Polish Economic Institute

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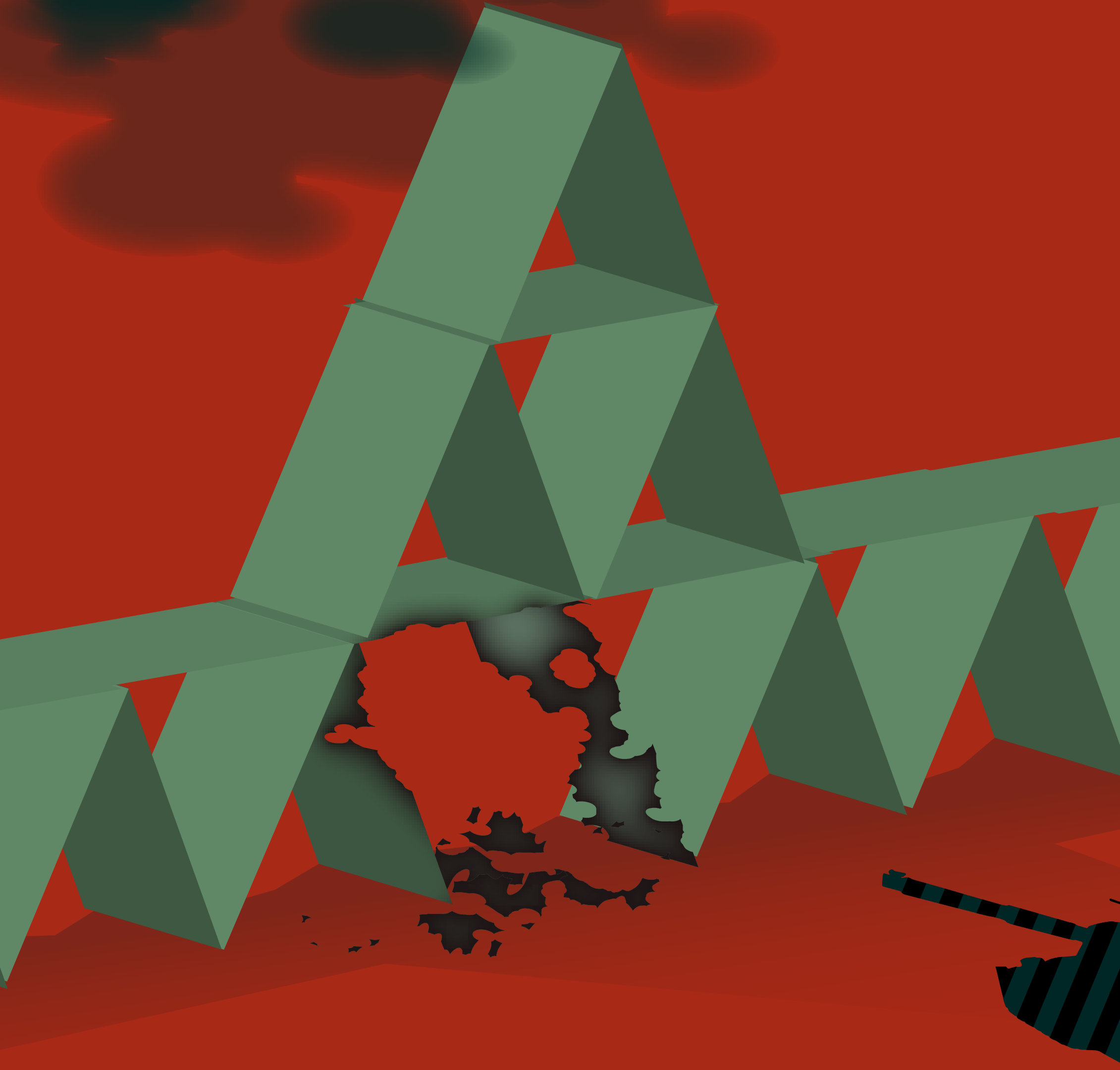
WARSAW



The climate costs of the Russian invasion

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Key numbers

212.7 million tonnes of CO_2-eq

climate cost of Russia's invasion of Ukraine in the moderate emissions scenario. This is 6% of the equivalent of all the EU's greenhouse gas emissions in 2022 and 53% of Poland's annual direct CO_2-eq emissions

EUR 16.6 billion

potential climate cost of Russia's invasion of Ukraine in the moderate emissions scenario. In this scenario, the climate costs will be equivalent to 10-19% of Ukraine's GDP

115 million tonnes of CO_2-eq emissions and EUR 8.9 billion

climate costs that could be avoided with Ukraine's green recovery

3.76 tonnes of CO_2

estimated emissions from one destroyed tank, according to the Ministry of Environmental Protection and Natural Resources of Ukraine

147,300-304,800 hectares

of forest may have been burnt during the invasion, according to estimates based on the monitoring of thermal anomalies by NASA FIRMS and EFFIS data

23.3 million tonnes of CO_2

potential emissions linked to the forced displacement of over 13.9 million Ukrainians and the emigration of 6.9 million of them

0.24 million tonnes of methane

may have been emitted as a result of damage to Ukrainian gas extraction, storage and transmission infrastructure between March and August 2022

4000 MW

of RES, 24% of Ukraine's installed RES capacity, may have been destroyed and damaged during the Russian invasion of Ukraine

Key findings

- **Total greenhouse gas emissions in February-September 2022 caused by Russia's invasion of Ukraine may have amounted to 98.1 million tonnes of CO_2 equivalent in the minimum emissions scenario, 212.7 million tonnes in the moderate one and as much as 326.9 million tonnes in the maximum emissions scenario.** We estimate the war's climate costs at EUR 6.5-25.5 billion. The Russian invasion of Ukraine has caused significant environmental and climate damage, which will require many years of work by the international community to make up for. The final assessment of these costs will be possible once the conflict is over.
- **A green recovery with the participation of the EU, UK and US could enable as much as 115 million tonnes of CO_2 emissions to be avoided and reduce the war's climate costs by EUR 8.9 billion.** Lower emissivity of European economies and the transfer of green technologies enabling a rapid recovery of destroyed and damaged RES power will be key to limiting the climate impact of Russian invasion.
- **Solar and onshore wind energy will have the largest RES potential in Ukraine's green recovery.** In 2016-2021, before the Russian invasion, the capacity of solar power plants installed in Ukraine increased eight-fold (by 7000 MW), while wind energy capacities rose three-fold (by 1200 MW). Long-term investments in this sector could help prevent the emission of as many as 39.5 million tonnes of CO_2 in 2022-2025, compared to a situation in which Ukraine lacks the support of investors from EU and NATO countries.
- **The value of emissions from fires in forests and built-up areas could amount to as much as 27.4 million tonnes of CO_2.** This is more than emissions by intra-EU flights in 2022-2023 (23 million tonnes), as forecast by the EEA. The Russian invasion is destroying thousands of hectares of Ukrainian forests and protected areas. According to our estimates, 50,000-305,000 hectares of forests have been burnt during conflict.

- **Rebuilding wartime damaged and the Ukrainian economy will make up the largest share (77%) of the war's climate costs in 2022 (in the moderate scenario)** in the absence of external support, due to this economy's high emission intensity. The climate costs linked to the movement and stay of Ukrainian war refugees due to the Russian invasion (10%), forest fires (6%) and the suspension of the development of Ukrainian-RES (6%) will have a significant impact on emissions, too. Moving military equipment and military operations account for a small share of the climate costs (less than 0.01%) compared to the scale of the damage they have caused.

Introduction

The Russian invasion of Ukraine on 24 February 2022 has affected not only people, states and economies. Another, often overlooked, victim of the war is the climate and natural environment. Climate crises triggered by war destroy the resources humans need to live and function.

Each conflict drives the next one, in the process known as the "treadmill of destruction" (Clark, Jorgenson, 2012).[1] Assessing the consequences of war is difficult, often ambiguous and requires complex estimates made in a situation of uncertainty. However, it should be a significant area in the analysis of the costs associated with the aggressor's and the invaded country's actions.

In this report, we analysed the multifaceted climate impact of the war on Ukraine's territory in February-September 2022. Given the significant differences between analytical centre's estimates, we present three scenarios: minimum, moderate and maximum emissions, using different sources and calculation methods. By the war's climate cost, we mean total CO_2 emissions linked to the movement of armies, the destruction of both sides' military equipment (outlined in the first part of the record), fires in forest and built-up areas (analysed in the second part), damage to energy infrastructure (part three), the movement of people displaced by the war (part four), rebuilding damaged caused by the war (part five), and the costs of delaying the development off Ukrainian RES and the the lengthening timeline for the reconstruction and modernisation of Ukraine's energy sector (part six).

In the report, we attempted to estimate the CO_2 emissions caused by the movements of armies and the destruction of Ukrainian and Russian military equipment. Furthermore, we used estimates by NASA and the Ukrainian government, as well as the NASA FIRMS system's data on thermal anomalies and EFFIS data on forest fires, to estimate the scale of the destruction of Ukraine's forest areas and its climate impact. Moreover, data on the functioning of Ukraine's transmission system and reports on damaged oil storage

[1] The "treadmill of destruction" is a self-fuelling cycle of competition for scarce resources, militarisation, armed conflicts, environmental and climate costs, and economic crises. The term was first used by Gregory Hooks and Chad Smith, deriving it from the critical thought of American sociologist Charles Wright Mills and the concept of the "treadmill of production" attributed to American sociologist Allan Schnaiberg. The term was first defined in 2005 in a research paper by Hooks and Smith entitled "Treadmills of Production and Destruction" (Hooks, Smith, 2005).

facilities were used to analyse the greenhouse gas emissions linked to the destruction of oil and gas reserves and gas pipeline leakage. UNHCR data were used to analyse the climate impact of wartime migration.

The scale of wartime destruction, recovery costs and modelling a scenario for the development of Ukrainian RES enable us to estimate the climate significance of the green recovery and the support that Ukraine should receive once the conflict ends. The results show the scale of the climate impact of Russia's invasion of Ukraine. In the report, we calculated previously unknown climate costs linked to Russian aggression.

