WORLD FROM SPACE

ARNIKA

AIR QUALITY IN UKRAINE

FROM SPACE

BEFORE AND DURING THE FULL-SCALE INVASION (2018-2024)

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World from Space

CONTENT

INTRODUCTION

WORLD FROM SPACE

- Czech technology company
- expertise in **Earth Observation**
  - agriculture, air pollution, urban environments, ...

- **2021 - report on air quality in Ukraine**
  - overall situation
  - impact of industry and population
  - focus on covid-19

- **2023 - report on air quality in Ukraine during the first months after invasion**

CONTEXT & GOALS

RUSSIAN INVASION

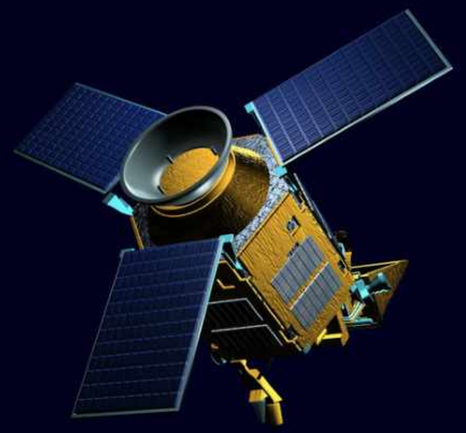
- Full-scale invasion began 24 Feb 2022
- Major disruption to economic activity, mobility, and infrastructure

STUDY GOALS

- Assess air quality in Ukraine prior and during the conflict using satellite data
- Provide an independent proof of the impacts of the war on the society and environment

DATA & METHODS

SENTINEL-5P



- **Satellite for atmosphere monitoring** (EU Copernicus Programme)

- **daily measurements**
- **from 2017**
- TROPOMI spectrometer
  - measures **NO_2**, CH_4, O_3, CH_2O, SO_2, CO and aerosols
- **resolution ~5.5 x 3.5 km**

NITROGEN DIOXIDE

- High **correlation w. anthropogenic activities**
- **Main sources** of NO2:
  - **Transportation** (especially diesel vehicles)
  - **Power generation** (especially coal-fired power plants)
  - **Industry** (e.g. production of nitric acid, oil refining, welding, and manufacturing
  - **Residential use** (e.g. gas stoves, water heaters, furnaces)

- **Sentinel-5p measures** concentrations in the **full atmospheric column**
  - units: mol/m2

CITIES & INDUSTRIAL FACILITIES

- **OpenStreetMap**
  - **populated places**
  - **administrative boundaries**

- **Global Energy Monitor**
  - **coal-fired power plants**
    - including information about status (active, mothballed, destroyed, ...)
    - information about shelling events
  - **iron & steel facilities**

PROCESSING

01 DOWNLOAD & PREPROCESSING

- Google Earth Engine + Python scripts
- high quality estimates filtering + cloud removal
- regular grid 1x1 km

02 TEMPORAL STATISTICS

- reference: **24 Feb – 30 Nov** 2018, 2019, 2021 (no winter, no COVID)
- Year 1: 24 Feb – 30 Nov 2022
- Year 2: 24 Feb – 30 Nov 2023
- Year 3: 24 Feb – 30 Nov 2024

03 ZONAL STATISTICS

- cities above 100 000 inhabitants (pre-invasion) + 10km buffer
- coal-powered power plants + 10km buffer
- iron & steel plants + 10km buffer

WEATHER NORMALIZATION

- **Meteorology strongly affects NO_2 levels**

- **This project:**
  - **simple correction applied**
    - subtraction/addition of national mean
- **Ideal approach:**
  - **business-as-usual NO_2 modelling**
  - using wind, temperature, boundary layer height

RESULTS

NO_2

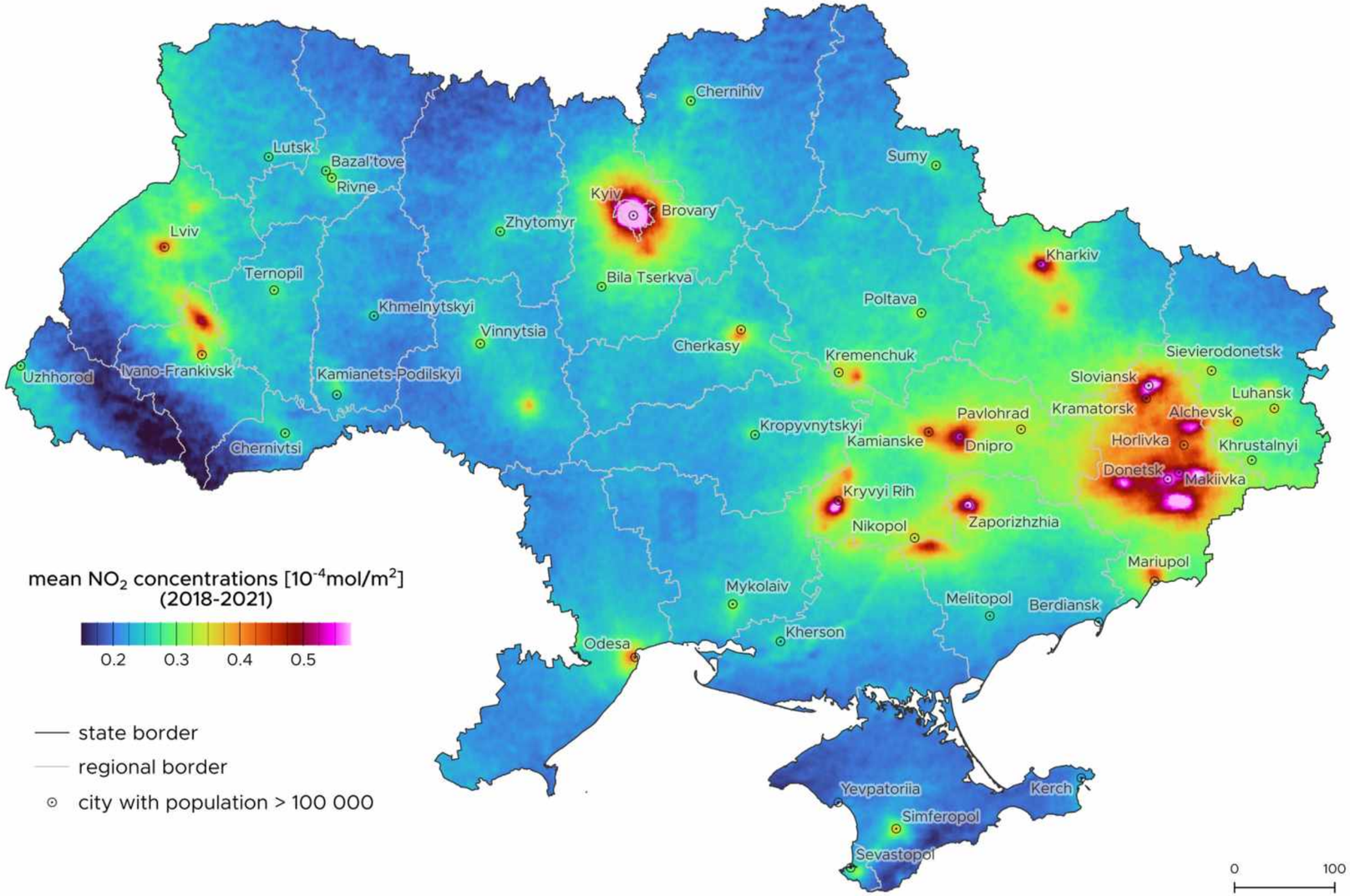
- Highest concentration
  - urban areas
  - industrial sites

