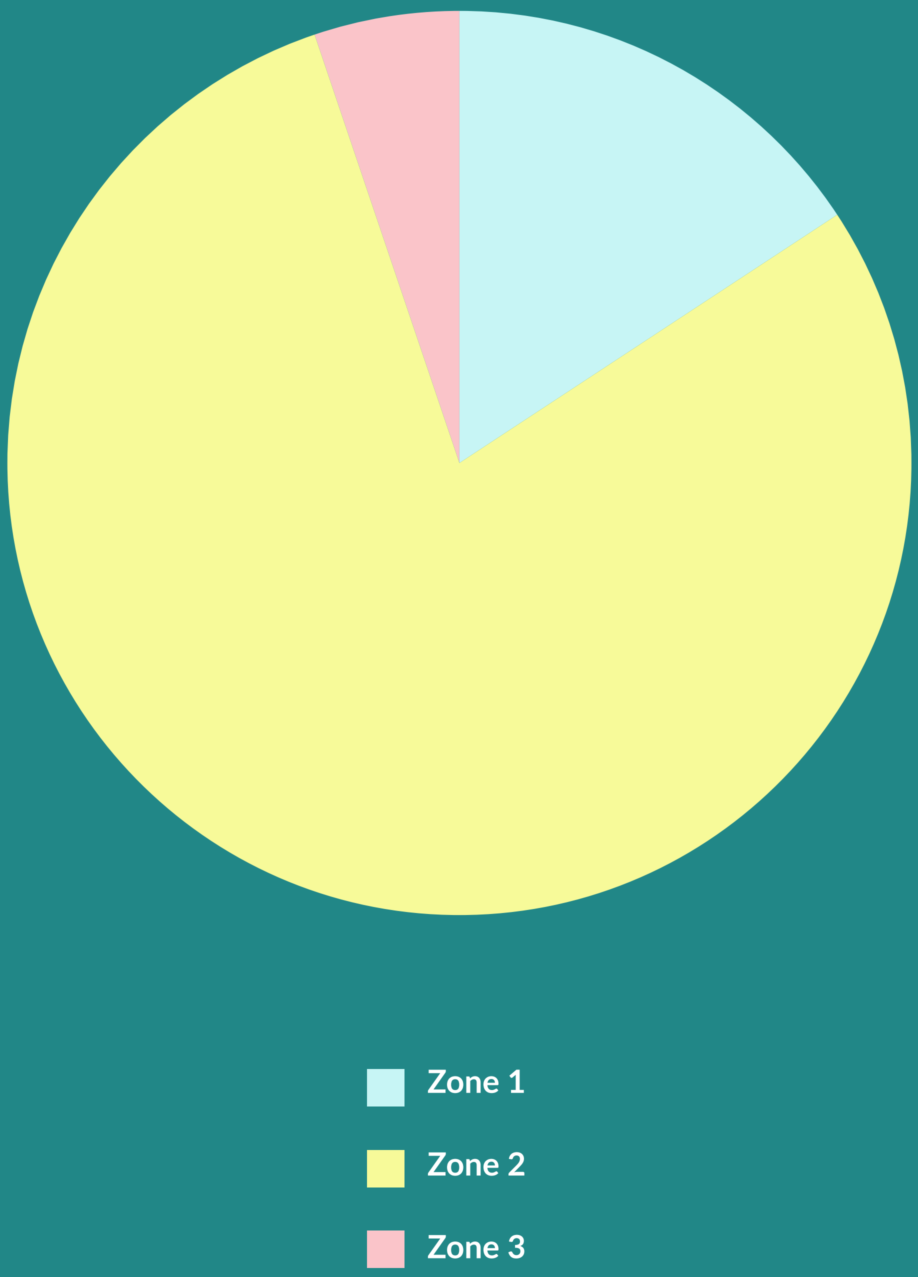
It is quite obvious from the above that the warfare led to a significant increase in both the number and area of fires.

Table 5 below shows the results of the calculations of greenhouse gas emissions. Please see the Annex for more detail regarding the calculation methodology.