Additional greenhouse gas emissions caused by the Russian invasion

Emissions linked to the concentration, movement and upkeep of the Russian armed forces

Calculating the exact level of emissions associated with army movement and operations would require full information about the number, weapons and location of military forces. This is generally impossible, both during the war and for years after it ends. The armed does not report the emissions linked to its operations and researchers studying the subject use general assumptions and estimates (Michaelowa et al., 2022). Yet since army operations are an integral part of every armed conflict, a list of climate costs should take into account at least approximate estimates relating to them.

Three main types of emissions linked to army movement and operations can be identified:

1. Greenhouse gas emissions linked to the concentration, movement and upkeep in Ukraine and in the Russian Federation of the Russian armed forces involved in the invasion,
2. Greenhouse gas emissions linked to the movement of the Ukrainian armed forces forced to defend their own territory,
3. Greenhouse gas emissions caused by damage to heavy equipment used by either side.

The emission-generation actions caused by Russian aggression began months before the invasion (24 February 2022). The Russian troops concentrated at the border, ranging between 150,000 (www1) and 170,000 (www2), had to be transported within Russia, equipped and prepared before the attack. In February 2022, experts from Ukrainian consultancy ТОВ «КТ-Енергія» estimated the level of emissions caused by the concentration of troops in 12.2021-02.2022 (60 days) at 136,000 tonnes of CO_2. However, they noted the calculations' incomplete nature, including the exclusion of the air force (www3) because it is difficult to monitor, and taking into account the movement of just 6 of the 20 Black Sea Fleet units (www4).

We used the assumptions of the authors of a report on the emissions caused by individual types of Russian armed forces (www5) to estimate the level of emissions caused by actions during the period preceding the escalation and during the first months of the invasion. The calculations were carried out for the concentration of Russian forces in 12.2021-02.2022 and the military operations in 02-07.2022.

Chart 1. CO_2 emissions caused by the concentration and movement of Russian and Ukrainian armed forces in 12.2021-06.2022 (tonnes)

① Emissions by Ukrainian warplanes, **10 087**
② Provisioning of Russian forces, **3 566**
③ Provisioning of Ukrainian forces, **1 748**

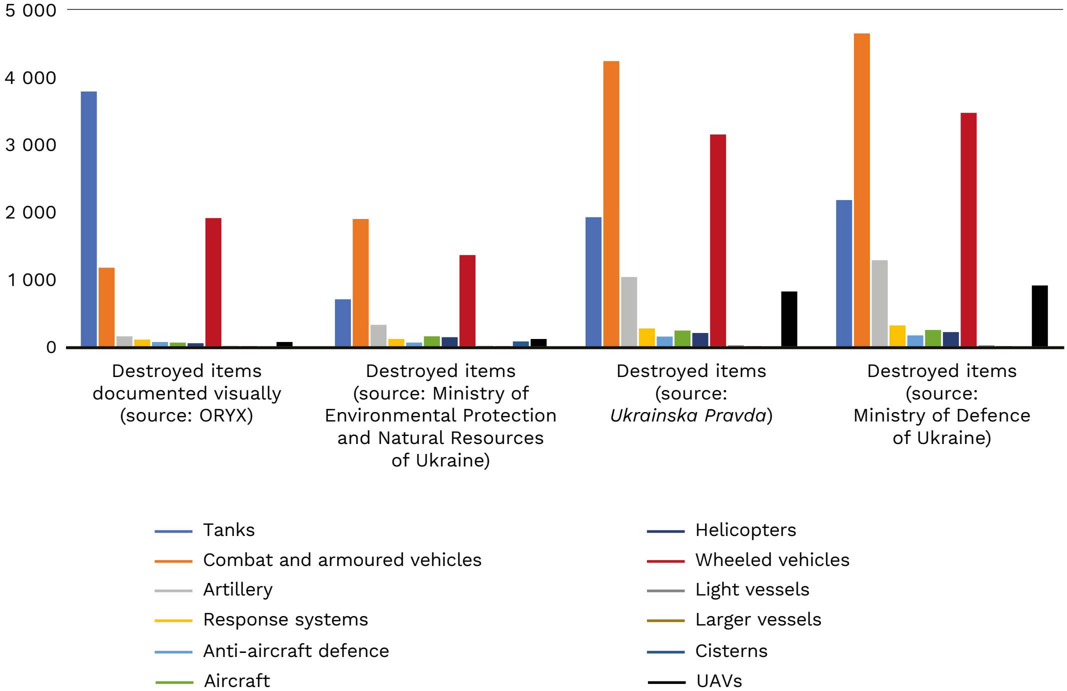
Source: prepared by PEI based on kt-energy.com.ua methodology and data from europarl.europa.eu and globalfirepower.com.

Based on these results, the total level of emissions caused by the Russian armed forces' operations can be estimated at 751,000 tonnes of CO_2. The following areas contributed the most: linked to the equipment and upkeep of Russian bases and armed forces (a total of 245,000 tonnes of CO_2), Russian warplanes' activity (142,000 tonnes of CO_2), Black Sea Fleet vessels' activity (187,000 tonnes of CO_2) and Russia's use of warplanes (at least 142,000 tonnes of CO_2). The emissions caused by the Ukrainian armed forces are more difficult to estimate due to the lack of adequate studies. In the report, we took into account the Ukrainian air force's activity (significantly lower than the Russian one's) (www6) and the costs of equipping the armed forces. However, we did not include the relocation of Russian and Ukrainian forces on Ukraine's territory due to its insignificant impact on the level of greenhouse gas emissions.

Emissions caused by the destruction of Russian and Ukrainian heavy equipment

The destruction of military equipment is one of the more discernible sources of greenhouse gas emissions. Usually, each side announces its own losses with a delay, as this data is directly linked to the assessment of the course of the hostilities. We tried to account for the significant differences the Ukrainian and the Russian estimates by juxtaposing data from a variety of sources.

Chart 2. Destroyed Russian military equipment, as of 16.09.2022 (number of items)



Source: prepared by PEI based on data from ORYX, the Ministry of Environmental Protection and Natural Resources of Ukraine, the *Ukrainska Pravda* newspaper and the Ministry of Defence of Ukraine.

The values obtained from various sources vary when it comes to both the type and number of destroyed weaponry. Given the similarity of the Ukrainian and Russian military equipment used during the first stage of the war, we adopted similar greenhouse gas emissions coefficients.

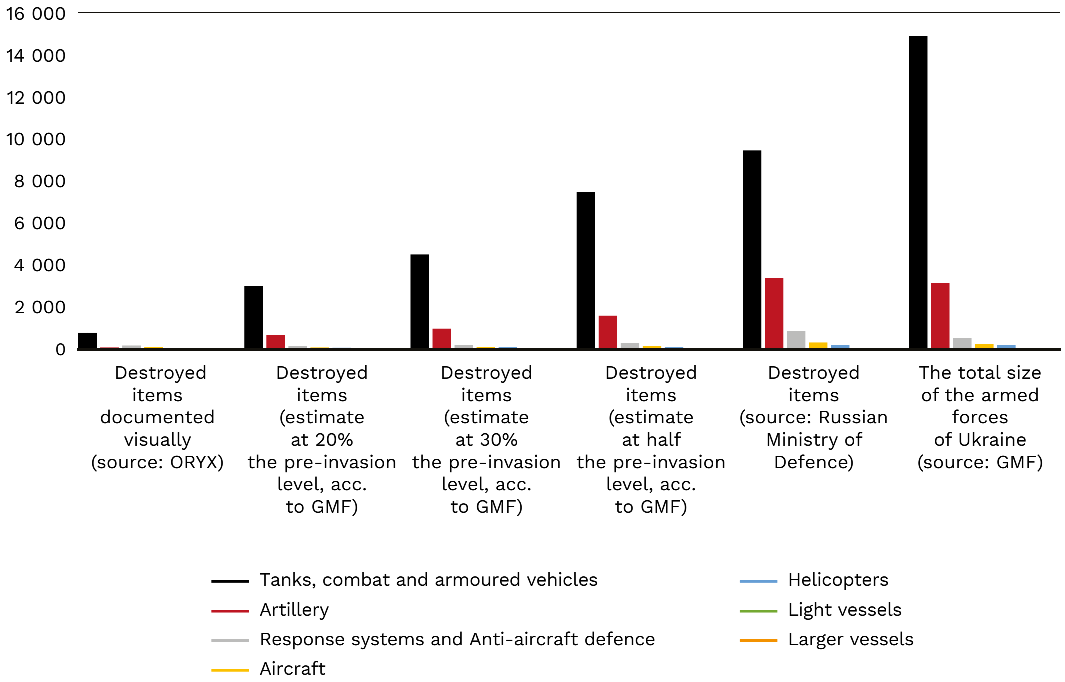
Table 1. Comparison of CO_2 emissions from destroyed Russian military equipment (tonnes)

Type of item	**Emissions (tonnes of CO_2/ destroyed item) (www5)**	**Emissions from destroyed items documented visually (ORYX; www7)**	**Emissions from destroyed items (Ukraine's Ministry of Natural Resources)**	**Emissions from destroyed items (*Ukrainska Pravda*; www8)**	**Emissions from destroyed items (Ukraine's Ministry of Defence; www9)**
Tanks	3.76	14 243	2 624	7 215	8 178
Combat and armoured vehicles	1.45	1 694	2 742	6 147	6 745
Artillery	1.73	260	557	1 785	2 213
Response systems	2.33	238	252	620	725
Anti-aircraft defence	1.83	121	101	265	302
Aircraft	35.93	1 940	5 390	8 408	8 767
Helicopters	4.57	215	617	905	973
Wheeled vehicles	0.53	1 011	720	1 669	1 839
Light vessels	500.65	3 505	3 004	7 009	7 009
Larger vessels	15.11	15	15	15	15
Cisterns	0.12	0	9	0	0
UAVs	0.02	1	2	16	18
Total emissions:	**-**	**23 241**	**16 032**	**34 054**	**36 784**

Source: prepared by PEI.

The destruction of Ukrainian equipment is much less visually documented (www5). We carried out a general estimate based on the percentage value of Ukraine's destroyed military potential. The data on Ukrainian losses reported by Russian's Ministry of Defence (www10) overstates Ukraine's total potential, which makes it not very credible, nor are the reports spread by Russian news agencies (www11; www12) suggesting that half of Ukraine's military potential has been destroyed.

Chart 3. Destroyed Ukrainian military equipment, as of 16.09.2022 (number of items)



Source: prepared by PEI based on data from ORYX, GMF and Russia's Ministry of Defence.

