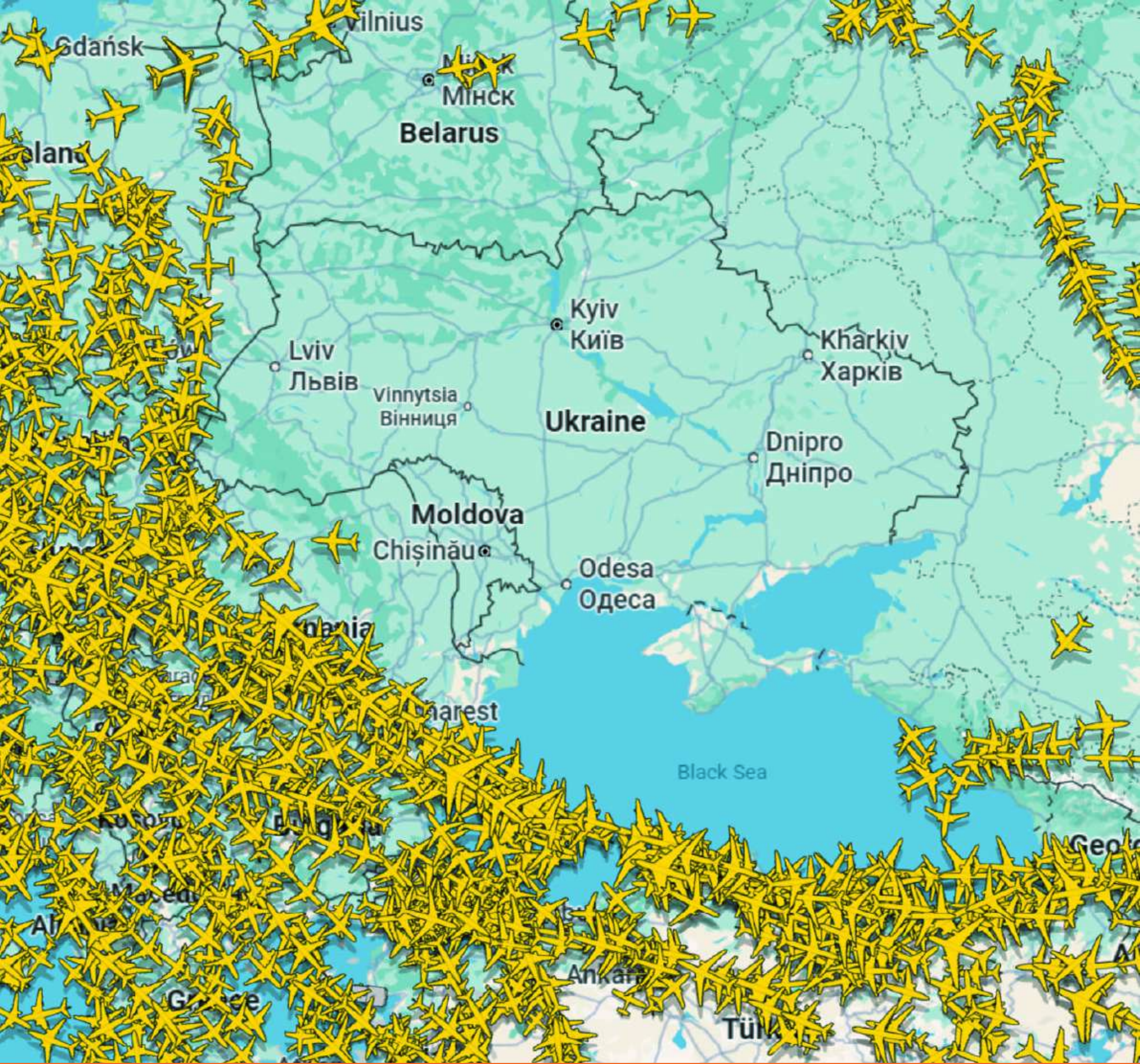

CLIMATE DAMAGE CAUSED BY RUSSIA’S WAR IN UKRAINE

24 February 2022 – 23 February 2025

By the Initiative on GHG Accounting of War

October 2025

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ACKNOWLEDGEMENTS

We would like to thank the following organisations for their contributions and insights:

Ministry of Economy, Environment and Agriculture of Ukraine

National Center for GHG Emission Inventory of Ukraine

Conflict and Environment Observatory

Kyiv School of Economics

One Click LCA

FlightRadar24

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екодія ecoaction.org.ua

FUNDING

This report was made possible with support by the European Climate Foundation (ECF). Proofreading and design was supported by the Swedish Society for Nature Conservation (SSNC).

The European Climate Foundation (ECF) is a philanthropic initiative helping to tackle the climate crisis by fostering the development of a net-zero emissions society at national, European, and global levels. The initiative supports over 700 partner organisations to drive urgent and ambitious policy in support of the objectives of the Paris Agreement, contribute to the public debate on climate action, and help deliver a socially responsible transition to a net-zero economy and sustainable society in Europe and around the world.

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European Climate Foundation

Swedish Society for Nature Conservation

The **Initiative on GHG accounting of war** was founded in March 2022 and is a group of experts in carbon footprinting. The Initiative has prepared five subsequent assessments of the war in Ukraine while also researching other ongoing armed conflicts. Recently, the Initiative has been focussing on the impact of increased military spending on military emissions. The Initiative cooperates with the Ministry of Economy, Environment and Agriculture of Ukraine but does the assessments independently and receives no instructions from the Ministry or other organisations.

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Executive Summary

With Russia's war against Ukraine ongoing, emissions of greenhouse gases (GHG) have continued to grow, as is shown in the figure below. This fifth assessment concludes that the GHG emissions attributable to three years since the full-scale invasion have increased to almost **237 million tCO_2e**. The emissions are the equivalent of the annual emissions of Austria, Hungary, Czech Republic and Slovakia combined. With the Social Cost of Carbon of 185 USD / tCO_2e applied, the climate damage caused by this war amounts to over **43 billion USD**.

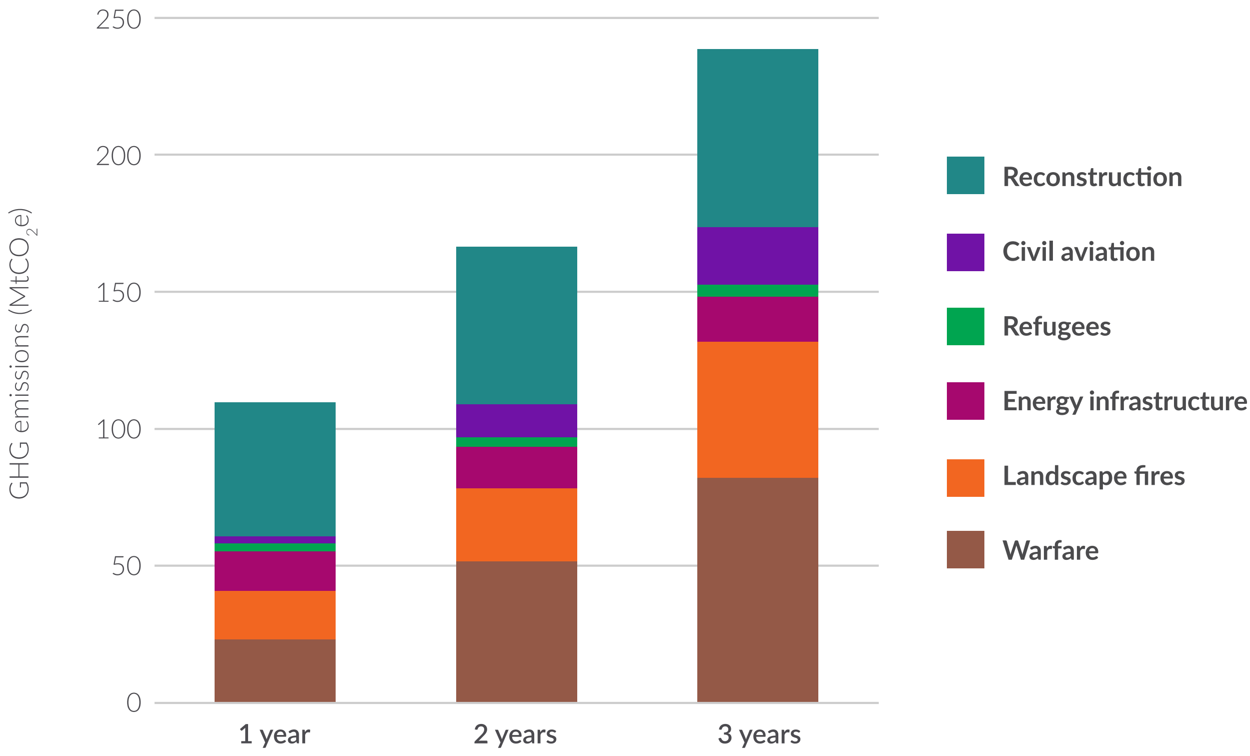

Figure 1: Growth of war emissions

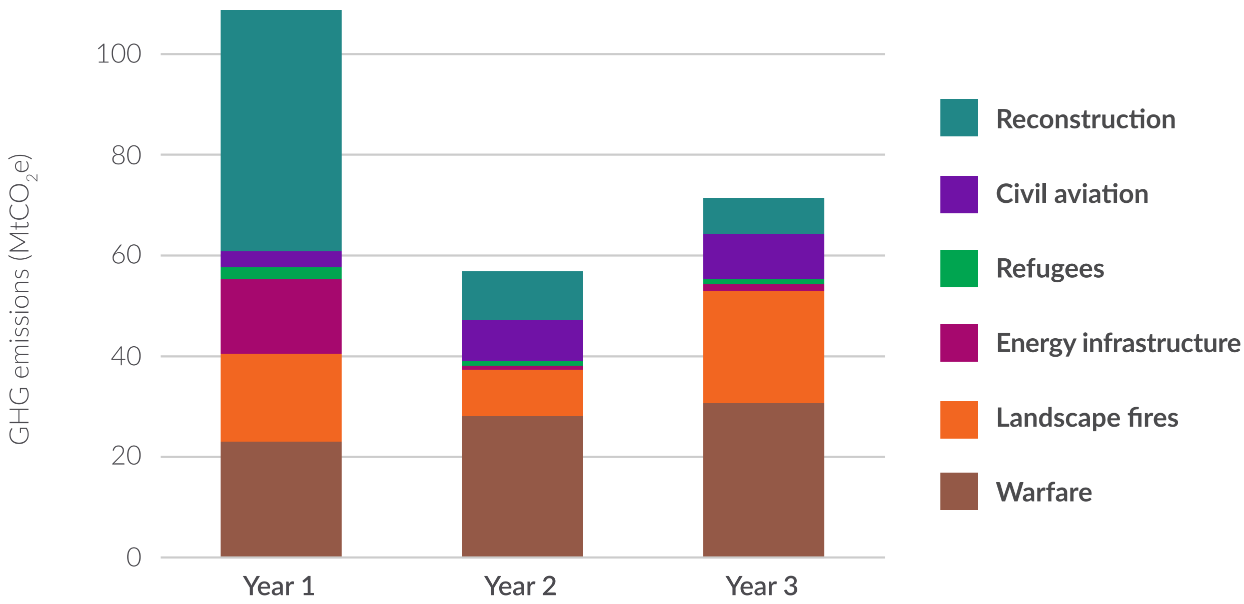

Figure 2: War emissions per 12-month period

The use of drones reduced ammunition use but increased the destruction of military equipment

As hostilities continue unabated, warfare has become the largest source of GHG emissions, adding up to **81.7 million tCO_2e** after three years of war. Fossil fuel used by tanks and fighter jets, large guzzlers of diesel and kerosine, make up the brunt of warfare emissions. The use of drones made ammunition use more effective and hence, less ammunition was involved in the third year into the war. At the same time, drones resulted in more efficient destruction of military equipment with losses and related GHG emissions increased compared to the second year of the war balancing out decreased emissions from ammunition use.

Conflict and climate change combined hit forests hard in 2024

Landscape fires caused by the war escalated dramatically in 2024, with the area of fires being more than 20 times the 2006–2021 average.[1] Emissions from natural landscape fires, including forests, increased, with 22.9 million tCO_2e in 2024 compared to 8.6 million tCO_2e in 2023 and 15.2 million tCO_2e in 2022, resulting in a new total of **46.7 million tCO_2e** or 49.4 million tCO_2e including fires in buildings. As shown in the figure below, the majority of landscape fires occurred at or near the frontlines or at border areas. Climatological analysis showed that the summer of 2024 was much drier than average for Ukraine, likely due to climate change. These dry conditions created an ideal setting for the fires caused by the ongoing hostilities to start as small ones and then expand into larger blazes. As it is not possible for firefighters to operate in the war zone, these fires rage on in an uncontrolled manner, growing larger in size and intensity. The year 2024 stands out as a worrying example of the cycle of destruction where climate change and armed conflict mutually reinforce each other, accelerating global warming.

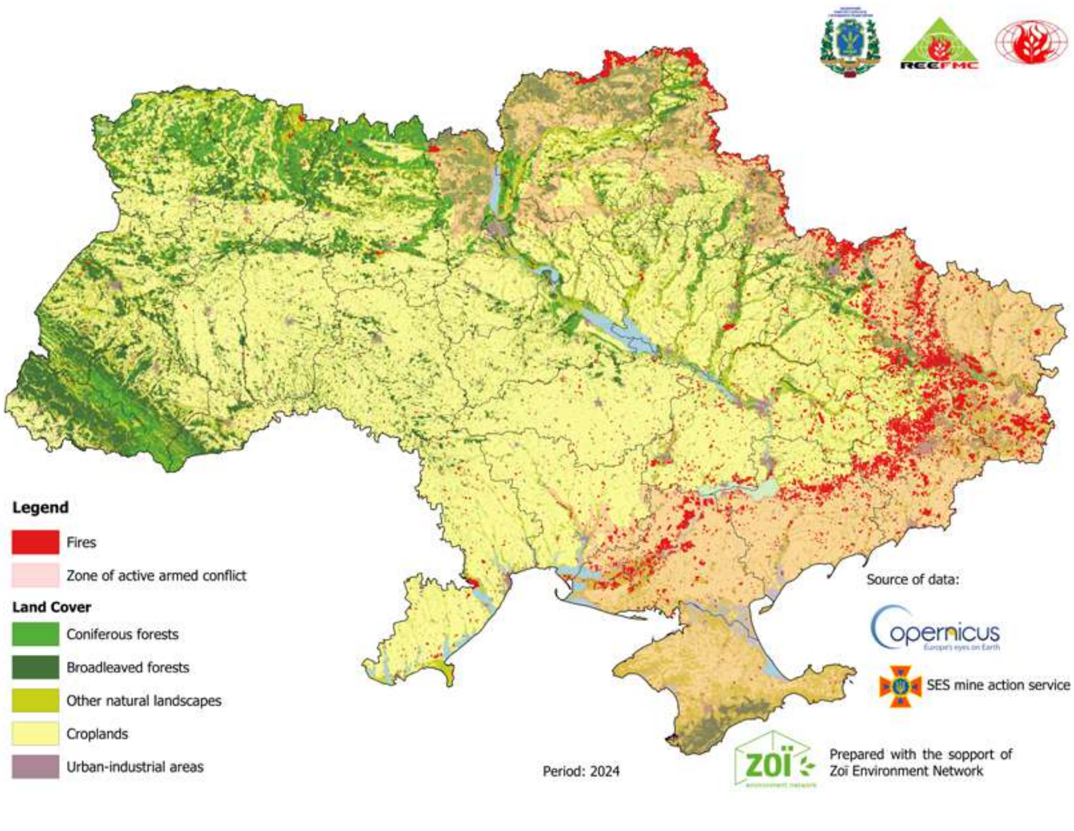

Figure 3: Natural landscape fires in 2024

1. https://forest-fire.emergency.copernicus.eu/apps/effis.statistics/estimates/Non_EU/2024/2006/2021

More oil depots and refineries went up in flames

Intensified attacks on oil depots and oil refineries led to a surge in emissions from 0.47 million tCO_2e in the second year to 0.81 million tCO_2e in the third year into the war. Continued attacks on Ukraine's energy infrastructure caused the release of not only CO_2 but also the extremely potent greenhouse gas SF_6, which is 24,000 times stronger as a greenhouse gas than CO_2. A recent article in *Nature*[2] slightly reduced previous estimations of the amount of methane, another potent greenhouse gas, that escaped from the Nord Stream pipelines.

Total emissions: 17 million tCO_2e.

Disruption of civil aviation continues

The closure of the Siberian airspace by Russia to many airlines has cut important east-west air routes between Europe and Asia for many Western carriers. The closure of Ukraine's airspace to commercial traffic has also disrupted flight routes within Europe, in particular in its eastern part and between Russia and Turkey. Carriers have been forced to take detours resulting in longer flight times as well as added fuel costs and higher GHG emissions. Emissions were in this assessment based on actual flight paths before and after the invasion.

Total emissions: 20.3 million tCO_2e.