  - Kyiv
  - Donetsk region
    - Sloviansk
    - Donetsk
  - Dnipropetrovsk, Kharkiv, and Zaporizhzhia r.

- Lowest concentration:
  - Carpathians
  - Crimea
  - northern regions (Zhytomyr, Chernihiv)

REFERENCE PERIOD

2018, 2019, 2021

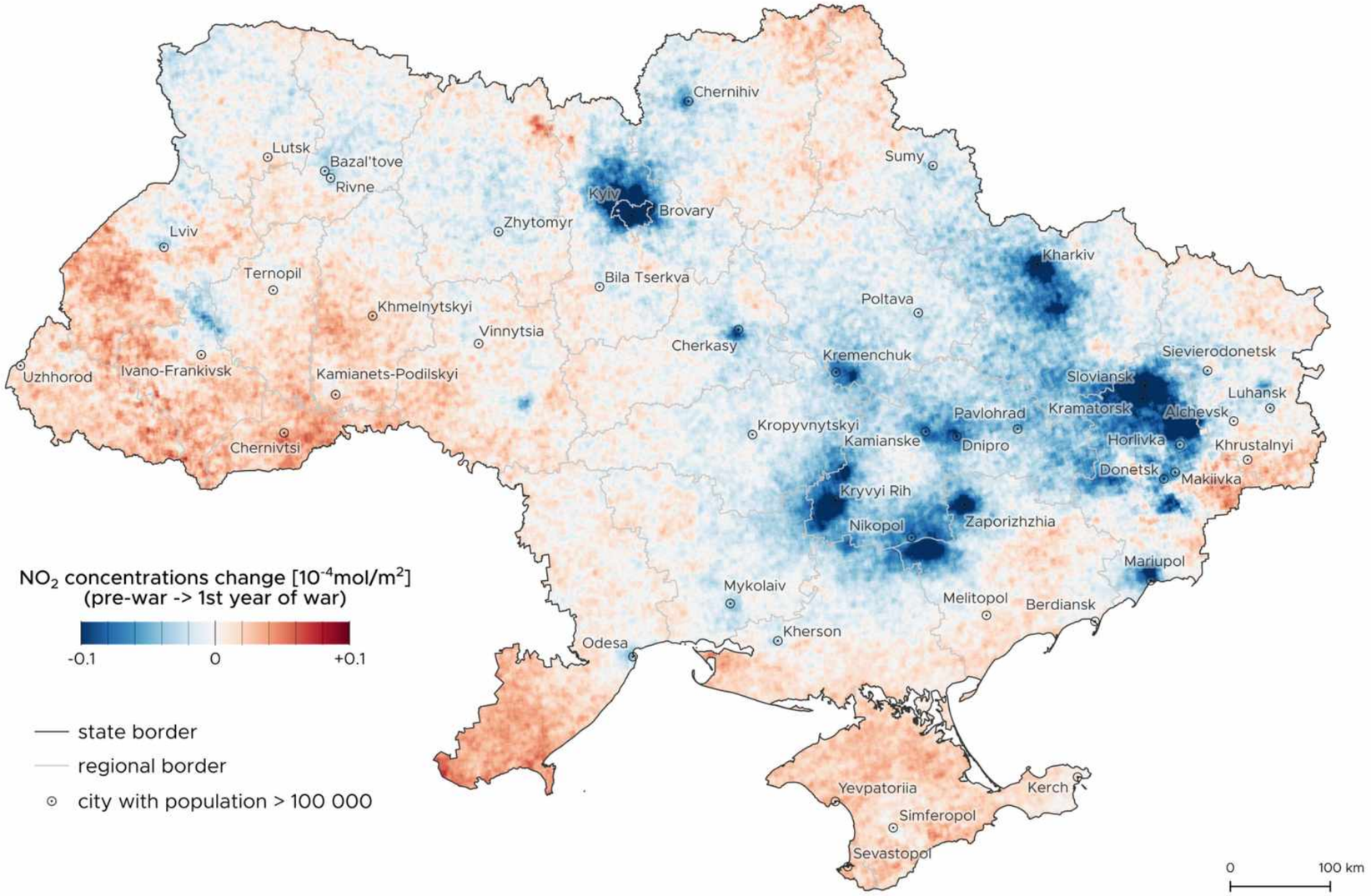


NO_2

- Abrupt decline:
  - Dnipropetrovsk r.
  - Kyiv
  - Kharkiv r.
  - large swaths of Donetsk and Zaporizhzhia r.
- Increase:
  - SE and NE borders of Ukraine
    - Russian control & advances?
  - W Ukraine
    - migration
    - weather?

