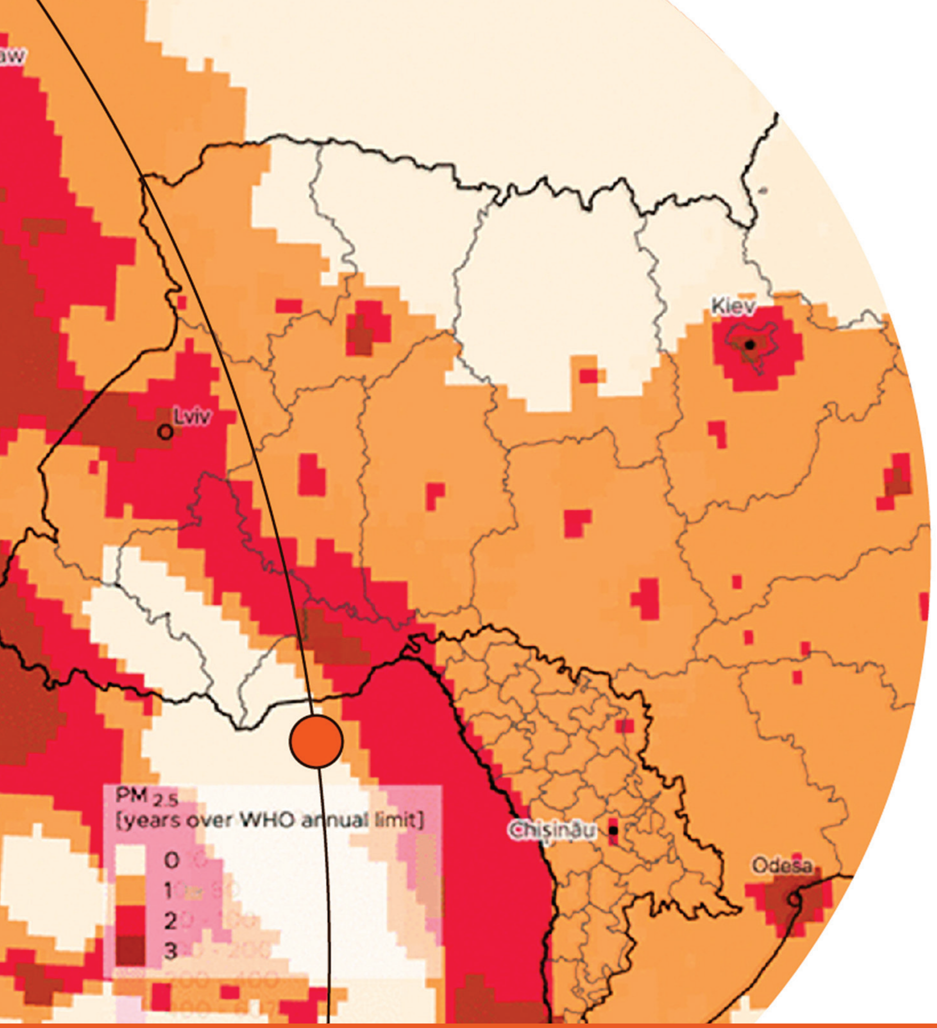

COVID-19 Impact on Air Quality in Ukraine and the Republic of Moldova

Work Order REPORT

Support requested by:

United Nations Development Programme (UNDP)

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- Roman Bohovic (CTO from World from Space)

PURPOSE

This document compiles the objectives and achievements of the Project together with the conclusions and findings. It will present how to support a larger service over other regions, countries and indicators. The potential of the methodology applied during the project will be described, but also its limitations, for UNDP and other stakeholders to be aware of the working flow and it's potential.

It is also intended for dissemination purposes, and provision of great potential of using EO for air quality analysis and their indicators.

1. Development Context and Background

1. Introduction

Services based on Earth Observation (EO) are useful tools for providing a wide range of past and present environmental information through the analysis and processing of historical information, present status and analytical data available.

Technology has now achieved the capacity of processing large amounts of data within a time frame and inside an affordable budget.

The particular advantages of EO in this context are the non-intrusive, objective and globally consistent nature of the information and the use of satellite mapping services provides many opportunities for the management and verification of the environmental practices associated with the development projects the banks are helping.

Through unique EO products, it is possible to map agriculture, land use and environment, water quality, energy availability. food security, coastal subsidence and forest state among other equally important data, which EO can gather effectively in areas with little ground information.

The European Comission's Copernicus programme Copernicus programme is aimed to make environmental monitoring a reality, delivering near-real-time data on a global level which can also be used for local and regional needs.

Through its own dedicated Sentinel satellites, various contributing missions and on-ground stations that collects information from in situ systems such as ground stations, which deliver data acquired by a multitude of sensors on the ground, at sea or in the air, Copernicus programme allows us to create value-added information by processing, comparing and analysing data that stretches back for years, and from this monitor changes, create forecasts, analyse patterns and generate maps that identify anomalies and features.

Over this, ESA has been collaborating with Development Banks and International Financial Institutions for a long time on monitoring development projects and its impact on the environment.

This collaboration has demonstrated the relevance of EO for Development projects, and has proven that it is a valuable tool for make cost effective, quick and incontrovertible assessments, that help to manage urban growth, protect forest, monitor water quality and broadly provides evidence of progress or baselines for remediate actions whenever an environmental transformation occurs as result of a development project.

Although larger initiatives and programmes are currently on execution (like EO4SD, an ESA initiative to support the uptake of EO-derived information in sustainable development), ***there is a need to cover small-scale and exploratory uses of EO products as a response to short-term, ad-hoc requests*** *f*rom Banks and international institutions. These requests demand an innovative approach and capacity to deliver within a short time frame, a solution that goes beyond standard product generation and that links the EO data with underlying statistical and geographic information in a creative way.

To achieve this, ESA is funding a Framework Contract (named: EO-Clinic) scheme to which this project belongs to.

Under this Framework Contract, several "Request for Proposal" are be issued to the contractors from different end users (banks and International Finance Institutions). These Requests can vary largely on its purposes and will address any or several of the following Thematic Groups: Agriculture, Climate Change, Coastal Zone Management, Disaster Risk Management, Energy and Natural Resources, Forestry, Marine Environment Management, Transport, Urban, Water Resources Management and Non-EO Information and Analytics.

This document is a result from Request for Proposal 9 (RFP009) of the EO-clinic Frame Contract, requested by the United Nations Development Programme (UNDP).

1.2 Request for proposal 009: COVID-19 Impact on Air Quality in Ukraine and the Republic of Moldova

This chapter summarises the objectives and approach of the requested EO support dealing referred in the Request for Proposal 9 (RFP009) of the EO-clinic Frame Contract, requested by United Nations Development Programme (UNDP).

The **main initial objective of this Request for Proposal number 009 (RFP009) is to support the UNDP and governments of Ukraine and Moldova to have an overview and detailed information on the status of air quality and emissions due to transport and industry, to contribute to better understan d the complex COVID-19 "before and after" situation in both countries, created by the limitations in mobility, changes in economic activity, and the additional influx of previously expatriated citizens**.

In order to respond to the current crisis, raise awareness of the central and local administrations, support with evidence-based decision making, and assess the impact of the crisis induced by the COVID-19 pandemic, UNDP together with the Ukrainian and Moldovan governments are stepping up efforts to collect new evidence, including from satellite Earth Observation (EO), in a multi-layered and multi-granular information approach.

Geospatial EO data is missing to a large extent and not yet fully used in Ukraine and Moldova for development purposes. Moreover, given the current COVID-19 crisis, EO and other new types of data is urgently required to provide for:

- Additional evidence around what is happening on the ground, especially in the absence or delayed collecting of statistical and other public data
- Improve situational awareness of the local and regional authorities around COVID-19 and its spread
- Support in assessing the immediate and long-term social and economic impact of COVID-19
- Support in building an Early Warning System (for the Government of the Republic of Moldova).

The results of this study are to be delivered to the Ukrainian and Moldovan UNDP representatives in the form of technical notes and images built upon existing EO datasets and data processing and visualization capabilities.

1.3 Initial request: Objectives, Work Logic and Expected Outputs

1.3.1 Information services to be delivered: Regional and Local Air Quality Indicators

Air quality, being partly determined by emissions of pollutants from human activities (and partly by changes in weather), is an indicator of the level of these activities. In situations of prolonged lockdown and over time, the expectation is that average levels of air pollution will go down.

This service shall use EO methods to characterise air quality parameters in order to better understand the air quality dynamics over the territories of Ukraine and Moldova. Parameters can include concentrations of particulate matter (PM10, PM2.5), trace gases (SOx, NOx, etc.) and other contaminants. Focus shall be put on anomalies during the COVID-19 pandemic, with respect to long-term averages, or at least the previous 5 years.

The analysis shall exploit the unprecedented capabilities of the Sentinel satellites, in particular Sentinel-5P and Copernicus services next to other available datasets from satellites (e.g. MODIS, MetOp) and non-satellite sources.

The Area of Interest of the work shall be the entire territories of the two countries, with emphasis on studying emissions from major urban and industrial areas (Kyiv, Kharkiv, Odesa, Dnipro for Ukraine, and all regions for Moldova).

For validation of results, a comparison with in-situ measurements are of fundamental importance. The Con-tractor shall, with the support of UNDP and their partners, investigate the availability of data from measurement networks in both countries, providing continuous measurements of pollutants and greenhouse gases concentrations. In-situ resources shall also be used to attempt to downscale satellite measurements to local scale, especially for urban areas and major (industrial) point polluters. Meteorological and climatological time series shall also be considered to assess climate change processes and individual pollution episodes.

Existing resources, such as the Copernicus CAMS COVID-19-related service1, the Sentinel-5P Mapping Ser-vice2, IQAir World Air Quality3, etc. shall be exploited whenever possible.

To be considered in the context of Ukraine's COVID-19 lockdown are the reductions in transportation and industrial activity occurring at the time of the year when open burning is commonplace. This also coincided with vast wildfires in the vicinity of several major cities (e.g. Kyiv). Accordingly, it will be necessary to take into account the negative impact on air quality caused by these sources of air pollution and ensure that these additional registered emissions do not distort the analysis.

The service shall also provide a simple web-based platform, accessible also through mobile devices, where the collected satellite- and non-satellite data will be available for visualisation, for a period of one year, as a mini-mum. Visualisation shall be possible for map data, but also for selected time series. To highlight the findings of the project, the web page shall also present at least two noteworthy and striking case studies for each country, as a visually-appealing and easy-to-understand story line or similar. The platform contents shall be in English, but the Contractor shall be ready to create translated versions (Romanian, Ukrainian, Russian) if deemed necessary. UNDP can potentially provide translation support.

2. What was Proposed to be Performed

2.1 Understanding of the requirements and proposed approach

Following requirements were identified within the RFP and our compliance statement is also summarised therein:

Table 1: **Requirement summary versus approach proposed.**

Requirement	Fulfilment	Comments
Using EO methods to characterise air quality dynamics over UA and MD.	Yes	*Sentinel 5P and CAMS products are used in order to analyze air quality dynamics*.
Focusing on anomalies during COVID-19 pandemic in compare to at least 5 previous years.	Yes	*Time series of 5 years of CAMS data set is used as well as the whole history archive of Sentinel 5P in order to define normal state and COVID19-related anomalies*.
Exploiting Sentinel satellites, Copernicus services and other sources.	Yes	*Sentinel 5P, CAMS, C3S, and other sources of data are used*.
AOI composing of entire countries with special focus on major urban and industrial areas in UA and all regions in MD.	Yes	*AOI will cover the whole area of both countries. Regional analysis will be based on the official administrative division of UA and MD.*
Comparison with in-situ measurements.	Yes	*In situ measurements provided by UNDP and partners will be compared to Sentinel 5P and CAMS data.*

Requirement	Fulfilment	Comments
Attempt to downscale satellite measurements with in situ resources.	Yes	*Satellite S5P data will be downscaled to 1km grid during the data processing. Further downscaling of S5P and CAMS data will be tested with in situ data provided by UNDP on major urban areas. As we do not have access to in situ data at the moment, we cannot propose a sound method for downscaling at this moment but it is part of the solution proposed. This could be, however, further discussed during the KOM*.
Analyzing time series of meteorological and climatological data for assessment of climate change processes and individual pollution episodes.	Yes	*Temperature, wind speed and other meteorological data from C3S will be used to assess the individual pollution episodes and showcases. Climate change processes will be also taken into account. However, overall assessment of climate change processes in the region will be done in a limited way following the scope of this analysis*.
Exploiting existing resources (CAMS COVID19, S5PMS, IQAir, etc.)	Yes	*CAMS COVID19 service will be used as a methodological background for the analysis. S5PMS will be used as an inspiration for the provided web platform. IQAir is to be used as supplementary information for analysis of Kyiv and Chisinau*.
Taking into account negative impacts of open burning and wildfires.	Yes	*Global Fire Assimilation System (GFAS) will be used to identify emissions from fires and the information will be considered in the analysis*.
Providing a simple web-based platform in English available on mobile phones.	Yes	*Web-based platform available on mobile phones will be provided in English language*.
Running the platform for at least 1 year.	Yes	*Platform will be available for 1 year, with possibility to extend the service for additional years*.
Presenting both maps and time series on the platform.	Yes	*Platform will consist of interactive maps and dashboards with time series dimension*.
Presenting "striking" case studies for UA (2) and MD (2).	Yes	*Total 4 web map stories will be presented, 2 for each country*.
Preparing platform for additional translations.	Yes	*The platform will be ready for additional language translations.*

The work logic of this particular Work Order has been defined to ensure the provision of an efficient service to UNDP and ESA, maximizing added value outputs, delivered on time and in the required format. Indeed, the work for this RFP is organized around five work packages (WP).

- **WP0**: The overall management and the successful implementation of the work as well as the delivery of the results. (everis)
- **WP1**:.This work package will consist of data acquisition and pre-processing for all input data for further analyses. (WfS)
- **WP2**: Data from the previous WP will be used for air quality and socioeconomic analyses and assessments. Based on output, a report on air quality monitoring, including suggestions on further use will be compiled. (WfS)
- **WP3:** Results from WP2 and WP3 will be used for promotion and public dissemination, including 4 web-stories and online platform. (WfS)
- **WP4**: This working package contains the final report writing, recommendations, and quality assurance of the results of WP 1, 2, 3 and 4. (everis)

Following outcomes are expected to be created within the cooperation:

- Pre-processed datasets for UA and MD (WP1)
- List of indicators from each datasource, resolution, hourly/monthly/seasonal/yearly aggregations (according to different regions and national, focus urban areas) (WP1)
- Report on air pollution in Ukraine (WP2)
- Report on air pollution in Moldova (WP2)
- Report on in-situ validation (WP2)
- Report on COVID era anomalies (WP2)
- Report on links between air quality and socioeconomic data (WP2)
- Suggestion on further use (WP2)
- Web-based platform, accessible also through mobile devices, showing map data and time series of information (WP3)
- Four visually appealing and content-rich stories showcasing results of the analysis. (WP3)
- Progress reports, Minutes of meeting (WP0)
- Work Order Final Report (WP4)

2.2 The partners

The overall EO-Clinic frame contract consortium is composed by thirteen companies. Twelve EO service providers, expert in a specific thematic group, but also, with expertise in most of them. And the prime contractor, everis aerospace and defense, an entity which primary expertise in management of challenging international development projects. This way, the key of the success lies on a well-structured and collaborative team, which members supporting each other in order to achieve outstanding results.

It is a **well-balanced team** formed by **one (1) multinational entity** leading the consortia, expert in managing international projects, **two (2) research organization** which provides state of the art techniques in term of EO solutions and **ten (10) SMEs** entities highly dynamic and specialized on EO solutions.

The main principles of the consortium are:

- **Highly reactive and dynamic structure** – for accommodating short-term, small and exploratory request from the end user.
- **Deep understanding and expertise on thematic EO products** – providing a wide coverage of range of skills and capabilities in terms of different EO study areas and products generation.
- **Client-oriented solutions** – always keeping in mind the scope and the necessities of the end-users. Their business activity and aiming to provide the best suited EO solutions for them.
- **Time-oriented project** execution – It is essential in this environment to deliver EO information on time against deadlines. This is the only approach for achieving what it is called “rapid-response” capability to the Bank users.

- **High quality assistance for end users** – usually, final users are not familiar EO technologies, even less, when innovative methodologies and techniques are applied. It is essential to provide assistance on final information for its correct exploitation.
- **Expand the knowledge through Europe** – thirteen companies, nine different countries. The consortium aims to promote European missions, generate value-adding services, and take European EO capabilities to the next step.

The complete thematic groups required by ESA for different Request for Proposals are fully addressed by the consortium members.