Figure 4: Example of airspace closure above Siberia: London–Tokyo

2. Methane Emissions from the Nord Stream Subsea Pipeline Leaks, Nature, January 2025. https://www.nature.com/articles/s41586-024-08396-8

Reconstruction of housing, public buildings and infrastructure will be a daunting task

Although most damage was caused during the first weeks of the conflict, frontline urban centres are still being severely damaged. Russian forces slowly but steadily occupied more territory in the east of Ukraine, leaving a trail of destruction. As Russia tries to weaken the Ukrainian economy, the category of Industry & Utilities saw the biggest increase in damage in the third year of the war. Rebuilding what was destroyed will require massive volumes of construction materials, of which carbon-intensive concrete and steel will cause over 80% of the future reconstruction emissions. **Total emissions: 64.2 million tCO_2e.**

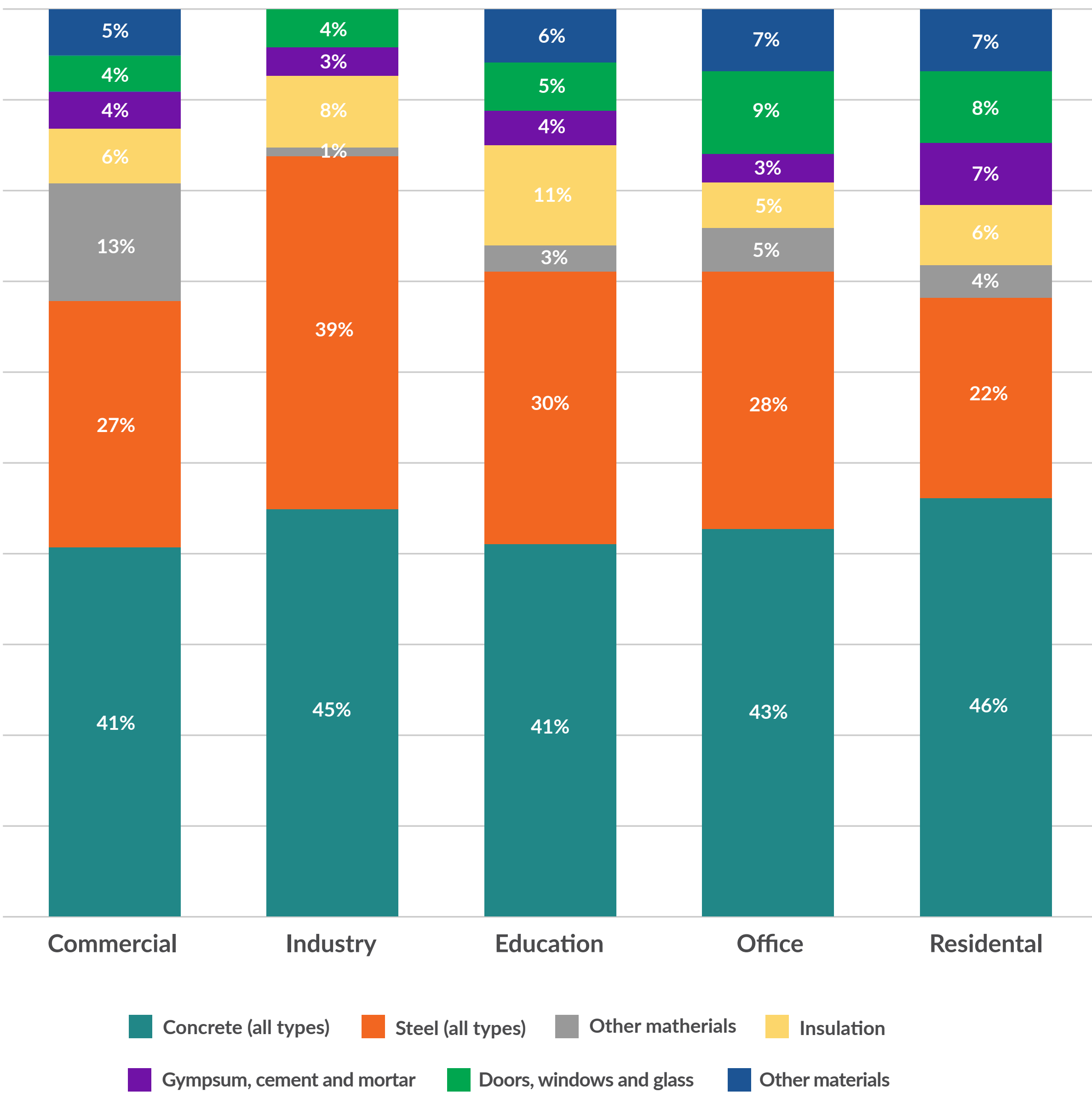

Figure 5: Construction emissions share by material and building type

Breakdown of total emissions

The share of each impact category is visualised in the pie chart below, while the absolute numbers are listed in the table. Whereas in the earlier assessments reconstruction emissions where the largest contributor, in this assessment, warfare emissions have overtaken reconstruction emissions as the largest contributing impact category.

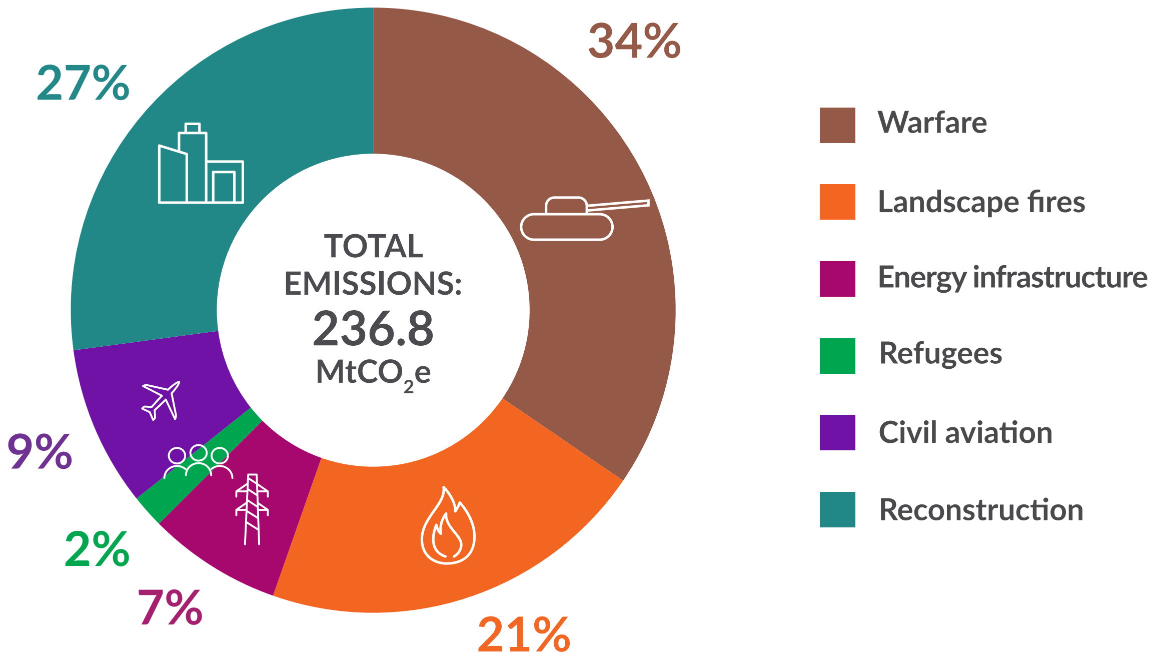

Figure 6: Distribution of emissions per impact category

Impact category	Emissions 3 years ($MtCO_2e$)	Percentage %
Warfare	81.7	34
Landscape fires	49.4	21
Energy infrastructure	17.0	7
Refugees	4.2	2
Civil aviation	20.3	9
Reconstruction	64.2	27
TOTAL	**236.8**	**100**

Table 1: Total GHG emissions after three years into the war

1. Introduction

On 24 February 2022, the Russian Federation launched an unprovoked, large-scale invasion of Ukraine. The war has been going on for more than three years, causing a humanitarian crisis with many people killed, injured, or fleeing their homes, with no end to the hostilities in sight.

A direct effect of the war includes significant GHG emissions. In a series of five assessments, we have estimated and documented those GHG emissions that can be attributed to all the events following the full-scale invasion. In other words, these emissions would not have occurred had the Russian Federation not invaded Ukraine.

The current report represents the fifth assessment over the three years of war, i.e. from 24 February 2022 up to 23 February 2025. In each assessment, data sources and methodologies have been improved and each assessment highlighted one or more specific topics, which are summarized below.

The **first assessment** of climate damage[3] was presented at the Climate Conference COP27 in Sharm-el-Sheik, Egypt on 9 November 2022[4], covering the first seven months into the war. The estimate included four impact categories: emissions from warfare, emissions from uncontrolled fires in forests and cities, emissions from the movement of refugees, and future emissions from the reconstruction of damaged and destroyed buildings, roads, and factories.

The **second assessment** of climate damage[5] provided an update of these four impact categories, covering the first 12 months into the war, i.e. from 24 February 2022 to 23 February 2023, and was presented at the UNFCCC Climate Conference in Bonn, Germany, on 7 June 2023.[6] A new impact category included the rerouting of flights due to airspace closures and the impact of the 2022 energy crisis on energy emissions in Europe. As it was argued, the energy crisis resulted in a significant reduction in gas consumption, but many other effects balanced out the emissions reductions. For more details, refer to the second assessment, Chapter 5.

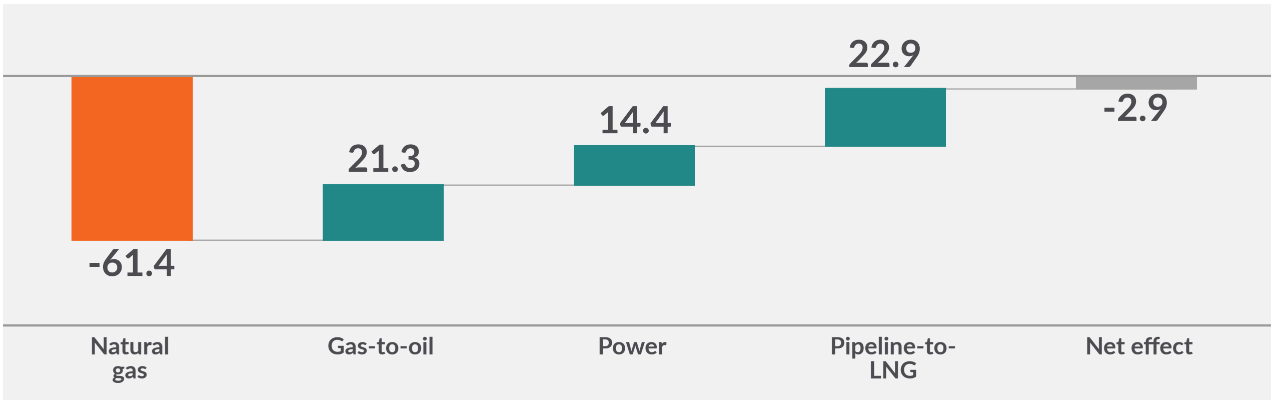

Figure 7: Year-on-year change (2021-2022) of emissions in the EU energy sector attributed to the war ($MtCO_2e$)

3. Climate Damage Caused by Russia's War in Ukraine, First Assessment. English: https://report1en.warbon.org. Ukrainian: https://report1ua.warbon.org
4. The recording of the side-event: https://www.youtube.com/watch?v=ynQbzwxTnBw
5. Climate Damage Caused by Russia's War in Ukraine, Second Assessment. English: https://report2en.warbon.org. Ukrainian: https://report2ua.warbon.org
6. The recording of the side-event: https://www.youtube.com/watch?app=desktop&v=6yW1hWQmgpc

The second assessment also addressed the impact on the overall emissions in Ukraine in 2022. Obviously, economic decline led to a decrease in country-wide emissions, but, as is being argued in Chapter 7 of the second assessment, many of the emissions shifted abroad together with the many refugees and shifted steel production.

The **third assessment** of climate damage[7] provided updates of all emission sources, covering 18 months into the war, i.e. from 24 February 2022 to 1 September 2023, and was presented at the Climate Conference COP28 in Dubai, United Arab Emirates, on 4 December 2023.[8]

The main topic of the third assessment was an analysis of the possibilities to hold the Russian Federation accountable for the climate damage caused. A methodology was presented to express the climate damage in monetary terms, thus identifying the amount that should be paid by Russia as compensation. For more details, refer to the third assessment, Chapter 2.

The potential to reduce reconstruction emissions through a green recovery was discussed and quantified in Chapter 3 of the third assessment, showing several ways how post-war reconstruction emissions could be avoided.

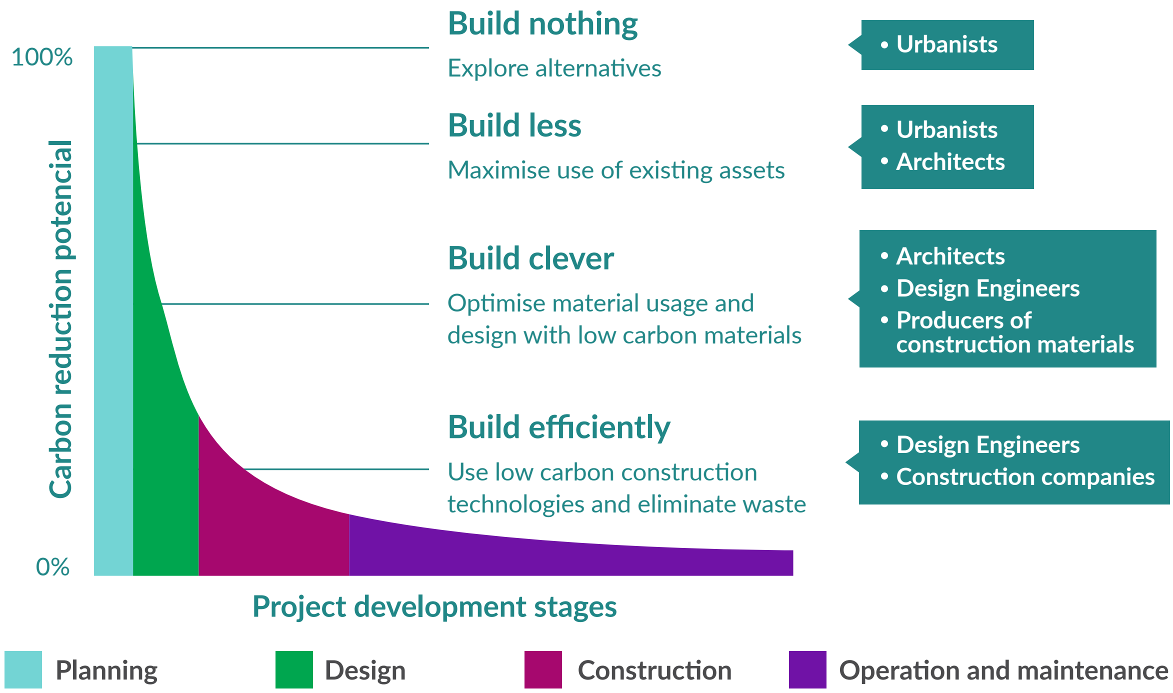

Figure 8: Potential to reduce embodied carbon and actors involved at different project development stages

The **fourth assessment**[9] covered 24 months since the start of the war until 23 February 2024 and was presented at the Ukraine Recovery Conference in Berlin on 13 June 2024. In this assessment, the main improvement was a fully updated methodology and data sources to determine emissions from landscape fires. Emissions from damages to fossil fuel infrastructure (oil depots, gas pipelines) and SF_6 emissions from high-voltage switches were included.

7. Climate Damage Caused by Russia's War in Ukraine, Third Assessment. English: https://report3en.warbon.org. Ukrainian: https://report3ua.warbon.org
8. The recording of the side-event: https://www.youtube.com/live/beFON17SeUw?si=zd16llsc_BHrFO9S
9. Climate Damage Caused by Russia's War in Ukraine, Fourth Assessment. English: https://report4en.warbon.org. Ukrainian: https://report4ua.warbon.org

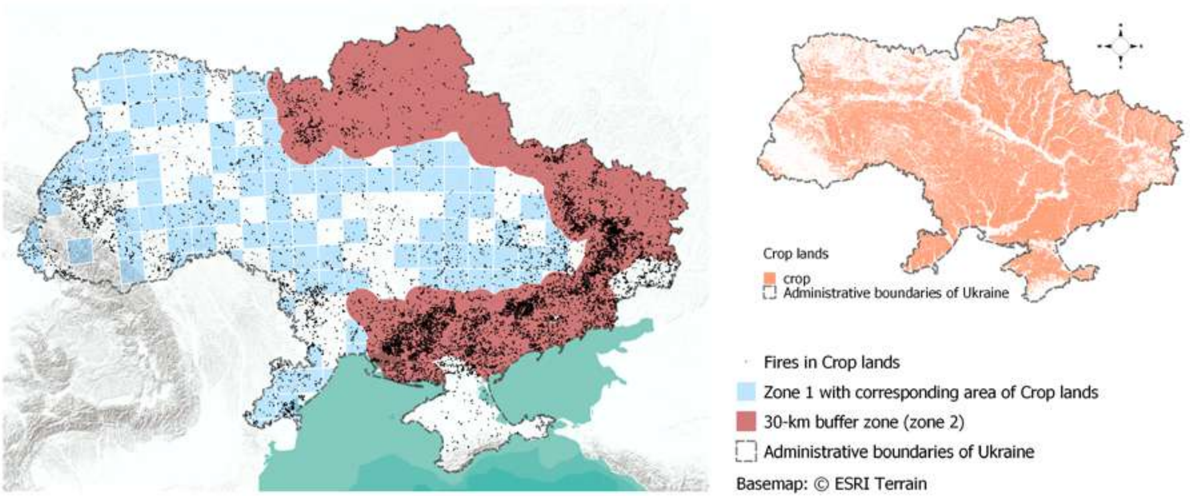

Figure 9: Estimated area of crop lands in zone 1 compared to the 30-km buffer zone

A geographical distribution of emissions (Ukraine, Russia, other countries) and a temporal distribution (direct and future emissions) was presented as well.

On 24 February 2025, a **preliminary assessment**[10] was released covering the three years of war, in which the same data sources and methodology were used as in the fourth assessment.

This current fifth assessment is the **full assessment** of the three years of war. The major updates and changes are:

- The assessment has been completely reformatted in line with the **Guidance on the Assessment of Conflict-Related GHG Emissions**.[11]
- A new approach was introduced to estimate emissions from fires in buildings.
- The impact category Civil Aviation has been completely revised based on the actual flight data of a representative week before and after the full-scale invasion.
- A consistent time series for each 12-month period was calculated for each impact category.

Please note that not all data sources, assumptions, methodological elements or emission factors are discussed in detail. For more details, the reader is encouraged to refer to the fourth assessment covering two years of war.

10. Climate Damage Caused by Russia's War in Ukraine, Preliminary Fifth Assessment. English: https://report5pren.warbon.org. Ukrainian: https://report4prua.warbon.org

11. Guidance on the Assessment of Conflict-Related GHG Emissions. English: https://reportguidanceen.warbon.org. Ukrainian: https://reportguidanceua.warbon.org

2. Application of the Guidance

In 2024 guidance was developed to assess conflict-related GHG emissions in a consistent and transparent way. This *Guidance on the Assessment of Conflict-Related GHG Emissions, Version 1.0*[12] (the "Guidance") was released during an official side-event at COP29 in Baku on 18 November 2024. This fifth assessment is applying this guidance fully.

The Guidance requires that the following elements are addressed for each impact category:

1. Time frame.
2. Geographical boundary.
3. Direct and indirect emissions.
4. Greenhouse gases covered.
5. Global Warming Potentials.
6. Methodological approach.
7. Emission factors.