According to the Russian Ministry of Defence's official data, the Russians allegedly destroyed 273 of the 206 Ukrainian planes that exist and 148 of Ukraine's 146 helicopters. This undermines the credibility of the reported data, especially since the visual documentation is scarce. For this reason, we did not use Russian Ministry of Defence data for further calculations. However, we present it in the table for illustrative purposes.

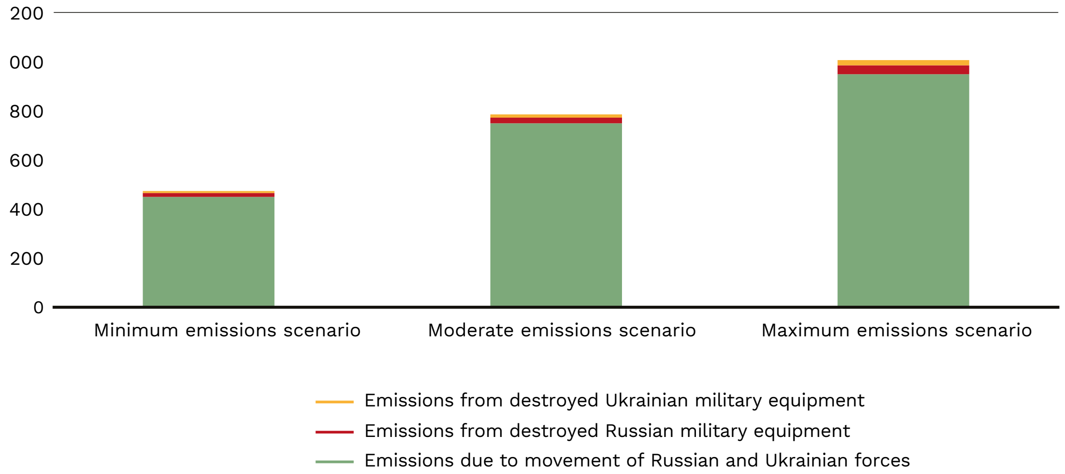
Table 2. Comparison of CO_2 emissions from destroyed Ukrainian military equipment (tonnes)

Type of item	Emissions(in tonnes of CO_2/ destroyed item) (www5)	Emissions from destroyed items documented visually (ORYX; www13)	Emissions from items (destruction estimated at 20% of pre-invasion level, acc. to GMF; www14)	Emissions from items (destruction estimated at 30% of pre-invasion level, acc. to GMF; www14)	Emissions from items (destruction estimated at 50% of pre-invasion level, acc. to GMF; www14)	Emissions from destroyed items (Russian Ministry of Defence; www15)
Tanks, combat and armoured vehicles	1.85	1 358	5 513	8 270	13 783	17 449
Artillery	1.73	73	1 074	1 612	2 688	5 778
Response systems and Anti-aircraft defence	1.97	250	193	290	483	1 613
Aircraft	35.93	1 617	1 473	2 228	3 701	9 809
Helicopters	4.57	50	133	201	334	676
Light vessels	2.52	10	8	10	18	
Larger vessels	9.44	28	9	9	19	
Total emissions:	**-**	**3 386**	**8 403**	**12 620**	**21 024**	**35 326**

Source: prepared by PEI.

Given the significant discrepancies in the data being discussed, we distinguished between three variants of the emissions linked to the military operations so far. In the minimum emissions scenario, the military operations are the logistical continuation of the pre-war manoeuvres by Russian troops. The moderate variant takes into account the reports by the Ukrainian side on the scale of the destroyed Russian equipment and the additional climate costs related to the stationing and upkeep of Russian troops in Ukraine. The maximum emissions scenario assumes that, in addition to the operating costs and damage identified, troop movements may have been underestimated, translating into the higher combustion of fossil fuels and higher logistics-related costs.

Chart 4. Total CO_2 emissions from military operations (thousands of tonnes)



Source: prepared by PEI based on data from ORYX, the Ministry of Environmental Protection and Natural Resources of Ukraine, the *Ukrainska Pravda* newspaper, Ukraine's Ministry of Defence, and GMF.

In the minimum emissions scenario, total emissions was estimated at around 474,000 tonnes of CO_2; this was 786,000 tonnes in the moderate scenario and 1,007,000 tonnes in the maximum scenario. A comparison of the emissions from army movement and destroyed equipment from both sides shows that the logistics of military operations has a greater climate impact than emissions from the destruction of tanks, planes or ships. In each of the variants analysed, emissions caused by the destruction of equipment are responsible for around 5% of the hostilities' total climate cost. The largest greenhouse gas emissions come from equipping troops, organising military operations, and the movement of planes and warships.

Greenhouse gas emissions due to fires caused by the war

Bombing, shelling, hampering firefighters' work, the chaos caused by the war and intentional ecosystem destruction to exert psychological pressure are some of the causes of the intensification of fires during armed conflicts.

According to NASA, over 100,000 hectares of forest may have been burnt during the first four months of the Russian invasion (www16). During this period, Ukraine recorded 78 times more fire alarms than in the corresponding period in previous years (www17). According to the estimates by the Ministry of Environmental Protection and Natural Resources of Ukraine, between 24.02 and 20.07.2022, around 8,300 hectares of forest (www5) were burnt (data as of 20.07.2022). Such significant differences in experts' estimates must lead to different levels of greenhouse gas emissions caused by fires during the Russian invasion.

In the report, we used three ways to calculate the potential greenhouse gas emissions caused by fires. This enabled us to take a critical look at the estimates by particular groups of experts and balance the effects of the potential over- or underestimation of the scale of the damage and emissions. The first methodology involved using the Ukrainian Ministry of Environmental Protection and Natural Resources' assumptions (www5). In the second methodology, we used data from NASA's Fire Information for Resource Management System (FIRMS) based on infrared thermal imaging of radiometric data (VIIRS) (www18), comparing it with data on Ukraine from the European Information System on Forest Fires (EFFIS) (www19). The third methodology was based on previous historical experience (Toon et al., 2007) estimating emissions caused by war damage (Owen, Toon, and Turco, 2008) for the estimated area of damage.

The first methodology was based on declarations of NASA and Ministry of Environmental Protection and Natural Resources of Ukraine. Both institutions were sharing their estimations of areas damaged by fires. The modified emissions factor estimates proposed by Ministry of Environmental Protection and Natural Resources of Ukraine were used to calculate the emission. This basic approach allowed to get rough approximation of emission, caused by fires.

Table 3. Methodology 1. CO_2 emissions caused by fires, estimated based on emission factors adopted (data as in September 2022)

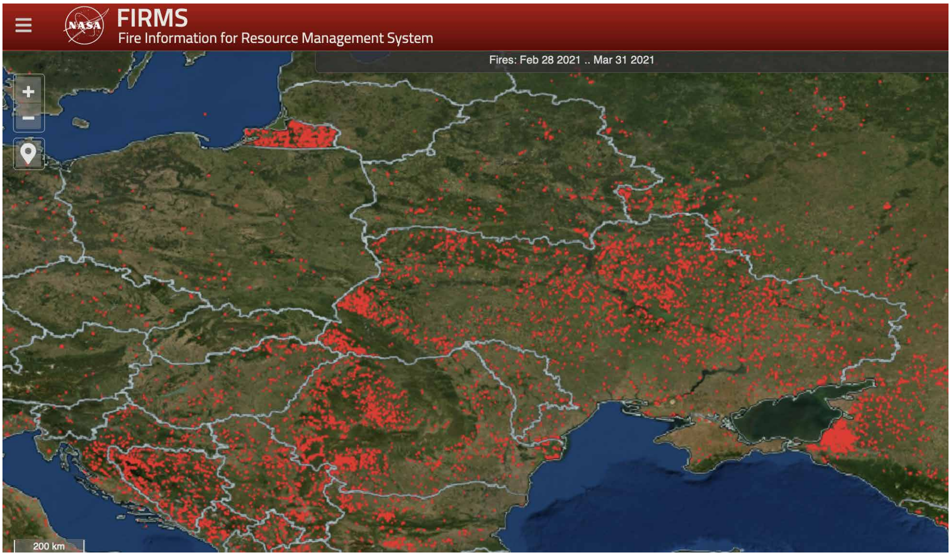
Calculation stages	Variant 1. Ministry of Environmental Protection and Natural Resources of Ukraine's estimates	Variant 2. NASA estimates
Areas damaged by fires (hectares)	59 574 (forests) 5 430 (other areas)	around 100 000 (forests)
Emissions for forest fires (tonnes of CO_2/hectare) (Bartowitz et al., 2022; www5)	90	90
Emissions for other areas (tonnes of CO_2/ha) (www5)	793.5	N/A
Total emissions caused by fires (millions of tonnes of CO_2)	9.7	9.0

Source: prepared by PEI based on estimates by NASA and the Ministry of Environmental Protection and Natural Resources of Ukraine.

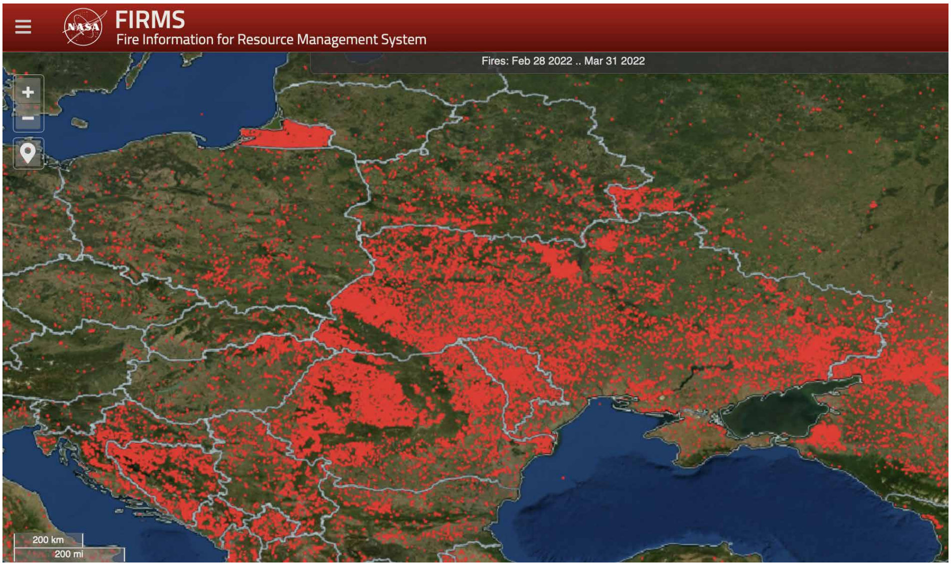
The second methodology was based on the statistical analysis of the overrepresentation of thermal anomalies in Ukraine during the hostilities. The aim was to find out how many more objects and areas burned during the Russian invasion than during the corresponding period in previous years.