This project in particular is performed by the following partners providing the best expertise for the specific purpose of the project:

<table>
<tr><th>Everis Aerospace and Defense S.L.</th><th>Prime Contractor: EO-clinic Frame Contract and project management and technical Coordination</th></tr>
<tr><td colspan="2">everis is a multinational group that offers to its clients services and solutions that add high value covering all the value chain areas of a company, from defining the strategy, to design, development, integration, implementation and maintenance of technological solutions.
everis Aerospace and Defence, the everis Group's Aerospace and Defence Division, offers global solutions for implementing critical systems in aerospace, defence, security and simulation sectors, integrating reliable and innovative technologies though proprietary development and through the SMEs with which the Group has strategic alliances as leading partners.</td></tr>
<tr><th>World from Space S.r.o</th><th>Subcontractor: Thematic Group 9-Urban Leader</th></tr>
<tr><td colspan="2">World from Space (WFS) is a start-up company established in September 2017, currently incubated in the South-Moravian Innovation Centre, Brno, Czech Republic. WFS is a company building on experience of its founders in the field of EO and environmental science. The company builds its core business around the interpretation of satellite data for various users. So far, we cooperate especially with cities.
Our vision consists of two main product lines of the company - Smart Cities and Smart Agriculture, with ongoing R&D bringing new topics according to customer needs. We want to put stress on transfer of knowledge and know-how from the scientific community to real use. Therefore, we intend to preserve our cooperation with universities and research institutions.
The company was awarded the Seal of Excellence under the Horizon 2020 SME instrument in 2018 for the project of vegetation dynamics and drought monitoring. WFS is a winner of ESA BIC Prague EOVation Masters 2018, ESA BIC EOVation Masters Scientific Article 2018 and it won the second place at the ESA BIC Prague City and climate hackathon 2018. We were part of the winning team of the ESA BIC Prague Agricultural hackathon 2017.
World From Space (WfS) is an Earth Observation company active in the agricultural sector, urban and land monitoring and management with focus on climate change adaptations. Core of the company's business is DynaCrop service, an API for agricultural software serving monitoring and analytical information based on satellite data. WfS is part of ESA's start-up ecosystem, member of ESA BIC Czech Republic, winner of the Copernicus Masters - Government Challenge 2018 and took part in Copernicus accelerator in 2019. The team of WfS consists of people from multiple domains: remote sensing, geoinformatics, IT, environmental management and smart agriculture. WfS is covering a wide range of skills including satellite data processing and interpretation (optical and radar systems), cloud computing, AI, backend development, GIS that are combined with agricultural, environmental and urban expert knowledge.</td></tr>
</table>

2.3 Work Logic proposed

The work logic of this particular Work Order has been defined to ensure the provision of an efficient service to UNDP and ESA, maximizing added value outputs, delivered on time and in the required format. Indeed, the work for this RFP is organized around five work packages (WP).

- **WP0**: The overall management and the successful implementation of the work as well as the delivery of the results. (everis)
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- Report on COVID era anomalies (WP2)
- Report on links between air quality and socioeconomic data (WP2)
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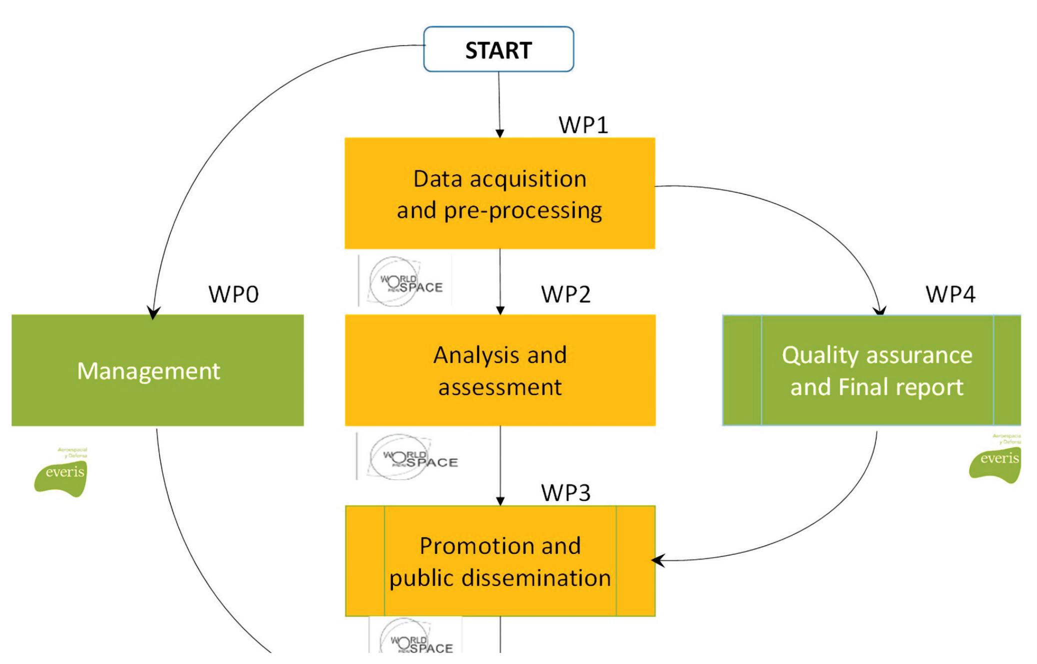
- Four visually appealing and content-rich stories showcasing results of the analysis. (WP3)
- Progress reports, Minutes of meeting (WP0)
- Work Order Final Report (WP4)

The high-level work logic is described in the following Figure:

Figure 1: **Work Logic of Work Order**



2.4 Description of Work packages.

2.4.1 WP0 - Management

Management activities of this project will be performed by everis. Management processes will follow the ones described in reference Management Proposal. In this proposal, only specific management aspects for this RFP are described. In order to control the progress of the work order with respect to cost, schedule and technical objectives, the following milestones are set up:

Table 2: **Milestones management.**

Milestones		Date
Kick-off Meeting (KOM)	Once the Work Order (WO) is launched, a KOM will be held by ESA, UNDP and Everis to review schedule, scope of the work and deliverables. It will be agreed the crop type selected, the Countries and the health indicators to be analysed.	T0
Acceptance Review	A final meeting with ESA, UNDP and Everis will be performed to review and accept the work done along the work order.	T0+8w

Other management-related tasks such as cost control procedures, progress reporting, meetings management, actions management and so on will be carried out as stated in Management Proposal. Moreover, the proposal manager will contribute to the final report with the conclusions obtained during the Work Order, and related to the estimation of feasibility, conditions and cost of an extended service.

2.4.2 WP1 Data acquisition and pre-processing

2.4.2.1 Objectives, tasks and methodology

Objective of this work package is to prepare all the necessary input data for the further analysis. The work package is divided into following tasks:

A. Satellite data from Sentinel-5p
B. CAMS data collection
C. C3S data collection
D. Burning areas data
E. In-situ and local data processing
F. Quality assessment and evaluation

2.4.2.1 Tasks:

WP1.A Satellite data from Sentinel-5p

Satellite data from Sentinel-5P will be obtained via Sentinel Hub (SH) operated by Sinergise. It is commercial platform that provides access to Earth observation data with a focus on Sentinel satellites that easy automated and cloud based processing of the data. Sentinel Hub supports Sentinel-5P level 2 (L2) data products which are geolocated and primary pre-processed to contain “qa_value”. The “qa_value” means “quality assurance value” and indicates the status and quality of each ground pixel. It is a continuous variable ranging from 0 (error) to 1 (no errors). For the most Sentinel-5p products, pixels under 0.5 values are filtered out (for NO2 product it is 0.75). The “qa_value” is an important parameter that reduces the seamless coverage of the areas of interest (Ukraine and Moldova) by S5P data and the proposed methodology takes it into account. NO2, SO2, and CO products (since May 2018 to June 2020) will be obtained via SH. Processing Sentinel-5p is in line with the guidelines of S5P Mission Performance Centre´s Readmi files[1].

It is important to take into account that quality of accessible pixels depends on weather conditions and other parameters and is generally defined by “qa_value”. S5P revisit time for Europe (including the area of Ukraine and Moldova) is more than once a day. It is due to a near-polar, sun-synchronous orbit of the satellite, there are scanning overlaps at higher latitudes, thus the processed images will comprise all available satellite measurement. Using all available data means combining different satellite orbits what leads to various grid sizes and orientations. To address this, all S5P satellite observations will be downscaled to obtain a regular grid with a resolution of 1 km x 1 km via SH. Data is automatically pre-processed and downloaded to cloud space using our proprietary Python scripts using SH service. Final processing steps are done on desktop GIS, namely QGIS to get monthly and seasonal averages over the area of Ukraine and Moldova. Season is defined as a 3 months period following climatic seasons (December-February, March-May, June-August, September-November) to get simplification of the air quality caused by weather conditions.

WP1.B CAMS data collection

CAMS data will be obtained via the Atmosphere Data Store (ADS). We will process CAMS European air quality forecasts dataset providing daily air quality re-analyses and forecasts for Europe. Obtained variables will be NO2, SO2, CO, PM10, PM2.5 and Ozone measurements available in a three-year rolling archive. Currently, European air quality forecasts data older than 3 years are available as European Air Quality - ENSEMBLE reanalysis at an “older”

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[1] https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File

version of ADS (to be shutdown on 2020, June 30th). It is assumed that datasets will be very soon migrated over to the Atmosphere Data Store (ADS). All demanded air pollution parameters in the dataset will be obtained in available 10 km x 10 km spatial resolution at surface level and 1-hour temporal resolution for 5 year time series. The ADS provides access to the dataset with API but it can be also downloaded in GRID and NetCDF format. Python script will be written to automatically download NetCDF files and compute daily (on focus areas), monthly and seasonal (December-February, March-May, June-August, September-November) values over the area of Ukraine and Moldova.

WP1.C C3S data collection

Climatic data from ERA5-Land monthly averaged data from 1981 to present and ERA5-Land hourly data from 1981 to present will be analysed in order to assess the meteorological and climatic variability of the area. Key pre-processed variables will include: 2m temperature, 10m u-component of wind, and 10 m v-component of wind. All demanded parameters will be obtained in GRIB file format in native 9 km spatial resolution at surface level and 1-hour temporal resolution for 5 year time series. The CDS provides access to the dataset with API but the data can be also downloaded. Python script will be written to automatically download and pre-process monthly/seasonal averages to Geotiff format for GIS analyses.

WP1.D Burning areas data

Wildfire analysis for the area will be performed in order to identify their impact on air quality during the COVID situation. The Copernicus European Forest Fire Information System (EFFIS) is very useful for identifying places with fires, however, the information on emissions from fires is missing. Therefore, CAMS Global Fire Assimilation System (GFAS) will be used to analyze daily emissions from fires. Data is available in GRIB format through the ECMWF WebAPI. Python scripts will be used to automatically download and pre-process data.

WP1.E In-situ and local data processing

Required data from the partners in Ukraine will include Administrative data from key municipalities; existing economic data, average salaries, GDP (regional), location of major industrial areas; official data from the State Statistical Service of Ukraine on NO2 emissions; and near-real time data on PM2.5, PM10 sourced from local civil society organisations. Required data from the partners in Moldova will include: official socio-economic data from the Moldova National Bureau of Statistics; data from air pollution sensors deployed by the State Hydrometeorological Service and by the Chișinău Municipality; data on major industrial areas and their reported emissions; the government's Draft Strategy for Air Protection containing information on air quality measurement networks and analyses and reports on air pollution from the Environment Agency; and Plans for the national EWS. Provided datasets will be processed in order to be combined with the air quality data processed in previous tasks. However, we do not know specifications, formats, spatial and temporal granularity of the data thus it is not possible to propose specific pre-processing.

WP1.F Quality assessment and evaluation

For the processing of the S5P data quality flag in accordance S5P Mission Performance Centre´s Readmi files[2] is used to filter unsatisfactory atmospheric conditions. This causes no-data holes in each acquisition what leads in different number of valid values entering each aggregation. This needs to be taken into account as low number of valid observation leads

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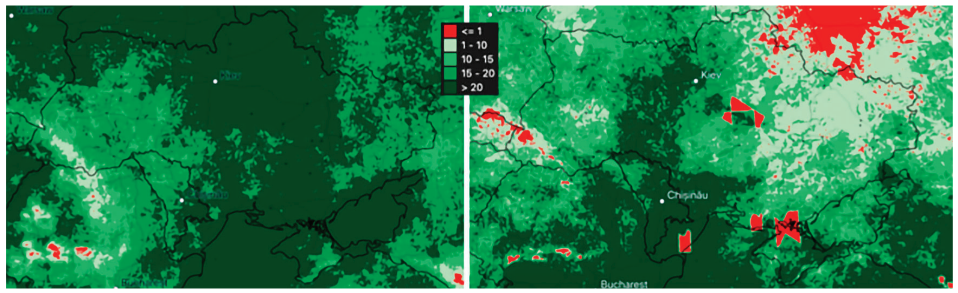
[2] https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File

to un-robust averages. This is shown at illustration below - number of valid observations differ between months and also spatially within same period. This is overcome by using also seasonal aggregates that might secure enough data and is than more robust.

Figure 2: **Comparison of valid pixels (count) from S5P satellite measurements in May 2018 (left picture) and December 2019 (right picture). Source: Contains modified Copernicus Sentinel-5p data [2019-2020] processed by WfS.**



2.4.2.3 Outputs

- Pre processed datasets for whole states - UA and MD
- List of indicators from each datasource, resolution, hourly/monthly/seasonal/yearly aggregations (according to different regions and national, focus urban areas) – see table below.

Table 3: **List of indicators processed from different data sources.**

Dataset name	Information about	Source	Original spatial resolution	Repossessed spatial resolution	Original temporal resolution	Reprocessed temporal resolution
NO2_s, SO2_s, CO_s	NO2, SO2, CO	S5P	7,5x3,5 km/ 5,5x3,5 km	1km	1-4x daily	monthly for countries, 10 days for COVID, original for cities
NO2_c, SO2_c, CO_c, PM10_c, PM2,5_c, Oz_c	NO2, SO2, CO, PM10, PM2,5, Ozone	CAMS	10x10km	10x10km	hourly / monthly	monthly for countries, daily for COVID, hourly for cities
NO2_i, SO2_i, CO_i, PM10_i, PM2,5_i, Oz_i	NO2, SO2, CO, PM10, PM2,5, Ozone	in situ	spot measurements	-	according to local partners	monthly for countries, daily for COVID, hourly for cities
NO2_g, SO2_g, CO_g, PM_2,5g, PM_g	NO2, SO2, CO, PM2,5, Total PM	GFAS	0,1 degree	0,1 degree	daily	monthly for countries, daily for COVID period
Temp, wind_u, wind_v	temperature, u-wind, v-wind	C3S	9x9km	9x9km	monthly, hourly	monthly for countries, daily for COVID, hourly for cities

2.4.3 WP2 Analysis and assessment

2.4.3.1 Objectives, tasks and methodology

Objective of this work package is to analyse and compare air quality data from different sources as well as socioeconomic datasets in order to identify normal state and COVID anomalies over Ukraine and Moldova.

The work package is divided into following tasks:

A. Air quality data analyses
B. Fusion of air quality and socioeconomic data analysis
C. Regional and focus (urban) areas comparison
D. COVID era evaluation
E. Suggestions for further use

2.4.3.2 Tasks:

WP2.A Data analyses (2015-2020)

Spatiotemporal analyses of the pre-processed data (from WP1) of S5P, CAMS, in-situ will be done at national level in the first step. The time series starting in May 2018 will be visualized within a web application (output WP3.B). Long-term concentrations of key air pollutants will be analyzed as a pixel based seasonal average (winter, spring, summer, autumn) in order to detect changes in seasonal trends. For the dataset, inter-comparison common grid will be introduced. Correlation statistics will be undertaken on monthly and seasonal time series.

In-situ data will be also analysed and compared, after agreeing with the required data sets and required format to allow this comparison.

WP2.B Fusion air quality and socioeconomic data analysis

This work package aims to make cross analyses of air quality data from Sentinel-5p and/or CAMS and socioeconomic data during COVID lockdown to find conceivable spatial and temporal links. The purpose is to enable initial assessment of potential socioeconomic impacts according to air quality change in subsequent comparable events (such as the second wave of COVID), if such relation is present and well understood. This task is highly dependent on the quality and granularity of the socioeconomic data that we ask from partner institutions. It needs to be stated that there is no strong scientific evidence of such relation and it is probable that the course of the future crisis will vary. The aim of this task is, however, to investigate this relation and set the base for easy, fast but elementary assessment.

WP2.C Regional and focus (urban) areas comparison

Air quality analyses at the national level will be further specified by undertaking analyses of air quality at regional level and selected cities for comparison. This will be done in QGIS running standard zonal statistics on the monthly data. Apart from monthly time series, mean values, consecutive differences and variability will be also computed for each unit. This analysis will be performed for following units:

- 25 Ukrainian regions (oblasts and Crimea)
- 490 raions (districts) of Ukraine

- 10 biggest cities in Ukraine (Kyiv, Kharkiv, Odessa, Dnipro, Donetsk, Zaporizhia, Lviv, Kryvyi Rih, Mykolaiv, Mariupol)
- 32 districts (raioane) of Moldova
- 3 biggest cities of Moldova (Chișinău, Tiraspol and Bălți)

An attempt to downscale S5P and CAMS measurements to local scale will be made with the use of in situ data provided by UNDP.

Results of this task will be presented in the report as well as in the web application (output of the task WP3.B) to address regional differences in air quality and its variability in time.

WP2.D COVID era evaluation

Proposed air quality analysis methodology is partly based on the Copernicus CAMS COVID-19-related service[3]. Two figures will be provided as well as in CAMS COVID-19-related service. In the first step, S5P daily data will be compared to the CAMS European air quality forecasts dataset (NO2, SO2, CO measurement). While CAMS COVID-19-related service generalized S5P scanning in 13:30 over the whole Europe, we specified scanning time appropriate for Ukraine and Moldova - 11:00 am, thus in our methodology we utilized for comparison the CAMS measurements taken at 11:00 am instead of at local noon. In the second step, we analyze CAMS data (including ozone, PM10 and PM2,5) on its own. A daily median (24 hours values for every day is used) and seven-day running average at national level will be processed. The time series will start on 1 February 2020.