The first five elements are described in this chapter for all impact categories. The methodological approach and emission factors are detailed within each individual impact category chapter. The following impact categories have been assessed:

1. Fuel consumption by militaries.
2. Use of ammunition.
3. Manufacturing of military equipment.
4. Fortifications.
5. Natural landscape fires.
6. Fires in the built environment.
7. Damage to the energy infrastructure.
8. Movement of refugees and IDPs.
9. Civil aviation.
10. Reconstruction.

The first four impact categories have been grouped under the category Warfare (Chapter 3), whereas Natural Landscape Fires and Fires in the Built Environment have been grouped under Landscape Fires (Chapter 4).

2.1 Timeframe

This assessment covers the period from 24 February 2022 up to and including 23 February 2025. In accordance with the Guidance, all emissions occurring before this period are considered to be *pre-conflict* emissions and emissions occurring after this period are *post-conflict* emissions.

12. Guidance on the Assessment of Conflict-Related GHG Emissions. English: https://reportguidanceen.warbon.org. Ukrainian: https://reportguidanceua.warbon.org

Emissions related to the use of ammunition (Chapter 3.2) and manufacturing of military equipment (Chapter 3.3) could have partly occurred before 24 February 2022. However, for simplicity, the associated manufacturing emissions are considered to have happened during the conflict period. For the impact category Reconstruction (Chapter 8), it is assumed that all reconstruction emissions will happen post-conflict, although some reconstruction activities in Ukraine have already started or, in some cases, even been completed.

2.2 Geographical boundary

According to the Guidance, the geographical boundary refers to the physical location where conflict impacts occur rather than where the resulting emissions are generated. The geographical boundary of the war constitutes Ukraine within its internationally recognized borders including the exclusive economic zone in the Black Sea for all impact categories. For the impact categories Warfare, Damage to Energy Infrastructure and Civil Aviation, the geographical boundary is extended to the Russian Federation.

Emissions can occur outside of the geographical boundary of the conflict, in particular those related to manufacturing of ammunition and military equipment, additional jet fuel consumption by rerouted airplanes and manufacturing of construction materials.

2.3 Direct and indirect emissions

Direct and indirect emissions have been categorised in accordance with the Guidance. An overview can be found in the summary table in Chapter 9.

2.4 Greenhouse gases covered

This assessment covers the accounting and reporting of the four out of six GHGs, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6).

Impact category	CO_2	CH_2	N_2O	SF_6
Fuel consumption by militaries	+	+	+	
Use of ammunition	+	+	+	
Manufacturing of military equipment	+			
Fortifications	+	+	+	
Damage to the energy infrastructure	+	+	+	+
Fires in the built environment	+	+	+	
Landscape fires	+	+	+	
Movement of refugees and IDPs	+	+	+	
Civil aviation	+			
Reconstruction	+	+	+	

Table 2: Greenhouse gases covered for each impact category

2.4 Global Warming Potentials

Global Warming Potentials with a 100-year time horizon (GWP_{100}) have been used in accordance with the IPCC AR5.

GHG	GWP_{100}
CO_2	1
CH_4 – non-fossil	28
CH_4 – fossil	30
N_2O	265
SF_6	23,500

Table 3: Global Warming Potentials for all assessed greenhouse gases

3. Warfare

3.1 Fuel Consumption by Militaries

3.1.1 General description

Fossil fuels are essential for military activities, as combat operations require large volumes of energy resources. This impact category encompasses all fuel consumption related to warfare, including fuel used by ground-based military equipment, military vessels, and aircrafts (the combat "tooth" of the military), as well as the fuel used by the supporting logistics "tail," which may involve both military and civilian equipment, vehicles, and installations.

Fuel supply during the war is associated with a complex supply chain, as fuel can be used by different arms of the military (e.g. units of the Ministry of Defence, National Guard, border control units, security services etc.), private businesses that are critical to the operation of the militaries and ensure supply of services and goods, regional state administration and local authorities, volunteers and other parties. Similarly, the procurement of fuels for the needs of military units and logistics could be secured via different channels. As a result, even if some official data on fuel procurement or use by the military are available, they are not representative of the total fuel use during the war.

3.1.2 Attribution

Even though modern armies are significant consumers of fossil fuels during peacetime, armed conflicts inevitably lead to a considerable increase in fuel consumption. Since the activity data given below reflect the estimated increase in fuel consumption, all calculated GHG emissions are attributed to the war.

3.1.3 Activity data

Estimation of the activity data was based on the combination of the Tier 1 and Tier 2 approaches:

- Tier 1: Approximate estimates based on indirect data and proxy indicators, such as the number of personnel involved in the conflict and the amount of fuel consumption per soldier or per typical military unit.
- Tier 2: Approximate estimates based on indirect data specific to the conflict assessed, such as procurement of fuel by parties involved in the conflict or changes in the volumes of fuel supply to the regions of the conflict and / or bordering regions.

Impact category	Estimate	Year 1	Year 2	Year 3	Total
Russian invading forces	Lower limit	2.37	2.64	2.64	**7.65**
	Average	3.55	5.38	5.97	**14.90**
	Upper limit	4.74	8.13	9.30	**22.17**
Ukrainian defence forces	Lower limit	0.80	0.80	0.80	**2.40**
	Average	1.20	1.20	1.20	**3.60**
	Upper limit	1.60	1.60	1.60	**4.80**
Landscape fires	**Average**	**4.75**	**6.58**	**7.17**	**18.50**

Table 4: Estimated fuel consumption (in million tonnes of fuel)

Fuel consumption by Russian forces was estimated using the data on increased fuel supply to the regions bordering Ukraine by railway (lower limit) and number of personnel involved in the war on the territory of Ukraine (upper limit). Significantly lower fuel consumption by Ukraine is explained by the benefits of interior lines of defence for Ukraine, fewer personnel involved and reliance on lighter equipment and vehicles, as well as longer supply-chain distances for the attacking country. A detailed description of the estimation approach is provided in the fourth assessment on climate damage following two years of war.

Emissions from long-distance arms deliveries were estimated based on the reported data on military aid supply both in physical[13] and monetary values.[14] The value of more than 150,000 tonnes of various military equipment delivered to Ukraine by the end of May 2023 was adjusted based on the reported amounts of military aid provided in monetary terms during different periods of the war. The transportation distance was determined based on the allocation of military aid provided by different countries and the approximate distance between a specific country and bases in Eastern Poland. Simplified assumptions were used to distribute cargo deliveries by mode of transportation for different countries (e.g. equal shares between air and sea transport for transatlantic routes and reliance on train transportation for deliveries within Europe with 20% air transport use for the deliveries from Southern and Northern European countries). There were no reliable data on long-distance military aid supply to Russia.

3.1.4 Emission factors

The following emission factors have been used:

- Direct emissions: 3.19 tCO_2/tonne of fuel
- Upstream emissions: 0.746 tCO_2e/tonne of fuel

3.1.5 GHG emissions

Emissions from fuel consumption by militaries are summarised in the table below.

	Year 1	Year 2	Year 3	Total
Russia	14.0	21.2	23.5	**58.7**
Ukraine	4.7	4.7	4.7	**14.1**
Military aid	0.3	0.1	0.3	**0.7**
Total	19.0	26.0	28.5	**73.5**

Table 5: Emissions resulting from fossil fuel consumption (in $MtCO_2e$)

13. Russia Recruited Operatives Online to Target Weapons Crossing Poland, https://www.washingtonpost.com/world/2023/08/18/ukraine-weapons-sabotage-gru-poland
14. Ukraine Support Tracker, https://www.ifw-kiel.de/topics/war-against-ukraine/ukraine-support-tracker/

3.2 Use of Ammunition

3.2.1 General description

This impact category covers GHG emissions associated with the manufacturing of ammunition, missiles, and explosives used during the war, as well as additional GHG emissions at the point of firing (e.g. due to the combustion of a propellant) and point of impact (e.g. due to the detonation of a warhead).

The effectiveness of ammunition and explosives is determined by two factors:

- volume of fire power, which determines the mass of ammunition and explosives used during warfare and related climate impact, and
- precision of ammunition, which determines the carbon intensity per military target.

The intensity of firepower and main types of ammunition used have significantly varied during the different periods of the war. While during the first year massive artillery fires were very common on different sections of the frontline, the declining stocks of artillery shells caused reduction in artillery fire intensity during the second and third years. Precision strike systems played crucial roles during some periods, but both parties were also continuously working on countermeasures reducing the former's effectiveness. Increase in drones' use during the second and third years of the war compensated for the declining availability of artillery munition. FPV drones came to play a significant role on the battlefield while destroying or damaging a large number of tanks and armoured vehicles, as well as hitting other military targets. Drones have caused a decline in GHG emissions from the use of ammunition but their effectiveness in terms of target identification and destruction has also led to higher GHG emissions from the destruction of military equipment (see impact category Manufacturing of Military Equipment).

3.2.2 Attribution

All embodied emissions associated with ammunition production, as well as emissions at the point of firing and point of impact are attributed to the war, since the level of emissions is directly dependent on the decisions on the level and types of ammunition use during the war.

3.2.3 Activity data

The Tier 1 approach based on the approximate estimates of the amount of artillery ammunition used was applied for the calculation as artillery is the key source of firepower during warfare and is responsible for the largest share of explosives used and associated GHG emissions. However, the estimated GHG emissions were adjusted to account for other main types of ammunition and explosives used. An adjustment factor of 1.2 was applied based on the analysis conducted during previous assessments.

The use of artillery and other types of ammunition depends on the intensity of warfare at different parts of the frontline and varies significantly since the beginning of the Russian invasion. Declining stocks and attacks on warehouses significantly reduced the intensity of artillery use during the course of the war, while new supply sources and expansion of manufacturing facilities allowed partly compensating for declining fire intensity.

At the beginning of the full-scale war, Russian artillery maintained a significant advantage over Ukraine with the disparity reaching a 10:1 ratio. Russia was firing up to 50,000 or even 60,000 shells per day, relying on the quantity of shells to make up for the lack of precision strike capability. The intensity of artillery use decreased during the second year of the war due to depleted stocks, with fire intensity reaching parity during some periods. However, with additional supplies from North Korea, Russian fire intensity was significantly higher during most of the periods. In 2024, Russia was firing around 10,000 shells a day compared to just 2,000 a day from the Ukrainian side.[15]

Additional GHG emissions are associated with the large-scale attacks on ammunition depots. Between September 2024 and February 2025, Ukraine has increased the scale and effectiveness of strikes deep inside Russia. In September 2024, several successful strikes on large ammunition depots were conducted, including strategic depots in Toropets and Tikhoretsk, which played a key role in supplying Russian forces with 120 mm and 82 mm mortar rounds, 122 mm rockets, small arms ammunition, various missiles, and explosive materials. The destruction of the Toropets depot alone is estimated to have resulted in the loss of 30,000 to 160,000 tonnes of munitions. In addition, the strike on the Karachev GRAU depot in October 2024 successfully destroyed two buildings though the broader ammunition depot remained intact.[16] In 2025, more than half of the 51st GRAU depot was destroyed, with 105,000 tonnes of ammunition exploded according to some estimates.[17] Another large-scale attack in early 2025 included destruction of ammunition storage at the Engels Air Base.[18]

The data used in the calculation of climate damage are provided in the table below, while more detailed information can be found in previous assessments.

Ammunition use	Estimate	Year 1	Year 2	Year 3	Total
Russian invading forces	Artillery rounds, units	9.000.000	4.140.000	3.600.000	**16.740.000**
	Artillery rounds, t	720.000	331.200	288.000	**1.339.200**
	Other ammunition and explosives, t	144.000	66.240	57.600	**267.840**
	Destroyed ammunition, t			135.000	**135.000**
Ukrainian defence forces	Artillery rounds, units	2.250.000	1.980.000	720.000	**4.950.000**
	Artillery rounds. t	180.000	158.400	57.600	**396.000**
	Other ammunition and explosives. t	36.000	31.680	11.520	**79.200**
	Destroyed ammunition, t				
Total	**Artillery rounds, units**	**11.250.000**	**6.120.000**	**4.320.000**	**21.690.000**
	Artillery rounds, t	**900.000**	**489.600**	**345.600**	**1.735.200**
	Other ammunition and explosives, t	**180.000**	**97.920**	**69.120**	**347.040**
	Destroyed ammunition, t			**135.000**	**135.000**
	Total, t	**1.080.000**	**587.520**	**549.720**	**2.217.240**

Table 6: Usage of ammunition by both military forces

15. Exclusive: Russia Producing Three Times more Artillery Shells than US and Europe for Ukraine, https://edition.cnn.com/2024/03/10/politics/russia-artillery-shell-production-us-europe-ukraine/index.html
16. Frontelligence Insight. Melting the Steel and Black Gold: A Comprehensive Analysis of Ukraine's Long-Range Strike Operations, https://frontelligence.substack.com/p/melting-the-steel-and-black-gold
17. UK Intel Shows Scale of Destruction at Russian Ammunition Depot, https://newsukraine.rbc.ua/news/uk-intel-shows-scale-of-destruction-at-russian-1747219356.html; What Satellite Images Reveal About the Destruction of russia's 51st GRAU Arsenal Near Moscow, https://en.defence-ua.com/analysis/what_satellite_images_reveal_about_the_destruction_of_russias_51st_grau_arsenal_near_moscow-14282.html
18. See reports at: https://x.com/NOELreports/status/1903436253334270231, https://x.com/tochnyi/status/1903210810723475852, https://x.com/bradyafr/status/1903134796705886219

3.2.4 Emission factors

GHG emissions from the use of ammunition were estimated using the emission factor for generic 155 mm ammunition based on the published extended environmental lifecycle assessment, which takes into account the global warming impact of the manufacturing of ammunition and propellants, as well as emissions at the point of firing and point of impact.[19] Emissions from other types of ammunition and explosives were estimated proportionally using the adjustment factor of 1.2 based on the analysis conducted during the fourth assessment following the two years of the war.

3.2.5 GHG emissions

Manufacturing of ammunition and explosives account for 98.5% of the total estimated climate impact, while the emissions at the point of firing and point of impact represent the remaining small share of the total GHG emissions from the use of ammunition.

	Year 1	Year 2	Year 3	Total
Manufacturing of ammunition (steel casing and explosives)	1.53	0.83	0.59	**2.95**
Manufacturing of propellants	0.64	0.36	0.25	**1.25**
Emissions at the point of firing and point of impact	0.03	0.02	0.01	**0.06**
Emissions from the use of other ammunition and explosives	0.44	0.24	0.17	**0.85**
Total	**2.64**	**1.45**	**1.02**	**5.11**

Table 7: Emissions resulting from the use of ammunition (in MtCO_2e)

3.3 Manufacturing of Military Equipment

3.3.1 General description

Military equipment is the core of any warfare activity, as it attacks the enemy, protects and supplies forces, builds fortifications, conducts surveillance, and executes many other tasks needed for the achievement of strategic and tactical goals.

This impact category covers GHG emissions related to the manufacturing of military equipment destroyed or damaged during the war, including embodied emissions of structural steels, alloyed steels, cast materials, light alloys, synthetic and composite materials, and other resources, as well as energy consumption during the manufacturing stage.

The number of destroyed pieces of military equipment significantly depends on the intensity of battles on the frontline and types of operations conducted. The initial failed blitzkrieg of Russian invading forces and intense battles during the first months of the war resulted in a huge amount of equipment losses during the first year of the war. As the frontline became steadier during the second year, equipment loss rates have significantly declined. However, with the growing use of drones during the third year of the war, the number of destroyed military equipment has grown substantially. Reconnaissance drones enhance the capability to identify targets, while FPV drones and other attack drones increase the equipment destruction rate.

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

3.3.2 Attribution

GHG emissions from the manufacturing of destroyed and damaged equipment are taken into account, while the emissions associated with building up the stocks of military equipment in different countries are not. All embodied emissions associated with the manufacturing of military equipment are attributed to the war.

3.3.3 Activity data

The Tier 2 approach was applied, relying on open source information on the losses of most of the key military equipment types (i.e. tanks, armoured fighting vehicles (AFVs), infantry fighting vehicles (IFVs), armoured personnel carriers (APCs), infantry mobility vehicles (IMVs), self-propelled artillery, multiple rocket launchers, trucks, vehicles and jeeps, aircrafts, helicopters and naval ships).

Forces	Estimate	Year 1	Year 2	Year 3	Total
Russian invading forces	Mass of destroyed equipment	158.917	36.252	69.402	**264.571**
	Mass of damaged equipment	13.924	2.556	767	**17.247**
	Mass of destroyed and not visually confirmed equipment	31.783	7.250	13.880	**52.913**
	Total mass of equipment	204.624	46.058	84.049	**334.731**
Ukrainian defence forces	Mass of destroyed equipment	45.891	9.695	22.574	**78.160**
	Mass of damaged equipment	8.127	1.808	3.949	**13.884**
	Mass of destroyed and not visually confirmed equipment	9.178	1.939	4.515	**15.632**
	Total mass of equipment	63.196	13.442	31.038	**107.676**
Total	**Mass of equipment**	**267.820**	**59.500**	**115.087**	**442.407**

Table 8: Mass of destroyed and damaged equipment (in tonnes)

Data on destroyed and damaged military equipment rely on the information from Oryx lists of visually confirmed losses during the war.[20] Oryx loss lists are based on visual evidence and exceptions are made only in rare cases where losses are officially confirmed by the side that suffered them or if confirmed by very reliable sources for the side that suffered those losses.[21]

20. Three-year status: https://x.com/Rebel44CZ/status/1893708452075090340; Full lists - Attack On Europe: Documenting Russian Equipment Losses During the 2022 Russian Invasion of Ukraine, https://www.oryxspioenkop.com/2022/02/attack-on-europe-documenting-equipment.html and Attack on Europe: Documenting Ukrainian Equipment Losses During the 2022 Russian Invasion of Ukraine, https://www.oryxspioenkop.com/2022/02/attack-on-europe-documenting-ukrainian.htm

21. See explanation of the methodology by the authors of the lists: https://x.com/Rebel44CZ/status/1878490738243068330

Forces	Type	Year 1	Year 2	Year 3	Total
Russian invading forces	Tanks	1.533	389	750	**2.672**
	Other armoured vehicles (AFV, IFV, APC, IMV)	3.002	1.033	2.407	**6.442**
	Trucks, Vehicles and Jeeps	2.212	285	605	**3.102**
Ukrainian defence forces	Tanks	432	102	225	**759**
	Other armoured vehicles (AFV, IFV, APC, IMV)	1.216	234	771	**2.221**
	Trucks, Vehicles and Jeeps	541	98	189	**828**

Table 9: Destroyed and damaged equipment (in units)

The estimations based on visually confirmed losses are very conservative and actual losses can be significantly higher. The analysis of high-resolution satellite images revealed a significant number of equipment losses not visible at videos or photos from the locations of intensive battles. Calculated emissions take into account that at least 20% of losses are not visually confirmed / not included in the lists and resulting GHG emissions are increased proportionally.