Map 1. Thermal anomalies on Ukraine's territory in March in 2021-2022

2021



2022

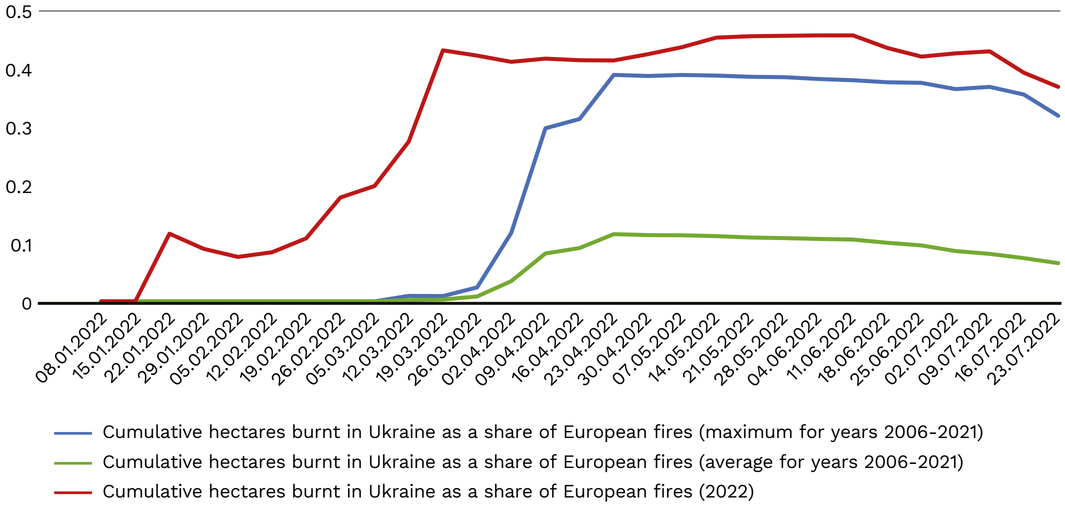


Source: prepared by PEI based on firms.modaps.eosdis.nasa.gov [accessed: 09.10.2022].

To estimate the size of the fires caused by the invasion, we used data from the FIRMS system comparing thermal anomalies in 2021 and 2022. The total daily capacity (frp) of thermal anomalies in Ukraine in 2022 was more than twice as high year on year (1,108 MW/day in 2022, compared to 404 MW/day in 2021). In Europe, the power of thermal anomalies increased from 6,558 MW/day in 2021 to 10,692 MW/day in 2022. The power of thermal anomalies in Ukraine accounted for 6.16% of European thermal anomalies in 2021 and as much as 10.37% in 2022. The Russian invasion increased these anomalies and the related emissions by approximately 40.5%. Based on these assumptions, of the 363,000 hectares that have burned in Ukraine since the invasion began on 24 February 2022 (www19), approximately 1,473,000 hectares were burned as a result of the invasion.

We obtained similar results using EFFIS data (www19). The area of Ukrainian forests burnt between February and July 2022 was 15% higher than the maximum during the corresponding period in 2006-2021. 59% of the fires in Ukraine in the first half of 2022 took place in March. In contrast, in 2006-2021, just 3.6% of fires in the first half of the year were recorded during that month.

Chart 5. Cumulative number of hectares of forest burnt in Ukraine in January-July 2022 as a share of the cumulative number of hectares of forest burnt in Europe in January-July 2006-2022



Source: prepared by PEI based on EFFIS data.

Table 4. Methodology 2. CO_2 emissions caused by fires estimated based on emission factors adopted

Calculation stages	Variant 1. Calculated by PEI based on monitoring of thermal anomalies by NASA FIRMS	Variant 2a. Calculated by PEI based on EFFIS data (overrepresentation of fires in Ukraine in 2022 compared to the 2006-2021 maximum, minimum emissions scenario)	Variant 2b. Calculated by PEI based on EFFIS data (overrepresentation of fires in Ukraine in 2022 compared to the average for 2006-2021, maximum emissions scenario)
Area of forests burned down as a result of the Russian invasion (thousands of hectares)	147.3	49.8	304.8
Emissions for forest fires (tonnes of CO_2/hectare) (Bartowitz et al., 2022; www5)	90	90	90
Total emissions as a result of fires (million tonnes of CO_2)	13.3	4.5	27.4

Source: prepared by PEI based on EFFIS and NASA FIRMS data.

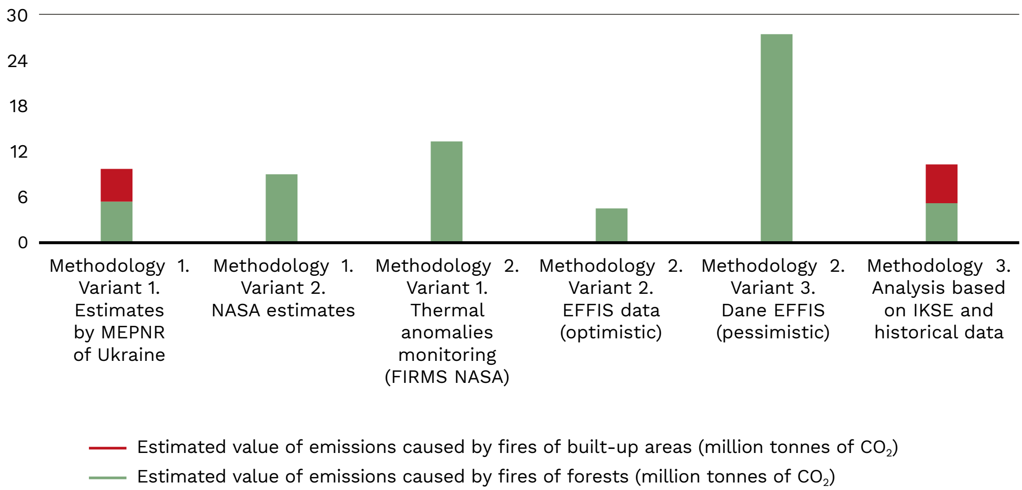
A comparison of the analyses based on FIRMS and EFFIS data points to the significant statistical overrepresentation of fires in Ukraine, compared to Europe in previous years. The comparison allows us to estimate that 49,800-304,800 hectares of Ukraine forests were destroyed by fires caused by the Russian invasion. This amounts to emissions ranging from 4.5 million tonnes of CO_2 (minimal emissions scenario) to 27.4 million tonnes of CO_2 (maximum emissions scenario).

The third methodology involved using historical experience so far (Toon et al., 2007) to estimate the emissions caused by wartime damage (Owen, Toon, Turco, 2008). For the assumed area and population density of the destroyed built-up areas, we calculated the destroyed mass of combustible substances using formula (1) (Owen, Toon, Turco, 2008).

$$M_t = 1{,}1 \times 10^4 \frac{kg}{person \times density\ of\ population} + 8{,}0 \times 10^6 \frac{kg}{km^2} \quad (1)$$

While performing calculations, we took into account the emissions generated for selected surfaces as a result of hostilities and fires. This methodology enabled us to include the potentially higher emissions associated with the destruction of facilities in urban areas (at least 2,300 facilities) (www20). The source of information about the damage in this methodology are the analyses by the Institute of the Kyiv School of Economics (IKSE). Since the start of the invasion, the Institute has been using reports (www21) of the wartime damage by the Russian armed forces (Institute of the Kyiv School of Economics, 2022). We estimate that at least 5.2 million tonnes of CO_2 was generated by damage in an area of 54.3 km^2 inhabited by around 125,000 people. In addition, the IKSE assumes that the size of forest areas damaged as a result of the invasion reached 7,109 hectares (approx. 5.1 million tonnes of CO_2). The total emissions as a result of fires estimated on the basis of this methodology was 10.3 million tonnes of CO_2.

Chart 6. CO_2 emissions caused by fires in forests and built-up areas (millions of tonnes)



Source: prepared by PEI based on calculations based on data from the Ministry of Environmental Protection and Natural Resources of Ukraine, NASA, the NASA FIRMS system, EFFIS and the Institute of the Kyiv School of Economics.

A comparison of the results obtained using each of the calculation methods points to significant disparities in the scale of damage to forest areas and the associated emissions, estimated at 4.5-27.4 million tonnes of CO_2. The emissions linked to damage to urban areas seems to have a less significant climate impact. The lowest estimate in relative terms, based on data from the Institute of the Kyiv School of Economics and Ukraine's government, put the area of destroyed forest areas at 7,000-8,000 hectares and the resulting emissions at 9.7-10.3 million tonnes of CO_2. **According to NASA estimates and the PEI's analyses based on NASA FIRMS monitoring of thermal anomalies, wartime damage to 100,000-147,000 hectares of forest areas caused emissions in the range of 9.02-13.3 million tonnes of CO_2.** The differences in the level of emissions in the analyses based the EFFIS model (4.5-27.4 million tonnes of CO_2) result from the difficulty of identifying the statistical scale of the overrepresentation of Ukrainian fires in 2022, compared to 2006-2021 period (49,800 hectares above the 2006-2021 maximum, 304,800 hectares above the 2006-2021 average).

Destruction of oil and gas reserves, pipeline leakage

The deliberate and accidental destruction of oil and gas reserves, as well as extraction, transfer and storage infrastructure, is a significant source of emissions during every armed conflict. During the first Persian Gulf war, emissions from burning oil fields exceeded 1.8 million tonnes of CO_2 per day (Hobbs, Radke, 1992), increasing global emissions from the burning of fossil fuels by 2% in 1991-1992 (Linden, Jerneloev, Egerup, 2004). Due to the destruction of oil and gas infrastructure by the Russian (www22) and Ukrainian (www23) armies, often by deliberate attacks (www24), emissions related to the burning of some of the reserves accumulated in storage during the hostilities (www25) should not be ruled out.