To determine the exclusion of the effects of emissions from fires that could influence actual impact of the reductions in transportation and industrial activity, a biomass burning emissions data obtained from CAMS Global Fire Assimilation System will be used. The product is based on Fire Radiative Power (FRP), an index used to compare and measure the intensity of fires to estimates the intensity and related emissions of fires. The data will be downloaded at daily temporal resolution and a spatial resolution of a regular lat-lon grid with about 11.1 km x 11.1 km for NO2, SO2, CO, PM2,5 and total PM. Obtained data will be downscaled to a spatial resolution of processed SP5 data (1 x 1 km) and area of intersect will be analyzed. Estimated quantity of emissions from fires will be taken into account and added to overall air pollutant concentrations during COVID-19 lockdown.

To validate the methodology and exclude an external influences of actual impact of the reductions in transportation and industrial activity, the C3S data will be used. Hourly and monthly temporal resolution will be used. To exclude the effect of temperature on pollution reduction during COVID-19, 2m temperature data will be compared to long-term averages for a given period. The averages will be compared on national and local (cities) level as well. A temporal resolution of processing will be: monthly for countries, daily for COVID-19 period, hourly for cities during the COVID-19 period. The same procedure will be used for the 10m u-component of wind, and 10 m v-component of wind obtained from the C3S. Wind direction and speed influence a path smoke pollution taken in the atmosphere where is detected by satellite measurement. Thus it is important to detect wind fluxis for a given period to estimate source of the pollution.

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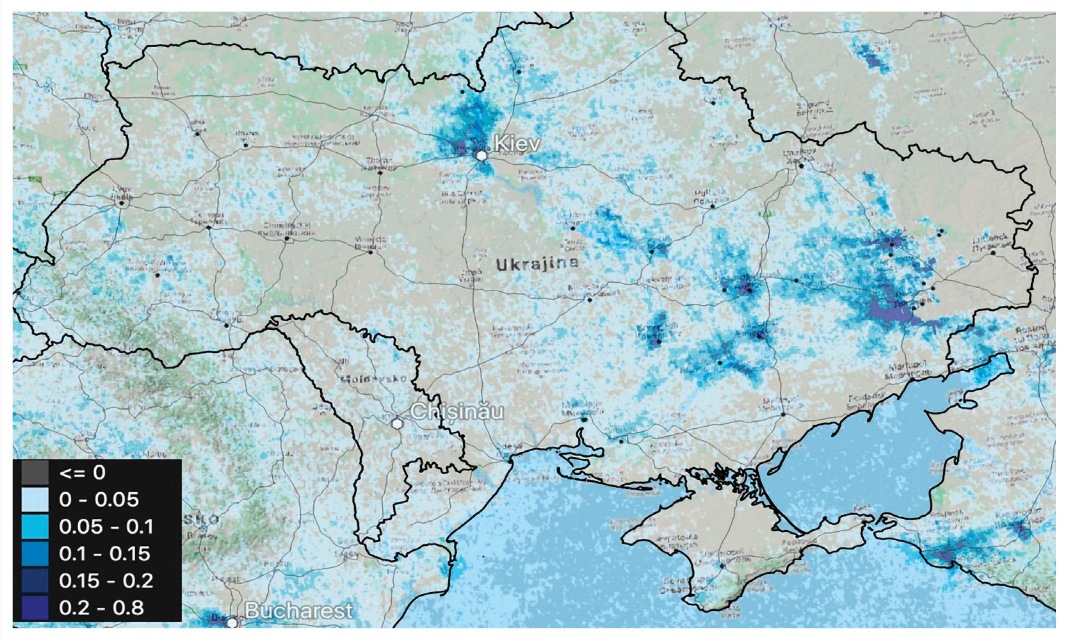
[3] https://atmosphere.copernicus.eu/european-air-quality-information-support-covid-19-crisis

Figure 3: **Decrease of NO2 levels during the COVID-19 situation March+May 2020 in Ukraine and Moldova from S5P satellite measurements (Compare to March+May 2019) without adjustments for open fires, climatic data etc.**



Source: Con-tains modified Copernicus Sentinel-5p data [2019-2020] processed by WfS

WP2.E Suggestions for further use

Part of this proposal is also dataset assessment and recommendations for monitoring. This task will assess and compare existing solutions such as Monthly climate explorer for COVID-19[4] and Copernicus Sentinel-5P Mapping Portal (**https://maps.s5p-pal.com/**) and proof of concept. Focus will be given on automation of the monitoring and standardisation (comparable methodology) with other satellite based products. In-situ measurements will be also considered and essential differences of observation acquisitions clearly explained. Suggestions for satellite based monitoring will be stated. Exploratory use of a combination of socioeconomic indicators and air quality data will be evaluated and possible experimental use will be suggested if considered viable.

2.4.3.3 Outputs

- Report on air pollution in Ukraine
- Report on air pollution in Moldova
- Report on in-situ validation
- Report on COVID era anomalies
- Report on links between air quality and socioeconomic data
- Suggestion on further use

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[4] https://cds.climate.copernicus.eu/cdsapp#!/software/app-c3s-monthly-climate-covid-19-explorer?tab=app

2.4.4 WP3 Promotion and public dissemination

2.4.4.1 Objectives, tasks and methodology

Objective of this work package is to produce attractive materials that could be further used and exploited by both decision makers and the public. One web application and 4 web stories will be produced, two for each of the countries. The work package is divided into following tasks:

A. Technical design of application and case studies topic

B. Web app implementation

C. Web stories

2.4.4.2 Tasks:

WP3.A Technical design of application and case studies topic

Information processed from different sources and processed for different temporal and spatial units described in WP1 will be presented to the public and partners in an interactive web application. For readability and presentation clarity, both the content and functionality will be designed within this task. It is clear that not all datasets can be presented in the application if the audience might not be overwhelmed. Selection of information presented will be done with the aim to maximize comprehension. Here is the initial list of proposed web application functionalities:

- air pollutant selection (dataset and product selection)
- running time series (from historical to recent information)
- datasets comparison (observed S5p and modelled CAMS)
- in-situ measurements (depending on data provided by local partners)
- comparison in-situ and S5P measurements (if possible - depending on data provided by local partners)
- split window - time periods comparison
- timescale (monthly or seasonal steps)
- navigation and zooming
- region comparison

Presentation of the case studies will be in the form of “story maps” - single pages with scrolling screens that consist of different graphs and maps, combining raster and vector data accompanied with explanatory text.

WP3.B Web app implementation

In this task, the web application will be programmed in JavaScript using Leaflet technology for raster data presentation in the tiles, CARTO for vector data presentation and Plot.ly library for graphs.

WP3.C 5 Web map stories

Additional GIS analyses, maps, graphs and visualisations for visually appealing presentation will be done. Data will be presented in the form of maps and graphs. For that Leaflet, CARTO and Plot.ly technologies will be used to present raster and vector information.

Following stories are proposed at the moment:

- Hotspots - 3 best and 3 worst places regarding air quality in UA/MD
- Storyline of impacts of COVID on air quality in UA/MD with respect to socioeconomic changes
- Effects of wildfires on air quality
- Weekday and weekend air quality fluctuation in urban areas
- Other ideas coming from the data analysis

Some of the stories might change if specific interesting information would be found in the data. The final four stories will be picked after the discussion on KOM and discussion with UNDP in week 4.

2.4.4.3 Outputs

- Web-based platform, accessible also through mobile devices, showing map data and time series of information
- Four visually appealing and content-rich web stories showcasing results of the analysis.

2.5 WP4 Quality Assurance, and Final Report

2.5.1.1 Objectives and tasks.

Main objectives of WP4 will be dedicated to ensure the overall quality of the service and report findings and conclusions acquired during the WO execution. An independent technical verification will be performed over the generated outputs. Moreover, quality assurance principles such as those described in the management section of the management proposal will be followed. Those procedures will be tailored to fit into the 4-week time frame, and then ensuring that a minimum quality is reached.

The second objective of WP4 will be the creation of a final report that states the guidelines for the success of the project. Conclusions and findings will be compiled in this report, and then well support a larger service over other regions, countries and indicators. The potential of the methodology applied during the WO will be described, but also its limitations. Then, UNDP and other stakeholders will be perfectly aware of the working flow and it's potential.

It is also considered to work with UNDP on dissemination activities, and support for determining the viability of using EO for mapping the crop types and their indicators.

To achieve the objectives, following tasks are identified, and will be agreed with ESA and UNDP:

- Task 4.1 - Independent Quality and Verification Check of the output products (according to the RFP requests in what concerns the Countries and crops combination).
- Task 4.2 - Final Report, which includes conclusions and guidelines to an extended project over a larger area.

2.5.1.2 Outputs.

The outputs of this working package will be compiled into the Work Order Final Report. It will include the verification and quality assurance metrics, but also the conclusions and findings of the performed services.

2.6 Input dataset required

Input data needed in order to execute proposed tasks will be primarily gathered from Copernicus programme that provides full, free and open access to data to serve general public. Thus primary data are available free of charge from Copernicus Sentinel-5p and Copernicus services and its data stores. Part of the proposed work (WP1.F and WP2.A) is to process, evaluate and compare data from in-situ measurements that are asked from local partners/authorities. List of required data from local Ukraine and Moldovan sources is presented further below.

- The following data stores/services will be used:
    - Sentinel Hub API
        - Sentinel 5P products
            - NO2
            - SO2
            - CO
    - CAMS Atmosphere Data Store API
        - CAMS European air quality forecasts - analysis product, 3 years rolling archive
            - Carbon monoxide
            - Nitrogen dioxide
            - Sulphur dioxide
            - Particulate matter d < 10 µm (PM10)
            - Particulate matter d < 2.5 µm (PM2.5)
            - Ozon
        - European Air Quality - ENSEMBLE reanalysis[5] (for more than 3 years old)
            - Carbon monoxide
            - Nitrogen dioxide
            - Sulphur dioxide
            - Particulate matter d < 10 µm (PM10)
            - Particulate matter d < 2.5 µm (PM2.5)
            - Ozon
    - ECMWF WebAPI
        - GFAS Fire Emissions
            - Carbon Monoxide
            - Sulfur Dioxide
            - Nitrogen Oxides
            - PM2,5
            - Total Particulate Matter
    - C3S Climate Data Store API
        - ERA5-Land monthly data from 1981 to present
            - 2m temperature
            - 10m u-component of wind
            - 10m v-component of wind
        - ERA5-Land hourly data from 1981 to present

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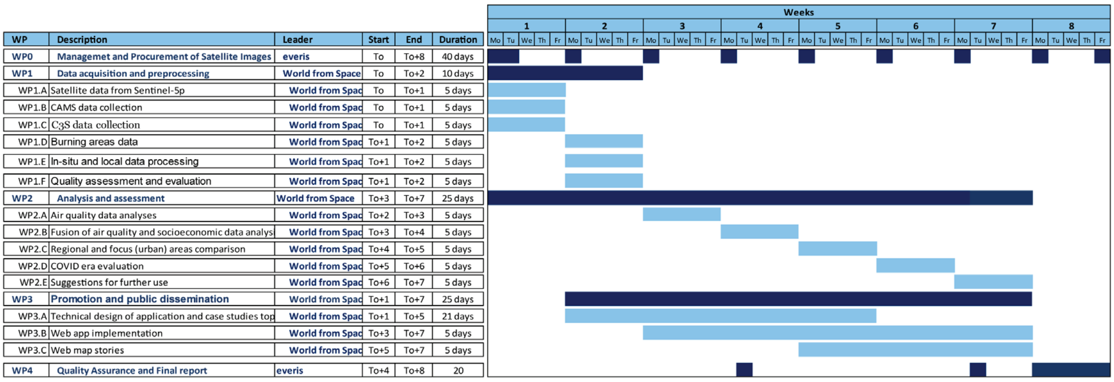
[5] Currently at https://www.regional.atmosphere.copernicus.eu, soon to be integrated into CAMS ADS

        - 2m temperature
        - 10m u-component of wind
        - 10m v-component of wind
- The required data from the partners in Ukraine
    - Administrative data from key municipalities
    - Existing economic data, average salaries, GDP (regional), location of major industrial areas;
    - Official data from the State Statistical Service of Ukraine on NO2 emissions
    - Near-real time data on PM2.5, PM10 sourced from local civil society organisations
- The required data from the partners in Moldova
    - Official socio-economic data from the Moldova National Bureau of Statistics
    - Data from air pollution sensors deployed by the State Hydrometeorological Service and by the Chișinău Municipality
    - Data on major industrial areas and their reported emissions
    - The government's Draft Strategy for Air Protection containing information on air quality measurement networks and analyses and reports on air pollution from the Environment Agency
    - Plans for the national EWS

Availability of this data in digital and transferable formats, preferably in CSV files, is crucial or also any digital table formats (excel or other). For raster and gridded data georeferenced GeoTiff format is preferred or any compatible raster format with georeference. For vector data, shapefile format is preferred but any GIS format is also feasible. English language translation is preferred)

2.7 Proposed Schedule

Planned schedule for the delivery of the services, counting from the release of the Work Order:



WP	Description	Leader	Start	End	Duration
WP0	**Managemet and Procurement of Satellite Images**	**everis**	To	To+8	40 days
WP1	**Data acquisition and preprocessing**	**World from Space**	To	To+2	10 days
WP1.A	Satellite data from Sentinel-5p	**World from Spac**	To	To+1	5 days
WP1.B	CAMS data collection	**World from Spac**	To	To+1	5 days
WP1.C	C3S data collection	**World from Spac**	To	To+1	5 days
WP1.D	Burning areas data	**World from Spac**	To+1	To+2	5 days
WP1.E	In-situ and local data processing	**World from Spac**	To+1	To+2	5 days
WP1.F	Quality assessment and evaluation	**World from Spac**	To+1	To+2	5 days
WP2	**Analysis and assessment**	**World from Space**	To+3	To+7	25 days
WP2.A	Air quality data analyses	**World from Spac**	To+2	To+3	5 days
WP2.B	Fusion of air quality and socioeconomic data analysi	**World from Spac**	To+3	To+4	5 days
WP2.C	Regional and focus (urban) areas comparison	**World from Spac**	To+4	To+5	5 days
WP2.D	COVID era evaluation	**World from Spac**	To+5	To+6	5 days
WP2.E	Suggestions for further use	**World from Spac**	To+6	To+7	5 days
WP3	**Promotion and public dissemination**	**World from Spac**	To+1	To+7	25 days
WP3.A	Technical design of application and case studies top	**World from Spac**	To+1	To+5	21 days
WP3.B	Web app implementation	**World from Spac**	To+3	To+7	5 days
WP3.C	Web map stories	**World from Spac**	To+5	To+7	5 days
WP4	**Quality Assurance and Final report**	**everis**	To+4	To+8	20

3. Results and Conclusions

3.1 WP0 – Management Conclusions

The project was managed following the initially planned schedule although some of the initial tasks were not easily performed, delaying the project few days from its initial schedule.

The initial Kick-off meeting plus three bi-weekly progress meetings were held, sending all Minutes of meeting by email to al participants just after the meeting.

A final acceptance review and close out meeting is also held 4 days after the initially planned end of the project.

3.2 WP1 results: Report on comparison of satellite, model and in-situ data

3.2.1 Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2) is an important gas present in both the troposphere and the stratosphere but also it is a key atmospheric pollutant produced by anthropogenic activities. According to the European Environment Agency 2019 Air Quality report[6], more than 60% of the NO_2 in European cities comes from motor vehicle exhaust. Other sources of NO_2 are petrol and metal refining, electricity generation from coal-fired power stations, other manufacturing industries and food processing. Natural sources of the gas come from microbiological processes in soils, wildfires and lightning. According to WHO[7], high nitrogen dioxide levels can lead to respiratory infections and reduced lung function and growth; and it is also linked with increased symptoms of bronchitis and asthma. An interaction of NO_2 with water and other chemicals in the atmosphere leads to the formation of acid rain, causing changes in forest and aquatic ecosystems.

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[6] https://www.eea.europa.eu//publications/air-quality-in-europe-2019

[7] https://www.euro.who.int/__data/assets/pdf_file/0017/123083/AQG2ndEd_7_1nitrogendioxide.pdf?ua=1

3.2.2 Carbon monoxide CO

Carbon monoxide (CO) is a colourless, tasteless and odorless poisonous gas. CO is generally considered as an important indirect greenhouse gas as it enhances the lifetime of greenhouse gases such as methane, halocarbons and tropospheric ozone. It is a product of incomplete combustion as encountered in the operation of vehicles, heating, coal power generation, and biomass burning. Approximately 40% of CO comes from natural sources like volcanic eruptions, emission of natural gases, degradation of vegetation and animals, and forest fires, and 60% comes from fossil fuel consumption, garbage disposal, tobacco smoke, and charcoal fires. In equatorial regions the oxidation of isoprene and biomass burning play the most important role in CO production, while in higher latitudes, fossil fuel combustion is the main source. According to WHO, "There is considerable evidence on human environmental and occupational exposures to carbon monoxide. The organs and tissues that are mostly affected include the brain, the cardiovascular system, exercising skeletal muscle and the developing fetus"[8]

The dominant sink of CO is oxidation by the hydroxyl radical, OH, the key reactive species of the troposphere:

$$CO + OH \rightarrow H + CO_2 \qquad (1)$$

Approximately 90% of CO (and 70% of OH) in the atmosphere on a global basis is consumed by this reaction, which is responsible for 1/6 of the atmospheric CO_2 source[9]. This process leads to an important feature of CO in extratropical latitudes that is its seasonal cycle. While CO accumulates in the atmosphere during winter when OH concentrations are low, in spring it is depleted rapidly due to reaction (1), as the warmer air carries more moisture, which produces more OH. Thus, in the northern hemisphere, CO concentrations are generally lowest in June, July and August[10].