Distribution of fires	Emissions from forest fires	Emissions from farm fires	Emissions from natural component fires	Emissions from fires in built-up areas	Total emissions
Zone 1	2,202	1,068	137	373	3,780
Zone 2	13,711	2,640	208	2,177	18,736
Zone 3	625	486	21	116	1,248
Ukraine	**16,538**	**4,194**	**366**	**2,666**	**23,764**

Table 5. Greenhouse gas emissions for 214 days of the war, thousand tCO_2e

Distribution
from GHG emissions from fires
in the different zones



Thus, for the seven months of the war in Ukraine:

- the total number of fires with an area of more than 1 ha increased 122 times compared to the same period in 2021, while their total area increased 38 times;
- 79% of greenhouse gas emissions from the war-related fires account for 20% of the territory of Ukraine — Zone 2, where ground warfare have been or are being conducted;
- the density of greenhouse gas emissions from fires in Zone 2 is 17 times higher than in Zone 1.

5. CIVILIAN INFRASTRUCTURE

Destroyed or damaged civilian infrastructure is an important component of the climate damage caused by Russia's invasion of Ukraine. Some of the repair works will happen with the war still ongoing, but the majority of the rebuilding or reconstructing will happen after the end of the warfare. These rehabilitation works will demand a significant amount of construction materials, the transportation of these materials to construction sites and the construction activities will require energy. All in all, reconstructing Ukraine will cause significant amount of GHG emissions.

Ukrainian authorities started collecting and assessing, in a systematic way, information about damaged or destroyed facilities soon after the beginning of the war. The information is broken down into different sectors like residential buildings, health care or infrastructure. This information, mainly aggregated from different Ukrainian Ministries, has been processed by the Kyiv School of Economics. Their report *Assessment of damages in Ukraine due to Russia's military aggression as of 1 September 2022*[15] is taken as a basis for this assessment. The overall damage assessment has been carried out in accordance with the methodology of the World Bank and in close cooperation with an expert team of the World Bank. Please see the report for more detail about the approach and methodology and an overview of destroyed and damaged facilities in various categories.

As an example, below you will find a list of the residential sector units (housing stock) that were available and then destroyed or damaged for the whole country. Similar lists are provided for each sector.

15. Assessment of damages in Ukraine due to Russia's military aggression as of 1 September 2022 https://kse.ua/wp-content/uploads/2022/10/ENG-Sep22_Working_Sep1_Damages-Report.docx.pdf

	UNIT	STOCK UNITS	DAMAGED UNITS
DESTROYED			
Apartment buildings	pcs.	178,921	6,153
Private houses	pcs.	8,984,976	65,847
Dormitories	pcs.	7,114	85
DAMAGED			
Apartment buildings	pcs.	178 921	9,490
Private houses	pcs.	8,984,976	54,069
Dormitories	pcs.	7 114	155