FIRST YEAR

2022



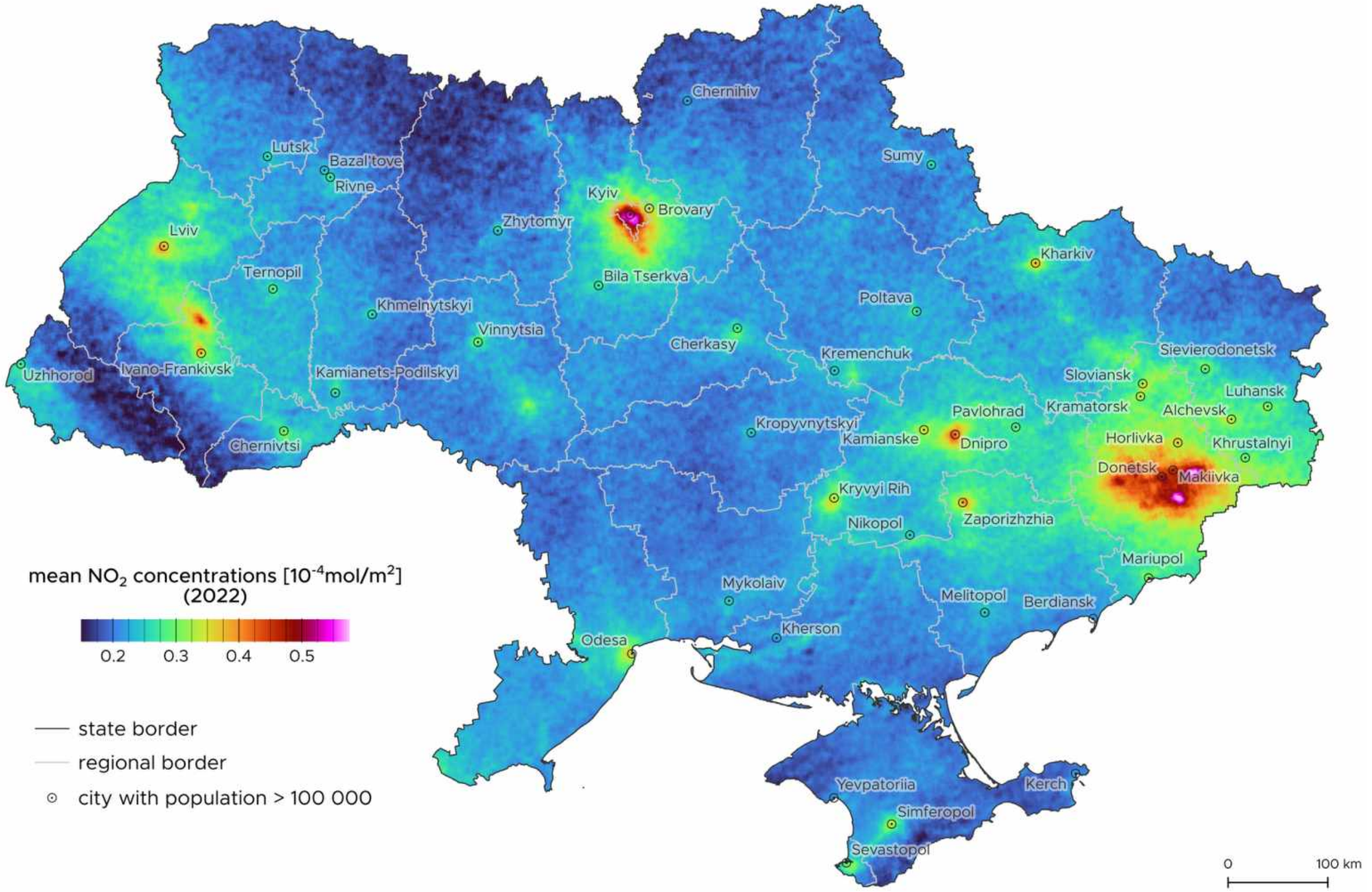
NO_2

- Kyiv
- Donetsk region:
  - highest concentrations in areas under Russian-backed control prior full-scale invasion
    - Starobesheve power station
    - Zuevskaya p.s.
  - Donetsk
  - Kurakhov p.s.