Fuels are each country's strategic resource, often decisive for a state's strength and military position (Erickson, 1978). It is in states' interest to provide limited information about their own losses, which could indicate that the war has taken an unfavourable turn. In this report, we used three variants to calculate the emissions related to the destruction of oil and gas reserves:

- the Ukrainian government's estimates, used in moderate emissions scenario,
- the minimal emissions scenario, assuming the destruction of some of the Ukrainian and Russian reserves in the region and considerate reduction of fossil fuels consumption,
- the maximum emissions scenario, taking into account partial infrastructure leakage.

Table 5. CO_2 emission coefficients from burning fuels

Type of fuel	Calorific value (GJ/kg)	Emissions (kg CO_2/GJ)	CO_2 emissions in the combustion process (kg CO_2/kg of fuel burnt)
Natural gas	0.0480	55.3	2.66
Oil	0.0423	73.3	3.10
Diesel	0.0430	74.1	3.19
Motor gasoline	0.0443	69.3	3.07
Aviation gasoline	0.0443	70.0	3.10

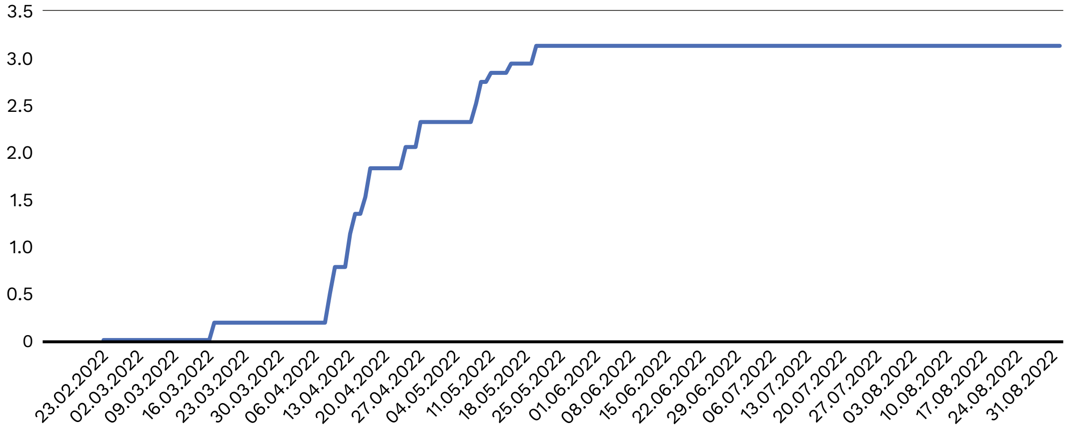
Source: prepared by PEI based on KOBIZE data.

According to the Ministry of Environmental Protection and Natural Resources of Ukraine, 144,300 tonnes of fuels were destroyed during the hostilities between 24.02.2022 and 29.08.2022, which translates into emissions of around 0.499 million tonnes of CO_2. Based on this, we adopted an overall fuel combustion emission coefficient of 3.46 kg of CO_2/kg of fuel, slightly above the coefficients proposed by KOBIZE (2020).

Gas Infrastructure Europe data does not suggest a decrease in the storage capacity available, which remained at 322-325 TWh (www26). However, analysts at the Institute of the Kyiv School of Economics pointed out the possible opposite trend: due to the war-induced decline in industrial consumption, gas was placed in underground storage (www27). Between March to September 2022, the amount of gas at Ukrainian storage facilities increased by 97%, from 44.9 TWh to 88.6 TWh (www26). Despite the economic costs of this operation (estimated by IKSE at around USD 1,000/1,000 Nm^3 of gas, or USD 3.98 billion for 43.7 TWh), it would mean a reduction in emissions related to the non-combustion of stored gas of 8.8 million tonnes of CO_2. Assuming the destruction of 40% of Ukrainian oil reserves — estimated at 1.0 million m^3 before the invasion (www28) as a result of the hostilities — and the burning the 20% of those accumulated before the invasion during the hostilities (which would not be included in the reported data), this would mean a reduction in CO_2 emissions of 7.0 million tonnes, related to the decline in gas consumption and exports.

In the maximum emissions scenario, we assumed larger-scale damage to primary oil reserves (around 0.8 million m^3) and the unsealing of gas pipelines (during attacks on gas infrastructure, including gas pipelines and the Shebelinka station) (www29) and compressor stations (enabling the use of the Sokhranovka transit point) (www30), causing direct emissions of methane into the atmosphere. From the start of the Russian invasion, the Ukrainian operator of the gas transmission system ТОВ Оператор ГТС України, reported damage and repair of the gas distribution network in the territories occupied and attacked by Russian forces (www31). In the maximum emissions scenario, we assume that the fall in consumption did not have a significant climate impact, compared to the harmful climate impact of natural gas leaks into the atmosphere as a result of gas leakage and the destruction of infrastructure. Methane is 25 times more harmful for climate as a greenhouse gas (www32), which means that even small amounts have a serious climate impact.

Chart 7. Cumulative size of sudden drops (>10% d/d) in daily gas transmission from the Sudzha and Sokhranovka directions via Ukraine's territory (in TWh)



Source: prepared by PEI based on ENTSOG data.

In maximum emissions scenario, we estimated that 3.13 TWh, or 0.24 million tonnes, of methane could have been released to atmosphere — the equivalent of 5.9 million tonnes of CO_2 emissions. Between 17.03.2022 and 20.05.2022, 14 cases of a sharp drop (over 10% d/d) in gas transmitted via pipelines were identified. We assumed that they are mainly caused by the unsealing of the infrastructure, resulting in the natural gas being released into the atmosphere.

Table 6. Value of CO_2 equivalent related to damage to oil and gas infrastructure (million tonnes of CO_2-eq)

Variants of damage to Ukraine's gas and fuel infrastructure	Oil reserve fires	Oil reserve fires	Limiting the transmission and industrial consumption of gas	Methane emissions caused by unsealing of gas infrastructure	Total
Variant 1. Ukrainian government's estimates	0.5 in total		-	-	0.5
Variant 2. (minimal emissions scenario); PEI estimates	1.1	0.7	-8.8	-	-7.0
Variant 2. (maximum emissions scenario). Partial unsealing of the gas infrastructure; PEI estimates	2.5	0.7	-	5.9	9.1

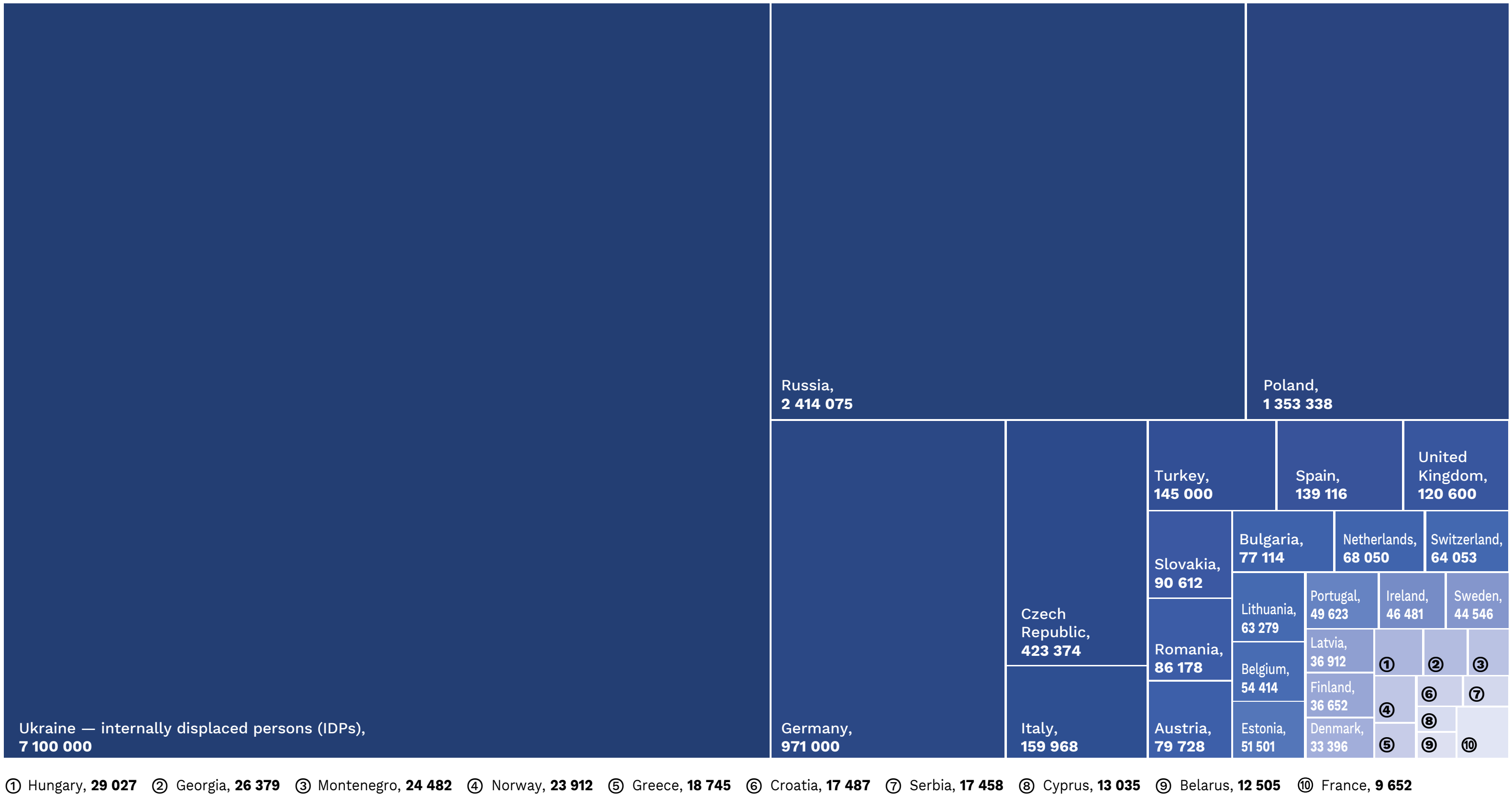
Source: prepared by PEI based on data from the Ukrainian government, the Institute of the Kyiv School of Economics, and estimates based on ENTSOG reports and data.