Table 6. Destroyed and damaged units in the residential sector

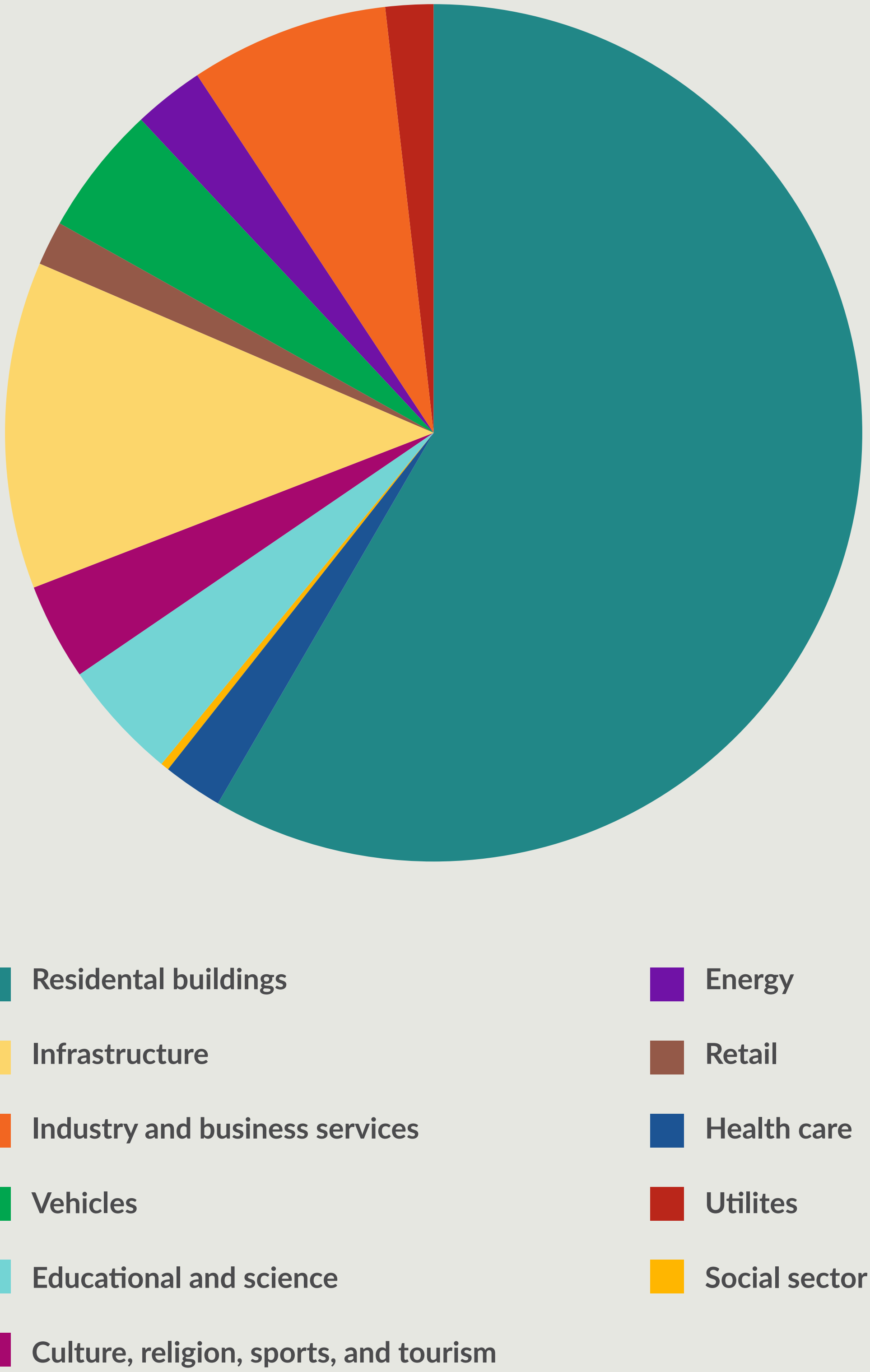
For the purposes of assessment of emissions from the reconstruction, it is assumed that the housing destroyed or damaged will be fully reconstructed. Obviously, the reconstruction of Ukraine will take into account changed circumstances and the actual needs of the country. For example, not all of the destroyed apartments will probably be renovated in the residential sector, given the shrinking of Ukraine's population. On the other hand, as Soviet-built apartments are rather small compared to modern standards, new apartments will probably be larger (rebound effect).

To determine GHG emissions from the reconstruction of the civilian infrastructure, the embodied carbon approach is used. Under this approach, all emissions, both direct and indirect, are estimated over the whole life cycle of a facility excluding, however, operational emissions. This methodological approach is described in more detail in the Annex. The assumption was made that fully destroyed facilities will be completely renovated, and 100% of the embodied carbon factor is therefore applied. A 33% factor was assumed for damaged facilities.

