

# Quantifying unaccounted greenhouse gas emissions due to the war in Ukraine – driver analysis, emission estimation, and implications for emissions reporting

Rostyslav Bun<sup>1,2</sup>, Gregg Marland<sup>3</sup>, Tomohiro Oda<sup>4,5,6</sup>, Linda See<sup>7</sup>, Enrique Puliafito<sup>8,9</sup>, Zbigniew Nahorski<sup>10,11</sup>, Mathias Jonas<sup>7</sup>, Vasyl Kovalyshyn<sup>12</sup>, Iolanda Ialongo<sup>13</sup>, Orysia Yashchun<sup>1,7</sup>, Zoriana Romanchuk<sup>1,7</sup>

<sup>1</sup>Lviv Polytechnic National University, Ukraine; <sup>2</sup>WSB University, Poland; <sup>3</sup>Appalachian State University, USA; <sup>4</sup>Universities Space Research Association, USA; <sup>5</sup>University of Maryland, USA; <sup>6</sup>Osaka University, Japan; <sup>7</sup>International Institute for Applied Systems Analysis, Austria; <sup>8</sup>Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina; <sup>9</sup>Mendoza Regional Faculty, National Technological University, Argentina; <sup>10</sup>Systems Research Institute PAN, Poland; <sup>11</sup>WIT University, Poland; <sup>12</sup>Lviv State University of Life Safety, Ukraine; <sup>13</sup>Finnish Meteorological Institute, Finland

## 1 Introduction

- Emissions reporting is important for understanding the global carbon cycle and for addressing global climate change.
- In a period of open conflict or war, military emissions increase significantly, and the international accounting system is not currently designed to account adequately for this source.



Figure 1 Emissions from a missile attack in Lviv, Ukraine

## 2 Materials and Methods

The major war-related emission processes from the territory of Ukraine not covered by current GHG inventory guidelines are:

- the use of bombs, missiles, barrel artillery, mines, grenades, and small arms;
- the consumption of oil products for military operations;
- fires at petroleum storage depots and refineries;
- fires in buildings and infrastructure facilities;
- fires on forests and agricultural lands;
- the decomposition of war-related garbage/waste.

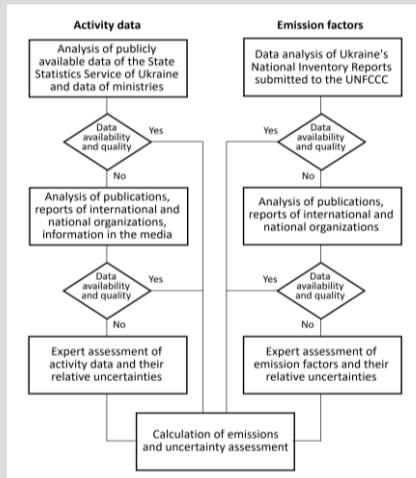


Figure 2 The steps to collect the data, to assess data quality, and to fill the gaps when information was missing.



Figure 3 The additional GHG emissions caused by military actions in Ukraine that have a chance of not being accounted for in official national reporting and global estimates.

## 3 Results and Discussion

**Table 1** Estimated war-related GHG emissions from the first 18 months of the 2022/2023 war in Ukraine (originated from the territory of Ukraine but due to their specificity will not be covered by Ukraine's next NIRs to the UNFCCC).

Emission sources	Emissions				Relative uncertainty, 95 percent confidence interval
	CO <sub>2</sub> , Mt	CH <sub>4</sub> , kt	N <sub>2</sub> O, kt	Total, MtCO <sub>2</sub> -eq.	
Use of bombs, missiles, barrel artillery, mines, etc.	0.28	–	–	0.28	+/- 54.2
Use of petroleum products for military actions	28.5	0.25	0.68	28.7	+/- 39.7
Fires of petroleum products at petroleum storage depots	5.4	0.21	0.04	5.43	+/- 20.3
Fires of buildings and infrastructure objects	17.8	5.0	0.73	18.1	+/- 49.8
Forest fires and fires of agricultural fields	21.1	63.3	3.5	23.8	+/- 38.2
Emissions from garbage/waste	–	36.8	–	1.03	+/- 69.4
<b>Total emissions:</b>	<b>73.1</b>	<b>105.6</b>	<b>4.96</b>	<b>77.2</b>	<b>+/- 22.3</b>