The losses accounted for in the estimation of climate damage do not consider civilian vehicles used and destroyed during the war. Reports show that due to the declining stocks of military equipment, Russian forces increased the use of civilian vehicles on the frontlines from March 2024 to February 2025.[22]

3.3.4 Emission factors

The amount of embodied carbon is very specific to a particular equipment type and there is almost no data on the lifecycle emissions associated with the manufacturing of military equipment. Hence, data for civil machinery and equipment (e.g. tractors, farm implements, trucks, construction equipment, etc.) were used as a proxy for the assessment of emissions associated with destroyed and damaged military equipment. Such approach is conservative, since manufacturing of military equipment is typically more energy- and resource-intensive.

The value of 6 kgCO_2 per kg of machinery has been applied as an indicative carbon footprint of military equipment, which corresponds to the recommended Tier 1 approach from the Guidance. See the fourth assessment following the two years of the war for more details.

3.3.5 GHG emissions

Forces	Year 1	Year 2	Year 3	Total
Russia	1.2	0.2	0.5	**1.9**
Ukraine	0.3	0.1	0.2	**0.6**
Total	**1.5**	**0.3**	**0.7**	**2.5**

Table 10: Emissions from destroyed and damaged equipment (in MtCO_2e)

This is a very conservative value as it takes into account only the key types of large equipment and machinery and does not account for the dozens of types of specific machines used during the war and different pieces of small equipment. It also focuses on the destroyed and damaged equipment only, while the emissions associated with building up the stocks of military equipment in different countries are not accounted for.

22. See https://x.com/AndrewPerpetua/status/1902364609446564027

3.4 Fortifications

3.4.1 General description

This impact category covers GHG emissions associated with the construction of fortifications, including trenches, strongholds, and other elements, in particular the use of large volumes of carbon intensive construction materials, such as steel, cement and concrete. Cement and concrete production are the key sources of GHG emissions assessed for this impact category.

Additional potential GHG emission sources related to the construction of field fortifications, such as emissions from the destruction of carbon pools in the soil and forested areas, fuel consumption during the operation of earth-moving equipment involved in trench digging, as well as future works for dismantling of fortifications and restoration of the landscape, are not considered in this assessment.

Construction of fortification lines depends on the dynamics on the battlefield and other factors, which have been changing over the three years of the war. During the first year of the war, the frontlines were very dynamic, the battles were very intense and, as a result, construction of fortification lines was limited. After the liberation of a significant part of the Ukrainian territory in autumn 2022, Russia has started construction of extensive multi-layer fortifications along the border with Ukraine and on the occupied territories of Ukraine behind the frontlines in preparation for Ukrainian counteroffensive. Construction and strengthening of fortifications have continued throughout 2023 and 2024 with bolstering of existing trenches with wood, concrete, or metal structures. As the line of contact became more static, Ukraine also directed significant resources to the construction of fortification lines along the whole frontline as well as along the Northern border of the country. Significant intensification of the use of drones has also affected the nature of the fortification structures required on the battlefield. With the sky saturated with reconnaissance and FPV drones and with other attack drones and aerial bombs being able to hit almost any identified position along the frontline, the role of large strongholds became less essential. Soldiers prioritize well-concealed positions and dugouts in the tree lines and other forested areas due to the lower risk of their destruction.

Construction of fortifications and protective structures extends far beyond the frontlines. With intensive attacks against civilian population and energy infrastructure throughout the country, Ukraine has launched a massive campaign on the installation of shelters in cities and towns and construction of protection structures around power substations and other critical infrastructure.

3.4.2 Attribution

All GHG emissions associated with the construction of fortifications are attributed to the war.

3.4.3 Activity data

Activity data on the volumes of concrete rely on the Tier 2 approach, which assumes the use of proxy estimates based on the information on the types and scale of fortifications constructed (e.g. using satellite data and identified fortification structures).

Construction of fortification lines involves a complex supply chain and various actors, which makes it difficult to track data on materials' procurement and use. In Ukraine, for instance, construction of fortification structures can be managed by the Ministry of Defence of Ukraine, State Special Transport Service of the Ministry of Defence, Agency for Restoration, regional and district state administrations, as well as military administrations of specific communities in the regions close to the frontlines or state borders. Large-scale construction of fortifications also requires involvement of construction machinery and construction services provided by civil construction companies.[23] The estimation of concrete volumes used for fortifications is based mostly on the analysis presented in the report following the two years of the war and proxy estimates. The impact assessed for the first two years of the war was allocated between the first and the second years using the 20/80 proportion taking into account the nature of the war. During the third year of the war, both Ukraine and Russia continued constructing fortifications, but limited information is available. Data for Russian fortifications rely on the estimates provided by the DeepState portal using the analysis of satellite images and other sources of information.[24] The total length of fortification lines constructed by invading Russian army increased from more than 6,000 km as of November 2023 (including 1,184 km of dragon teeth lines) to 8,312 km as of early 2025. The length of the dragon's teeth lines increased by approximately one third during the third year mainly due to accounting for the fortification structures in Russian regions bordering Ukraine. Data for Ukrainian fortifications were assessed based on the length of the frontline as described in the two-year report and taking into account the fact that in 2024 the Ukrainian army built massive defensive fortifications along the entire frontline to slow down the Russian army.[25]

The following assumptions have been applied:

- for dragon's teeth lines: 750 units per km (three lines with 250 units per km in each; additional details and analysis provided in the two-year report);
- for other fortification lines with the known estimated length of trenches and other elements (Russian): 20 t of concrete per km of fortification lines;
- for other fortification lines without data on the estimated length of trenches and other elements (Ukrainian): 80 t of concrete per km of the frontline;
- for protective structures behind the frontline: estimation based on the two-year report and assuming a 30% share of concrete use for critical infrastructure protection during the third year.

Forces	Estimate	Year 1	Year 2	Year 3	Total
Russian invading forces	Concrete used for dragon's teeth manufacturing	213.000	852.000	320.000	**1.385.000**
	Concrete used for other fortification structures	24.000	96.000	46.000	**166.000**
	Total amount of concrete used for fortifications	237.000	948.000	366.000	**1.551.000**
Ukrainian defence forces	Concrete used for dragon's teeth manufacturing	24.000	96.000	36.000	**156.000**
	Concrete used for other fortification structures	32.000	128.000	160.000	**320.000**
	Concrete used for shelters and check-points	8.000	32.000	32.000	**72.000**
	Concrete used for the protection of critical infrastructure	-	720.000	216.000	**936.000**
	Total amount of concrete used for fortifications	64.000	976.000	444.000	**1.484.000**
Total	**Total amount of concrete used for fortifications**	**301.000**	**1.924.000**	**810.000**	**3.035.000**

Table 11: Concrete volumes for fortifications (in tonnes)

23. See for additional details: https://www.slovoidilo.ua/2024/06/05/infografika/bezpeka/fortyfikaczijni-sporudy-yak-vlashtovanyj-proces-budivnycztva, https://www.radiosvoboda.org/a/shcho-vidbuvayet%CA%B9sya-z-fortyfikatsiyamy/32873058.html, https://texty.org.ua/fragments/112029/evolyuciya-dotiv-yak-sporudzhuyut-suchasni-vohnevi-sporudy-foto/

24. DeepState, https://t.me/DeepStateUA/22180, https://t.me/DeepStateUA/18121, https://deepstatemap.live/#7/

25. See https://x.com/clement_molin/status/1939354419562189300

3.4.4 Emission factors

The assumed density of concrete is 2.4 t/m^3 and the emission factor of concrete is 0.5 tCO_2e/m^3 of concrete based on B40 concrete class.

3.4.5 GHG emissions

Resulting GHG emissions from the construction of fortifications are presented in the table below.

Forces	Year 1	Year 2	Year 3	Total
Russia	0.05	0.20	0.08	**0.33**
Ukraine	0.01	0.20	0.09	**0.30**
Total	**0.06**	**0.40**	**0.17**	**0.63**

Table 12: GHG emissions resulting from fortifications (in $MtCO_2e$)

3.5 Total GHG Emissions from Warfare

Forces	Year 1	Year 2	Year 3	Total
Fossil fuel RU	14.0	21.2	23.5	**58.7**
Fossil fuel UA	4.7	4.7	4.7	**14.1**
Fossil fuel military aid	0.3	0.1	0.3	**0.7**
Ammunition	2.6	1.5	1.0	**5.1**
Equipment	1.5	0.3	0.7	**2.5**
Fortifications	0.06	0.40	0.17	**0.63**
Total	**23.16**	**28.20**	**30.37**	**81.7**

Table 13: GHG emissions resulting from warfare (in $MtCO_2e$)

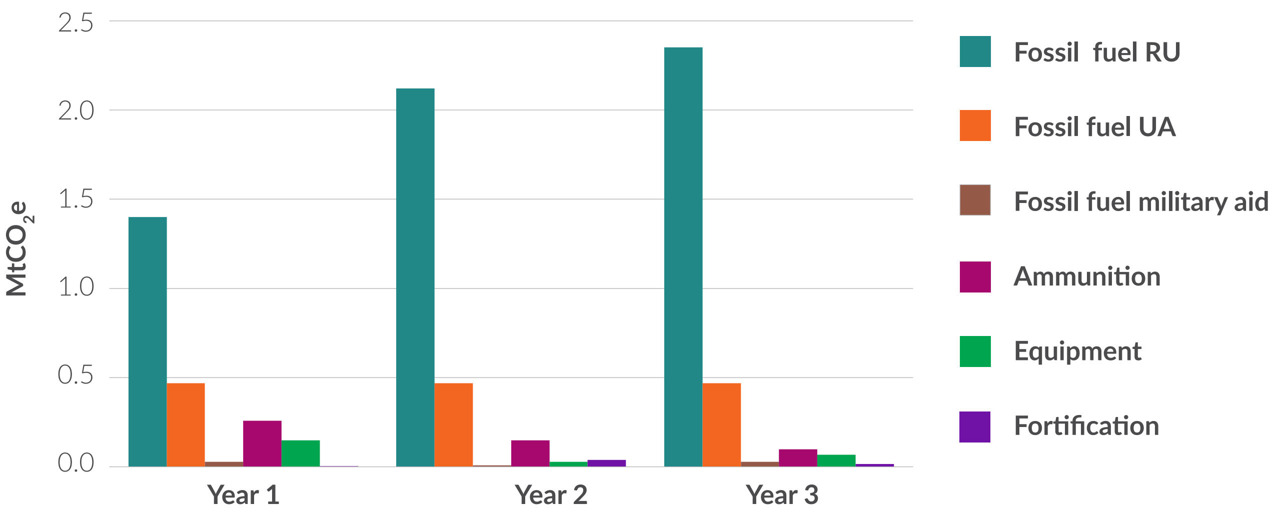

Figure 10: GHG emissions resulting from warfare

4. Landscape Fires

4.1 Natural Landscape Fires

4.1.1 General description

According to the UN Food and Agricultural Organisation's (FAO) definition, landscape fires are human-related land-use fires, prescribed management fires, and wildfires burning in live and dead vegetation of natural, cultural, and urban-industrial landscapes.[26] In Ukraine, several agencies collect statistical data on fires — but none of them cover all landscape fires. Hence, the assessment of war-related emissions from all types of landscape fires in this report is based on fire statistics of the Regional Eastern Europe Fire Monitoring Center (REEFMC), which is financially supported by Zoï Environment Network and the National University of Life and Environmental Sciences of Ukraine.[27]

4.1.2 Attribution

During peace time, there were numerous, mostly human-related, ignition sources in the landscapes of Ukraine: starting from intentional burning of crop residues on fields to fires on small patches of land ignited by rural populations near their villages and negligence fires from citizens that visit forests. The war has affected the amount, areas, and intensity of fires and related GHG emissions via the direct impact of shelling, presence of large numbers of soldiers and various potential sources of ignition, occupation of territories, and reduced capacity of landscape fire management in Ukraine. On top of that, climate change and extreme fire weather events increase the risks of uncontrollable burning, especially along the frontline, where there is no response from fire brigades.

Attributing fires to the war is essential in order to separate them from normal, peaceful circumstances. It is impossible to determine for each individual fire whether the cause is war-related, while using previous years as a reference is problematic due to significantly different weather conditions and the lack of reliable historical data for comparison. Therefore, a methodology has been applied to attribute the *direct* impact of the war, in which the occurrence of fires close to the frontline is compared to the same landscape type away from the frontline. This methodology is briefly described below, but more detailed in the two-years war report.

Further away from the frontline, the direct impact of the war is limited. However, an *indirect* impact of the war can be observed as the war has reduced firefighting capacities since personnel has been drafted to the army, limited availability of using video surveillance for fire detection, and firefighting equipment has been brought to the war zone or airspace has been closed to firefighting planes.

4.1.3 Methodology and emission factors

To calculate emissions from natural landscape fires, the following steps have been taken:

1. Mapping of fires.
2. Buffer zone delineation.
3. Biomass loss and GHG emissions.
4. Attribution.

26. FAO Fire Management Voluntary Guidelines, https://www.fao.org/4/j9255e/j9255e00.pdf
27. https://nubip.edu.ua/node/9087/2

A brief description of each step is provided below. For a more detailed description, refer to the fourth assessment covering the two years of the war.

Step 1: Mapping of fires

As the first step of the methodology, in the period from 24 February 2022 to 23 February 2025, all fires in the territory of Ukraine were delineated by visual inspection of Sentinel 2 time series. A group of trained photo interpreters analysed Sentinel 2 mosaics within 1 km radius of the hotspot location, obtained from the MODIS satellite sensor to identify ongoing fires or recent burn scars and the fire perimeters were outlined manually.

Step 2: Buffer zone delineation

As the second step, a buffer zone was established. This study used daily frontlines created by Zoï Environment Network. Based on the daily progression of the frontline since 24 February 2022, three zones were delineated:

- Zone 1: Ukrainian territory not impacted by the ground-based warfare, i.e. outside of the 30-km buffer zone.
- Zone 2: Accumulated 30-km buffer zone on both sides of the moving frontline.
- Zone 3: Occupied territories, including those occupied since 2014 but outside of the 30-km buffer zone.

As for the buffer zone, a cumulative buffer of 30 km on both sides of the frontline for a given date is used. Thus, the buffer refers to the maximum area of direct war impact observed since the beginning of the invasion. Some areas of Ukraine have been liberated since then, but they are of limited access to firefighters due to the presence of mines or unexploded ordnance. Therefore, we *accumulate* a 30-km buffer zone during the three years of the war.

Step 3: Biomass loss and GHG emissions

Within the third step, carbon emissions from fires are determined for different landcover types as follows.

Carbon emissions from forest fires

To estimate carbon emissions from forest fires, species and age structure of forest stands were determined. This helped measure total biomass volumes and identify the specifics of biomass losses resulting from forest fires of different severities. Based on the data from the last forest assessment in Ukraine,[28] the ratio of age groups was determined for each region of Ukraine: young, middle-aged and premature, mature, and overmature.

Future biomass losses and, hence, GHG emissions for forest stands adversely affected by fires were estimated based on expert assessments of potential post-fire stand losses.

Carbon emissions from cropland fires

Determination of the dominant species structure of the sown areas of crops was done based on area distribution by crop structure. According to the Ministry of Agrarian Policy and Food of Ukraine, wheat, barley, sunflower, and corn dominated the crop structure, covering almost 85% of the sown areas. The following ratios of the mentioned crops were used: wheat — 37.3%, barley — 10.8%, sunflower — 26.1%, and corn — 25.8%.

28. Handbook of the Forest Fund of Ukraine, 2012

Estimation of the yield and volume of crop biomass

The yield of the mentioned crops (in t/ha) within each region was determined based on national statistics data[29]. The amount of biomass was determined using the coefficients of the total yield of surface and root residues of crops depending on the main products' yield.[30]

Carbon emissions from fires in other natural landscapes

Using the official website of the State Statistics Service of Ukraine for geodesy, cartography, and cadastre, the regional structure of other landscape types was determined. The regional structure of landscapes, in addition to forest areas and arable land, also includes hayfields, fallows, and pastures. Based on the Land Directory of Ukraine data,[31] the share of each of the listed types of agricultural landscapes within each region was calculated. Productivity and biomass volumes were determined by landscape types. The productivity of the mentioned types of landscapes (in t/ha) within each region was estimated based on scientific data from numerous botanical and ecological publications and grouped by natural zones of Ukraine. Biomass losses were differentiated depending on the level of site damage and landscape type.

Step 4: Attribution

The fourth step of the methodology is to attribute fires in the buffer zone to the war, i.e. to demonstrate that these fires were not caused by other natural factors or normal human activities. Landscape fires in the buffer zone (Zone 2) were compared with fires in identical landscapes under similar circumstances not directly impacted by the war (Zone 1). Under similar circumstances, we mean the same landcover type in the same season and with the same Fire Weather Index (FWI). Calculating the difference in emissions between both landscape types, we determine additional emissions *directly* caused by the war.

The Canadian Forest Fire Weather Index, which is available through the Copernicus data service[32], has been used as FWI. The categories of fire danger based on FWI were assigned to all fires across Ukraine's territory taking into account their geographical locations. In order to estimate war-related emissions from landscape fires, the total amount of GHG emissions released by fires in the buffer zone was multiplied by attribution coefficients for each landcover type, season, and FWI class.

Whereas fires in the buffer zone were attributed to the war as described above, in the territories not directly impacted by the warfare (Zone 1), the impact is more difficult to attribute. Cruise missiles and drones have caused damage far behind the frontlines, even in the west of Ukraine, close to the Polish border, and may have ignited wildfires. However, the major impact of the war in Zone 1 is reduced firefighting capabilities: contrary to the buffer zone, these fires are in most cases accessible, but fire management activities are limited due to the lack of firefighters for many men and women enlisted in the army. Extinguishing fires from the air can be hampered as the airspace is often closed by order of the army or by Ukrainian authorities.