3.2.3 Sulfur dioxide SO_2

Sulfur dioxide (SO_2) enters the atmosphere through natural and anthropogenic sources and can be found in both the stratosphere where it has a lifetime of several weeks and in the troposphere where its lifetime is in the order of days. Only about 30% of the emitted SO_2 comes from natural sources such as volcanoes. Anthropogenic sources include coal-fired power stations, industrial processes or other fossil fuel burning activities (such as domestic heating). Man-made contributions are of the greatest concern in Europe. According to WHO[11]: "SO_2 can affect the respiratory system and the functions of the lungs and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract. Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels". An interaction of SO_2 with water forms sulfuric acid which is the main component of acid rain.

3.2.4 Ozone O_3

Ozone (O_3) in the troposphere is almost entirely a secondary air pollutant, attributable to several different sources. One is the intrusion of stratospheric O_3, especially in Spring when the stratospheric-tropospheric air exchange is greatest[12]. The other sources

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[8] https://www.euro.who.int/__data/assets/pdf_file/0020/123059/AQG2ndEd_5_5carbonmonoxide.PDF

[9] https://pubs.rsc.org/en/content/articlelanding/2002/cp/b204827m#!divAbstract

[10] https://sos.noaa.gov/datasets/carbon-monoxide-2008-2011/

[11] https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[12] https://www.researchgate.net/profile/Morton_Lippmann/publication/20495965_Health_Effects_of_Ozone_a_Critical_Review/links/56bcd55f08ae5e7ba40f6dcb/Health-Effects-of-Ozone-a-Critical-Review.pdf

include photochemical reactions in the presence of sunlight and precursor pollutants, such as the oxides of nitrogen (NOx) and volatile organic compounds (VOCs). It is destroyed by reactions with NO_2 and is deposited to the ground. Several studies have shown that ozone concentrations correlate with various other toxic photochemical oxidants arising from similar sources, including the peroxyacyl nitrates, nitric acid and hydrogen peroxide[13]. Measures to control tropospheric ozone levels focus its precursor gas emissions, but are likely to also control the levels and impacts of a number of these other pollutants. Hemispheric background concentrations of tropospheric ozone vary in time and space but can reach 8-hours average levels of around 80 $\mu g/m^3$. These arise from both anthropogenic and biogenic emissions (e.g. VOCs from vegetation). Besides local air pollution sources, meteorological factors, planetary (atmospheric) boundary layer processes and regional/long range transport play important roles in determining the O_3 concentrations function on the topography of the observational site.

Several epidemiological and experimental researches suggested a strong correlation between exposure to O_3, NO_2, or other combustion traffic related products and increased susceptibility to and morbidity from respiratory infection[14]. Human exposures to high ambient ozone levels, such as those commonly found in many cities, can lead to reversible symptoms of lung inflammation and decreased lung function. It can also aggravate the symptoms of asthma and other pre-existing lung diseases. Chronic exposure to such ozone concentrations can lead to small but significant permanent decreases in lung function[15].

3.2.5 Particulate matter (PM2.5 and PM10)

Particulate matter or atmospheric aerosols are solid or liquid particles suspended in the air and capable of free movement in the atmosphere. They are classified by size, rather than their chemical properties. Based on size, particulate matter is often divided into two main groups: a) the coarse fraction that contains the larger particles with a size ranging from 2.5 to 10 µm ($PM_{2.5}$ - PM_{10}), and b) the fine fraction that contains the smaller ones with a size up to 2.5 µm ($PM_{2.5}$). The former is primarily produced by mechanical processes such as construction activities, road dust re-suspension and wind, whereas the latter originates primarily from combustion sources, including domestic heating and transport. Other significant sources include industrial processes and power plants. Naturally, particles are released into the atmosphere during volcanic activities, fires, erosion and from seawater.

The effect depends on the size, chemical composition and shape, but generally concerns the respiratory and cardiovascular systems. According to WHO: "Long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardiopulmonary mortality by 6–13% per 10 µg/m3 of $PM_{2.5}$"[16]. Particulate matter PM can act as catalysts for chemical reactions on their surface. Thus, the toxic effect of PM is enhanced by the content of other pollutants in the air. All these features make impossible to clearly define the "safe" concentration of PM in the air.

3.2.6 WHO Air quality guidelines

In order to provide guidance in reducing the health impacts of air pollution, to inform policy-makers and to provide appropriate targets for a broad range of policy options for

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[13] https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1

[14] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7274116/

[15] https://twobtech.com/citations/pubs/2008_Brodin.pdf

[16] https://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf

air quality management in different parts of the world, the World Health Organization (WHO) experts publish the WHO Air quality guidelines document. The document is based on expert evaluation of current scientific evidence. For the purpose of the presented analysis we utilized information given in the 2005 version of the document.

In addition to the AQG values, for selected pollutants WHO offers the so called interim targets (IT), designed to be achievable with successive and sustained abatement measures. These values shall be assessed in the further chapters where needed.

3.2.7 Sentinel-5p data

Sentinel-5p (S-5p) mission is a satellite devoted to atmosphere monitoring launched in October 2017 as a part of the EU Copernicus Programme. It carries a spectrometer TROPOMI (TROPOspheric Monitoring Instrument) covering wavelength bands between the ultraviolet and the shortwave infrared. S-5p measures gases such as NO_2, ozone, formaldehyde, SO_2, methane, carbon monoxide and aerosols daily with a spatial resolution of about 5.5 km x 3.5 km (7 km to 5.5 km until August 2019).

Satellite data from S-5p are obtained via Sentinel Hub (SH) operated by Sinergise. Sentinel Hub supports S-5p level 2 (L2) data products which are geolocated, primarily pre-processed and contain “qa_value”. The “qa_value” means “quality assurance value” and indicates the status and quality of each ground pixel. It is a continuous variable ranging from 0 (error) to 1 (no errors). For most S-5p products, pixels under 0.5 values are filtered out (for NO_2 products it is 0.75). The “qa_value” is an important parameter that reduces the seamless coverage of the areas of interest by S-5p data that the proposed methodology takes into account. NO_2, SO_2, and CO products (May 2018 to July 2020) are obtained via SH.

S-5p satellite data products are mostly measured and provided in mol/m^2 units. NO_2 product gives the total atmospheric NO_2 column between the surface and the top of the troposphere[17] (tropospheric column). CO clear sky TROPOMI observations provide CO total columns with sensitivity to the tropospheric boundary layer[18]. SO_2 observations gives the total atmospheric column between the surface and the tropopause[19].

When using S-5p satellite data, it is important to take into account the difference in how the values are measured. Health limit values are usually given in units used for ground-based measuring instruments. Therefore, converting values from satellite imagery (mol/m^2) to ground-based units (µg/m^3) is not recommended[20].

3.2.7.1 Quality flags and observation frequency

It is important to take into account that quality of accessible pixels is highly dependent on weather conditions, sensor errors and other parameters, including cloud cover. Altogether, it is generally defined by “qa_value”. The S-5p revisit time for Europe (including the area of Ukraine) is more than once a day. There are scanning overlaps at higher latitudes due to a near-polar, sun-synchronous orbit of the satellite. Thus, the processed data comprise all available satellite measurements. Using all available data means combining data from several satellite orbits with varying grid sizes and orientations. To address this, all S-5p satellite observations were downscaled to obtain a regular grid with a resolution of 1 km x 1 km via SH. The data was automatically pre-processed and downloaded to cloud

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[17] https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5p-Nitrogen-Dioxide-Level-2-Product-Readme-File

[18] http://www.tropomi.eu/data-products/carbon-monoxide

[19] https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Formaldehyde-Readme.pdf

[20] https://www.researchgate.net/post/How_can_I_convert_the_unit_from_molecules_cm2_to_ppm

space using our proprietary Python scripts using SH service. Final processing steps were done on desktop GIS to get monthly and selected seasonal averages per pixel over the whole area. Season was defined as a 3 months period of winter (December-February) and summer (June-August) to get simplification of the air quality caused by weather conditions. For every single pollutant, a total average per pixel for the whole referenced period is processed as well.

3.2.8 Copernicus Atmosphere Monitoring Service(CAMS)

As S-5p satellite does not provide monitoring of particulate matter ($PM_{2.5}$ and PM_{10}) concentrations, and as the concentrations of ozone monitored by S-5p mainly represent its stratospheric concentrations, these were obtained through the Copernicus Atmosphere Monitoring Service (CAMS) instead.

CAMS, part of the Copernicus Programme implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF)[21], provides global, quality-controlled information related to air pollution, solar energy, greenhouse gases and climate forcing. Over Europe, CAMS produces specific daily air quality analyses and forecasts at a spatial resolution of 0.1××0.1 degrees (approx. 10××10 km). Nine european air quality forecasting systems are utilized in the production, using a median ensemble from individual outputs[22]. Furthermore, the analysis combines model data with real ground observations (provided by the European Environment Agency (EEA)) resulting in a complete and consistent dataset using various data assimilation techniques. In parallel, air quality forecasts are produced once a day, for the next four days. Both, the analysis and the forecast, are available at hourly time steps at eight height levels: surface, 50 m, 250 m, 500 m, 1 000 m, 2 000 m, 3 000 m, and 5 000 m.

For the purpose of the presented analysis, the surface level concentrations of $PM_{2.5}$, PM_{10}, and ozone have been obtained through the Atmosphere Data Store (ADS) - a distributed data and information system which provides access to all CAMS datasets through unified web and API interfaces. In order to keep the observation time in line with the values monitored by the S-5p satellite, daily concentrations modelled for 13:00 UTC have been used. As the database of CAMS data offered through the ADS consists of 3 years of the most recent data (so called rolling archive), our analysis of $PM_{2.5}$ and PM_{10} concentrations covers the period from August 10 2017 to July 31 2020.

Moreover, in order to compare the results from two independent sources, in conjunction with the values measured by the S-5p satellite, we utilized the modelled concentration values at surface level for NO_2, CO, and SO_2, also provided by CAMS. The same period of observation has been used as in the case of other pollutants, i.e. August 10 2017 to July 31 2020.

3.2.9 In-situ measurements

In-situ measurements of air pollution are a standard way to monitor and assess quality of the air. Measurement networks are often run by state meteorological institutes. This kind of monitoring has long standing methodology, requires high-end instrumental equipment, professional staff, instrument calibration and quality controls and data post processing. These requirements determine that such a consistent and dense network is an expensive and extensive task. Moreover, in-situ measurements provide spot information relevant only for very limited surroundings. Thus, for comprehensive assessment or as an input for modelling continuous interpolation dense network is required. Such measurements

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[21] https://www.ecmwf.int/

[22] https://atmosphere.copernicus.eu/sites/default/files/2020-01/ENSEMBLE_Fact_Sheet_2020.pdf

are not available in Ukraine nor Moldova. Several official measurements are done, but are relevant just for specific areas affected usually by concrete sources of pollution - traffic, industrial operation, power plant, etc.

Another approach is to build a platform for citizen measurements that is on the rise with availability of affordable IoT sensors including those for air quality monitoring. This brings not only above mentioned limitations of the discrete measurements, but also inconsistency in data caused by use of different sensors and missing or unequal quality controls and calibrations. Averages based on in-situ measurements for cities Kyiv and Chernivtsi are depicted in FIGURE 4 and FIGURE 5 below.

3.2.10 Suggestion on further use

When assessing air pollution, it is crucial to distinguish among different measurement approaches that are not easily comparable: they differ in the units they are measured, the spatial resolution and also the vertical resolution.

The three main data sources dealt with in this project are:

- satellite observations from Sentinel-5p
- modelled data form Copernicus Atmosphere Monitoring Service
- ground in-situ measurements.

Regarding the S-5p observations, they are new data regarding the lifetime and also the measurement approach. Thus, there are a lot of uncertainties when used to assess air pollution, but data is improving as new versions of processing algorithms are introduced. The most important difference comparing S-5p measures with both CAMS and in-situ data is that S-5p measures pollutants along the atmosphere vertical column, not only near the surface. For pollutants that are not just near the surface e.g. particulate matter, it is different. This leads also to different measurement units (mol/m^2) which makes it difficult to compare with ***standard*** datasets. Sentinel-5p air pollution measurements are thus less sensitive to local sources. Lower spatial resolution makes it insensitive to pollution on street level. The distribution of satellite measured air pollution does not take into account anthropogenic sources only, it includes a result of naturally occurring processes as well. However, it shows very well and reliable regional distribution and temporal dynamics.

Regarding CAMS data, they are standardised modelled products run at global level. It has the advantage of long and consistent time series with no missing values. Data is computed as predictions that are later corrected with real measured values (reanalyses). Local in-situ measurements as well as weather data and also satellite data are all inputs for the model. However, accuracy of model/reanalysis is only as high as the accuracy of the input data, thus regions with sparse measurement networks do not adapt well for local and unusual events. Low spatial resolution as well as modelling approach make it unsensitive for local dynamics and sources.

At last, ground in-situ measurements bring precise data for very specific areas thus are very helpful for specific spot assessment. Because of that, they are relevant for concrete locations but cannot bring comprehensive information for wider areas such as a complete city. These differences are visible in FIGURE 4 and FIGURE 5 for which dense network of measurements are needed. Consistent, stable, equally dense and controlled in-situ measurement network would benefit the overall assessment of air pollution.

Saveecobot initiative is an interesting and promising achievement in that respect. To assess this dataset, additional time is needed for their quality checks and data harmonisation.

3.3 WP2 results: Analysis and assessment

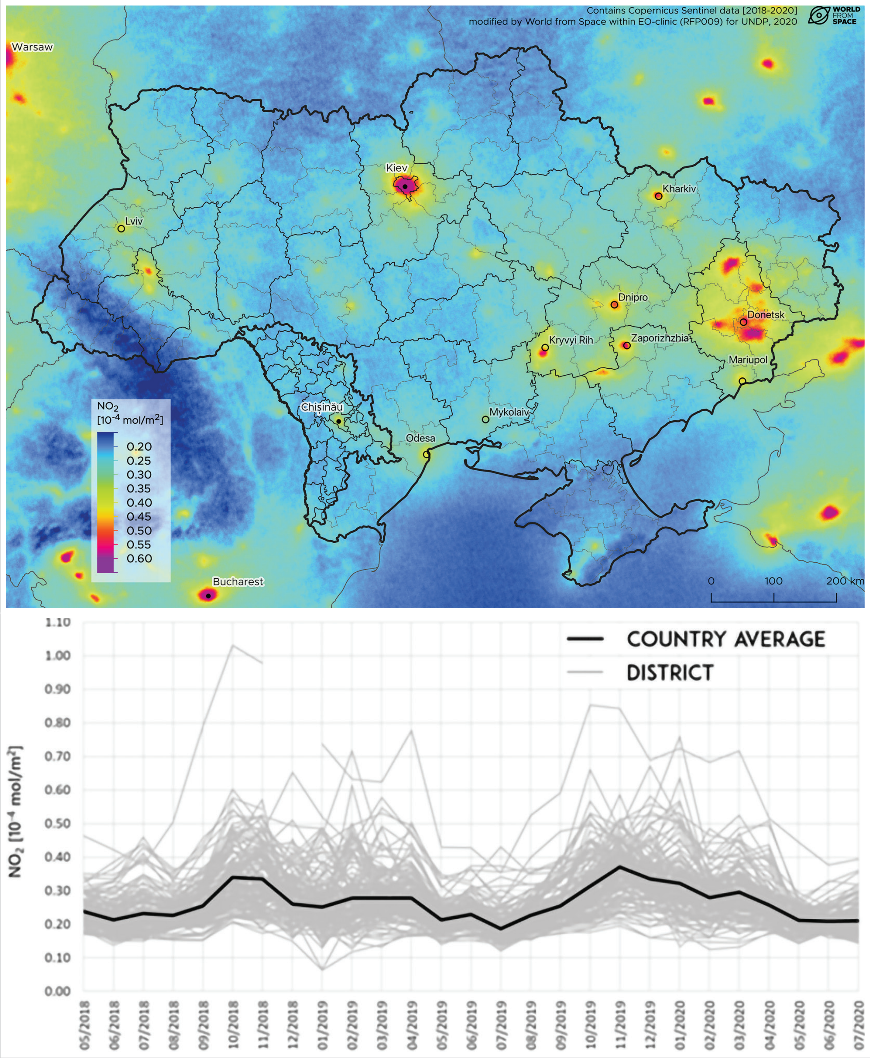
3.3.1 Report on Air Pollution in Ukraine and Moldova

This chapter provides an overview of the main statistical indicators of individual pollutants obtained from the Copernicus Sentinel-5p (S-5p) satellite data and CAMS models, providing a map of average concentrations throughout the country and also a chart displaying the development of average concentrations in the country over the observed period.