ITEM	Emissions, th. tCO_2e	Emissions, %
Residential buildings	28,432	58,4
Social sector	1,055	2,2
Health care	96	0,2
Educational and science	2,232	4,6
Culture, religion, sports, and tourism	1,818	3,7
Infrastructure	6,006	12,3
Retail	814	1,7
Vehicles	2,448	5,0
Energy	1,314	2,7
Industry and business services	3,615	7,4
Utilities	840	1,7
TOTAL	**48,670**	**100**

Table 7. Overview of reconstruction emissions in the civilian sector for various categories

Distribution of GHG emissions for the reconstruction of the civilian infrastructure



As one can see, the residential sector accounts for the majority of the emissions (almost 60%). If we add to this number the emissions from other sectors that consist mainly of buildings (health care, education, etc), the share will increase to 70%. The infrastructure comes second with 12%. The shares of the energy and utilities sectors are a relatively low but, following Russia's recent attacks against both sectors, they are likely to increase in a future update.

The current methodology (please see the Annex for more detail) is based on current business practice used in Central and Eastern Europe. The production of cement and bricks is an important source of GHG emissions in the construction sector. Low-carbon construction materials have become available and became increasingly popular. Examples are bio-based materials like timber, cross-laminated timber (CLT) or flax. These construction materials act as carbon sinks (biogenic storage) as the trees or plants absorbed carbon dioxide when they were growing. Ukraine will have the opportunity to apply some of these low-carbon technologies through the Built-Back-Better Framework although, given the scale of destruction, a large share of renovation works will still use traditional construction methods.

6. CONCLUSIONS

At the moment of writing, the full-scale invasion of Ukraine by the Russian Federation is entering its ninth month. Residential blocks and various industries have been damaged or completely destroyed and Russia continues to strike civilian facilities. In October, the energy and water infrastructure sectors were especially targeted, making living conditions in Ukraine even more difficult with the winter approach (these damages have not yet been taken into account in this study).

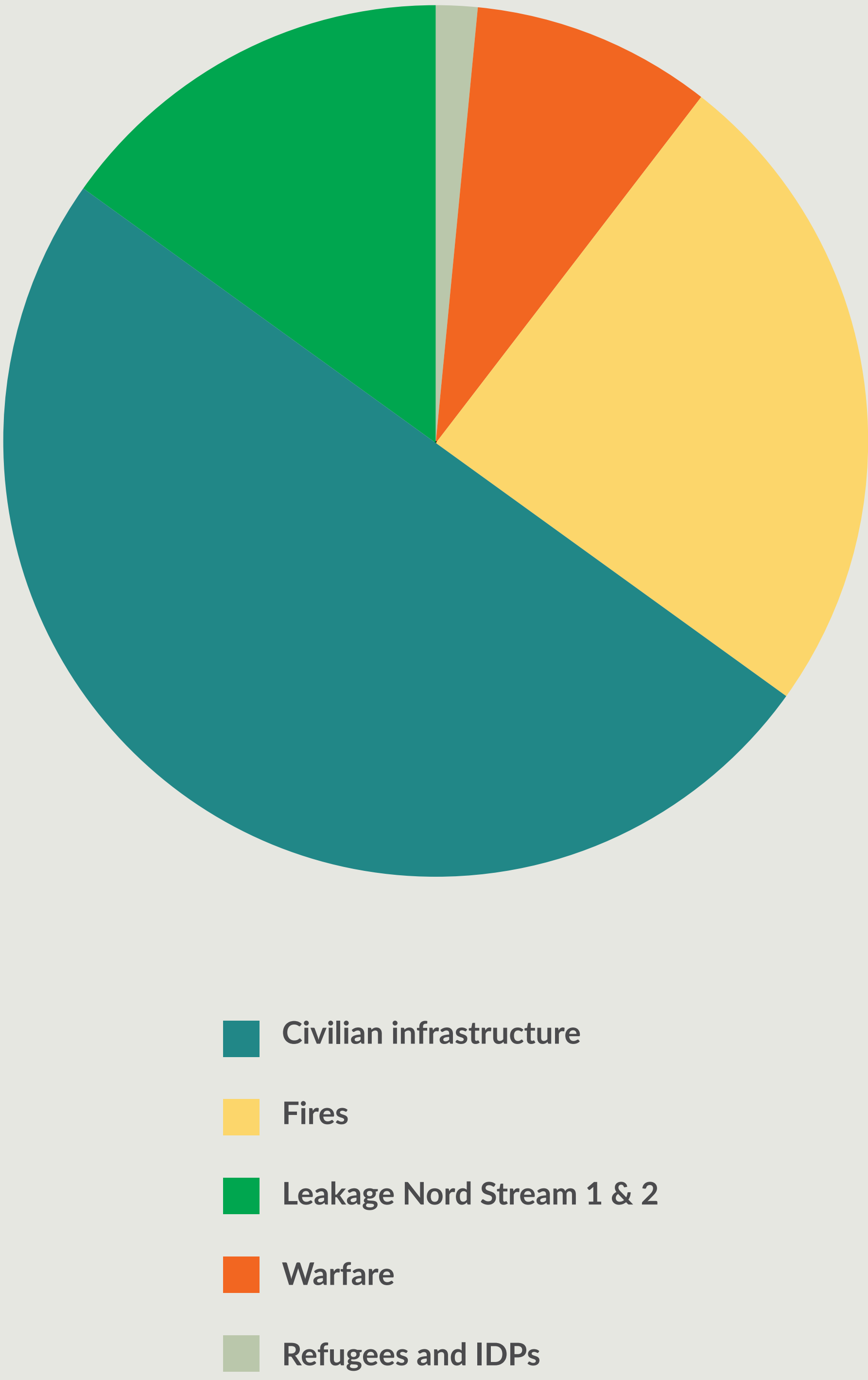
GHG emissions from the Russian invasion of Ukraine are significant and include both emissions from preparation for the war (e.g., the relocation of troops, training activities, staging before the invasion, the manufacture of munitions and equipment, etc.) and the warfare (e.g., emissions from fuel combustion by armour and vehicles, logistics trucks and aircraft, emissions from the firing of munitions and explosions, etc.) and post-war emissions (e.g. emissions associated with the reconstruction activities).