Moreover, many fire trucks and other firefighting equipment have been brought to the war zone to assist in firefighting activities in urban areas. According to the Kyiv School of Economics data, Ukraine had a total of 4,216 firefighting trucks, of which 1,629 were damaged or destroyed.[33] This is a destruction rate of 38%, including fire trucks used for both urban and

29. Verner, I.E. (Ed.). (2021). Statistical yearbook of Ukraine 2020. https://ukrstat.gov.ua/druk/publicat/kat_u/2021/zb/11/Yearbook_2020_e.pdf
30. A.V. Kokhana,, I.D. Glushchenko, (2015). Current situation and ways to improve soil fertility in Poltava region in modern conditions of agricultural production. https://dspace.pdau.edu.ua/server/api/core/bitstreams/505eccad-4804-4c9b-bc88-12317e089c9b/content
31. Land Directory of Ukraine, https://agropolit.com/spetsproekty/705-zemelniy-dovidnik-ukrayini--baza-danih-pro-zemelniy-fond-krayini
32. Database of Copernicus: https://cds.climate.copernicus.eu/cdsapp#!/dataset/cems-fire-historical-v1?tab=overview
33. Annex 10 of the Report on Damages to Infrastructure from the Destruction Caused by Russia's Military Aggression against Ukraine as of January 2024, KSE, https://kse.ua/wp-content/uploads/2024/05/Eng_01.01.24_Damages_Report.pdf

landscape fires. Since authorities prioritise fighting urban fires, most likely, even less fire trucks will be available to extinguish natural landscape fires. Nevertheless, we use this figure as a proxy to estimate the reduction in firefighting capabilities and to estimate the emissions from fires that are indirectly caused by the war, realising that the uncertainty of this estimation is higher compared to the emissions directly caused by the war in the buffer zone.

4.1.4 GHG emissions

The area of mapped natural landscape fires for the whole of Ukraine, before attribution, is presented in the table below.

Landcover type	Year 1	Year 2	Year 3	Total
Coniferous forests	37.9	23.5	63.5	**124.9**
Deciduous forests	45.6	9.4	51.6	**106.6**
Croplands	370.3	263.4	428.3	**1062.0**
Wetlands	28.7	5.8	20.7	**55.2**
Other vegetation lands	269.2	142.8	282.7	**694.7**
Total	**751.7**	**444.9**	**846.8**	**2043.4**

Table 14: Area of natural landscape fires (in thousand hectares)

During the three years of the war, out of a total of 2043.4 thousand hectares of natural landscape fires, 1573.8 thousand hectares of fires burned in the buffer zone (=77%). The buffer zone only represents one third of the total territory of Ukraine so the intensity of fires (in burned ha/km^2 of territory) is some six time higher. When only looking at fires in coniferous forests that ratio is even higher with 117.5 out of 124.9 thousand hectares occurred in the buffer zone (=94%).

When zooming into natural landscape fires in Zone 2 and comparing all fires with those fires attributed to the war, the table below shows that almost 9 out of 10 fires in Zone 2 can be attributed to the war.

Landcover type	All	Attributed to the war	Factor
Coniferous forests	117.5	110.6	94%
Deciduous forests	69.5	58.2	84%
Croplands	880.9	775.6	88%
Wetlands	24.5	19.9	81%
Other vegetation lands	481.3	415.0	86%
Total	**1573.7**	**1379.3**	**88%**

Table 15. Area of natural landscape fires in Zone 2 during the three war years (in thousand hectares)

When converting landscape fires into GHG emissions as described above, the following results are obtained.

Landcover type	Year 1		Year 2		Year 3		Total
	Zone 1	Zone 2	Zone 1	Zone 2	Zone 1	Zone 2	
Coniferous forests	0.21	6.44	0.02	3.66	0.38	8.85	**19.56**
Deciduous forests	1.84	2.74	0.24	1.44	0.95	8.10	**15.31**
Croplands	0.16	2.62	0.12	2.46	0.11	3.00	**8.47**
Wetlands	0.09	0.12	0.02	0.03	0.06	0.13	**0.45**
Other vegetation lands	0.24	0.73	0.06	0.50	0.17	1.21	**2.91**
Total	**2.54**	**12.65**	**0.46**	**8.09**	**1.67**	**21.29**	**46.70**

Table 16: Emissions from natural landscape fires attributed to the war (in $MtCO_2e$)

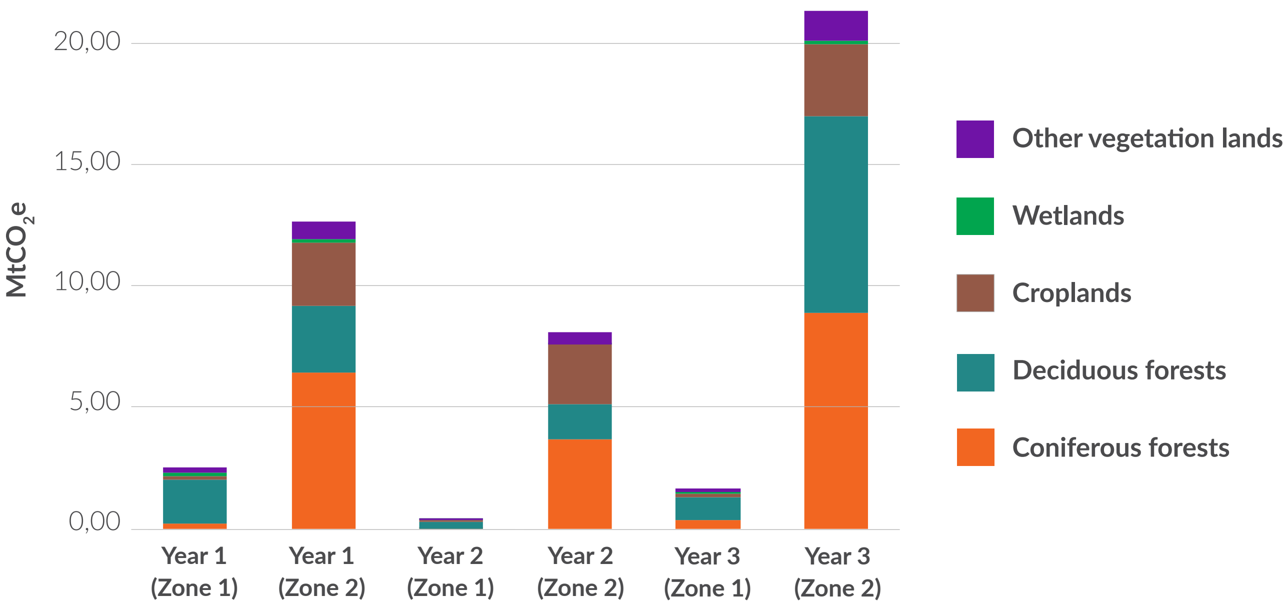

Figure 11: Emissions from natural landscape fires attributed to the war

Of a total of 46.55 million tCO_2e emissions caused by natural landscape fires, some 14.18 million tCO_2e were emitted directly, while future emissions from the degradation of dead forests will amount to 32.37 million tCO_2e.

4.2 Fires in the Built Environment

4.2.1 General description

The attacks on civilian infrastructure caused uncontrolled fires of combustible materials in buildings, factories, and utilities, thus leading to GHG emissions. A wide range of buildings have been damaged or destroyed, as detailed under the impact category Reconstruction. Current estimation takes into account only residential buildings fires. To estimate emissions, it is necessary to know the amount of combustible materials, which is currently unknown for other buildings types, like hospitals, factories, or public utilities.

Buildings involve different types of combustible materials. Examples of wooden products are structural elements in roofs and attics, decorative elements like wainscoting or household items like furniture. Other combustible materials are mainly household plastics.

In this estimation, only emissions from wood and wooden products are considered since there is some information on the amount of these combustible materials in residential buildings.

4.2.2 Attribution

Fires in buildings are a normal phenomenon that occurs during peacetime as well. However, in that situation, the number of fires is significantly smaller than currently is the case in Ukraine. Therefore, all the emissions calculated below are attributed to the war.

4.2.3 Calculation method

Emissions from buildings include both immediate emissions from fires and future emissions from the combustion or degradation of wooden materials: larger wooden fragments from these buildings will likely be scavenged to be used for heating in the absence of other energy sources, leading to future emissions, whereas smaller fragments will end up in improvised landfills and decay.

It was assumed that of residential buildings classified as *destroyed*, all combustible wooden products would be converted into emissions. Of that, 20% burnt, which caused *immediate* GHG emissions. The remaining 80% of wooden products were damaged only mechanically by shelling, explosions, or military vehicles, leading to future emissions through combustion for energy generation or decay.

Regarding *damaged* buildings, it was assumed that in terms of GHG emissions, one damaged multi-apartment building is equivalent to 15% of a destroyed building, and one damaged individual building is equivalent to 20% of a destroyed building.

4.2.4 Activity data

The assessment of GHG emissions from fires and destruction of residential buildings is based on the data on destroyed and damaged buildings gathered by the Kyiv School of Economics[34] for the period until November 2024 as well as other publicly available data.[35]

	Year 1	Year 2	Year 3	Total
Destroyed				
Multi-apartment buildings	6.10	0.91	0.23	**7.24**
Individual buildings	66.62	2.18	3.34	**72.14**
Damaged				
Multi-apartment buildings	11.76	7.93	0.89	**20.58**
Individual buildings	63.39	55.46	12.20	**131.05**
Total	**147.87**	**66.48**	**16.66**	**231.01**

Table 17: Number of destroyed and damaged buildings in Ukraine (in thousand units)

4.2.5 Emission factors

To estimate the average amount of wood and wooden materials in individual buildings (or rather households), an expert assessment of more than 20 owners of such households was used. This resulted in 10.63 m^3 of wood including the floor, windows and doors, furniture, stairs and ceilings, attics and roof constructions, outbuildings, and fences. The figure reflects the specifics of households in the east and south of Ukraine. Using a similar expert assessment, the average amount of wooden materials in one apartment in a multi-apartment building was measured at 3.49 m^3. It covers the floor, doors, windows, furniture, and the share of roof constructions, which is insignificant in the south of Ukraine. The average number of apartments in a multi-apartment building was used as 48.6 (the average area of a multi-apartment building of 2,867 m^2 divided by the average area of one apartment of 59 m^2).

When calculating emissions, it was assumed that most of the wood used in residential buildings is dry conifer burnt in an open fire. The corresponding emission factor of 1.653 kgCO_2e/kg wood was used.

4.2.6 GHG emissions

The calculated emissions are provided in the table below.

	Year 1	Year 2	Year 3	Total
Immediate emissions	0.42	0.09	0.02	**0.53**
Future emissions	1.67	0.38	0.09	**2.14**
Total	**2.09**	**0.47**	**0.11**	**2.67**

Table 18: Emissions from destroyed and damaged residential buildings (in MtCO_2e)

34. Report on Damages to Infrastructure from the Destruction Cause by Russia's Military Aggression against Ukraine as of November 2024. Kyiv School of Economics, 2025. https://kse.ua/wp-content/uploads/2025/02/KSE_Damages_Report-November-2024---ENG.pdf
35. https://biz.nv.ua/ukr/consmarket/skilki-zhitla-zruynuvala-rosiya-v-ukrajini-za-chas-povnomasshtabnogo-vtorgnennya-50500032.html

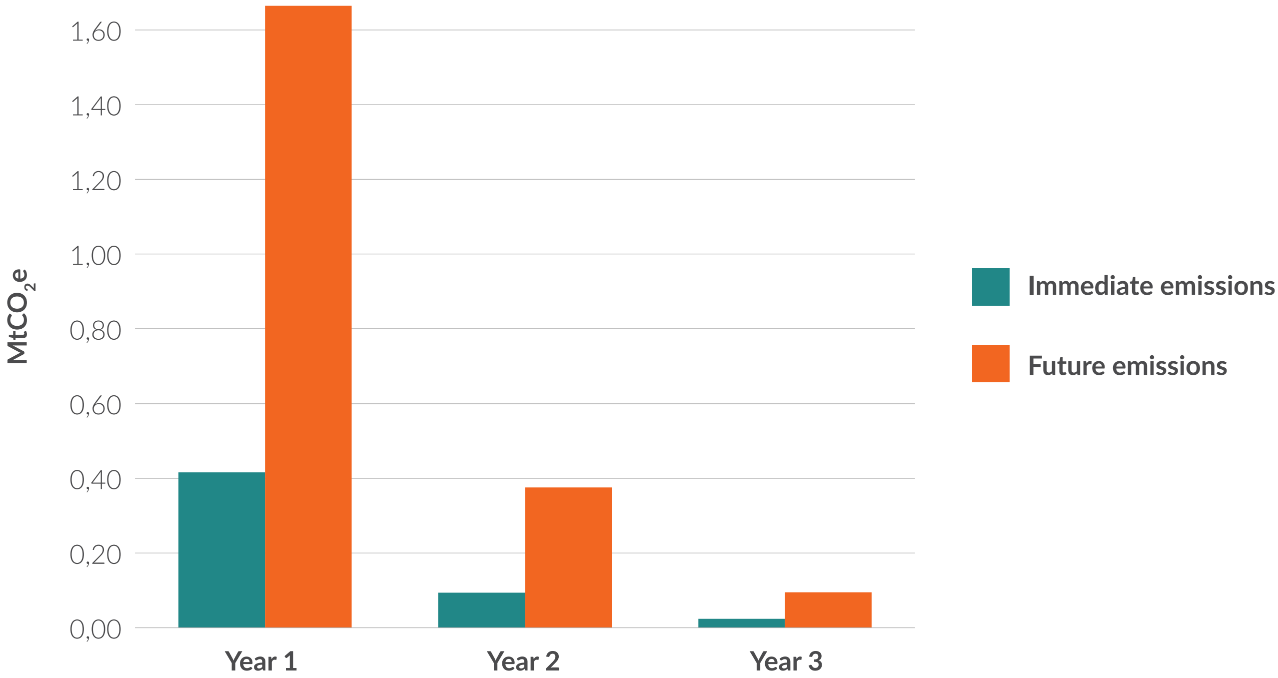

Figure 12: Emissions from destroyed and damaged residential buildings

As has been mentioned earlier, these calculations do not cover emissions from burning other combustible materials found in every household or apartment in a multi-apartment building, namely, clothes, shoes, books, plastic, etc. Hence, the numbers provided are an underestimation of the actual emissions.

Photograph: Thomas Peter/Reuters

4.3 Total GHG Emissions from Landscape Fires

	Year 1	Year 2	Year 3	Total
Natural landscapes (Zone 2)	12.65	8.09	21.29	**42.03**
Natural landscapes (Zone 1)	2.54	0.46	1.67	**4.67**
Buildings	2.08	0.47	0.12	**2.67**
Total	**17.27**	**9.02**	**23.08**	**49.37**

Table 19: Overview of GHG emissions from landscape fires (in $MtCO_2e$)

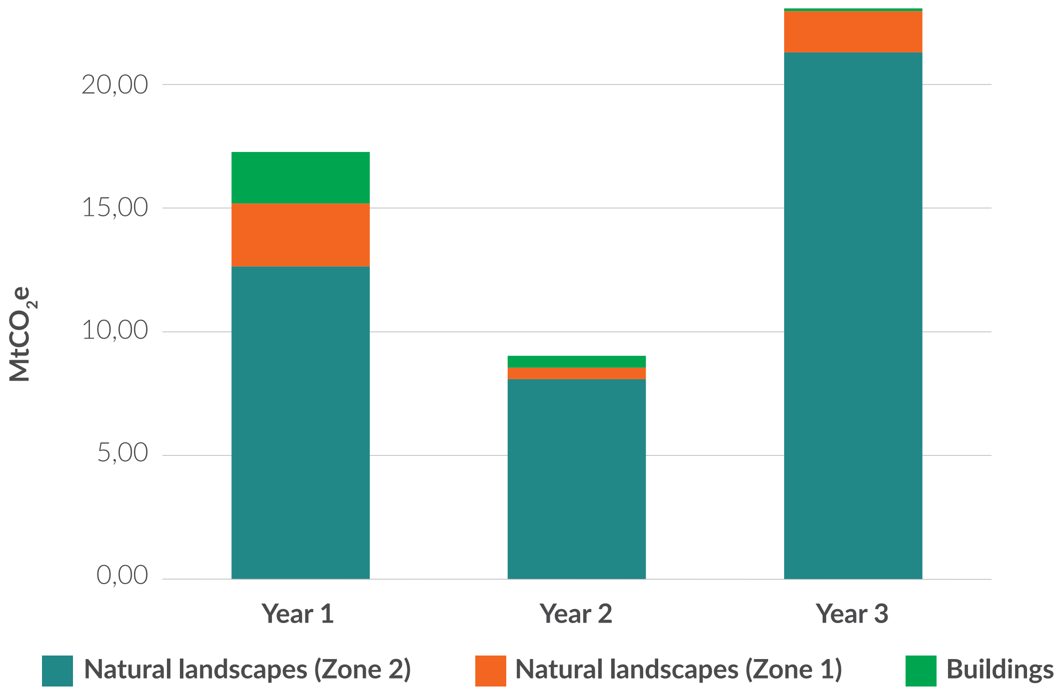

Figure 13: GHG emissions from all landscape fires

5. Energy Infrastructure

5.1 General description

Energy and fossil fuel infrastructure was often attacked during the three years of the war, as its destruction can significantly weaken an adversary's capacity to conduct military operations. This occurred both due to the direct impact through the loss of fuel reserves and indirect impact due to degrading the economy and diminishing the ability to sustain and finance the war effort. In addition, energy and fossil fuel infrastructure situated near combat zones was intentionally or unintentionally damaged during military activities.

5.2 Attribution

All GHG emissions associated with the destruction of energy infrastructure are attributed to the war.

5.3 Methodological approach and activity data

Activity data on energy infrastructure damage were collected mostly using a simplified Tier 1 approach, while in some cases results of a more detailed analysis were available and applied (Tier 2):

- Volume of the fuel burnt due to liquid fuel / oil infrastructure destruction was estimated based on indirect data and proxy indicators, such as the number of fuel tanks destroyed or damaged, while in some cases estimates relied on more detailed investigations with the recorded data on the size and volumes of fuel tanks and assessment of the level of damage available.
- Volume of the natural gas burnt and leaked due to natural gas infrastructure destruction was estimated based on indirect data and proxy indicators, such as the number of incidents and assumed proxy per incident, while in some cases estimates relied on more detailed investigations with the data on GHG emissions available (e.g. Nord Stream pipelines and Black Sea gas platforms).
- Volume of the SF_6 leaked due to electricity infrastructure destruction was estimated based on the national inventory of SF_6 volumes in electricity system and assessment of the level of damage of high-voltage transmission infrastructure.