3.3.1.1 Nitrogen dioxide NO2 (S-5p)

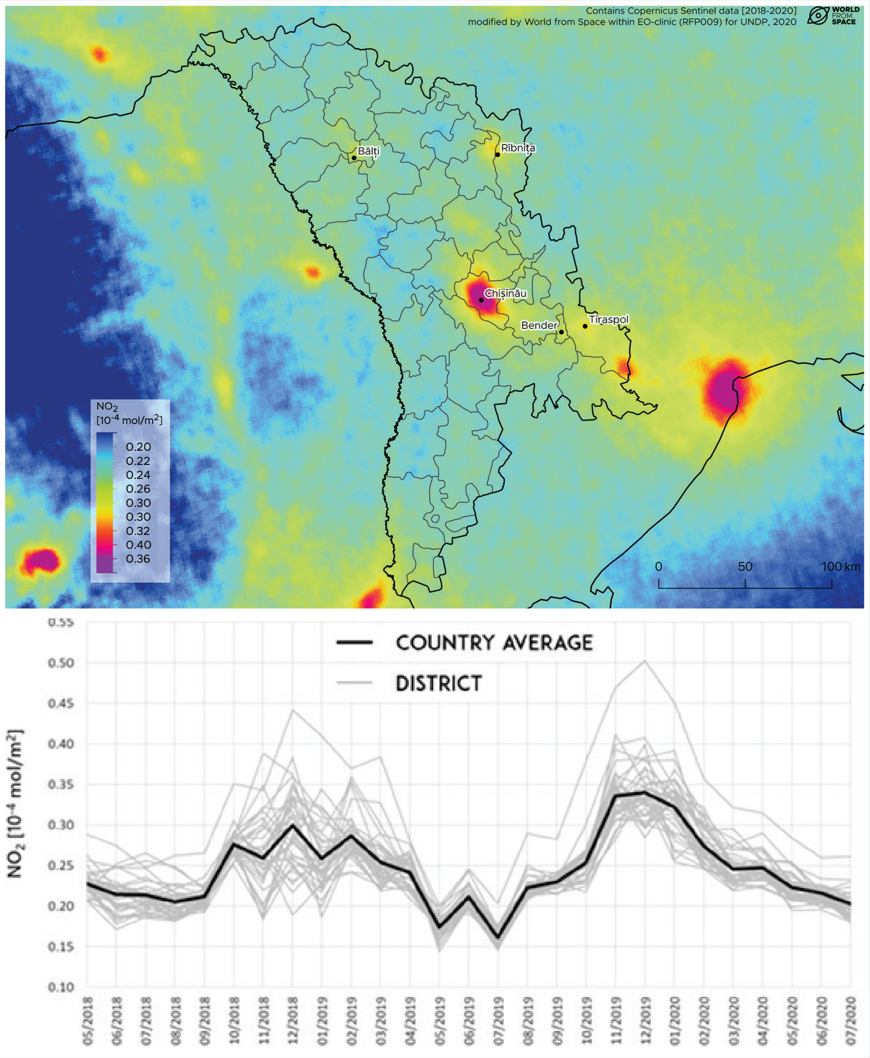
The following tables presents shows the average concentration of NO2 over Ukraine and Moldova: 1) over the period of May 2018 to July 2020 obtained from the Copernicus S-5p satellite data and 2) the average monthly concentrations.

Figure 4: Concentration of NO_2 over Ukraine from S-5p data.



Contains Copernicus Sentinel data [2018-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Figure 5: **Concentration of NO_2 over Moldova from S-5p data.**



3.3.1.2 Nitrogen dioxide NO2 (CAMS)

Figures below displays the average concentrations of NO_2 over Ukraine and Moldova between August 2017 and July 2020 as well as the average monthly concentrations of NO_2 obtained from the Copernicus Atmosphere Monitoring Service.

Figure 6: **Average concentrations of NO_2 in Ukraine and Moldova between August 2017 and July 2020 obtained from the CAMS data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

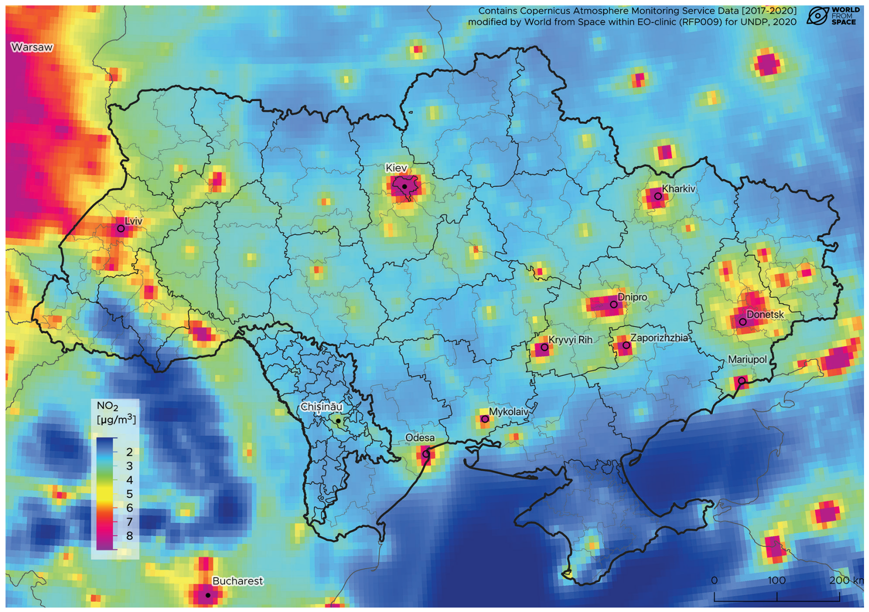


Figure 7: **Average monthly concentrations of NO_2 in the districts of Ukraine between August 2017 and July 2020 obtained from the CAMS data. (Contains modified Copernicus Atmosphere Moni toring Service Information [2020])**

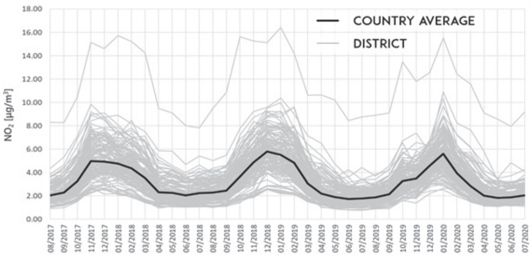
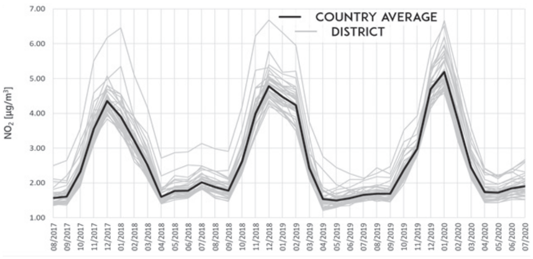


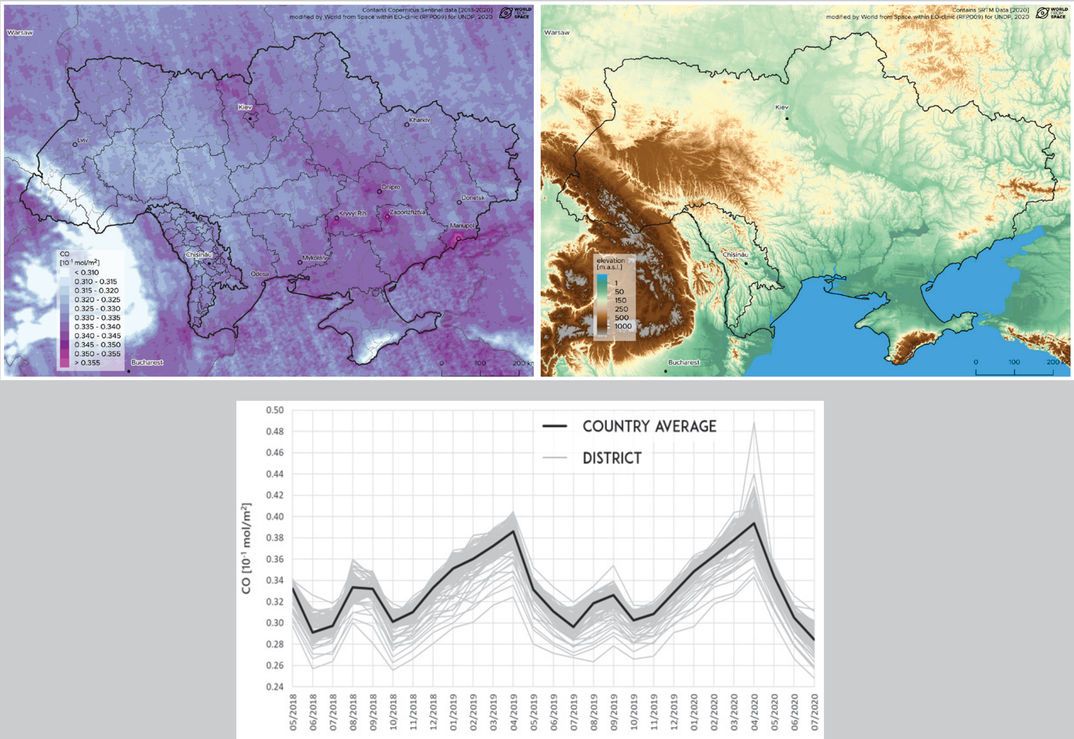
Figure 8: **Average monthly concentrations of NO_2 in the districts of Moldova between August 2017 and July 2020 obtained from the CAMS data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.1.3 Carbon monoxide CO (S-5p)

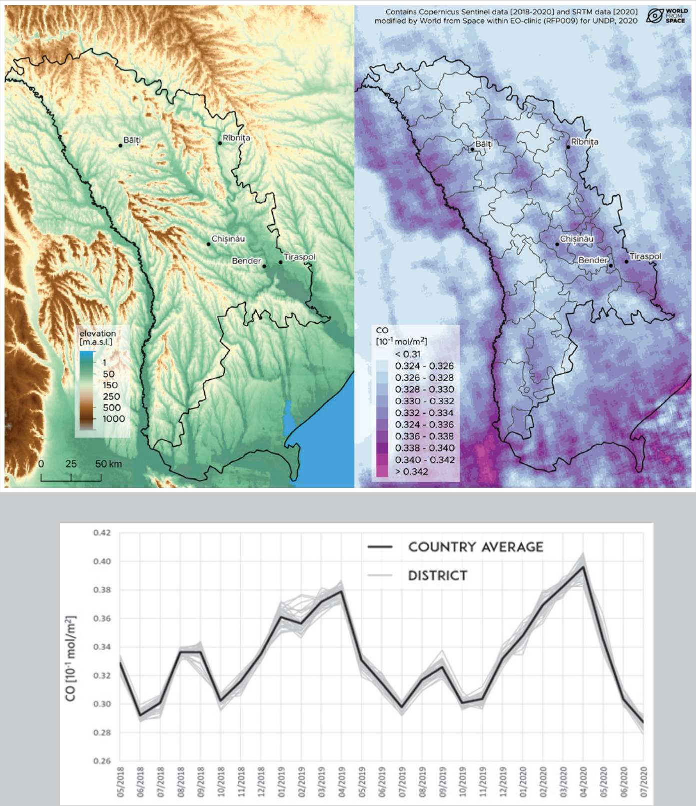
The following figure presents the spatial distribution of the average CO concentrations in Ukraine and Moldova between May 2018 and July 2020 as well as the terrain elevation in the same area, from which the natural high negative correlation between CO concentrations and elevation can be spotted.

Figure 9: **Carbon monoxide CO in UKRAINE (S-5p)**


Contains Copernicus Sentinel data [2018-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Contains SRTM Data [2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Figure 10: **Carbon monoxide CO in MOLDOVA (S-5p)**


Contains Copernicus Sentinel data [2018-2020] and SRTM data [2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

3.3.1.4 Carbon monoxide CO (CAMS)

A similar distribution of CO concentrations within Ukraine and Moldova, as in the case of S-5p data, can be observed from the analysis of CAMS modelled values.

Figure 11: Average concentrations of carbon monoxide over Ukraine and Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])

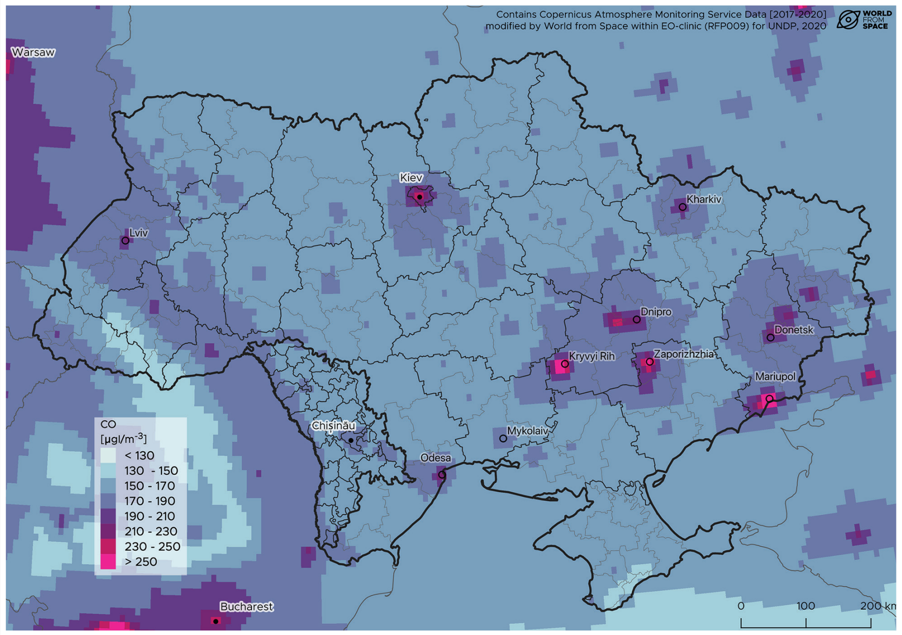


Figure 12: Average monthly concentrations of carbon monoxide in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])

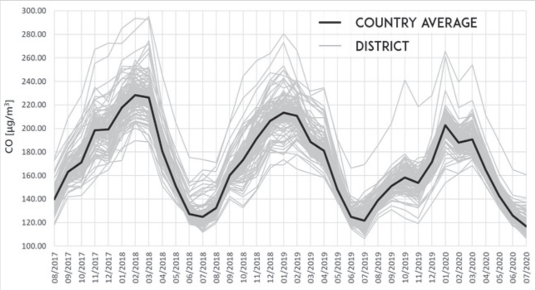
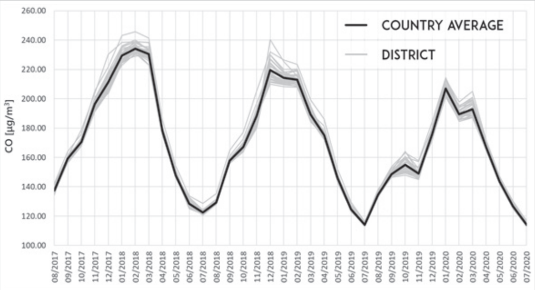


Figure 13: Average monthly concentrations of carbon monoxide in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])



3.3.1.5 Sulfur dioxide SO2 (S-5p)

Figure 20 below shows the distribution of mean SO_2 concentrations in Ukraine and Moldova between May 2018 and July 2020 as well as the monthly concentrations respectively.

Figure 14: **Average concentrations of SO_2 over Ukraine and Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

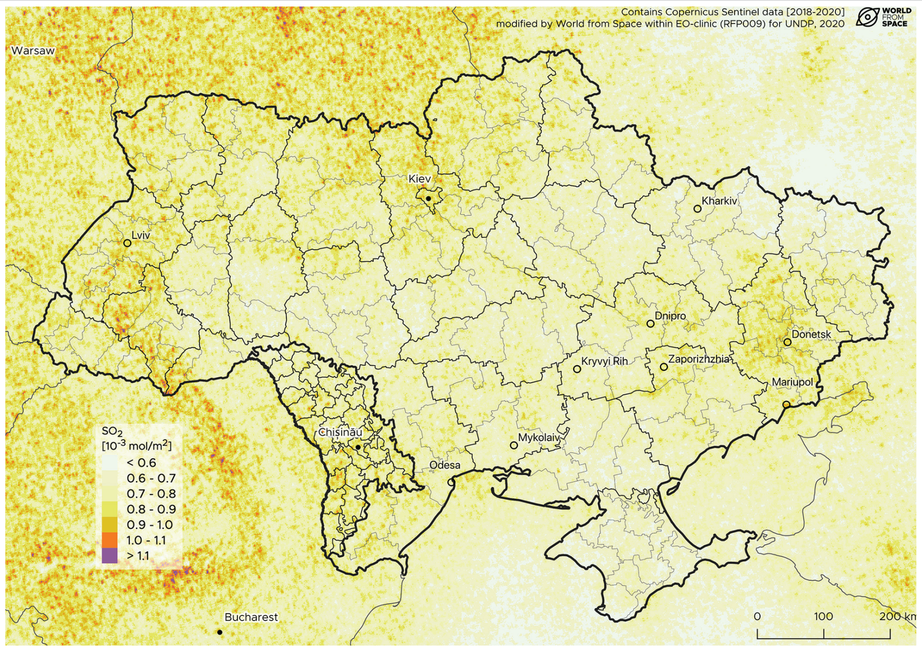


Figure 15: **Count of valid SO_2 for winter season months of 2018/2019 and 2019/2020 over Ukraine and Moldova ob-tained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