In the table below, an overview of the GHG emissions of the four sectors, including the leakage from the Nord Stream 1 & 2 pipelines, is provided.

SECTOR	Emissions, th. tCO_2e	Emissions, %
Movement of refugees	1,397	1.4
Warfare	8,855	9.1
Fires	23,764	24.4
Reconstruction of civilian infrastructure	48,670	50.0
Leakage from the Nord Stream 1 & 2 pipelines	14,600	15.0
TOTAL	**97,286**	**100.0**

Table 8. Overview of GHG emissions from the various sectors

Distribution of GHG emissions



As is seen from the above, the reconstruction of civilian infrastructure accounts for the largest share of emissions with 50% of the total emissions. Fires, in both forest and built-up areas, add up to a quarter. Almost 10% is emitted by the warfare. Interestingly, the leakage from the Nord Stream 1 & 2 pipelines released large amounts of natural gas (consisting of methane, a potent greenhouse gas), leading to a significant GHG emission, which is larger than the current assessments of emissions from the warfare.

After the seven months of the full-fledged war, the total emissions already add up to the total GHG emissions over the same period in a country like the Netherlands.

Data about the emissions from the warfare is very limited due to the secret nature of information on military operations, equipment and materials used and other factors impacting the volumes of emissions. Therefore, only some major sources of GHG emissions could be identified and quantified based on information from various open sources. The actual emission levels caused by the Russian aggression are likely to be significantly higher. Additional studies would be required to quantify the impact of both emissions that have already occurred (to refine the estimates made and to factor additional emissions sources) and emissions associated with the post-war reconstruction in Ukraine. Higher transparency of military-related information about climate impact in peace and war time should be promoted to gain a better understanding of potential emission sources and factors defining the scale of the climate impact.