5.3.1 Large-scale events: Nord Stream pipelines and Black Sea gas platforms

Though not directly related to the warfare activities, the sabotage of the Nord Stream 1 & 2 pipelines on 26 September 2022 has been included in this assessment, as it resulted in GHG emissions that most likely would have not occurred had the Russian Federation not invaded Ukraine. Recent airborne observations have revealed that Nord Stream pipeline leaks had released 465 ± 20 kt of methane into the atmosphere.[36] Similar estimates (443-486 kt of methane) have been reported in other recent studies.[37] While this constitutes the largest recorded transient anthropogenic methane emission event, the updated estimate of 465 kt of methane is lower than the initial ones and corresponds to 13.0 million tCO_2e of GHG emissions.

36. Reum, F., Marshall, J., Bittig, H.C. et al. Airborne Observations Reveal the Fate of the Methane from the Nord Stream Pipelines. Nat Commun 16, 351 (2025). https://doi.org/10.1038/s41467-024-53780-7

37. Mohrmann, M., C. Biddle, L., Rehder, G. et al. Nord Stream Methane Leaks Spread Across 14% of Baltic Waters. Nat Commun 16, 281 (2025). https://doi.org/10.1038/s41467-024-53779-0

The damage of gas exploration infrastructure at the Black Sea, caused by active combat events and attacks, resulted in a long-term fire that started in June 2022 and continued for months. According to the estimates made by the Conflict and Environment Observatory (CEOBS), uncontrolled gas flaring between 20 June 2022 and 17 November 2023 resulted in the combustion of 189.2 million m^3 of natural gas (estimated using the data collected at night by the VIIRS instrument and processed by special tools).[38] Based on CEOBS estimates, at least **0.34 million tCO_2e** have been released due to the natural gas flaring. Because of active combat activities, it was not possible to extinguish the fire nor to stop the gas flow. Natural gas flaring continued, while additional fires resulting from the ongoing battles on the Black Sea were detected on other wells. As of November 2024, there were four thermal anomalies on the Black Sea in the area between Odesa region and occupied Crimea.[39] The FIRMS system confirms the continuation of the fires[40] and additional GHG emissions between 17 November 2023 and 23 February 2025 (based on the daily average emission rates from the case study prepared by CEOBS) are estimated at **0.31 million tCO_2e**. Total climate impact would correspond to **0.65 million tCO_2e**. The actual climate impact could be even higher, considering the incomplete combustion of natural gas and potential methane leakage.

5.3.2 Onshore gas production and transportation infrastructure

During the three years of the war, there were hundreds of cases of damage to gas transportation pipelines and gas distribution networks of different size, as well as targeted attacks on gas production sites and gas storage facilities. Emissions from such events depend on the size of the targeted or affected pipelines or other infrastructure, as well as response measures undertaken. Typically, damage of gas pipelines is accompanied by fire and methane combusting, leading to CO_2 emissions. However, damage to the distribution networks could also be associated with methane leakage into the atmosphere involving a higher climate impact. Emissions could be higher in case of damaging large high-pressure gas transportation pipelines, which affects longer network sections.

Attacks on gas infrastructure intensified during the third year of the war as Russia tried to destroy gas production sites and the above-ground infrastructure of gas storage sites to undermine the access to gas reserves and reliability of Ukrainian gas storage infrastructure for European partners. In early 2025, there were several large-scale missile attacks on the gas production sites in Poltava and Kharkiv regions, but also gas transportation infrastructure in Ternopil and other regions.[41] During 2024–2025, facilities of state-owned production company Ukrgasvydobuvannya were attacked 34 times, with the largest attack in February 2025 affecting almost 50% of gas production capacity of the company.

Only in Kherson region, during 2024 there were 1,829 cases of damages to the gas distribution system and 1,813 cases of damages to internal gas networks.[42] Considering the length of the frontline and combat areas, the total number of attacks on gas distribution networks and internal gas networks likely exceeds several dozen thousands cases per year. Though the damage of natural gas infrastructure is frequent, currently, there is no detailed inventory of such events available for our analysis.

38. Case study: Emissions from Damaged Black Sea Gas Infrastructure, https://ceobs.org/ukraine-conflict-environmental-briefing-the-climate-crisis/#5; https://ceobs.org/ukraine-damage-map-bk-1-stationary-gas-drilling-platform/
39. Satellite Imagery Reveals Ongoing Fires at Russian-Occupied Offshore Gas Platforms in Black Sea, https://euromaidanpress.com/2024/11/07/satellite-imagery-reveals-ongoing-fires-at-russian-occupied-offshore-gas-platforms-in-black-sea/
40. FIRMS, https://firms.modaps.eosdis.nasa.gov/map/#d:24hrs;@31.6,44.9,8.9z
41. Russia is Systematically Attacking Ukraine's Gas Infrastructure (infographic), https://texty.org.ua/articles/114638/russia-is-systematically-attacking-ukraines-gas-infrastructure-infographic/
42. Khersongas, https://gaz.kherson.ua/?p=6683

For the two years of the war, its overall climate impact was assumed to be below 0.1 million tCO_2e (equivalent to approximately 25 million m^3 of natural gas losses each year). Even though the attacks on gas infrastructure intensified during the third year of the war, a similar scale of GHG emissions was assumed in this assessment due to the lack of data and high uncertainty of previous estimates. Such level of impact would correspond to approximately 100 large-scale attacks with an average loss of 50,000 m^3 of natural gas each and more than 20,000 small-scale attacks with the loss below 1,000 m^3 of natural gas during each attack.

More reliable activity data (Tier 3) could become available after the war, as the Ministry of Energy of Ukraine has adopted a special methodology for the estimation of natural gas losses caused by warfare activities, in particular the volume of natural gas leaks after the damage of natural gas pipelines and other infrastructure due to warfare activities.[43] Operators of natural gas distribution grids are expected to provide information to the Ministry of Energy of Ukraine on a monthly basis, including estimated volumes, information on warfare activities, confirmation of relation between the damage to natural gas infrastructure and warfare activities, duration of gas leakage and other details.

5.3.3 Oil depots and oil refineries

Attacks on fuel storage facilities in Ukraine started from the first hours of the large-scale war in February 2022 and at least 15 oil product storage facilities were attacked in different regions across Ukraine by the end of March 2022.[44] For the first two years of the war, the total amount of fuel burned as a result of these attacks was conservatively assessed at 200,000 tonnes, of which 144,000 tonnes were lost during the first year of the war. On the territory of Russia and occupied territories of Ukraine, at least several dozens of attacks on oil product storage facilities and oil refinery plants were reported during the first two years of the war. Though information on the resulting general damage and amount of fuel burnt is limited, based on the data available from news reports, it was assumed that reservoirs with over 100,000 m^3 of fuel storage volume could have been destroyed or damaged due to these attacks (84,300 tonnes of fuel burnt).

In several waves of attacks on Russian oil infrastructure during March–August 2024, oil storage tanks with the capacity of up to 50,000 m^3 might have been affected. The recorded attacks include both small-scale events affecting one or two oil storage tanks and large-scale attacks destroying large oil storage sites. An example of a large-scale attack during this period is an attack on an oil depot in Proletarsk, where a fire lasted for more than a week and at least 15 oil tanks were completely destroyed.[45] Other examples include an attack on an oil terminal in Yartsevo in Smolensk region in April 2024 and an attack on the Atlas oil depot in Rostov region in August 2024.[46]

A joint research project by Frontelligence Insight and Radio Free Europe/Radio Liberty tracked 100 cases of strikes on Russian energy infrastructure (oil or gas storage facilities and oil and gas refineries) only during the period of September 2024–February 2025, including 67 successful ones (for the remaining 33 strikes, the results are unknown). According to the study, attacks on oil and gas production facilities and natural resource storage sites resulted in the

43. Наказ Міністерства енергетики України від 11.07.2023 № 216 «Про затвердження Методики визначення вартості втрат (витоку) природного газу у разі пошкодження газопроводів та газорозподільних станцій, завданих Україні внаслідок збройної агресії Російської Федерації», https://zakon.rada.gov.ua/laws/show/z1555-23#Text

44. Аналітична довідка про пожежі та їх наслідки в Україні за 3 місяці 2022 року, https://idundcz.dsns.gov.ua/upload/6/2/1/7/8/8/XphKg30Ai9vGQwOfXkyehPgvP9FayYEVHyWC1P8F.pdf

45. See https://x.com/MT_Anderson/status/1826982323750899794, https://www.pravda.com.ua/eng/news/2024/08/18/7470844/, https://www.pravda.com.ua/eng/news/2024/08/26/7471915/

46. UAVs Hit Fuel Depot of Atlas Plant in the Rostov Region, https://militarnyi.com/en/news/uavs-hit-fuel-depot-of-atlas-plant-in-the-rostov-region/

destruction of oil products storage tanks with the volume of 172,000 m^3 and additional damage to the storage tanks with the volume of 115,000 m^3. The largest strike on an oil storage facility in terms of total damage occurred on 7 October 2024, when 11 tanks with the total volume of 69,000 m^3 were destroyed in Feodosia (annexed Crimea).[47]

Overall, during the third year of the war, the impact of attacks on oil infrastructure in Russia could have resulted in the combustion of 150,000 tonnes of fuel (based on the data described above and assuming 70% occupancy rate for oil tanks and 30% combustion factor for the damaged oil tanks). For Ukraine, the impact of the third year of the war was assumed equal to the amount of fuel destroyed during the second year of the war (56,000 tonnes of fuel).

Attacks on oil infrastructure continued as the war entered its fourth year and climate damage continues to grow. Examples of large-scale recent events include an attack on a pipeline complex near the village of Kavkazskaya in Krasnodar region that transports oil to Novorossiysk[48], a crude oil pumping station Kropotkinskaya in Krasnodar Krai[49], oil storage facility near Tuapse refinery[50] and others.

5.3.4 SF_6 emissions from electric equipment

Sulphur hexafluoride (SF_6) is used for high-voltage and medium-voltage switchgear for insulation (e.g. gas-insulated switchgear) and breaking (circuit breakers and load break switches) and has the largest global warming potential of all GHGs (GWP_{100} = 23,500). Even under normal conditions, SF_6 emissions occur due to leaking or poor gas handling practices during equipment installation, maintenance, and decommissioning. Fires or other disruptive events can cause sudden and severe damage to equipment and SF_6 emissions.[51]

High-voltage and medium-voltage substations in Ukraine were among the priority targets during the intensive attacks on the energy system, in particular, during the first year of the war (2022–2023 autumn-winter period). Ukrenergo reported that during the 2022–2023 heating season, 1,200 missiles and drones were used to attack energy facilities, which resulted in the damage of 43% of high-voltage infrastructure facilities. At least 42 high-voltage transformers were destroyed and damaged and about 500 units of different equipment were supplied by international partners to support the recovery work.[52]

Official data on SF_6 use in Ukraine during the recent years involve a high degree of uncertainty. According to the national GHG inventory, the total amount of SF_6 in operated gas-insulated equipment in Ukraine has increased from 426 tonnes in 2021 to 461 tonnes in 2022 and 486 tonnes in 2023.[53] Large-scale losses are not reflected in the national inventory.

The two-year climate damage report assumed that at least 10% of SF_6 contained in the system could have been emitted during the large-scale attacks on high-voltage electricity transmission infrastructure during the first year of the war. This resulted in the estimated emissions of 42.6 tonnes of SF_6 or about 1 million tCO_2e. As the scale of attacks on electricity transmission in-

47. Frontelligence Insight. Melting the Steel and Black Gold: A Comprehensive Analysis of Ukraine's Long-Range Strike Operations, https://frontelligence.substack.com/p/melting-the-steel-and-black-gold
48. Russia's Kavkazskaya Oil Depot in Krasnodar Fire Rages for a Week After Drone Attack, https://united24media.com/latest-news/russias-kavkazskaya-oil-depot-in-krasnodar-fire-rages-for-a-week-after-drone-attack-7041
49. See https://x.com/JayinKyiv/status/1902874276551602658
50. Drone Strike Ignites Major Blaze at Russian Oil Facility Supplying Military Fuel, https://united24media.com/latest-news/drone-strike-ignites-major-blaze-at-russian-oil-facility-supplying-military-fuel-6716
51. Overview of SF_6 Emissions Sources and Reduction Options in Electric Power Systems, https://www.epa.gov/eps-partnership/overview-sf6-emissions-sources-and-reduction-options-electric-power-systems
52. Ukrenergo, https://ua.energy/dlia_zmi/proon-ta-yaponiya-dostavyla-v-ukrayinu-potuzhni-avtotransformatory-z-metoyu-bezperebijnogo-energozabezpechennya-dlya-bilsh-nizh-piv-miljona-lyudej and https://i-visti.com/news/13010-v-ukrenergo-pdbili-pdsumki-nayvazhchogo- opalyuvalnogo-sezonu-v-storyi.html
53. Ukraine. 2025 National Inventory Document (NID), https://unfccc.int/documents/646259

frastructure decreased during the following years, the estimated emissions for the second and third years are assumed at the level of 10% from the emissions during the first year.

5.4 Emission factors

The destruction or damage of energy infrastructure results in several types of GHG emissions, such as:

- Fuel combustion – emissions from the burning of stored fuels in damaged facilities or depots, as well as natural gas combustion within gas transportation infrastructure and natural gas production or storage facilities.
- Methane leakage – from ruptured gas pipelines or storage facilities, which can release large amounts of methane, a potent GHG.
- Uncontrolled leakages of SF_6 – a highly potent GHG used as an insulating gas in electrical transmission and distribution equipment, which can be released into the atmosphere when the infrastructure is damaged.

The following sources of emission factors were applied:

- direct emissions from fuel combustion – default IPCC emission factors and national emission factors defined in the most recent national GHG inventory;
- upstream emissions – values reported by the Department for Energy Security and Net Zero;
- CH_4 and SF_6 leakages – based on the global warming potential of relevant gases.

5.5 GHG emissions

The resulting GHG emissions are summarised below.

	Year 1	Year 2	Year 3	Total
Large-scale events	13.18	0.24	0.24	**13.66**
Onshore gas production and infrastructure	0.05	0.05	0.05	**0.15**
Oil depots and refineries	0.65	0.47	0.82	**1.94**
SF_6	1.00	0.10	0.10	**1.2**
Total	**14.9**	**0.9**	**1.2**	**17.0**

Table 20: Total emissions from damaged and destroyed energy infrastructure (in $MtCO_2e$)

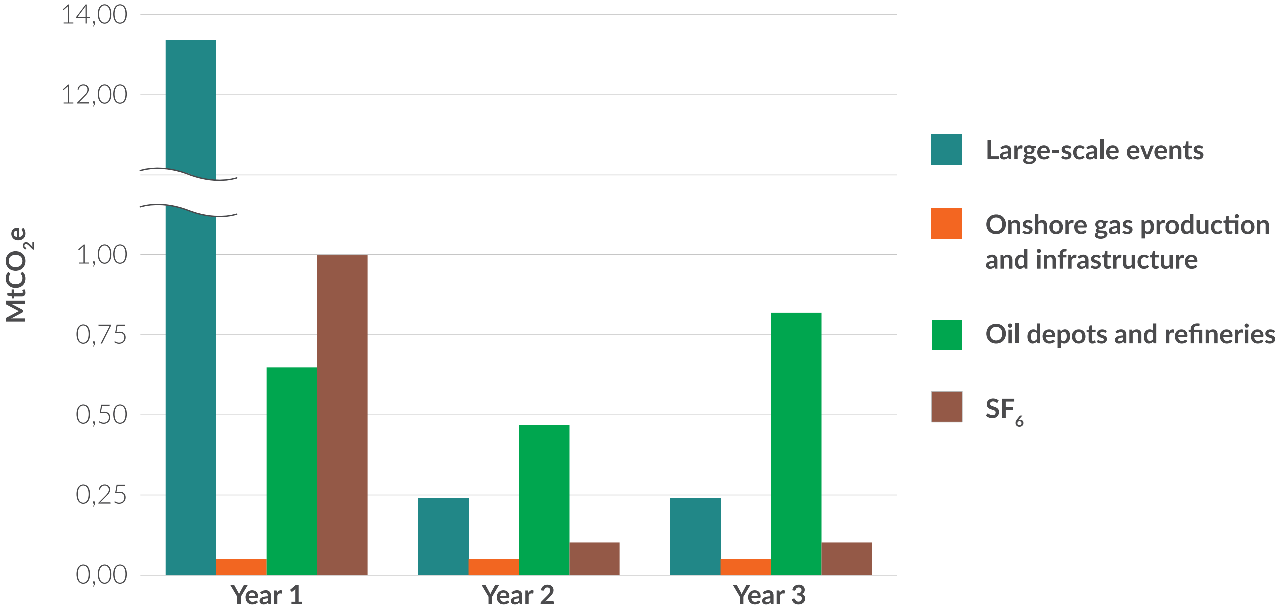

Figure 14: GHG emissions from damaged and destroyed energy infrastructure

Photo: DTEK

6. Refugees and IDPs

6.1 General description

Immediately after the invasion on 24 February 2022, many Ukrainians decided to leave their homes. People fled westwards, staying in Ukraine as Internally Displaced Persons (IDPs), or went abroad to other European countries or even further as Refugees. Furthermore, many Russians have left the country to avoid draft into the military, prosecution, or for other reasons. Given the fact that the conflict has been ongoing for several years, many refugees have returned home or moved elsewhere. Refugees remaining abroad visit their family and friends staying in Ukraine. Resulting emissions from all these movements have been estimated below.

6.2 Attribution

Had the full-scale invasion not taken place, no movement of refugees would have been observed; therefore, all emissions of movements are attributed to the war. As the timeframe of the reporting period starts on 24 February 2022, previous movements of refugees are not taken into account.

6.3 Calculation method

Emissions are calculated separately for each category of movement, being:

- IDPs in Ukraine.
- Refugees fleeing abroad.
- Russians leaving the Russian Federation.

For each category, the initial number of movements, the travelled distance and the mode of transport is estimated. The same is done for refugees returning home or visiting Ukraine.

6.4 Activity data

Data on Refugees have been drawn from the UNHCR,[54] which provides an overview of the number of refugees registered in each country. The database has been retrieved at regular intervals and, in case a country observed a decrease in refugees, it was assumed those refugees returned home. For the refugees that remain in Europe, it was assumed they visit Ukraine on average once a year, with only 20% of refugees overseas visiting Ukraine in the third year.

Data on IDPs have been collected by the International Organization for Migration (IOM), a UN body, through its Displacement Tracking Matrix (DTM).[55] The data shows the number of IDPs and the number of returnees over time. The highest number of both categories was multiplied by an average travelled distance to obtain passenger kilometres. The highest number of IDPs was observed in May 2022 with a total of 8.03 million persons, while the highest number of returnees was in September 2022 with a total of 6.04 million persons. The average travelled distance is 434 km based on government reporting on the origin and destination of IDPs in the early phase of the war.