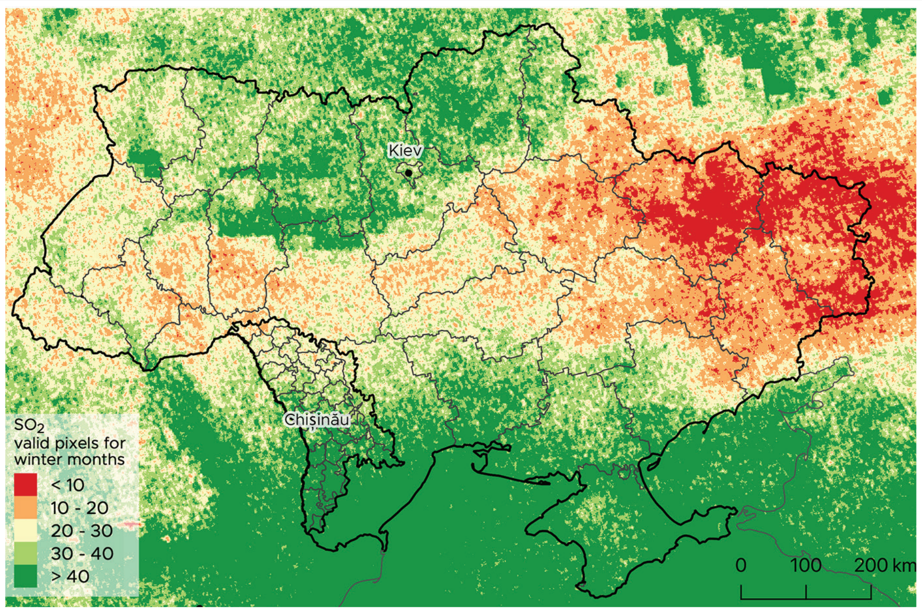


Figure 16: **Median concentrations of SO_2 over Ukraine and Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modi-fied Copernicus Sentinel data [2020])**

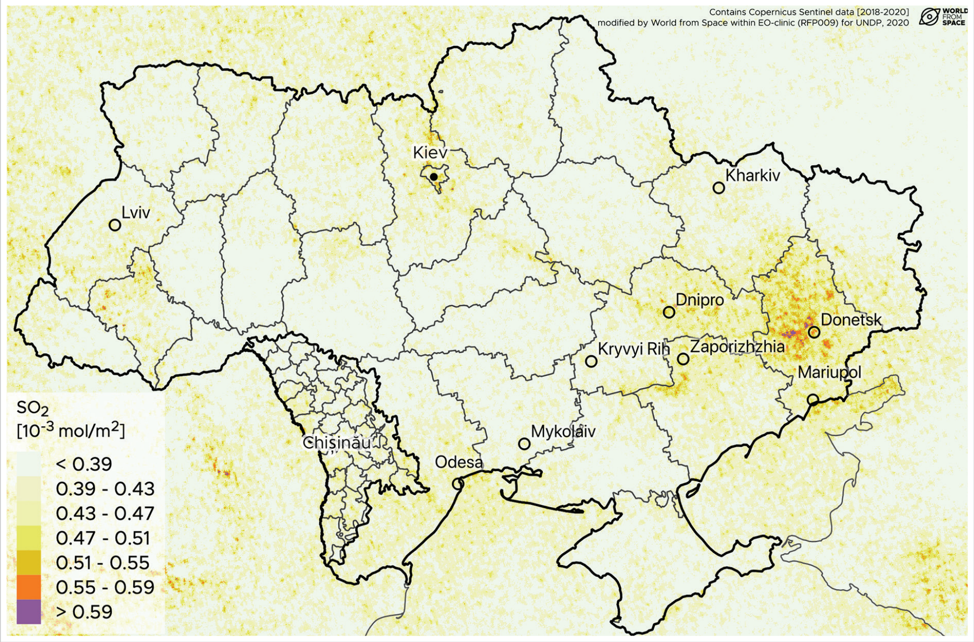


Figure 17: **Median values of overall concentrations of SO_2 over Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

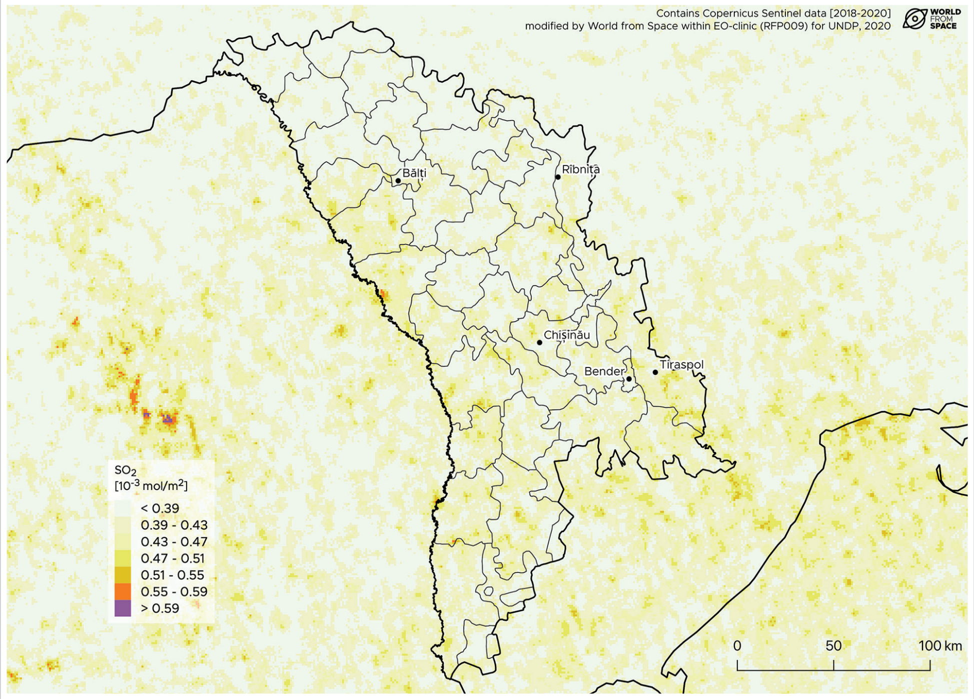


Figure 18: **Average monthly concen-trations of sulfur dioxide in the districts of Ukraine between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Con-tains modified Copernicus Sentinel data [2020])**

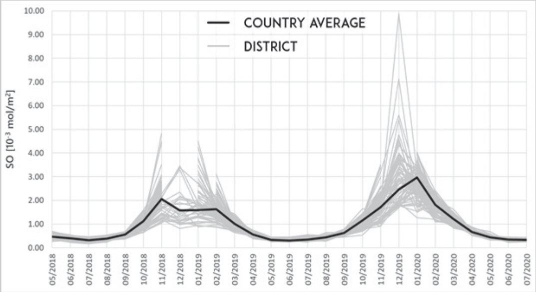
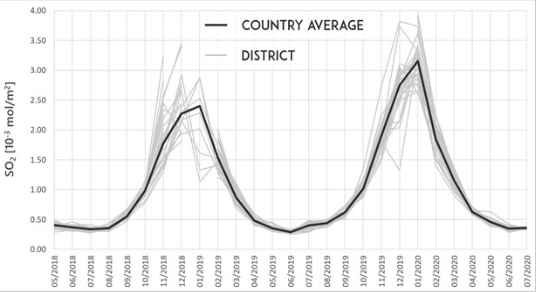


Figure 19: **Average monthly concen-trations of sulfur dioxide in the districts of Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Con-tains modified Copernicus Sentinel data [2020])**



3.3.1.6 Sulfur dioxide SO2 (CAMS)

The average concentrations of O_3 between August 2017 and July 2020, derived from the hourly concentration values provided by the S-5p, as well as the monthly a are presented in figures below for both Ukraine and Moldva.

Figure 20: **Average concentrations of sulfur dioxide over Ukraine and Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Moni-toring Service Information [2020])**

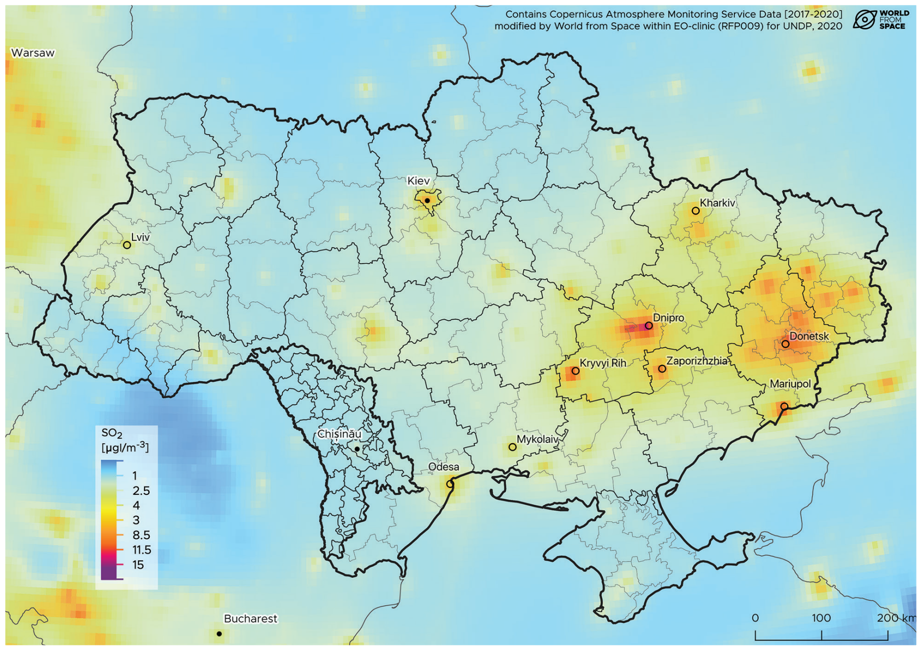


Figure 21: **Average monthly concentrations of sulfur dioxide in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

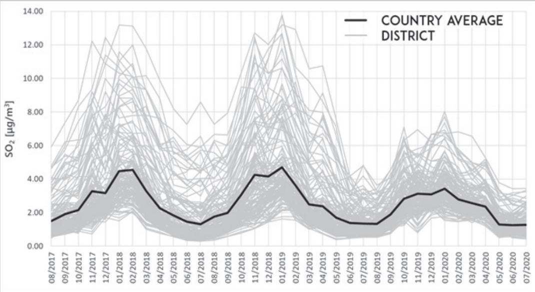
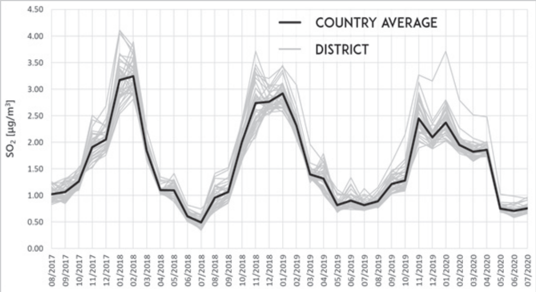


Figure 22: **Average monthly concentrations of sulfur dioxide in the districts of Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.1.7 Ozone O3 (CAMS)

The average concentrations of O_3 between August 2017 and July 2020, derived from the hourly concentration values provided by the CAMS, as well as the monthly concentrations are presented in figures below for both Ukraine and Moldva.

Figure 23: **Average concentrations of O_3 over Ukraine and Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

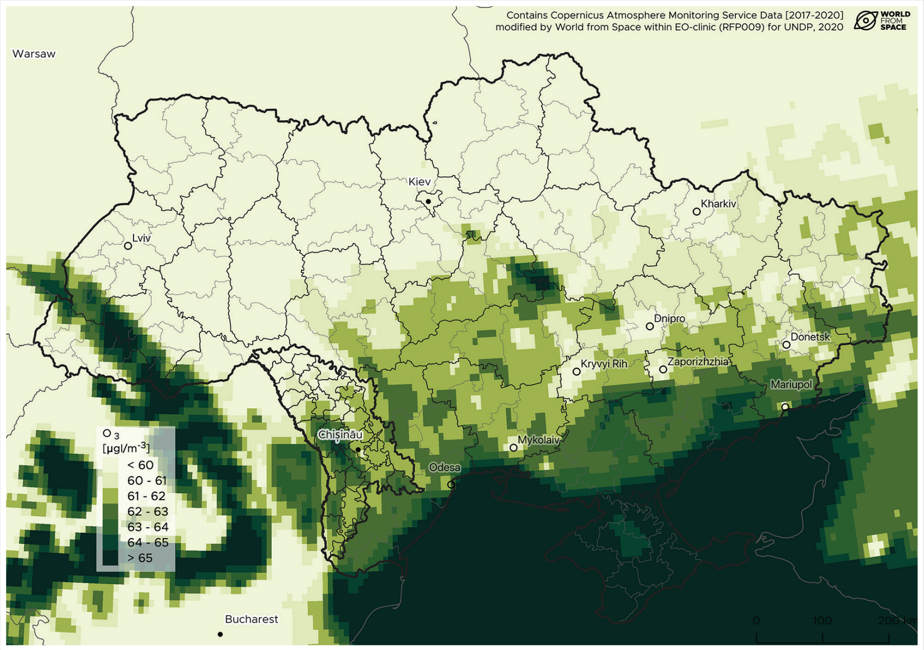


Figure 24: Number of days when the WHO 8-hour limit for O_3 was exceeded over Ukraine and Moldova between August 2017 and July 2020. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020]).

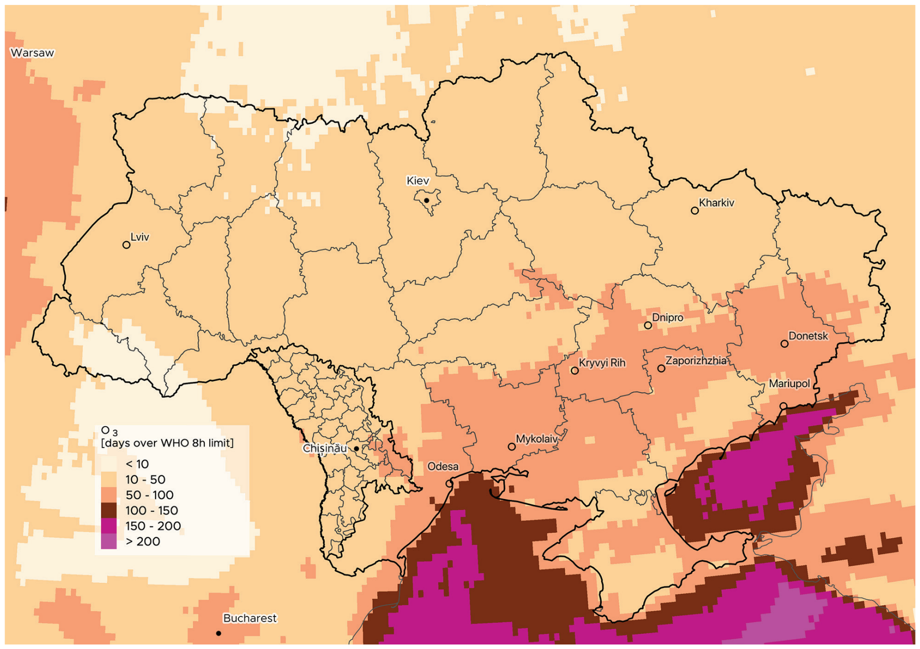


Figure 25: Mean concentrations of O_3 over Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Con-tains modified Copernicus Atmosphere Monitoring Ser-vice Information [2020])

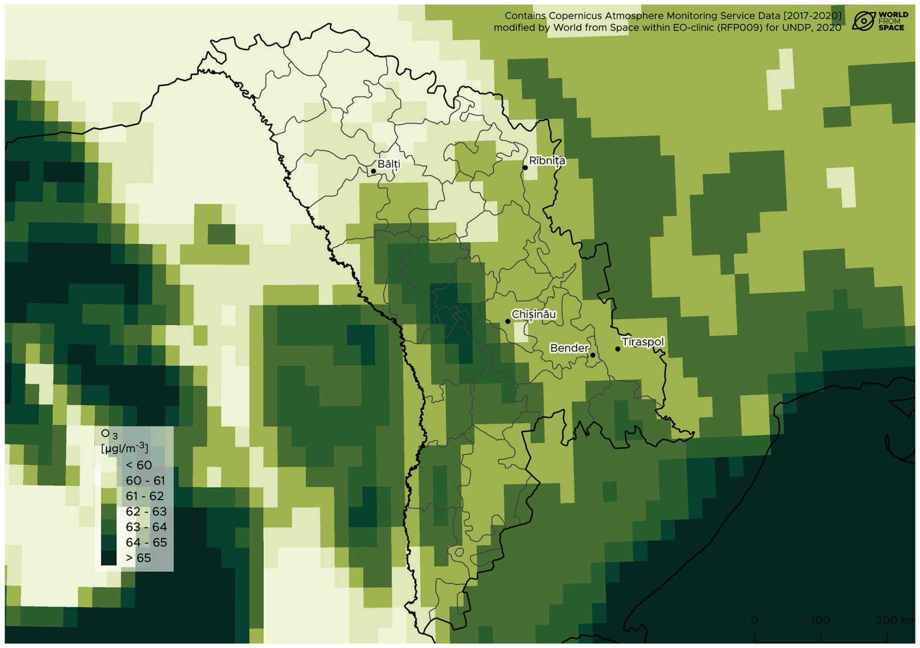


Figure 26: **Average monthly concentrations of O_3 in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

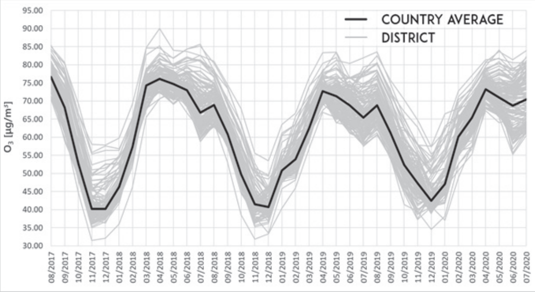
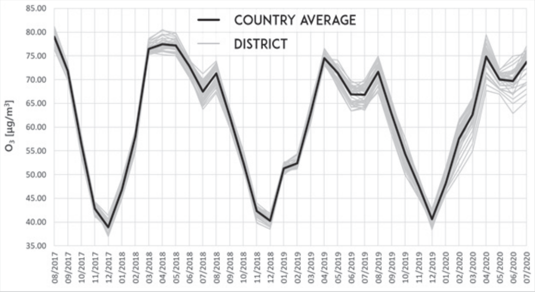


Figure 27: **Average monthly concentrations of O_3 in the districts of Moldova between August 2017 and July 2020 ob-tained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.1.8 Particulate Matter 2.5 (CAMS)

The average concentrations of Particulate Matter 2.5 between August 2017 and July 2020, derived from the hourly concentration values provided by the CAMS, as well as the monthly concentrations are presented in figures below for both Ukraine and Moldva.