The Russian invasion's impact on emissions from the extraction, transport and use of fossil fuels remains inconclusive. The Ukrainian government estimates the climate cost of the burning of oil reserves at approximately 0.5 million tonnes of CO_2 equivalent. However, this may be an underestimate due to the relatively low total size of the destroyed fuels (144,300 tonnes of CO_2-eq). In the minimal emissions scenario, their reduction as a result of the lower production and industrial consumption of gas is more significant than fires of oil and gas reserves, which means a reduction in CO_2 emissions of 7.0 million tonnes of CO_2-eq. In the maximum emissions scenario, which took into account the potential partial unsealing of gas infrastructure as a result of the hostilities, as well as efforts to avoid reporting losses due to the market's interest in Ukraine's gas reserves (www33), the negative effect of unsealing and fires translates into 9.1 million tonnes of CO_2-eq emissions.

Emissions due to forced migration

Migration is a significant factor, accounting for over 8% of global CO_2 emissions (Liang et al., 2020). Large-scale, uncontrolled migration caused by armed conflicts generates emissions that contribute to climate change and, consequently, to further conflicts and migration, making up a self-perpetuating social phenomenon known as the "treadmill of destruction" (Hooks and Smith, 2004). The invasion of Ukraine led to unprecedented migration on a European scale (Duszczyk, Kaczmarczyk, 2022). According to estimates by the United Nations High Commissioner for Refugees (UNHCR), in February-September 2022, 13.7 million people left Ukraine, and 6.5 million people entered it (www34). Overall, the number of Ukrainians forced to migrate in February-August 2022 as a result of the Russian invasion was estimated at around 13.9 million.

Chart 8. Number of war refugees and people forced to migrate from Ukraine permanently abroad, registered in individual countries (as of 30.08.2022)



Source: prepared by PEI based on UNHCR data (www34).

We divided the emissions caused by wartime migration into those caused by the movement of refugees and their stay in the host country. In the case of the transport of refugees, we distinguished between Ukrainian internally displaced persons (IDPs) (7.1 million people), who moved west from the areas affected by the fighting, without leaving Ukraine's territory, and refugees who decided to emigrate (6.8 million people). We assumed that 50% used rail transport (trains) and 50% road transport (buses).

Table 7. Emissions as a result of the forced movement of refugees from Ukraine to host countries during the Russian invasion

Host country	Number of refugees	Assumed distance (km)	Assumed emissions from transport (trains and buses) (kg CO_2/ passenger*km)	CO_2 emissions linked to movement of refugees (million tonnes of CO_2)
Ukraina – IDPs	7 100 000	700	0.09735	0.48
Russia (including forced resettlements)	2 414 075	965	0.09735	0.23
Germany	971 000	1 790	0.09735	0.17
Poland	1 353 338	1 098	0.09735	0.14
Spain	139 116	3 997	0.09735	0.05
Czech Republic	423 374	1 243	0.09735	0.05
Italy	159 968	2 529	0.09735	0.04
Turkey	145 000	2 155	0.09735	0.03
Britain	120 600	2 557	0.09735	0.03
Portugal	49 623	4 050	0.09735	0.02
Ireland	46 481	3 264	0.09735	0.01
Austria	79 728	1 831	0.09735	0.01
Switzerland	64 053	2 204	0.09735	0.01
Netherlands	68 050	2 060	0.09735	0.01
Belgium	54 414	2 219	0.09735	0.01
Slovakia	90 612	1 220	0.09735	0.01
Sweden	44 546	2 414	0.09735	0.01
Bulgaria	77 114	1 255	0.09735	0.01
Romania	86 178	922	0.09735	0.01
Other countries	439 625	-	0.09735	0.08
Total	**13 926 895**	**-**	**0.09735**	**1.42**

Source: prepared by PEI based on EC data (www35) and PEI's TRANSPASSPOL model (Maj, Miniszewski, Rabiega, 2022).

The largest transport-related emissions, estimated at 1.42 million tonnes of CO_2, were caused by the displacement of people within Ukraine. A significant number of IDPs (7.1 million) traveled relatively short distances (up to 700 km). This was responsible for around 0.48 million tonnes of CO_2 (34% of emissions from the transport of refugees). The movement of refugees to Russia (which, despite the fact that Russia invaded Ukraine, remains the important migration destination due to the significant Ukrainian diaspora and resettlement of Ukrainian citizens forced by Russian military), Poland, Germany and Spain was responsible for 0.59 million tonnes of CO_2 emissions and 42% of emissions from the transport of refugees.

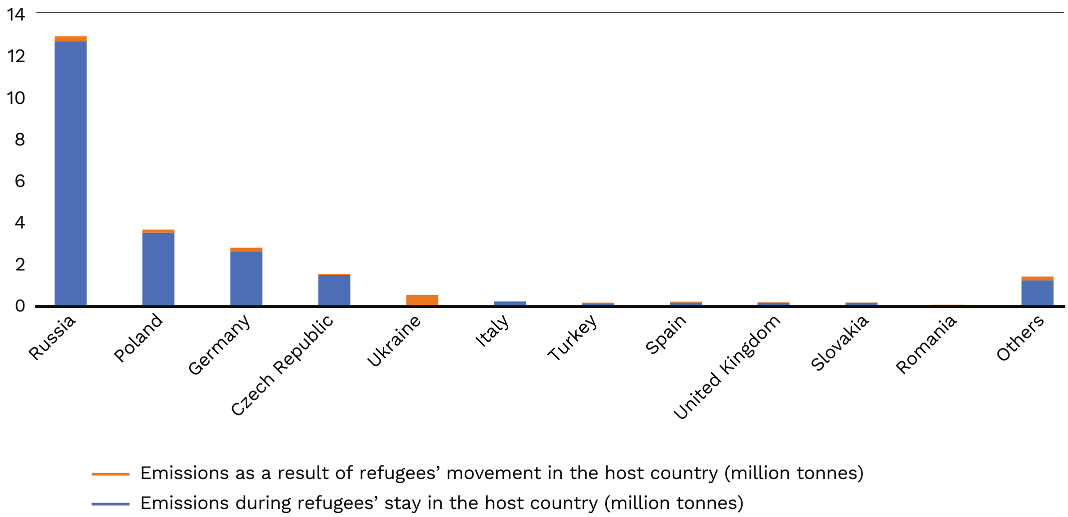
Table 8. Emissions by refugees during stay in host countries in 2022

Host country	Number of refugees	Additional CO_2 emissions due to differences in consumption compared to Ukraine (3.94 tonnes of CO_2/ person*year)	CO_2 emissions linked to refugees staying for 8 months (million tonnes of CO_2)
Russia (including forced resettlements)	2 414 075	7.86	12.65
Poland	1 353 338	3.84	3.46
Germany	971 000	3.98	2.58
Czech Republic	423 374	5.09	1.44
Italy	159 968	1.37	0.15
Turkey	145 000	0.82	0.08
Spain	139 116	1.15	0.11
Britain	120 600	1.28	0.10
Slovakia	90 612	1.76	0.11
Romania	86 178	-0.12	-0.01
Other	923 852	-	1.18
Total	**6 827 113**	**-**	**21.84**

Note: we assumed that all refugees on average will spend 8 months in the host country in 2022.
Source: calculated by PEI based on UNHCR (www34) and World Development Indicators data (www41).

Further emissions caused by refugees’ stay abroad were estimated by comparing emissions per citizen in Ukraine and the host country. The additional emissions result from differences in the emissivity of the economy of the host country and of Ukraine. In some cases (Romania, Georgia), it was slightly negative. The emissions caused by refugees’ stay in Russia, Poland and Germany were the largest, accounting for 86% of emissions caused by refugees’ stay (18.7 million tonnes of CO_2). These emissions would have been more than twice as high (an additional 25.4 million tonnes) if Ukrainian IDPs had gone abroad.

Chart 9. Further CO_2 emissions caused by migration (million tonnes)



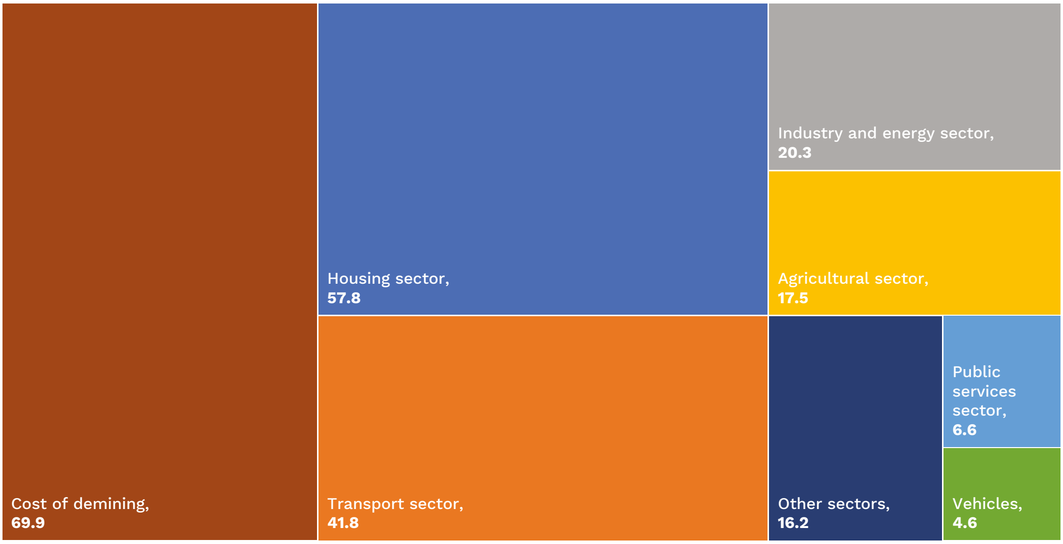
Source: prepared by PEI based on UNHCR and WDI data.

We estimate that refugees’ displacement and stay has so far led to additional emissions of 23.3 million tonnes of CO_2 in total. As many refugees use low-emission forms of transport, such as trains, the impact of their movement is 15 times lower than that of their stay in the host country. The stay itself is responsible for 94% of the emissions caused by migration. The movement of 7.1 million IDPs (www34) in Ukraine generated emissions of 0.48 million tonnes of CO_2 (2% of the total emissions caused by wartime migration).