- W Ukraine - Burshtyn power station

FIRST YEAR

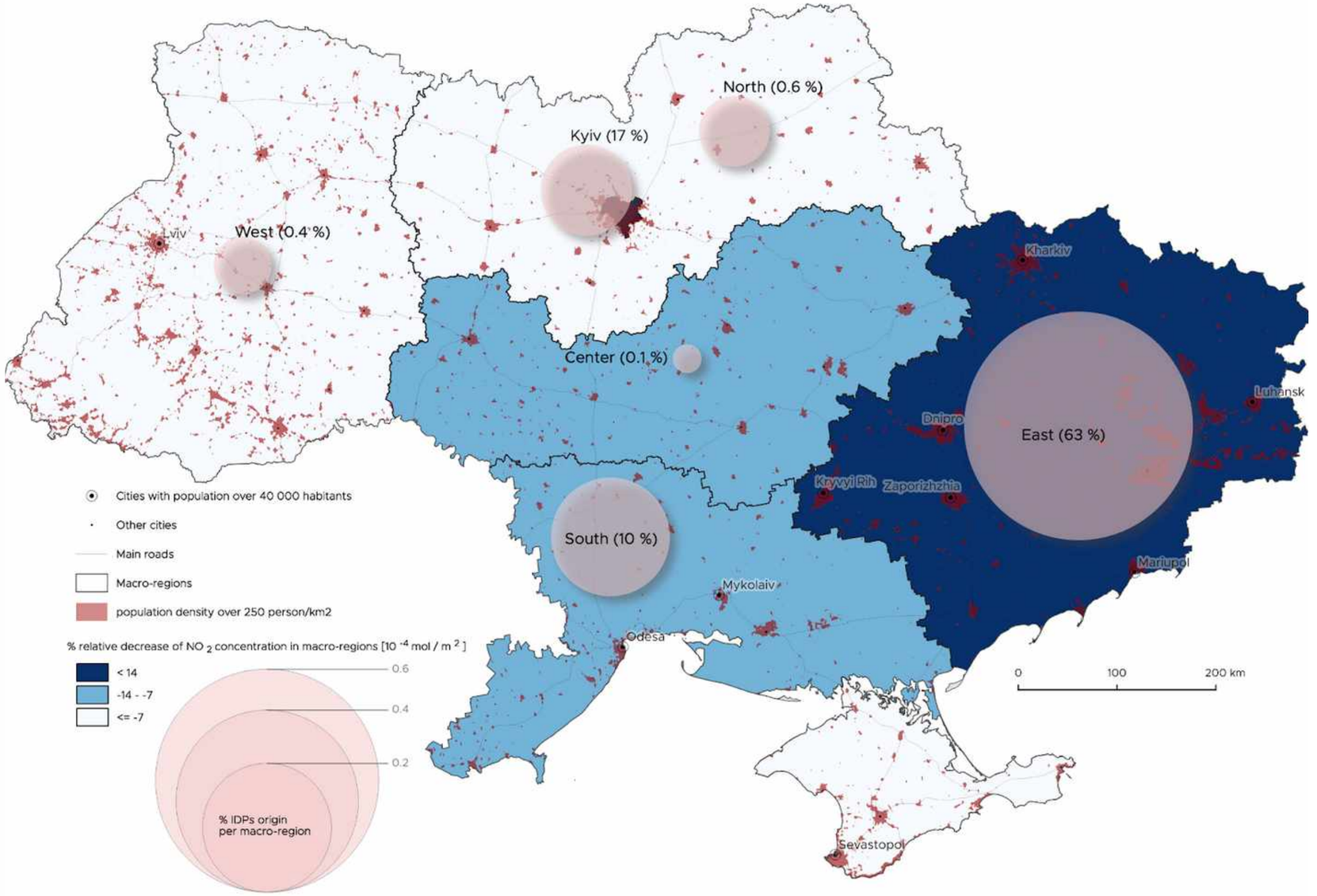
2022



NO_2

- Correlation between internally displaced people (IDPs) and NO2 change
- Largest share of IDPs & largest NO2 reduction - macroregion East

FIRST YEAR
INTERNAL DISPLACEMENT

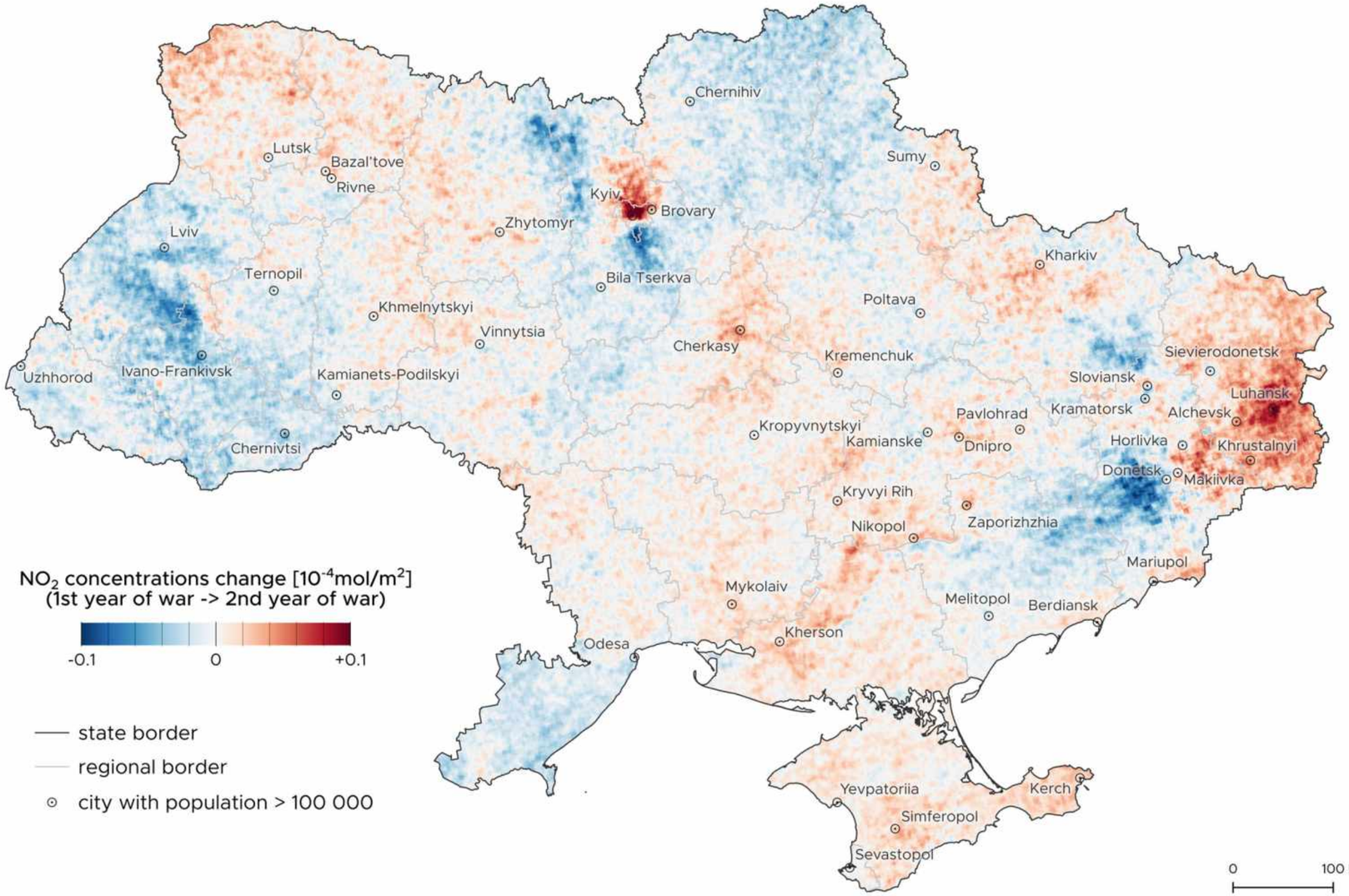


NO_2

- Mixed trends
- Increase:
  - Kyiv (N)
    - human activity recovery
  - Luhansk
- Decrease:
  - Kyiv (S)
    - Trypilska power station
  - W of Donetsk
    - Kurakhove power station (shelling)