The key sources of GHG emissions covered by this interim assessment include emissions associated with the reconstruction of civilian infrastructure, natural ecosystem and farm fires, leakage from the Nord Stream pipelines, fuel combustion during the warfare, and the movement of refugees. Other sources of emissions, which are not covered by this assessment and would further increase the impact, include emissions from the destruction of fuel storage and production facilities (e.g., oil storage sites and the long-term flaring of natural gas wells in the Black Sea), emissions from the intentional flaring of natural gas due to blocked supplies to Europe, and emissions associated with the manufacture and supply of military equipment.

The Russian invasion of Ukraine will have a long-lasting impact on climate change and GHG emissions. In particular, it is likely that the redirection of energy flows and the rethinking of the role of natural gas as a bridge fuel will occur in the short- or mid-term. Impact of the war in Ukraine may also result in policy changes in many countries throughout Europe and the world. In addition, the redirection of investment flows in Ukraine is very likely to occur after the war. For instance, a significant share of financial resources that were estimated to be required for the implementation of Ukraine's Nationally Determined Contribution (NDC) is likely to be redirected to the post-war reconstruction. Such long-term impacts bring significant risks of further adverse effects on the climate and growth of GHG emissions (e.g. due to a higher reliance on coal as a substitute for natural gas, slowing down the introduction of new climate policies, reliance on carbon-intensive infrastructure, etc). Efforts should be made to reduce the likelihood of such risks occurring, to create opportunities for green recovery of Ukraine and to accelerate the transition to a green sustainable economy in the EU and worldwide.

Green recovery opportunities should be investigated and become materialised as part of international efforts to support the reconstruction of Ukraine after the war. Such opportunities could include reliance on low-carbon materials for the reconstruction of damaged and destroyed civilian infrastructure, support of distributed renewable energy generation and energy storage, and the use of climate finance instruments to attract additional investments.

Annex 1.
Methodological components

REFUGEES

A. The number of people travelled; their departures and destinations

Displacements can be broken down into two main groups moving from, and within, Ukraine. Data on the refugees that left Ukraine for other countries was gathered and published by the UNHCR[16].

Data on internally displaced persons was gathered by the government of Ukraine and communicated to the Center for Environmental Initiatives Ecoaction.

B. Transport modes

The use of transport modes was assessed subject to standardised assumptions. The assumption was made that a combination of not more than two of the below transport modes was used for international travels to each destination country:

- Petrol car, 4 passengers
- National railways
- Bus
- Domestic flight (= short-haul flight, narrow-body aircraft)
- Long-haul flight, economy (wide–body aircraft)

The choice of a transport mode was determined by a distance to Ukraine and the availability of the relevant transport mode. We have assumed that, in many cases, the first half of the journey was done by petrol car. For the second half of the journey, we have assumed as follows:

- For countries neighbouring Ukraine: petrol car, 4 passengers
- For countries in North-West Europe: national railways
- For countries in South Europe, North Europe, the Baltic, the Caucasus and islands states: domestic flight
- For the US, Canada and Australia: long-haul flight, entire journey
- For Russia and Belarus: bus, entire journey

We have not differentiated between various types of cars, fuel or occupancies.

C. CO_2 emissions per person kilometre for each of those transport modes

To assess CO_2 emissions per person kilometre, we have used the 2019 data published by the UK Department for Business, Energy & Industrial Strategy: Greenhouse gas reporting: conversion factors 2019[17]. These factors may vary slightly depending on the country.

16. https://data.unhcr.org/en/situations/ukraine
17. https://ourworldindata.org/grapher/co2-transport-mode