The climate costs of recovery

The Russian invasion has destroyed EUR 95.4 billion worth of infrastructure. The losses caused by impediments in its functioning amount to an additional EUR 126.7 billion (Institute of the Kyiv School of Economics). The infrastructure destroyed by the aggressor will need to be restored and recreated, a process that will entail further CO_2 emissions. Post-war reconstruction is a complex, multi-stage process — accurate calculations should cover the variation in emissions during the design, construction and operation phases of individual facilities (Ongpeng et al., 2019). For the purposes of this report, we made preliminary estimates that may provide a starting point for more accurate estimates after the war.

Chart 10. Minimal costs of rebuilding destroyed and damaged infrastructure in Ukraine according to IKSE (billion EUR)



Source: prepared by PEI based on analysis by the Institute of the Kyiv School of Economics.

According to the IKSE, the minimum cost of rebuilding infrastructure is EUR 235 billion. This is comparable to the total cost of the hostilities related to the illegal annexation of the Autonomous Republic of Crimea and the so-called Luhansk People's Republic and Donetsk People's Republic in 2014-2021, which is estimated at around USD 280 billion (www36). The list of reconstruction costs proposed by Ukrainian and international analytical centres may be a starting point for further analysis.

Table 9. Estimated costs of Ukraine's recovery (billion EUR)

Institution estimating the cost of Ukraine's recovery	Estimated cost of Ukraine's recovery (billion EUR)
Minimal cost of rebuilding destroyed and damaged infrastructure (IKSE)	235
Minimum estimates by UN (destroyed infrastructure EUR 100 billion) and minimum estimates by WTO (economic costs EUR 147 billion)	247
Centre for Economic Policy Research analysis	200-500
Joint estimates by the Word Bank, European Commission and Ukrainian government (www37)	350
CEPR estimates na based on World Bank data	440
Estimates by the Institute of the Kyiv School of Economics (National Council..., 2022)	565
Estimates by the Ukrainian government	600
Analysis by the Ukraine Recovery Conference (National Recovery Council, 2022) and reports by the National Council for the Recovery of Ukraine from the War (National Council..., 2022)	750
Assumptions by Ukraine Invest	1 000

Source: prepared by PEI based on IKSE, UN, WTO, CEPR, EC and Ukrainian government data.

The cost of Ukraine's reconstruction is estimated at EUR 200-500 billion, or — in more pessimistic scenarios — even twice as much. The costs are higher than the cost of rebuilding the infrastructure because they involve not only technical reconstruction, but also the restoration of social and economic life in areas affected by the war. Ukrainian institutions estimate the cost of the reconstruction at EUR 564-749 billion and international centres at EUR 440-500 billion. Some of the estimates (UkraineInvest) is as high as USD 1,000 billion (www38).

For further calculations, we adopted three scenarios:

- a minimum costs – EUR 250 billion,
- a moderate costs – EUR 564 billion,
- a maximum costs – EUR 750 billion.

We also adopted three calculation valiants:

- variant 1 – significant EU, UK and US involvement in the recovery,
- variant 2 – support from the EU,
- variant 3 – Ukraine's carries out the recovery alone.

Variants 1 and 2 assume that the recovery process will involve lower emissions, which partly results from the lower intensity of emissions of the EU, US and UK economies. This may constitute an additional incentive to implement a green recovery plan (www39) or green Marshall plan (www40).

Table 10. The climate costs of Ukraine's recovery (million tonnes of CO_2)

Recovery cost scenarios	Variant 1. Recovery carried out 35% by Ukraine, 30% by EU, 5% by UK and 30% by US	Variant 2. Recovery carried out 70% by Ukraine and 30% by EU	Variant 3. Ukraine carries out recovery alone
Assumed emissivity of the recovery process (kg CO_2/EUR)(www41)	0.21	0.25	0.31
Minimum costs scenario (250 billion EUR) (million tonnes of CO_2)	52.5	62.5	77.5
Moderate costs scenario (564 billion EUR) (million tonnes of CO_2)	118.4	141.0	174.8
Maximum costs scenario (750 billion EUR) (million tonnes of CO_2)	157,5	187.5	232.5

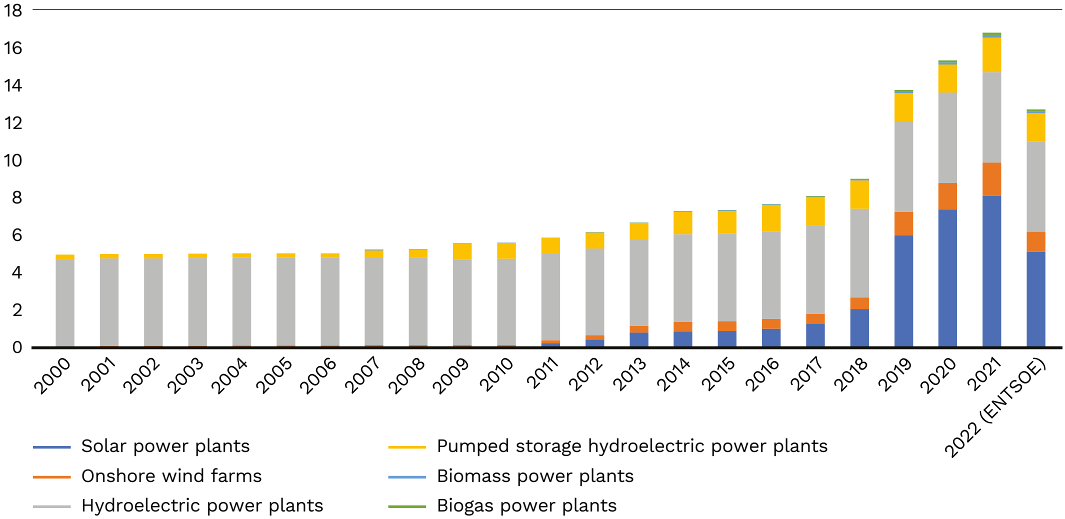
Source: prepared by PEI based World Bank, IKSE, UN, WTO, CEPR, EC and Ukrainian government data.

Rebuilding the damage caused by the war could contribute to emissions of as much as 232.5 million tonnes of CO_2, more than Ukraine's total annual emissions of CO_2 (www42). This number may be much higher due to the ongoing nature of the conflict and hostilities. The maximum scenario is over 25% lower than the estimates by some analysts associated with the Ukrainian government. Ukraine's cooperation with the EU and the US will be of key importance in reducing total emissions. Due to these economies' lower emissivity, the CO_2 emissions caused by the recovery could be 13% lower if they are partly financed partly by the EU, and up to 32% lower if the EU, US and UK economies are involved. The Transatlantic coalition's involvement in Ukraine's recovery could therefore reduce the emissions caused by the recovery by up to 75 million tonnes of CO_2; that is, by 28% more than the sum of emissions reductions year on year in the whole EU in 2022-2024 (58.5 million tonnes of CO_2). Ukraine's green recovery could also be an opportunity to modernise the country's energy, housing and industrial sectors, significantly reducing emissions in the post-war future (www43).

The costs of a halted transition. The war and the development of RES in Ukraine

In 2017-2021, Ukrainian RES capacity increased from 8.0 GW to over 16.7 GW, with an average annual increase of over 20% (www43). The ENTSOE data on Ukrainian RES capacity in 2022 is much lower (in September 2022, the 12.7 GW of RES capacity were connected). This may point to the significant scale of wartime damage, which not only made it difficult to develop RES, but also deprived Ukraine of the fruits of several years of green transition. If the growth of 2020-2021 had continued in 2022, Ukraine would have over 18 GW of installed RES capacity. The suspension — or even reversal — of the Ukrainian economy's rapid transition by the Russian invasion will have a measurable and long-term impact on the Ukrainian economy's emissions.

Chart 11. Installed capacity in RES in Ukraine (GW)



Note: in our calculations, we only used RES capacity connected to the transmission and distribution grid.

Source: prepared by PEI based on IRENA (www44) and ENTSOE data (www45), September 2022.

The war may have led to the damage and destruction of at least 4 GW of RES, 24% of installed RES capacity in Ukraine and halted the development of new RES (at least 1.6 GW). Up to 3 GW of installed capacity in wind energy and around 700 MW in photovoltaics may have been destroyed. Rebuilding this potential could take at least three years and will require intensive investment in Ukrainian renewable energy.

Table 11. The volume of emissions caused by destruction and delay in the development of Ukrainian RES as a result of the invasion

Scenario for the recovery of Ukrainian RES	Installed RES capacity in September 2022 (GW)	Installed RES capacity in 2025 (forecast, GW)	Estimated emissions of the Ukrainian electricity sector in 2022-2025 (million tonnes of CO_2)	Additional emissions caused by the war in 2022-2025 (million tonnes of CO_2)
Reference scenario (no invasion)	18.0	24.0	200.5	-
Scenario 1. No funds for green transition	12.7	14.0	234.1	33.6
Scenario 2. Halting the deve-lopment of RES	12.7	22.6	215.2	14.7
Scenario 3. Ukraine's green recovery	12.7	32.0	194.6	-5.9

Source: prepared by PEI based on IPCC and IRENA data.

The climate cost of the invasion depends on the scale of the damage and the pace at which RES are rebuilt — it might range from 14.7 to 33.6 million tonnes of CO_2. The International Energy Agency estimated the Ukrainian energy sector's total greenhouse gas emissions in 2019 at around 80 million tonnes of CO_2. The highest emissions are linked to the need to increase the use of installed capacity of coal- and gas-fired power plants.

The EU's active involvement in the development of RES after the war ends could reduce the Ukrainian energy sector's emissions by 5.9 million tonnes of CO_2 compared to the reference scenario (no Russian invasion). If Ukraine does not receive any support, the climate cost linked to damage and unbuilt RES will amount to at least 33,6 million tonnes of CO_2. Partial support for Ukraine in its recovery process would more than halve this additional climate cost — to 14.7 million tonnes of CO_2.