SECOND YEAR

2023

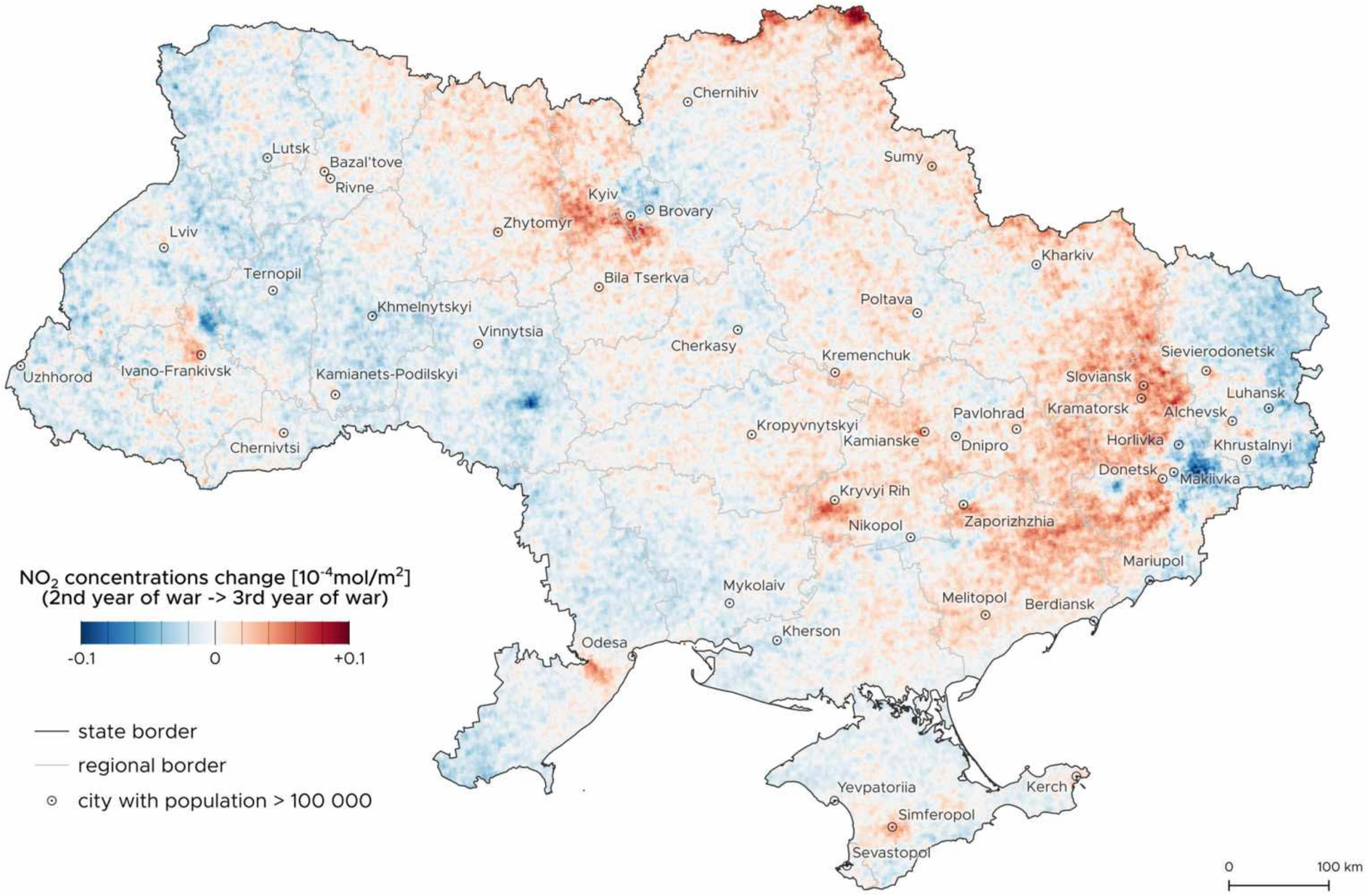


NO_2

- Increases in industrial regions (Dnipro, Zaporizhzhia)
  - war-related activities?
  - diesel generators
  - weather?
- Increase in most of Kyiv - NE exception (Dobropylska power station)

- Declines near damaged/destroyed plants: Kurakhove, Dobrotvir, Burshtyn, Ladyzhyn