Figure 28: **Average concentrations of particles smaller than 2.5 µm ($PM_{2.5}$) in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

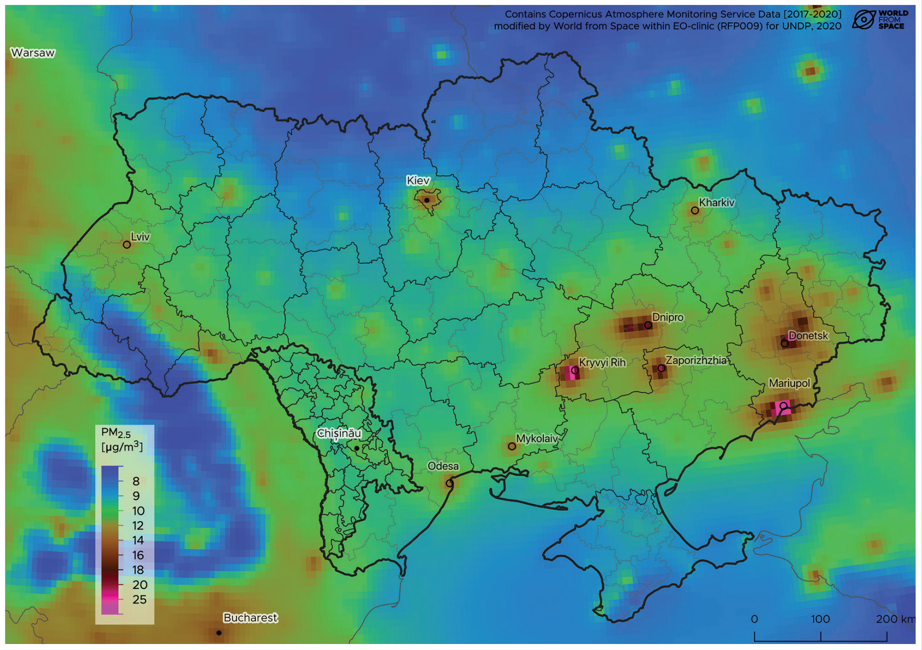

Contains Copernicus Atmosphere Monitoring Service Data [2017-2020]
modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Figure 29: **Number of days with the $PM_{2.5}$ WHO 24-hour AQG value exceeded in Ukraine and Moldova be-tween August 2017 and July 2020 (Contains modified Co-pernicus Atmosphere Monitoring Service Information [2020])**

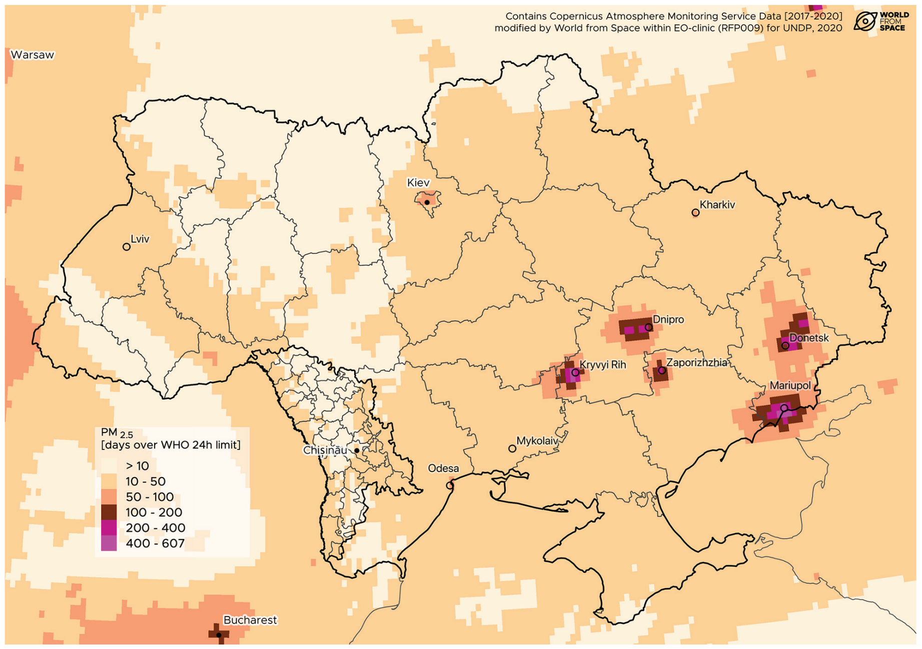


Figure 30: **Number of years when the WHO annual limit for $PM_{2.5}$ was exceeded over Ukraine and Moldova be-tween August 2017 and July 2020. (Contains modified Co-pernicus Atmosphere Monitoring Service Information [2020])**

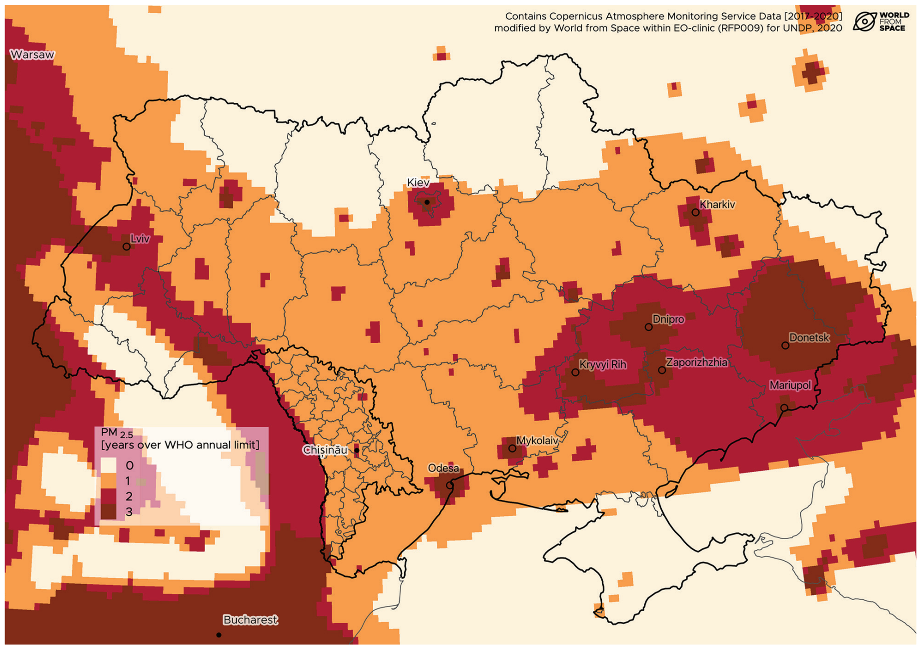


Figure 31: Average monthly concentrations of particles smaller than 2.5 µm ($PM_{2.5}$) in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. The AQG, IT-3, and IT-2 abbreviations represent the Air Quality Guideline, Interim Target 3, and Interim Target 2, respectively, all proposed by the WHO. (Contains modi-fied Copernicus Atmosphere Monitoring Service Infor-mation [2020])

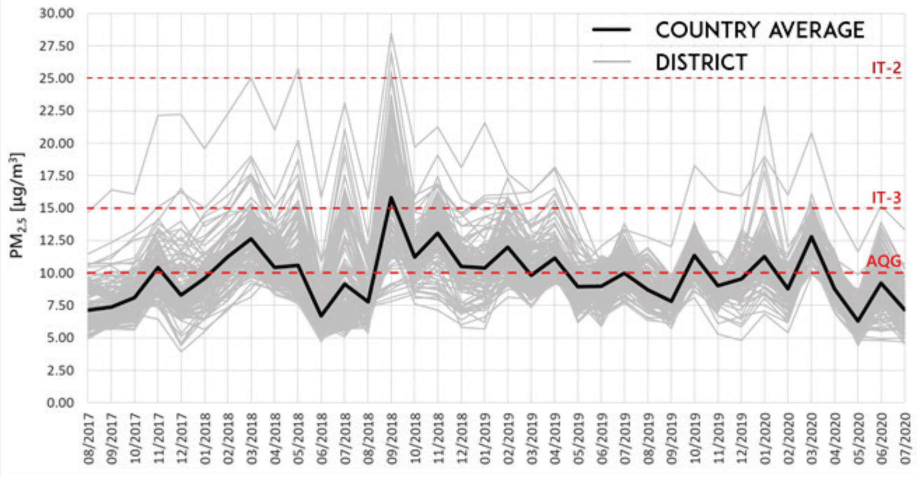


Figure 32: Average concentrations of $PM_{2.5}$ over Mol-dova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Con-tains modified Copernicus Atmosphere Monitoring Service Information [2020])

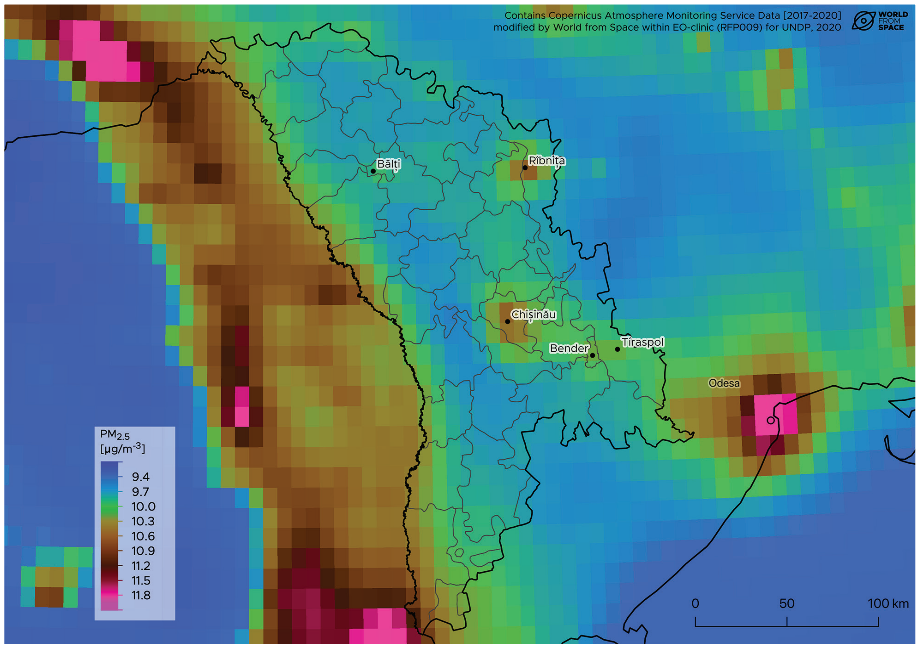
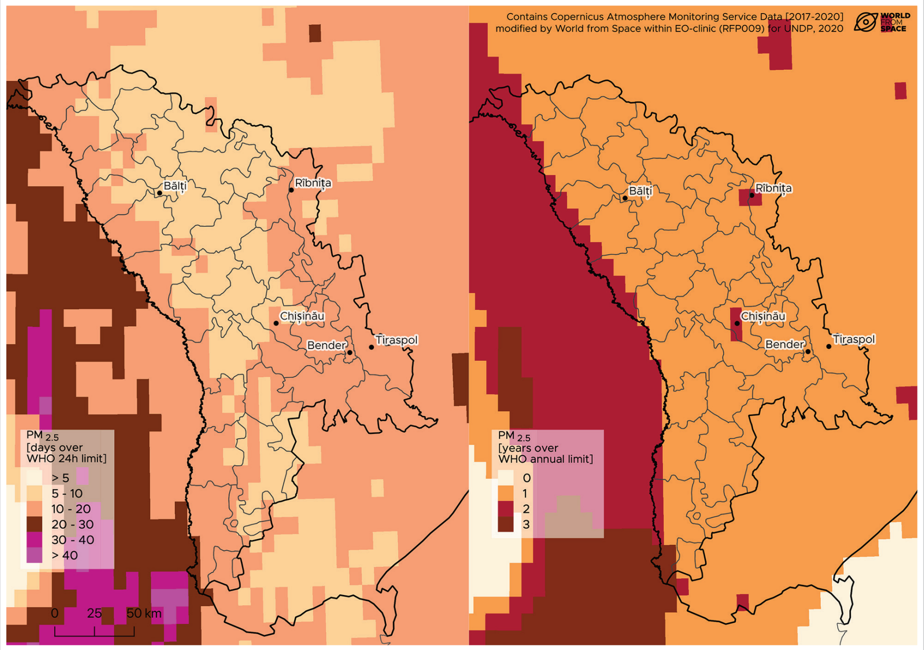
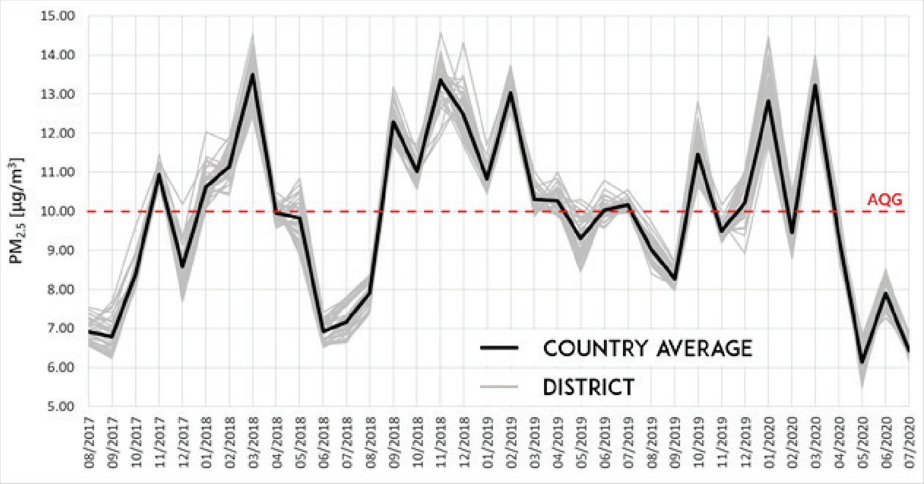


Figure 33: **Number of days with the $PM_{2.5}$ WHO 24-hour mean AQG value exceeded (left) and number of years with the $PM_{2.5}$ WHO annual-mean AQG value ex-ceeded (right) over Moldova between August 2017 and July 2020. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



Contains Copernicus Atmosphere Monitoring Service Data [2017-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Figure 34: **Average monthly concentrations of $PM_{2.5}$ in the districts of Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. The AQG abbreviation represents the Air Quality Guideline proposed by the WHO. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.1.9 Particulate Matter 10 (CAMS)

The average concentrations of Particulate Matter 10 between August 2017 and July 2020, derived from the hourly concentration values provided by the CAMS, as well as the monthly concentrations are presented in figures below for both Ukraine and Moldva.