Table 12. Additional installed capacity in Ukraine, required amount of support and cost of additional investments in green energy

Recovery process scenario adopted	Solar power plants (MW)	Wind farms (MW)	Biofuel (MW)	Biogas power plants (MW)	Total support (billion EUR)	Potential reduction of climate costs (million tonnes of CO_2)
Scenario 2. Halted development of RES	6 866 (EUR 7.9 billion)	1 500 (EUR 2.0 billion)	129 (EUR 0.2 billion)	105 (EUR 0.1 billion)	9.1	18.9
Scenario 3. Green recovery	14 371 (EUR 16.5 billion)	3 139 (EUR 4.0 billion)	271 (EUR 0.3 billion)	219 (EUR 0.3 billion)	21.2	39.5

Source: prepared by PEI based on IPCC and IRENA data.

EU countries' active involvement in Ukraine's green recovery and development would require supporting it in the construction of 14.4 GW worth of solar power plants and 3.1 GW of wind farms. The climate cost of this kind of investment would be EUR 21.2 billion, but it would reduce Ukraine's emissions by at least 39.5 million tonnes of CO_2. The dynamic support of the development of Ukrainian RES (EUR 21.2 billion for a 39.5 million tonne reduction in CO_2 emissions) would be over 12 times more effective in terms of climate protection than EU countries' less defined, general involvement in Ukraine's recovery process (EUR 232 billion for 33.8 million tonnes reduction in CO_2 emissions).

Russian “ecocide” during the invasion of Ukraine

The invasion of Ukraine entails not only climate costs linked to increased greenhouse gas emissions, but also significant environmental costs linked to the intentional and involuntary destruction of the environment, pollution of the water, air and soil, and the resulting decline in biodiversity. For years, it will be more difficult for the ecosystem to function, and the living conditions of people, animals and plants will deteriorate.

“Ecocide” is the intentional destruction of the environment, usually linked to the desire to defeat the other side during hostilities. The term was coined by American biologist Arthur W. Galston, who drew attention to the environmental dimension of the Vietnam War linked to the use of napalm by the US army (Galston, 2001). An intentional attack — aware of its long-term and serious environmental damage — is a war crime in accordance with the Rome Statute of the International Criminal Court (Rome Statute…, 1998), which Russia withdrew from in 2016. The use of actions during military conflicts that may cause long-term serious and widespread environmental damage is also prohibited by the Additional Protocol of 1977 to the Geneva Conventions, which Russia withdrew from in 2019 (Additional Protocol…, 1977). Both Ukrainian (8-15 years imprisonment) (Criminal Code of Ukraine, 2022, 441 ККУ України) and Russian (12-20 years imprisonment) law deems “ecocide” a crime (Criminal Code of the Russian Federation, 2022, 358 УК РФ).

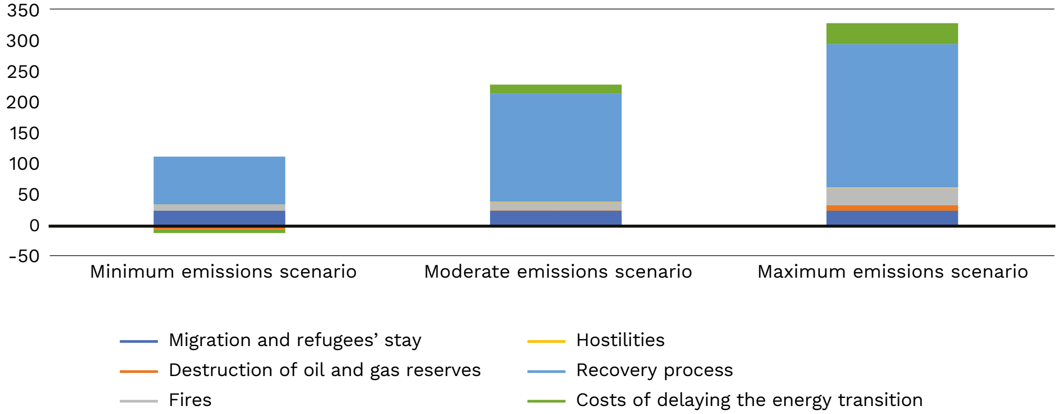
Since the start of the Russian invasion, Ukrainian NGO Center for Environmental Initiatives Ecoaction (Ekodiya) has identified over 514 cases of the intentional destruction of the environment (www47). These are primarily the destruction of industrial sites (more than 280 cases), terrestrial and marine ecosystems (more than 90 cases), and energy infrastructure (more than 90 cases). The Ministry of Environmental Protection and Natural Resources of Ukraine is monitoring the damage linked to Russian troops’ activity on an ongoing basis. It has received over 730 reports documenting Russia’s anti-environmental activity (www5). In September 2022, the Ministry estimated the minimum environmental costs caused by the Russian invasion at UAH 224.9 billion (EUR 6.1 billion).

Conclusion. The invasion's total climate cost

The climate costs of Russia's invasion of Ukraine amount to 98-327 million tonnes of CO_2-eq. This may mean greater climate damage than the pre-pandemic annual direct CO_2 emissions of Ukraine (170.4 million tonnes of CO_2) (www46), Poland (267.6 million tonnes) (www48) or Italy (280.4 million tonnes) (www49). The several-fold differences between the scenarios result primarily from significant discrepancies in the sources documenting the scale of damage, recovery costs, and the area of burnt forest areas. The Russian occupation of Ukraine — in place since 2014, with the Russian invasion that began 24 February 2022 as its latest instalment — makes it impossible for experts and international institutions to obtain unambiguous information on the condition of Ukrainian forest areas and energy infrastructure. The value obtained, estimated in September 2022, will increase if the Russian Federation continues its efforts to further escalate the conflict.

Emissions related to the need to rebuild wartime damage, mass displacement of war refugees, the suspension of the development of Ukrainian RES and forest fires will be the most significant. The hostilities themselves — such as troop displacement, emissions from destroyed military equipment, and the destruction of oil and gas reserves — will have a much smaller climate impact, accounting for less than 3% of total emissions in each scenario.

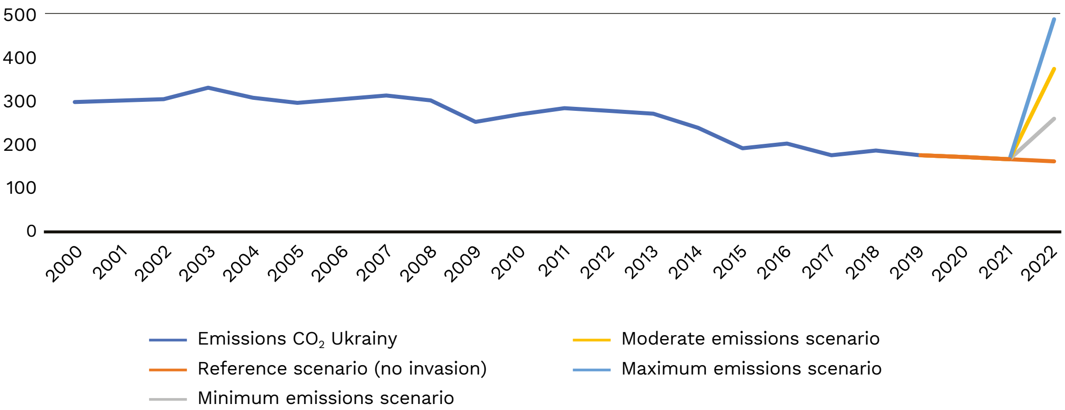
Chart 12. The climate costs of the Russian invasion of Ukraine (million tonnes of CO_2-eq)



Source: prepared by PEI.

In the maximum scenario, the emissions caused by the Russian invasion are 9.4% of the projected CO_2 emissions of the entire EU 2022 (www49). This is more than the value of the total assumed reduction of greenhouse gas emissions in the EU (year on year) in 2023-2030 (estimated by the European Environment Agency at around 326.7 million tonnes of CO_2-eq). In this scenario, Ukraine does not receive EU and US support in the recovery process, which leads to a long delay in the green transition of the entire region and generates an additional 266.1 million tonnes of CO_2-eq. This is indisputably a negative scenario, which will affect not only Ukraine, but all of Europe and other countries affected by the climate catastrophe.

Chart 13. Climate costs of Russian invasion of Ukraine (million tonnes of CO_2) juxtaposed with Ukraine's emissions in the past



Note: Ukraine's emissions based on World Bank data for 2000-2019 (www50).

Source: prepared by PEI.

Due to the significant scale of the potential climate costs, we have attempted to estimate the financial costs related to greenhouse gas emissions linked to the war. The starting point was the average prices of ETS certificates for 2022 and the average futures prices of EU ETS for 2023-2024.

Table 13. An attempt to estimate the climate costs of the invasion of Ukraine

Calculation scenario adopted	Climate cost of the Russian invasion (million tonnes of CO_2-eq)	Estimate 1. Average annual price of ETS in 2022 (January-September, billion EUR)	Estimate 2. Futures prices of EU ETS for 2023-2024 (September 2022, billion EUR)
		65.9 EUR/t CO_2	78 EUR/t CO_2
Minimum emissions scenario	98.1	6.5	7.6
Moderate emissions scenario	212.7	14.0	16.6
Maximum emissions scenario	326.9	21.5	25.5

Source: prepared by PEI based on ICE (www51) Ember data (Sandbag Climate Campaign CIC) (www52).

Even based on the minimum emissions scenario, we estimated that the war's climate costs would amount to at least EUR 6.5 billion, over 4% of Ukraine's GDP prior to the COVID-19 pandemic (www50). The more moderate estimate is 10-12% of Ukraine's GDP, while the maximum emissions scenario points to costs of 16-19% of Ukraine's GDP. This is significant climate damage caused by military aggression — not only to Ukraine, but to the entire international community. The costs of removing this damage should be borne by the Russian Federation.

Ukraine's green recovery with the participation of the EU, UK and US will enable it to avoid as much as 115 million tonnes of CO_2 emissions and reduce the war's climate costs by EUR 8.9 billion. The international community will be able to reduce the total climate costs of the invasion significantly (by 43-58%, depending on the scenario). In each scenario, the involvement of the EU's member states, the UK and the US in the ecological reconstruction of Ukrainian infrastructure and the revival of the Ukrainian economy will be key. Support for the development of Ukrainian RES, including solar power and wind farms, will be particularly important. Poland, which actively supported Ukraine during the Russian invasion and hosted over 1.3 million Ukrainian refugees during the first months of the war, has a chance to play a major role in this process and help limit the climate impact of the Russian invasion.

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