THIRD YEAR
2024

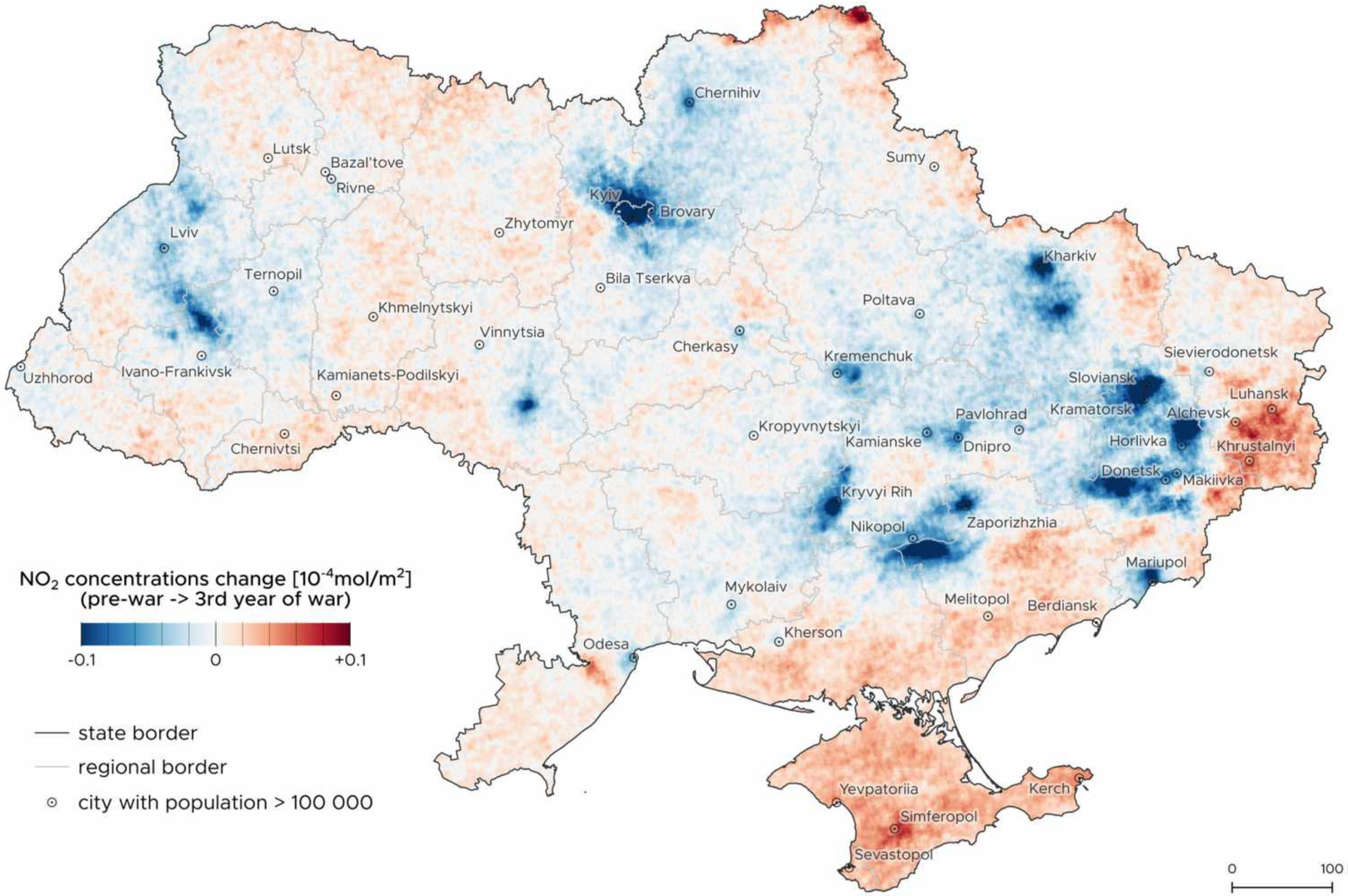


NO_2

- **Largest decreases** in **eastern industrial regions and around coal-fired power stations**
  - shutdowns,
  - infrastructure destruction
  - depopulation
- Local **increases** in **Crimea, border regions, occupied cities**
  - military activities
  - alternative energy sources (generators, solid fuel)

CUMULATIVE CHANGES

2018-2021 → 2024



NO_2

- **Most polluted pre-war cities saw strongest decreases**
  - **Sloviansk: −38% in Year 1 (-29% total)**
  - **Kramatorsk: −24% total**
  - **Kharkiv: −22%**
  - **Kyiv: −21%**
- **Most cases - sharpest decline in the first year**
- **Some cities later**
  - **Ivano-Frankivsk, Lviv, Odesa**
- **Occupied cities show smaller decreases or increases** (Donetsk, Makiivka - ~10% decrease, Luhansk, Alchevsk, Crimea cities ~10-20% increase)

CITIES
ABOVE 100 000 INHABITANTS

Average NO_2 Concentration (10^{-4}mol/m²) and Year-to-Year Change for Ukrainian Cities >100k

City	Pre-war ranking	Pre-war	2022	2023	2024	Overall change	2024 ranking
Kyiv	1	0.765	0.525 (-31%)	0.596 (+14%)	0.604 (+1%)	0.604 (-21%)	1
Sloviansk	2	0.538	0.335 (-38%)	0.338 (+1%)	0.380 (+12%)	0.380 (-29%)	7
Donetsk	3	0.535	0.485 (-9%)	0.463 (-5%)	0.477 (+3%)	0.477 (-11%)	2
Makiivka	4	0.514	0.466 (-9%)	0.474 (+2%)	0.465 (-2%)	0.465 (-10%)	3
Zaporizhzhia	5	0.493	0.366 (-26%)	0.385 (+5%)	0.403 (+5%)	0.403 (-18%)	5
Dnipro	6	0.486	0.409 (-16%)	0.426 (+4%)	0.431 (+1%)	0.431 (-11%)	4
Brovary	7	0.476	0.362 (-24%)	0.399 (+10%)	0.383 (-4%)	0.383 (-20%)	6
Kramatorsk	8	0.474	0.332 (-30%)	0.326 (-2%)	0.361 (+11%)	0.361 (-24%)	13
Kryvyi Rih	9	0.467	0.339 (-27%)	0.351 (+4%)	0.373 (+6%)	0.373 (-20%)	10
Kharkiv	10	0.466	0.341 (-27%)	0.362 (+6%)	0.361 (-0%)	0.361 (-23%)	12
Horlivka	11	0.434	0.368 (-15%)	0.374 (+2%)	0.357 (-5%)	0.357 (-18%)	16
Kamianske	12	0.406	0.339 (-17%)	0.339 (-0%)	0.361 (+7%)	0.361 (-11%)	11
Mariupol	13	0.396	0.315 (-20%)	0.322 (+2%)	0.311 (-3%)	0.311 (-21%)	23
Lviv	14	0.382	0.373 (-2%)	0.343 (-8%)	0.340 (-1%)	0.340 (-11%)	18
Odesa	15	0.381	0.354 (-7%)	0.338 (-4%)	0.345 (+2%)	0.345 (-10%)	17
Nikopol	16	0.359	0.282 (-21%)	0.292 (+4%)	0.287 (-1%)	0.287 (-20%)	26
Ivano-Frankivsk	17	0.344	0.350 (+2%)	0.311 (-11%)	0.332 (+7%)	0.332 (-3%)	19
Cherkasy	18	0.342	0.290 (-15%)	0.324 (+12%)	0.319 (-2%)	0.319 (-7%)	20
Alchevsk	19	0.341	0.337 (-1%)	0.374 (+11%)	0.375 (+0%)	0.375 (+10%)	9