**"Peace time" vs "War time"**  
First 18 months of the 2022/2023 war in Ukraine:

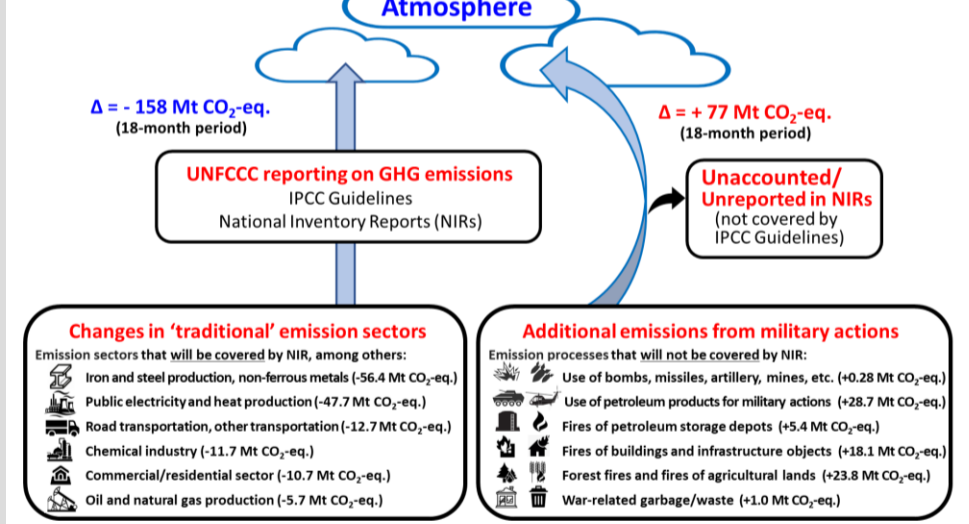


Figure 4 Estimation of decreased GHG emissions due to a reduction in traditional human activities in Ukraine during the first 18 months of the 2022/2023 war, and identified major, war-related, additional emissions from the territory of Ukraine not covered by current GHG inventory guidelines.

## 4 Conclusions

- During a war, GHG emissions due to military actions can increase significantly.
- The impact of conflict on GHG emissions extends well beyond the time and place of the physical conflict.
- The IPCC guidelines do not explicitly consider wartime GHG emission reporting.
- War-related GHG emissions for the first 18 months of the war in Ukraine were 77 MtCO<sub>2</sub>-eq.
- The relative uncertainty of war-related emissions in Ukraine is estimated to be 22% (95% CI).

## References

- Bun R., Marland G., Oda T., See L., Puliafito E., Nahorski Z., Jonas M., Kovalyshyn V., Ialongo I., Yashchun O., Romanchuk Z. (2024) Tracking unaccounted greenhouse gas emissions due to the war in Ukraine since 2022. *Science of The Total Environment*, 914:169879. DOI: 10.1016/j.scitotenv.2024.169879.
- Ialongo I., Bun R., Hakkarainen J., Virta H., Oda T. (2023) Satellites capture socioeconomic disruptions during the 2022 full-scale war in Ukraine. *Scientific Reports*, 13:14954. DOI: 10.1038/s41598-023-42118-w
- Ukraine's Greenhouse Gas Inventory 1990-2021 (2023). Annual NIR for Submission under the UNFCCC and the Kyoto Protocol. Ministry of Environmental Protection and Natural Resources of Ukraine.



Figure 4 Map of Ukraine including the occupied areas and territories with the highest CO<sub>2</sub> emissions.