Russians leaving Russia are not tracked by either of the two UN organisations, the UNHCR

54. Ukraine Refugee Situation, UNHCR. https://data.unhcr.org/en/situations/ukraine
55. Ukraine Displacement Tracking Matrix, IOM. https://dtm.iom.int/ukraine

or the IOM. An article on Wikipedia[56] reports a total of 900,000 individuals having left Russia by October 2022, citing a variety of sources. Russians have left for Turkey, Georgia, Armenia, Serbia, Kazakhstan, the United Arab Emirates, Finland and many other countries. While no exact numbers are available on the distribution between different countries, we estimate the emissions conservatively by assuming that 700,000 of them left by airplane over a distance of 4,000 km, representing an average of trips from Moscow to Antalya, Belgrade, Almaty, and Dubai, while 200,000 individuals left by cars, with four persons inside, over a distance of 2,500 km, representing trips from Moscow to Tbilisi, Yerevan, or Astana. We have assumed that 15% returned to Russia in the second year[57] and another 15% returned in the third year of the war.

6.5 Emission factors

Emission factors in gCO_2e per passenger kilometre (pkm) have been taken from official UK reporting for the year 2022[58] for the following transportation modes:

- Coach 27.3 gCO_2e/pkm
- Petrol car, 4 passengers 42.6 gCO_2e/pkm
- National rail 35.4 gCO_2e/pkm
- Short-haul flight 151.0 gCO_2e/pkm
- Long-haul flight 147.9 gCO_2e/pkm

Aviation emission factors are taken for economy class and include the impact of increased warming from aviation emissions at altitude.

6.6 GHG emissions

The resulting emissions are provided in the table below.

	Year 1	Year 2	Year 3	Total
Refugees	1.53	0.87	1.04	**3.44**
IDPs	0.13	0.04	0.04	**0.21**
Russians	0.44	0.07	0.04	**0.55**
Total	**2.10**	**0.98**	**1.12**	**4.20**

Table 21: Overview of transport emissions from refugees, IDPs, and Russians (in $MtCO_2e$)

56. See https://en.wikipedia.org/wiki/Russian_emigration_following_the_Russian_invasion_of_Ukraine
57. https://www.themoscowtimes.com/2023/10/25/15-of-russians-who-fled-war-mobilization-have-returned-survey-a82885
58. https://ourworldindata.org/grapher/carbon-footprint-travel-mode

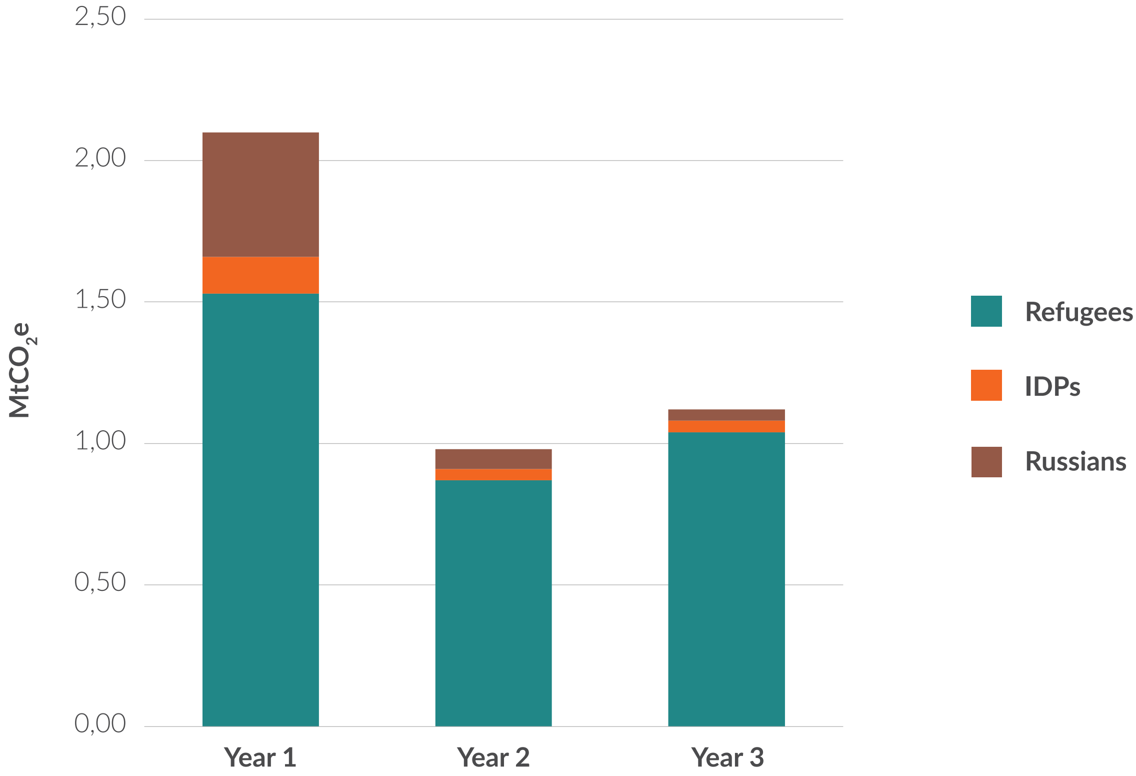

Figure 15: Emissions caused by refugees, IDPs, and Russians

Not all movements can be determined using data sources, which leads to an underestimation of emissions. For example, not all Refugees unregister when returning home. Furthermore, the number of refugees who returned home declined after peaking in September 2022, suggesting that some fled again.

7. Civil Aviation

7.1 General description

Russia's war in Ukraine has a significant impact on aviation. The closure of Ukraine's airspace to commercial traffic and various airspace bans issued by Western countries and Russia have cut important east-west airways between Europe and Asia for many Western carriers, making nearly 18 million km^2 inaccessible for overflights. Carriers were forced to take detours on routes to East and Southeast Asia resulting in longer flight times, as well as added fuel costs and higher emissions.

Although only European and North American carriers are explicitly banned from Russian airspace, Asian airlines, including JAL, ANA, Korean Air, Cathay Pacific, Singapore Airlines and Asiana are all avoiding Russian airspace. Similarly, Australian airlines are avoiding Russian airspace as a precautionary move.

The following airspaces have either been closed due to safety concerns or as a result of sanctions:

- Russian airspace: Russia has closed Russian airspace for the airlines of 36 'unfriendly' countries[59].
- Western airspace: The EU, US, UK, Canada, Norway, Switzerland, Iceland and several Balkan states have closed their airspace to Russian and Belorussian airlines.
- Ukrainian airspace: The airspace above Ukraine is closed to all air traffic and direct flights to/from Ukraine are suspended due to ongoing hostilities. Furthermore, airspace in the south-west of Russia close to Ukraine is closed for all civil air traffic.

The impact on flights can be summarised as follows:

1. Travel between Europe and Asia requires a detour in order to avoid **Siberian airspace**. This is only applicable to Western airlines from 'unfriendly' countries. Other airlines, like the ones from the Middle East of China, can still use Russian airspace.
2. Travel between North America and Asia is affected as well, avoiding flying over Kamchatka in the **Russian Far East**.
3. Travel between Kaliningrad and the Russian mainland requires a significant detour to avoid **European airspace**, and so do flights from Moscow to Cuba.
4. Some flights in the eastern part of Europe now need to circumvent **Ukrainian airspace**.
5. Many flights over the south-west of Russia are required to keep a safe distance f**rom the Ukrainian border**.
6. Direct travel between Russia and several European and North America destinations is suspended, and therefore requires at least one transfer in a third country.
7. Travel to/from Ukraine requires ground travel to the nearest airport in Europe, mainly in Poland.

7.2 Attribution

Air traffic patterns are continuously changing, while air traffic is recovering from the COVID pandemic. Therefore, comparing historic pre-war flight emissions with current flight patterns

59. https://www.alternativeairlines.com/airlines-flying-over-russian-airspace

would not be a valid approach to attribute additional carbon emissions to airspace closures. Air traffic and passenger flows should be reconstructed in the absence of airspace closures and this counter-factual situation should be compared to actual emissions. This way, the increase in emissions can be attributed to the war. In practise, a full reconstruction of such 'no war situation' would be very complicated, if not impossible, in particular as time passes by. Furthermore, a shift from direct flights to the ones with a detour, as mentioned above under points 6 and 7, cannot be covered. However, for the affected direct flights, mentioned under points 1–5, an approximation can be made, which is described below.

7.3 Calculation method

Increased aviation emissions are determined by calculating an increased flight distance of each unique arrival-departure airline pair post-invasion compared to the pre-invasion route based on real flight paths. Fuel consumption of each unique pair post-invasion was calculated based on the latest ICAO methodology.[60] Then, it was assumed that each flight pre-invasion, without airspace closures, would have flown a shorter route and corresponding fuel consumption was calculated.

7.4 Activity data

We received a data set from Flightradar24.com containing all flights worldwide during the period 23–30 September 2021 (i.e. pre-invasion) and the same period in 2023 (post-invasion). For each flight, the data contained the airport of departure, airport of arrival, airline, aircraft type and GPS coordinates of the aircraft during the whole flight. Out of this dataset, only flights that flew over Russia, Belarus or Ukraine in 2021 were considered. For each unique arrival-departure airline pair, the average travel distance in 2021 and 2023 was calculated. Flights with a flight distance shorter than 400 kilometres were excluded, and so were flights with an increase of travel distance by less than 3%.

A visual check of these flights was performed to filter out those where increased travel distance was not related to airspace closures. These were mainly domestic flights in Russia east of the Urals. All flights of the 7–8-day period were added and extrapolated to a full year.

7.5 Emission factors

The emission factor of kerosine (3.16 kgCO_2/kg of fuel) has been used to calculate the increase in emissions. Other GHGs, radiative forcing of vapour trails or upstream emissions from kerosine production have not been taken into account.

60. ICAO Carbon Emissions Calculator Methodology, version 13.1, Aug 2024, Appendix C: ICAO Fuel Consumption Table.

7.6 GHG emissions

Examples of rerouting of flights pre-invasion and post-invasion are visualised below for each type of detours.

Figure 16: Example of airspace closure above Siberia (1): London–Tokyo

Figure 17: Example of airspace closure above Kamchatka (2): Anchorage–Zhengzhou

Figure 18: Example of airspace closure above the EU (3a): Kaliningrad–Moscow

Figure 19: Example of airspace closure above the EU (3b): Moscow–Cayo Coco

Figure 20: Example of airspace closure above Ukraine (4): Chisinau–Warsaw

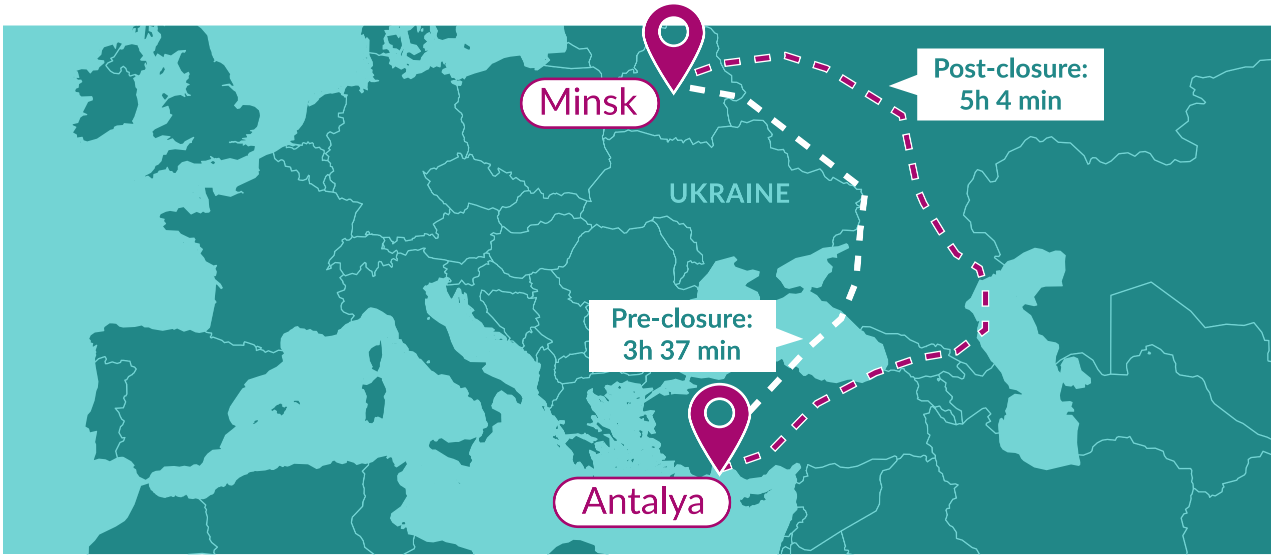

Figure 21: Example of airspace closure above the south-west of Russia: Minsk–Antalya[61]

Annually, over 353,000 flights were affected by airspace closures with an increase of carbon emissions by 3.7 million tCO_2 on an annualised basis. All flights and their pre- and post-invasion trajectories can be viewed at the following tableau: https://public.tableau.com/app/profile/leroy8630/viz/Warbon/warbon

This approach relies on the actual flown flight paths but has some limitations leading to a considerable underestimation of carbon emissions. The main limitation is that only arrival-departure airline pairs that existed both in 2021 and 2023 are taken into account. Due to the dynamics of the aviation industry recovering from the COVID period, this means that arrival-departure airline pairs that were relaunched in 2022/2023 but did not fly in 2021 are not considered.

The period of 23–30 September was selected as a representative week and extrapolated to a full year. Seasonal flights that did not operate during 23–30 September 2021/2023 are therefore not included. Another limitation is that, as mentioned above, only direct flights are taken into account, whereas passenger flows could have been affected significantly. This is in

61. Ukraine closed its airspace to Russian and Belorussian airlines in May 2021 following the forced landing of a Ryanair flight from Greece to Lithuania in Minsk.

particular the case for passengers to/from Russia that have to fly through third countries, like Turkey or Serbia, and flights to/from Ukraine which have been suspended, requiring travellers to travel over land to an airport in Europe to continue their journey.

A paper published in *Nature*[62] tried to estimate the emissions increase while relying not on the actual flight data but on flights modelling. It concluded that the increase in emissions in 2022 was 0.5% of global aviation emissions rising to 1% or 8.2 million tCO_2 in 2023. Assuming the same percentage for 2024, the emissions increase is as follows:

	Year 1	Year 2	Year 3	Total
Civil Aviation	3.3	8.2	8.8	**20.3**

Table 22: GHG emissions caused by detours of civil airplanes (in $MtCO_2$)

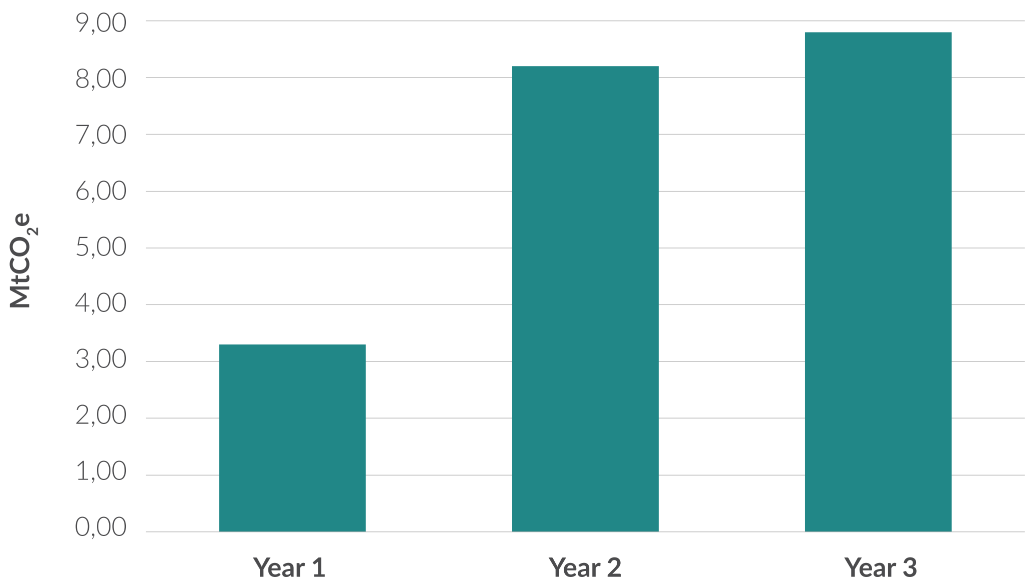

Figure 22: Increased GHG emissions caused by detours of civil aviation

62. Airspace Restrictions due to Conflicts Increased Global Aviation's Carbon Dioxide Emissions in 2023. https://www.nature.com/articles/s43247-024-01956-w

8. Reconstruction

8.1 General description

Destroyed or damaged civilian infrastructure is an important component of the climate damage caused by Russia's war in Ukraine. Many buildings, like apartment blocks, hospitals, kindergartens, and commercial and industrial buildings, have been damaged or destroyed. Utilities, roads, vehicles, and industries suffered significant damage. Reconstruction will cause significant emissions, mainly due to the use of carbon intensive building materials like cement and steel.

8.2 Attribution

Construction is a normal activity during peacetime and some impacted infrastructure would have been (re)built in the absence of the conflict as well. Typical lifetime of buildings or other infrastructure is over 50 years; hence, reconstruction emissions should theoretically be discounted: 2% for each 12 months of the conflict. However, given the fact the level of uncertainty of the activity data and emission factors is higher, discounting has been omitted in line with the Guidance.

A lifecycle approach is used to determine reconstruction emissions. Some lifecycle elements are disregarded, in particular maintenance, replacement and refurbishment, as those activities would have happened at the damaged or destroyed buildings as well.

Damage to buildings and other infrastructure caused by the armed conflict (and not by other causes) has been determined and collected by the Kyiv School of Economics as described below.

8.3 Calculation methodology

To assess emissions from the reconstruction of civilian infrastructure, the embodied carbon approach is used.

The different types of properties were grouped into three categories:

- The first category, Buildings, comprises residential sector, health care, social sector, education and science, culture, religion, sports, tourism and retail. These objects mainly include buildings.
- The second category, Transport & Infrastructure, comprises infrastructure, vehicles and agricultural machinery. These objects are a mixture of civil engineering objects, e.g. bridges and roads, plus transport vehicles of different types.
- The third category, Industry & Utilities, comprises the energy sector, industry and business services, digital infrastructure and utilities. These objects mainly include machinery and equipment combined with buildings (factories) housing the machinery.