NO_2

COAL POWER PLANTS

- Emissions strongly linked to operational status
- Sharp declines in Year 1 (economic slowdown)
  - Zaporizhia (-33%)
  - Vuglegirska (-33%)
  - Kramatorskaya (-31%)
- Additional drops due to shelling: Kurakhov, Trypilska, Burshtyn, Ladyzhyn
- Zuevskaya (Donetsk)
  - large drop in 2024 despite no confirmed shelling

NO_2 Changes for Coal Power Plants

Plant name	Location	Pre-war	2022	2023	2024	Overall change
Burshtyn power station	Ivano-Frankivsk	0.432	0.401 (-7%)	0.381 (-5%)	0.346 (-9%)	0.346 (-20%)
Cherkasy power station	Cherkasy	0.356	0.296 (-17%)	0.331 (+12%)	0.330 (-0%)	0.330 (-7%)
Chernihiv power station	Chernihiv	0.279	0.234 (-16%)	0.226 (-4%)	0.225 (-0%)	0.225 (-20%)
Darnytska power station	Kyiv	0.668	0.482 (-28%)	0.534 (+11%)	0.536 (+0%)	0.536 (-20%)
Dobrotvir power station	Staryi Dobrotvir	0.318	0.319 (+0%)	0.292 (-9%)	0.266 (-9%)	0.266 (-16%)
Kalush power station	Kalush	0.306	0.304 (-1%)	0.261 (-14%)	0.275 (+5%)	0.275 (-10%)
Kramatorskaya power station	Kramatorsk	0.482	0.333 (-31%)	0.325 (-2%)	0.360 (+11%)	0.360 (-25%)
Kryvorizka power station	Zelenodolsk	0.334	0.277 (-17%)	0.306 (+11%)	0.319 (+4%)	0.319 (-4%)
Kurakhov power station	Kurakhove	0.511	0.456 (-11%)	0.392 (-14%)	0.380 (-3%)	0.380 (-26%)
Ladyzhyn power station	Ladyzhyn	0.323	0.299 (-8%)	0.305 (+2%)	0.254 (-17%)	0.254 (-21%)
Luganskaya power station	Shchastya	0.322	0.282 (-12%)	0.348 (+23%)	0.336 (-3%)	0.336 (+4%)
Myronivskyi power station	Myronivskyi	0.452	0.330 (-27%)	0.351 (+6%)	0.348 (-1%)	0.348 (-23%)
Prydniprovska power station	Dnipropetrovsk	0.441	0.378 (-14%)	0.398 (+5%)	0.406 (+2%)	0.406 (-8%)
Slavyansk power station	Mykolaivka	0.499	0.337 (-32%)	0.344 (+2%)	0.384 (+12%)	0.384 (-23%)
Starobesheve power station	Novyi Svit	0.571	0.531 (-7%)	0.539 (+2%)	0.521 (-3%)	0.521 (-9%)
Trypilska power station	Ukrainka	0.395	0.386 (-2%)	0.336 (-13%)	0.353 (+5%)	0.353 (-11%)
Vuglegirska power station	Svitlodarsk	0.493	0.333 (-33%)	0.347 (+4%)	0.344 (-1%)	0.344 (-30%)
Zaporizhia power station	Enerhodar	0.416	0.281 (-33%)	0.277 (-1%)	0.277 (+0%)	0.277 (-33%)
Zmiivska power station	Komsomolske	0.367	0.272 (-26%)	0.280 (+3%)	0.281 (+1%)	0.281 (-23%)
Zuevskaya power station	Zuhres	0.502	0.514 (+2%)	0.556 (+8%)	0.475 (-15%)	0.475 (-5%)

NO_2

IRON & STEEL PLANTS

- **Decline:**
  - **Mariupol plants** (Azovstal, Ilyich): 20–21% drops
  - **ArcelorMittal Kryvyi Rih**: –20% (mix of slowdown + modernization)
  - **Zaporizhstal**: –17%
- Plants in Russian-controlled areas: **small changes or increases**
  - **Donetsk** Met. Plant
  - **Yuzovsky** Met. Plant
  - **Alchevsk** Met. Plant

Average NO_2 Concentration (10^{-4}mol/m²) and Year-to-Year Change for Iron & Steel Plants