FUNCTIONAL UNIT – ARTILLERY ROUND	Total 152/155 mm munitions weight for various types of projectiles ranges from 42.6 to 46.9 kg and explosive fill weight ranges from 5.85 to 11.30 kg (the weight of propellant is not included).[18] Artillery munitions consist of a warhead, propellant charge, and fuse. Generic 155 mm ammunition, for which life cycle assessment of environmental impact was reported, has the overall weight of 77 kg with container, including: • warhead – 44.5 kg, including 35.5 kg of steel casing and 8.5 kg of composition B explosive; • propellant charge – 9.67 kg, including 9.5 kg of triple base powder; • fuse – 1 kg; • steel container – 22 kg (reusable). There is no information on carbon footprint of other types of artillery munitions (152 mm and 122 mm rounds used by Russia) and the assessment is therefore based on the data for generic 155 mm munitions.
EMISSIONS FROM ENERGETIC MATERIAL MANUFACTURING	Global warming impact of energetic materials used in explosives varies from 5.06 to 42.4 kg CO_2e per kg of material with most estimates ranging from 5.06 to 12.9 kg CO_2e per kg of material (i.e. 5.06 kg CO_2e for TNT, 6.53 kg CO_2e for nitrocellulose, 8.59 kg CO_2e for RDX).[19] For composition B explosive, which is typically used in artillery projectiles and other munitions (standard composition includes 59.5% RDX and 39.4% TNT phlegmatised with 1% paraffin wax), the weighted average global warming impact would be 7.1 kg CO_2e per kg of material.
EMISSIONS FROM ARTILLERY ROUND MANUFACTURING	Thus, the carbon footprint of materials used for the manufacturing of 155 mm projectiles would be 136 kg CO_2e and would consist of: • 60.35 kg CO_2e for the manufacture of composition B explosive; • 75.62 for the manufacture of steel casing.[20]
EMISSIONS AT THE POINT OF FIRING	Carbon dioxide emissions at the point of firing (associated with the generic 155 mm ammunition) are 2.74 kg CO_2e.
EMISSIONS DURING DETONATION	Carbon dioxide emissions during detonation (associated with the generic 155 mm ammunition) are 0.19 kg CO_2e per 155 mm ammunition round.

Table 9. Specific emission factors related to ammunitions

16. https://data.unhcr.org/en/situations/ukraine
17. https://ourworldindata.org/grapher/co2-transport-mode
18. Explosive weapon effects – final report, GICHD, Geneva, February 2017, http://characterisationexplosiveweapons.org/studies/annex-b-152-155-artillery-version/
19. Carlos Miguel Baptista Ferreira, Extended environmental Life-cycle assessment of munitions: Addressing chemical toxicity hazard on human health, https://estudogeral.sib.uc.pt/bitstream/10316/42309/4/Extended%20environmental%20life-cycle%20assessment%20of%20munitions%3A%20adressing%20chemical%20toxicity%20hazard%20on%20human%20health.pdf
20. Assuming emission factor of 2.13 kg CO2e per kg from ICE Database (cradle to gate, A1-A3 modules), embodied carbon value for Steel seamless tube, World average. https://circularecology.com/embodied-carbon-footprint-database.html

FIRES

Zone 1 fires analysis.
We have conducted a time-spatial analysis of the relationship between air raid alerts in the Ukrainian regions (Statistics on air raid alerts in Ukraine[21]) and 2,066 fire sites recorded by the EFFIS service based on Sentinel satellite data for 214 days of the war in Zone 1.

In fact, air raid alerts sounded 15,324 times over this period. But since 496 alerts were issued on one calendar day and cancelled on the next day, it should therefore be considered, for the purposes of the study of the relationship, that air raid alert sounded 10,120 times (3,537 pairs: calendar day*region) in 151 cities and 5,699 times in other populated areas (2,953 pairs: calendar day*separate populated area) in 24 regions.

Figure 3. Fires (with an area exceeding 1 ha) in Zone 1 in the Regions and areas covered by air raid alerts (with a 6 km buffer).

Nº	INDICATOR	INDICATOR VALUE	PERCENTAGE, %
1	The number of fires with an area exceeding 1 ha and occurring in the territory of the Regions on the same calendar day as the air raid alert was issued for a given Region	1692	81.90
2	The number of fires with an area exceeding 1 ha and occurring in the territory of the Regions on the calendar day following the day when the air raid alert was issued for a given Region	195	9.44
TOTAL		**1887**	**91.34**

Table 10. Time-spatial analysis of the relationship between air raid alerts in Ukraine and fires with an area exceeding 1 ha in Zone 1 for 214 days of the war

21. Statistics on air raid alerts in Ukraine https://air-alarms.in.ua/en

Zone 2 fires analysis.
It is quite obvious from the above that the warfare led to a significant increase in both the number and area of fires in this zone.