For the *Buildings* category, the embodied carbon is based on the average buildings' areas, data on which were provided by the Kyiv School of Economics multiplied by an emission factor expressed in $kgCO_2e/m^2$.

For the category of *Transport & Infrastructure*, embodied carbon factors were considered for different types of objects, like tCO_2e/km of a damaged road or tCO_2e of a damaged car. Where embodied carbon factors were not available, spend-based emission factors were used based on the Environmentally Extended Input Output (EEIO) analysis. These factors reflect the amount of carbon emitted when purchasing a certain good or service for a certain value (tCO_2e/USD).

For the category of *Industry & Utilities*, all emissions were calculated based on the EEIO approach with the replacement value as input.

The assumption was made that fully destroyed facilities will be completely rebuilt, and 100% of the emission factor is therefore applied. For damaged property, a generic factor of 33% was applied to the embodied carbon factor unless a pro rata adjustment could be derived from replacement value for destroyed and damaged property.

8.4 Activity data

The KSE has aggregated information on damaged or destroyed facilities, including the destruction of assets and infrastructure in those territories that where occupied after 24 February 2022, coming from different Ukrainian ministries, other governmental sources or from open sources. Where information is not available or restricted due to security reasons, the KSE uses estimations to provide a comprehensive picture. Their overall damage assessment has been carried out in accordance with the methodology of the World Bank with monetary damages representing the replacement value. The KSE report is the basis for the activity data.

For this assessment, we have used the KSE report on damage and losses assessment for the period of 24 February 2022–30 November 2024.[63] In addition, we have used a second source to establish the amount of residential building damaged and destroyed in the period of 1 December 2024–23 February 2025. Damage to non-residential buildings and other categories was not included for these three months, meaning there will be a slight underreporting of reconstruction emissions.

8.5 Emission factors

Emission factors for buildings

To reflect the most recent construction practice used in the region to determine the embodied emission factor of buildings, a database of One Click LCA[64], a software programme to perform Life Cycle Assessments (LCA) for buildings, was used. This database contains LCAs of recently designed buildings of different types in various countries. From this database, LCAs performed in 16 countries in Central and Eastern Europe in the past three years were selected to calculate an average CEF. Depending on the building type, the average was based on 4 to 100 building designs.

Apartment buildings	Emission factor (kgCO_2e/m^2)
Apartment buildings	408
Cultural buildings	295
Educational buildings	419
Hotels and similar buildings	445
Industrial production buildings	398
Office buildings	379
Retail and wholesale buildings	401
Warehouses	305

Table 23: Emission factors per building types for lifecycle stages A1-A3, A4-A5, and C1-C4

63. Report on Damages to Infrastructure from the Destruction Caused by Russia's Military Aggression against Ukraine as of November 2024, https://kse.ua/about-the-school/news/damages-to-ukraine-s-infrastructure-due-to-the-war-have-risen-to-170-billion-kse-institute-estimate-as-of-november-2024/

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

Emission factors for infrastructure and vehicles

For roads, a study estimated the lifecycle emissions of different types of roads.[65] Most of the roads in Ukraine are single-2 lane and only the construction stage is taken into account as road operation and maintenance emissions would happen on existing roads as well. For a single-2 lane road, embodied carbon adds up to 711 kg CO_2e per kilometre of a road.

The embodied carbon of a passenger car was taken as a reference to determine the emission factor of other vehicle types by multiplying the factor by the relative weight of other vehicles.

Apartment buildings	Emission factor ($kgCO_2e/m^2$)
Passenger cars	5.6
Trolleybuses	40.7
Trams	125.4
Buses	49.5
Fire trucks	89.6
Agricultural machinery	28.2

Table 24: Emission factors per vehicle type

For certain infrastructural elements, like bridges, EEIO-based factors mentioned below were used.

Emission factors based on the EEIO analysis

Spent-based emission factors for the United Kingdom were used[66] converted into USD using the average 2022 exchange rate of 1.23 GBP/USD.

Activity	SIC Code	$kgCO_2e$/USD
Electric equipment	27	1159
Machinery and equipment	28	713
Motor vehicles, trailers, and semi-trailers	29	672
Air and spacecraft and related machinery	30.3	504
Buildings and building construction works	41.2	344
Constructions and construction works for civil engineering	41.1-2	401
Average buildings and machinery		529
Average construction and machinery		780

Table 25: Spent-based emission factors per activity

65. Lokesh, K., Densley-Tingley, D. and Marsden, G. (2022), Measuring Road Infrastructure Carbon: A 'Critical' in Transport's Journey to Net-Zero, Leeds: DecarboN8 Research Network, https://decarbon8.org.uk/wp-content/uploads/sites/59/2022/02/Measuring-Road-Infrastructure-Carbon.pdf
66. UK Department for Environment, Food & Rural Affairs, Conversion Factors $KgCO_2$ per £ Spent, by SIC Code 2022, https://www.gov.uk/government/statistics/uks-carbon-footprint

8.5 GHG emissions

The results are provided in the table and figure below.

Category	Year 1	Year 2	Year 3	Total
Buildings	18.5	4.5	1.1	**24.1**
Transport & Infrastructure	16.0	0.9	0.6	**17.5**
Industry & Utilities	13.4	4.0	4.8	**22.2**
Total reconstruction	**47.9**	**9.4**	**6.5**	**63.8**

Table 26: Overview of reconstruction emissions (in $MtCO_2e$)

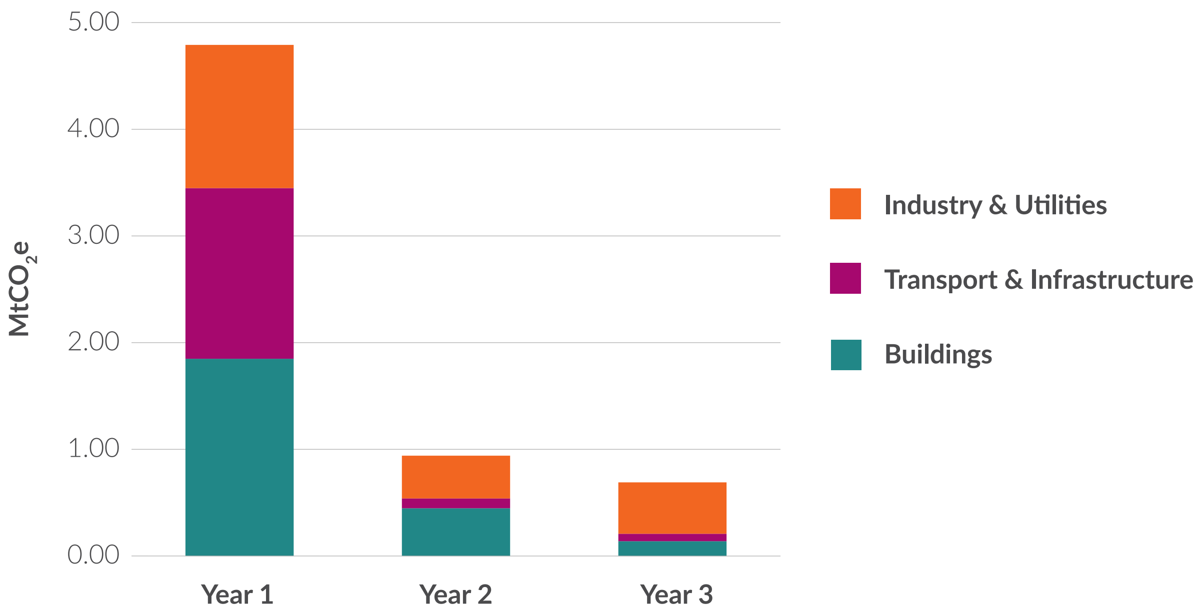

Figure 23: Reconstruction emissions for each year

Please note that above table and figure depict the year in which damage or destruction occurred. As the majority of reconstruction is expected after the end of the war, also the associated emissions will happen later.

For the purposes of assessment of emissions from reconstruction, assumptions had to be made on how reconstruction will look like. One of the assumptions is that the housing stock destroyed or damaged will be fully reconstructed as was before the war. Obviously, the reconstruction of Ukraine will take into account the 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, as not all refugees will return. On the other hand, as Soviet-built apartments are rather small compared to modern standards, new apartments will probably be larger in size. The emission factors for buildings were based on averages from Central and Eastern Europe, while construction emissions in Ukraine are probably higher.

9. Summary

9.1 Total emissions per 12-month period

Impact category	Year 1		Year 2		Year 3	
	Emissions ($MtCO_2e$)	Percentage (%)	Emissions ($MtCO_2e$)	Percentage (%)	Emissions ($MtCO_2e$)	Percentage (%)
Warfare	23.2	21%	28.2	49%	30.4	43%
Landscape fires	17.3	16%	9.0	16%	23.1	32%
Energy infrastructure	14.9	14%	0.9	2%	1.2	2%
Refugees	2.1	2%	1.0	2%	1.1	2%
Civil aviation	3.3	3%	8.2	14%	8.8	12%
Reconstruction	47.9	44%	9.4	17%	6.9	9%
Total	**108.7**	**100**	**56.7**	**100**	**71.5**	**100**

Table 27: GHG emissions per year

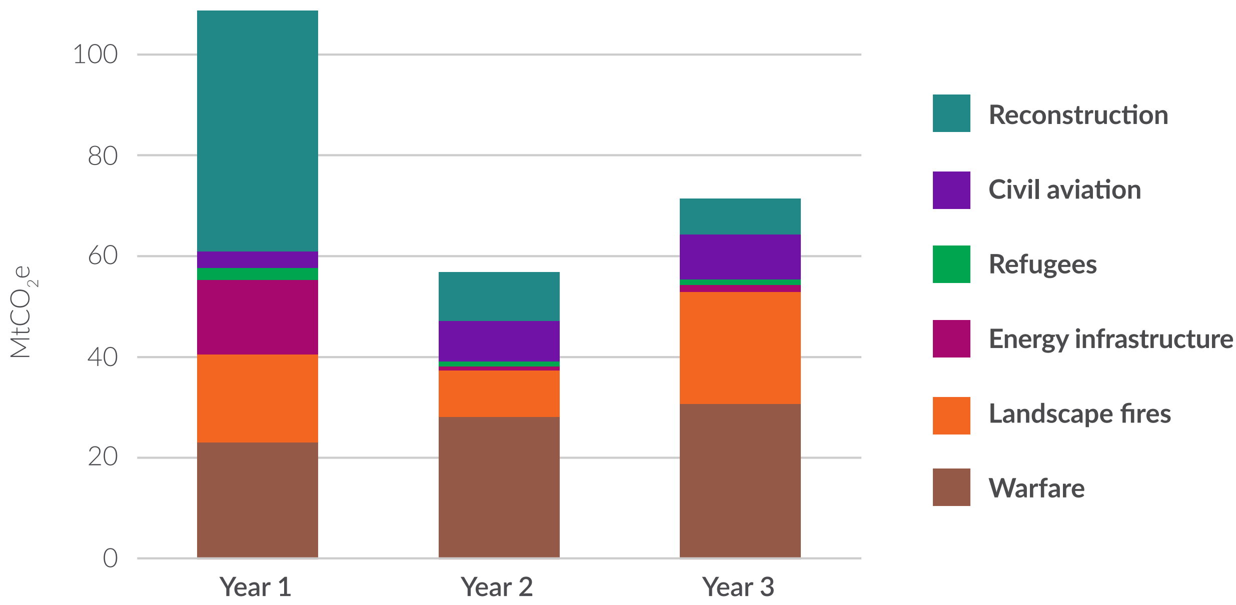

Figure 24: GHG emissions per year

9.2 Cumulative emissions

Impact category	First year		Two years		Three years	
	Emissions ($MtCO_2e$)	Percentage (%)	Emissions ($MtCO_2e$)	Percentage (%)	Emissions ($MtCO_2e$)	Percentage (%)
Warfare	23.2	21	51.4	31	81.7	34
Landscape fires	17.3	16	26.3	16	49.4	21
Energy infrastructure	14.9	14	15.7	9	17.0	7
Refugees	2.1	2	3.1	2	4.2	2
Civil aviation	3.3	3	11.5	7	20.3	9
Reconstruction	47.9	44	57.3	35	64.2	27
Total	**108.7**	**100**	**165.3**	**100**	**236.8**	**100**

Table 28: Cumulative emissions after three years

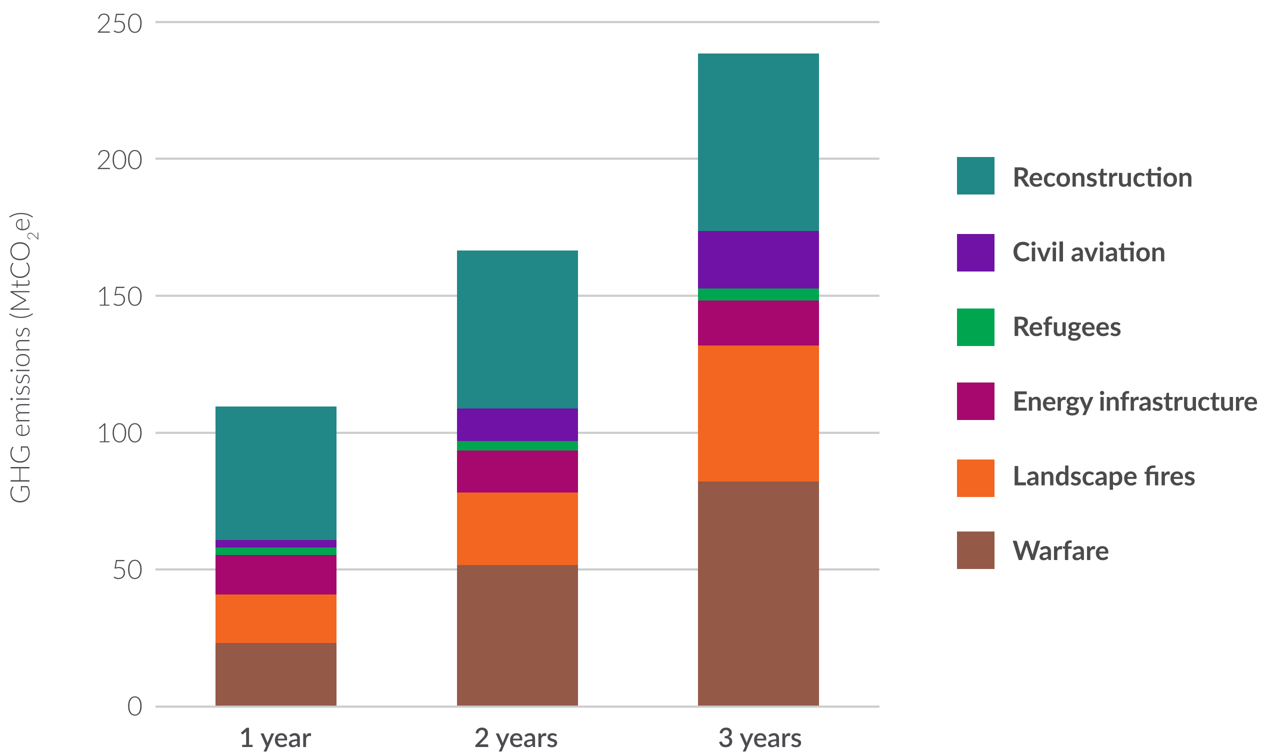

Figure 25: Cumulative emissions after three years

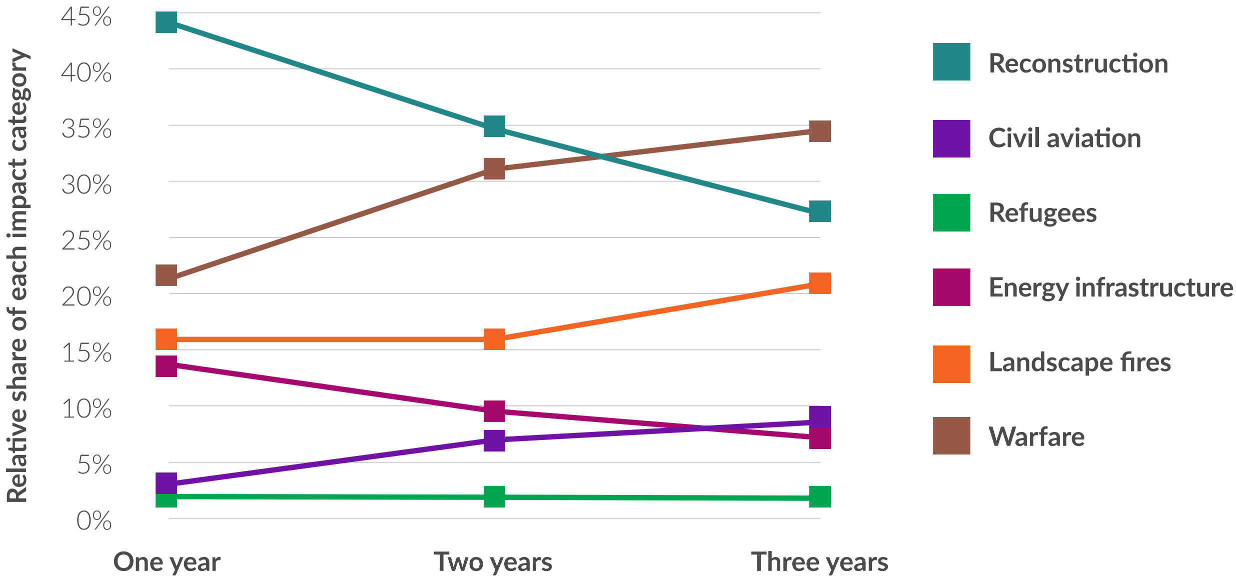

Figure 26: Relative share of each impact category

9.3 Pre-conflict, conflict and post-conflict emissions

Impact category	Pre-conflict	Conflict	Post-conflict
Fuel consumption by militaries	0	73.5	0
Use of ammunition	0	5.1	0
Manufacturing of military equipment	0	2.5	0
Fortifications	0	0.6	0
Damage to the energy infrastructure	0	17.0	0
Landscape fires	0	14.8	34.6
Total direct conflict-related emissions	**0**	**113.5**	**34.6**
Movement of refugees and IDPs	0	4.2	0
Civil aviation	0	20.3	0
Reconstruction	0	0	64.2
Total indirect conflict-related emissions	**0**	**24.5**	**64.2**
Total conflict-related emissions	**0**	**138.0**	**98.8**

Table 29: Pre-conflict, conflict and post-conflict emissions