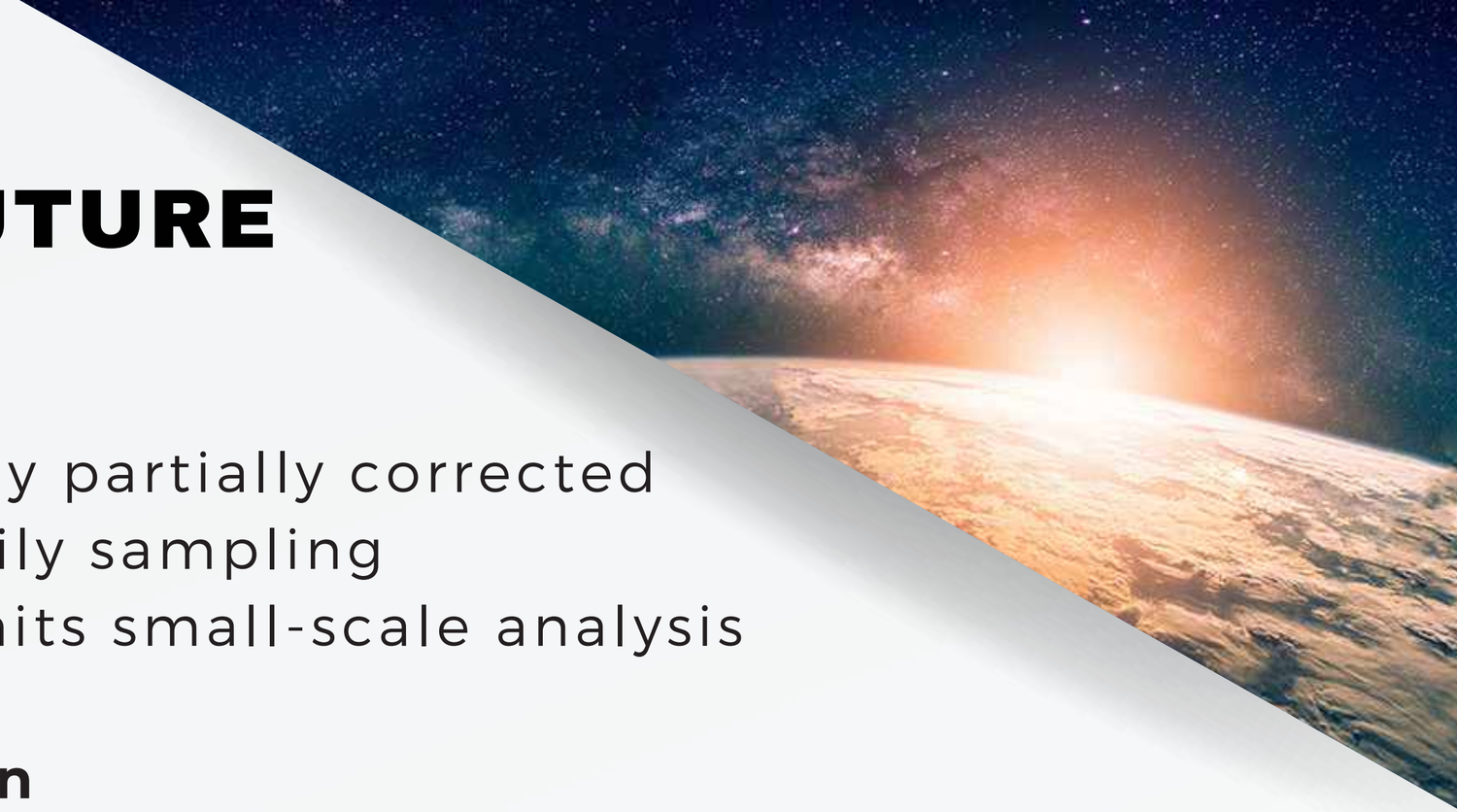
Plant name	Location	Province	Pre-war ranking	Pre-war	2022	2023	2024	Overall change	2024 ranking
Donetsk Metallurgical Plant	Donetsk	Donetsk	1	0.534	0.488 (-8%)	0.468 (-4%)	0.482 (+3%)	0.482 (-10%)	1
Yuzovsky Metallurgical Plant	Donetsk	Donetsk	1	0.534	0.488 (-8%)	0.468 (-4%)	0.482 (+3%)	0.482 (-10%)	1
ArcelorMittal Kryvyi Rih steel plant	Kryvyi Rih	Dnipropetrovsk	3	0.487	0.343 (-30%)	0.355 (+3%)	0.388 (+9%)	0.388 (-20%)	6
Metinvest Zaporizhstal steel plant	Zaporizhzhia	Zaporizhzhia	4	0.481	0.365 (-24%)	0.385 (+6%)	0.398 (+4%)	0.398 (-17%)	5
DCH Dnipro Metallurgical Plant	Dnipro	Dnipropetrovsk	5	0.478	0.399 (-16%)	0.414 (+4%)	0.420 (+2%)	0.420 (-12%)	3
Interpipe Steel Plant	Dnipro	Dnipropetrovsk	6	0.462	0.391 (-15%)	0.409 (+4%)	0.412 (+1%)	0.412 (-11%)	4
Yenakiieve Metallurgical Plant	Yenakiieve	Donetsk	7	0.426	0.372 (-13%)	0.414 (+11%)	0.380 (-8%)	0.380 (-11%)	7
Metallurgical Plant Kametstal	Kamianske	Dnipropetrovsk	8	0.404	0.337 (-17%)	0.339 (+0%)	0.360 (+6%)	0.360 (-11%)	9
Metinvest Ilyich Iron and Steel Works	Mariupol	Donetsk	9	0.394	0.311 (-21%)	0.323 (+4%)	0.313 (-3%)	0.313 (-21%)	10
Azovstal Iron and Steel Works	Mariupol	Donetsk	10	0.389	0.316 (-19%)	0.323 (+2%)	0.312 (-3%)	0.312 (-20%)	11
Alchevsk Metallurgical Plant	Alchevsk	Luhansk	11	0.344	0.338 (-2%)	0.371 (+10%)	0.372 (+0%)	0.372 (+8%)	8

SUMMARY

CONCLUSIONS

- First year dominated by collapse of economic & industrial activity
- Later years influenced by infrastructure attacks and reconstruction
- Occupied regions show distinct behavior
- NO_2 serves as a robust proxy for war-related disruption

LIMITATIONS & FUTURE RESEARCH



- **Weather influence** only partially corrected
- **Cloud cover** affects daily sampling
- Satellite **resolution** limits small-scale analysis

- **Weather normalization**
- **CAMS (Copernicus Atmosphere monitoring Service) data** inclusion
  - PM10, PM2.5
- **Wider environmental impact assessment**
  - **fire detection, forest loss, agricultural land impact**

ARNIKA

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Funded by
the European Union