Zone 3 fires analysis.
In accordance with the provisions of the Convention with Respect to the Laws and Customs of War on Land (HAGUE, II) (29 July 1899[22]) articles 23,43, 55), the occupying country is responsible for these fires.

To calculate greenhouse gas emissions, relevant ratios from the 2006 Methodological recommendations of the Intergovernmental Panel on Climate Change[23] were used for forest and farm fires and the ratios from the Methodology for calculating fugitive emissions of polluting substances or mixtures of such substances into atmospheric air as a result of emergency situations and/or during martial law period and assessing damage caused, as approved by order No. 175 of the Ministry of the Environment of 13 April 2022, were used for fires in built-up areas.

22. https://avalon.law.yale.edu/19th_century/hague02.asp,
23. https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

CIVILIAN INFRASTRUCTURE

The determination of the Carbon Emission Factor (CEF) for different facilities is an important component of the methodology. Where the sector involved buildings, the average size of each building was first provided by the Kyiv School of Economics (in m^2/unit) and then multiplied by relevant carbon emission factor (in tCO_2e/m^2) to obtain the CEF (tCO_2e/unit).

The embodied carbon approach is used to determine the CEF per m^2. Under this approach, all emissions, both direct and indirect, are estimated over the whole life cycle of a facility, excluding, however, operational emissions (in the case of a building, operational emissions are, for example, heating). For buildings, the life cycle, according to EN-15978, is split as follows:

PRODUCT STAGE	Raw material supply	**A1**
	Transport	**A2**
	Manufacturing	**A3**
CONSTRUCTION PROCESS STAGE	Transport to building site	**A4**
	Installation into building	**A5**
USE STAGE	Use / application	**B1**
	Maintenance	**B2**
	Repair	**B3**
	Replacement	**B4**
	Refurbishment	**B5**
	Operational energy use	**B6**
	Operational water use	**B7**
END-OF-LIFE STAGE	Deconstruction / demolition	**C1**
	Transport	**C2**
	Waste processing	**C3**
	Disposal	**C4**

Table 11. Life Cycle Stages of buildings

To determine embodied carbon, stages A1-A3, A4, B4-B5 and C1-C4 are taken into account. End-of-Life stages C1-C3 will occur first, after which reconstruction stages A1-A4 will happen. To avoid double-counting, operational carbon emissions from use stages B1-B3 and B6-B7 are omitted as they would have happened in existing buildings as well.

To reflect the most recent construction practice used in the region to determine the Embodied Carbon Emission Factor of buildings, a database of One Click LCA[24], a software programme to perform Life Cycle Assessments (LCA) for buildings, was used. This database contains LCAs of recently designed buildings of different building types in various countries. Out of this database, LCAs performed in 16 countries in Central and Eastern Europe in the past three years were selected to calculated an average CEF. Depending on the building type, the average was based on 4 to 100 building designs.

BUILDING TYPE	CEF ($kgCO_2e/m^2$)
Apartment buildings	575
Cultural buildings	474
Educational buildings	643
Hotels and similar buildings	401
Industrial production buildings	475
Office buildings	529
Retail and wholesale buildings	632
Warehouses	415

Table 12. Specific Carbon Emission Factor per building type

The civilian sector covers more than just buildings. For example, in the case of some infrastructural facilities, such as roads, and vehicles the embodied CEF is expressed in tCO_2e/km and $tCO_2e/unit$, respectively. Similar to buildings, operational carbon is excluded as in the case of fuel consumption by vehicles given that operational carbon emissions would have been emitted by damaged or destroyed facilities as well.

24. One Click LCA website: https://www.oneclicklca.com