Figure 35: Average concentrations of particles smaller than 10 µm (PM_{10}) in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Con-tains modified Copernicus Atmosphere Monitoring Ser-vice Information [2020])

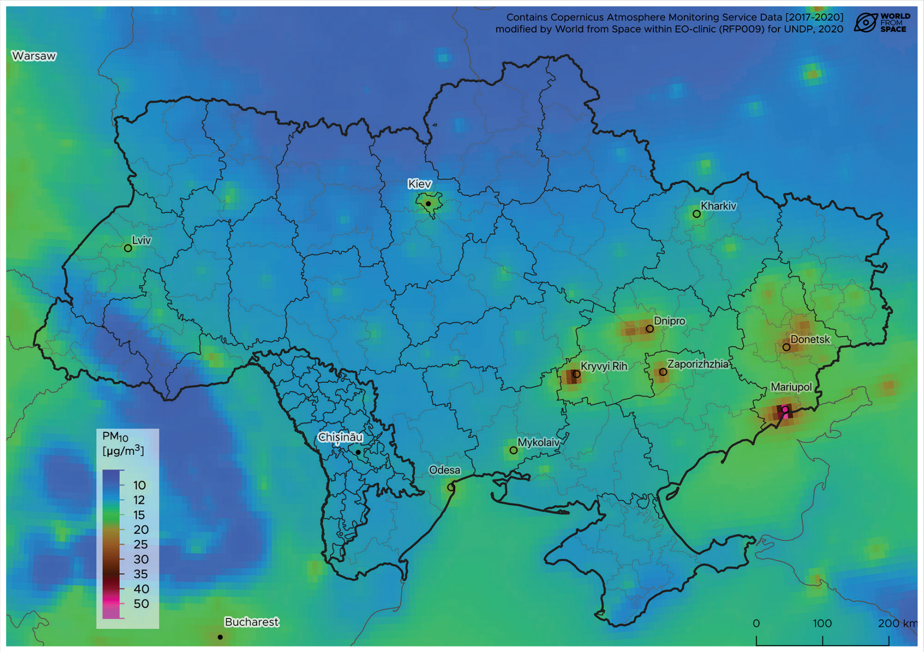


Figure 36: Number of years when the WHO annual limit for PM_{10} was exceeded over Ukraine and Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])

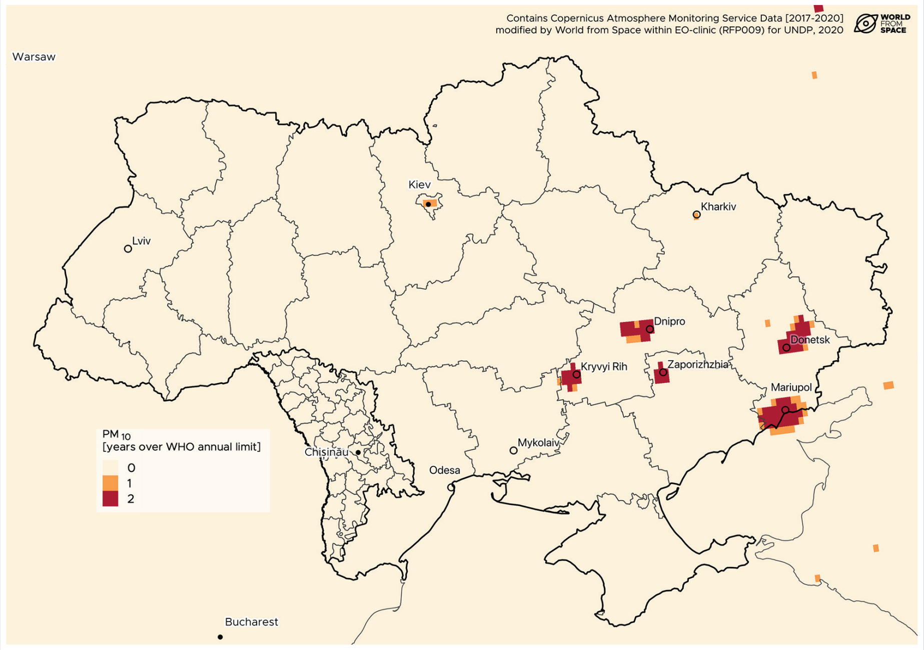


Figure 37: Number of days when the WHO 24-hour limit for PM_{10} was exceeded over Ukraine and Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])

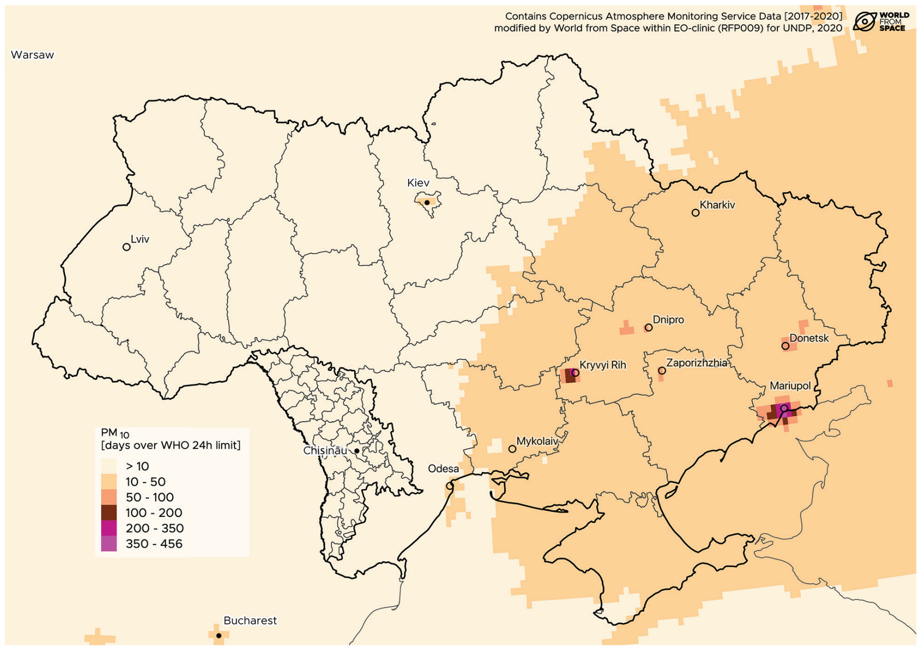


Figure 38: Average concentrations of PM_{10} over Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])

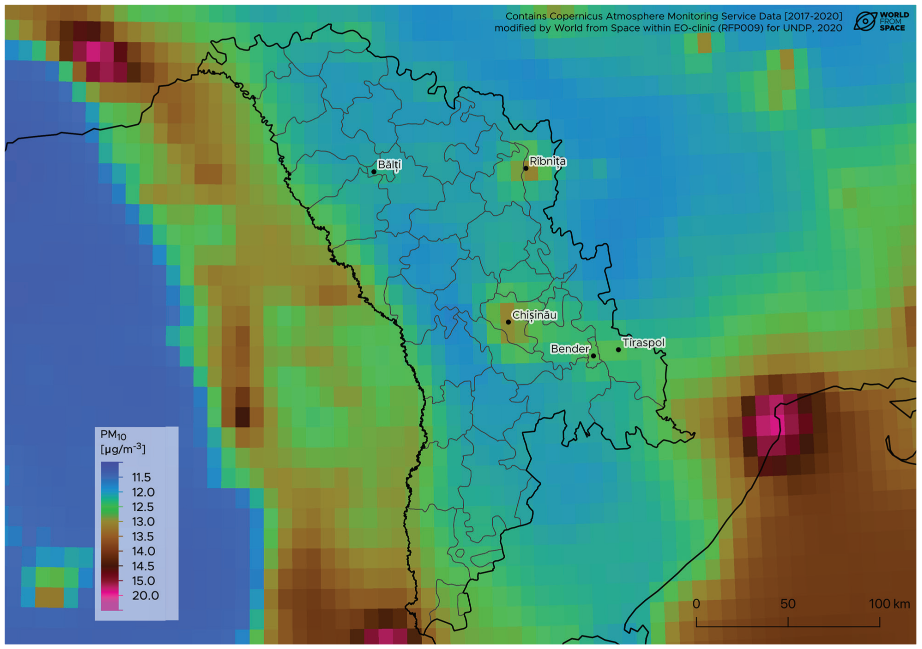


Figure 39: **Average monthly concentrations of parti-cles smaller than 10 µm (PM_{10}) in the districts of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. The AQG and IT-3 abbreviations represent the Air Quality Guideline and the Interim Target 3, respectively, both proposed by the WHO. (Contains modified Copernicus Atmosphere Monitoring Service Infor-mation [2020])**

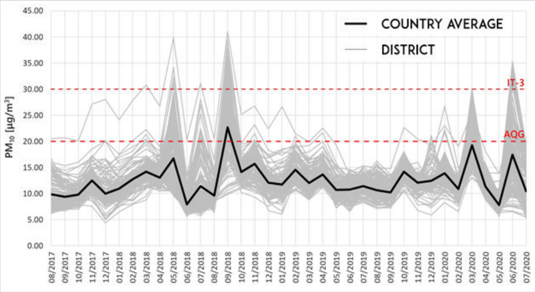
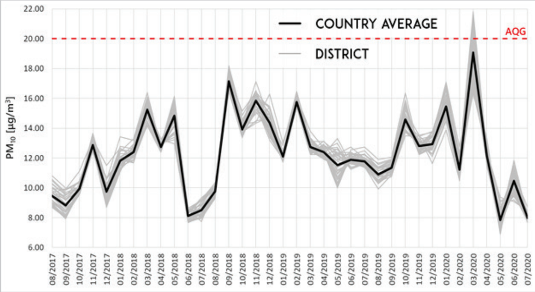


Figure 40: **Average monthly concentrations of PM_{10} in the districts of Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. The AQG abbreviation represents the Air Quality Guideline proposed by the WHO. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.2 Report on regional and focus (urban) areas air pollution

3.3.2.1 Ukraine

Regional distribution of air pollution in Ukraine regions based on S-5p is displayed in table below, together with information about average concentrations of pollutants based on data from the Copernicus Atmosphere Monitoring Service. For more detailed information on a district level, please see tables in Appendix B of TN1.

Table 4: **Sample table of the average concentrations of carbon monoxide, nitrogen dioxide, and sulfur dioxide in the regions of Ukraine between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

	Pollutant		
Region	**CO [10^{-1}mol/m²]**	**NO_2 [10^{-4}mol/m²]**	**SO_2 [10^{-3}mol/m²]**
Crimea	0.326	0.211	0.652
Dnipropetrovsk	0.332	0.313	0.730
……			

Table 5: **Sample table of the average concentration of carbon monoxide, nitrogen dioxide, ozone, particulate matter 2.5, particulate matter 10, and sulfur dioxide in the regions of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service In-formation [2020])**

	Pollutant					
Region	CO [µg/m3]	NO2 [µg/m3]	O3 [µg/m3]	PM2.5 [µg/m3]	PM10 [µg/m3]	SO2 [µg/m3]
Crimea	157.57	1.86	68.31	8.90	12.32	1.60
Dnipropetrovsk	180.13	3.85	61.00	11.72	15.04	4.80
Donetsk	180.38	4.45	61.60	12.76	16.86	5.99

For the analysis of urban areas performed in this project, ten largest urban areas were selected based on their population. Air pollution is assessed based on both S-5p and CAMS data. Tables with data as follows are presented in detail in the TN of the project:

Table 6: **Sample table with the average concentration of carbon monoxide, nitrogen dioxide, and sulfur dioxide in the selected urban areas of Ukraine between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

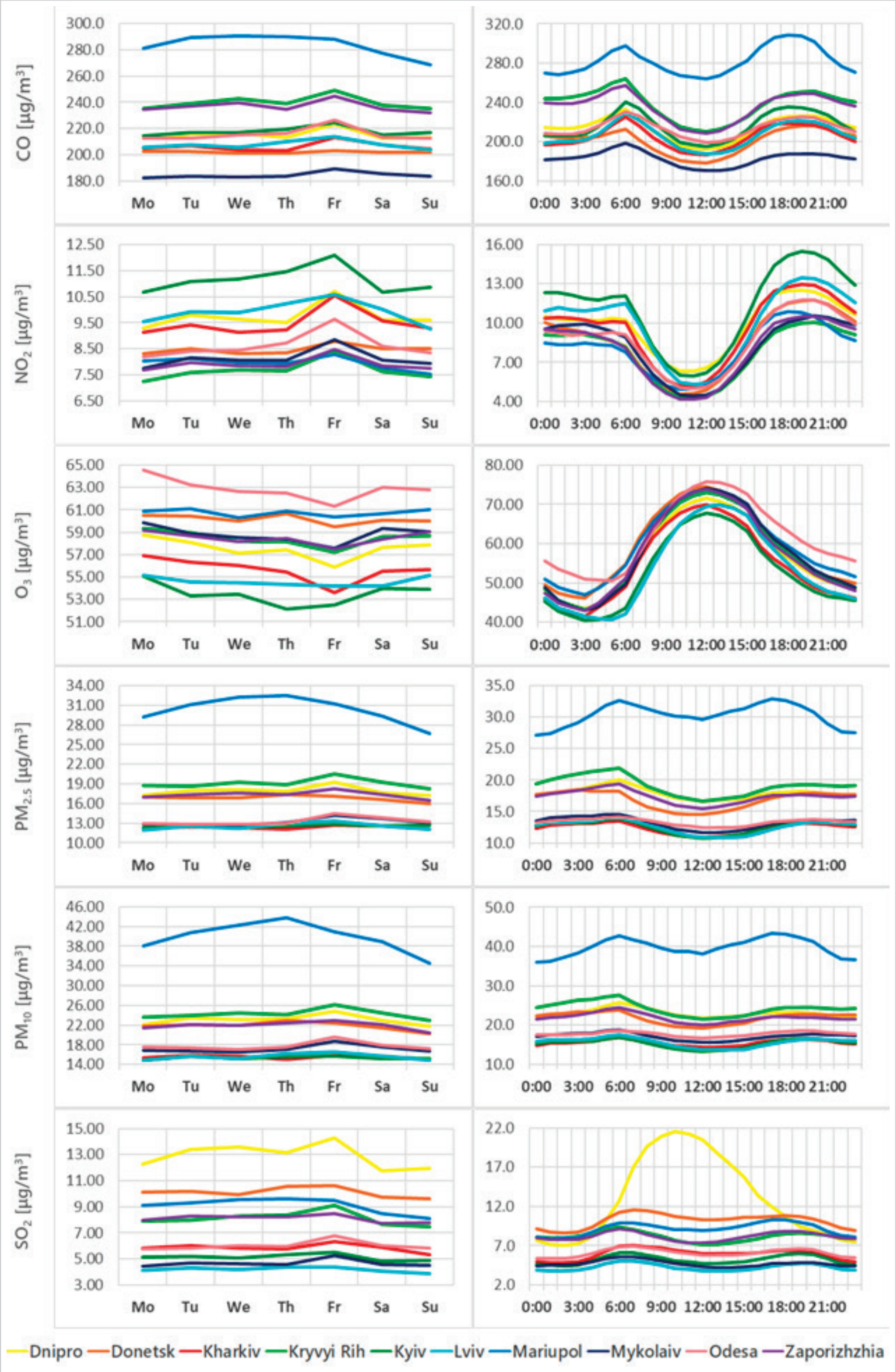
	Pollutant		
City	CO [10^{-1}mol/m^2]	NO$_2$ [10^{-4}mol/m^2]	SO$_2$ [10^{-1}mol/m^2]
Dnipro	0.337	0.451	0.773
Donetsk	0.329	0.496	0.845
Kharkiv	0.330	0.450	0.722
Kryvyi Rih	0.338	0.433	0.739

Table 7: **Sample table with the average concentration of carbon monoxide, nitrogen dioxide, ozone, particulate matter 2.5, par-ticulate matter 10, and sulfur dioxide in the selected urban areas of Ukraine between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data.**

	Pollutant					
City	CO [µg/m^3]	NO$_2$ [µg/m^3]	O$_3$ [µg/m^3]	PM$_{2.5}$ [µg/m^3]	PM$_{10}$ [µg/m^3]	SO$_2$ [µg/m^3]
Dnipro	215.02	9.73	57.52	17.88	22.98	12.90
Donetsk	201.91	8.46	60.14	16.77	21.75	10.11
Kharkiv	205.99	9.46	55.62	12.29	15.44	5.86
Kryvyi Rih	239.41	7.65	58.46	19.02	24.16	8.08
Kyiv	217.43	11.13	53.47	12.52	15.23	5.12

Air pollution varies across the regions, but also across the time. The following figure presents the analysis of air pollution levels depending on the time of day and days of the week.

Figure 41: **Average weekday (right) and hourly (left) concentrations of CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, and SO_2 within the 10 largest cities of Ukraine by population between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.2.2 Moldova

Regional distribution of air pollution in Moldova regions based on S-5p is displayed in table below, together with information about average concentrations of pollutants based on data from the Copernicus Atmosphere Monitoring Service. For more detailed information on a district level, please see tables in Appendix B of TN1.

Table 8: **ample table of the average concentra-tion of carbon monoxide, nitrogen dioxide, and sulfur dioxide in the districts of Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

	Pollutant		
District	**CO** **[10^{-1}mol/m^2]**	**NO_2** **[10^{-4}mol/m^2]**	**SO_2** **[10^{-3}mol/m^2]**
Anenii Noi	0.329	0.258	0.779
Bălţi	0.325	0.252	0.808

Table 9: **ample table of the average concentra-tion of carbon monoxide, nitrogen dioxide, and sulfur dioxide in the districts of Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel data [2020])**

	Pollutant					
District/pollutant	CO [µg/m3]	NO2 [µg/m3]	O3 [µg/m3]	PM2.5 [µg/m3]	PM10 [µg/m3]	SO2 [µg/m3]
Anenii Noi	169.94	2.72	61.58	9.98	12.38	1.66
Bălţi	171.22	2.91	60.75	9.88	12.23	1.60
Basara-beasca	166.72	2.38	62.16	9.73	12.09	1.53

For the analysis of urban areas performed in this project, three main urban areas were selected based on their population. Air pollution is assessed based on both S-5p and CAMS data. Tables with data as follows are presented in detail in the TN of the project:

Table 10: **Average concentration of carbon monoxide, nitro-gen dioxide, and sulfur dioxide in the selected ur-ban areas of Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. (Contains modified Copernicus Sentinel da-ta [2020])**

	Pollutant		
City	CO [10^{-1}mol/m^2]	NO_2 [10^{-4}mol/m^2]	SO_2 [10^{-1}mol/m^2]
Bălți	0.326	0.257	0.775
Chișinău	0.330	0.374	0.806
Tiraspol	0.332	0.286	0.814
Country average	**0.327**	**0.240**	**0.768**

Table 11: **Average concentration of carbon monoxide, nitrogen dioxide, ozone, particulate matter 2.5, particulate matter 10, and sulfur di-oxide in the selected urban areas of Moldova between August 2017 and July 2020 obtained from the Copernicus Atmosphere Moni-toring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

	Pollutant					
City	CO [µg/m^3]	NO_2 [µg/m^3]	O_3 [µg/m^3]	$PM_{2.5}$ [µg/m^3]	PM_{10} [µg/m^3]	SO_2 [µg/m^3]
Bălți	171.72	3.01	60.75	9.90	12.25	1.62
Chișinău	177.37	4.01	61.33	10.43	12.90	2.11
Tiraspol	172.84	3.32	61.50	10.09	12.54	1.95
Country average	**169.09**	**2.63**	**61.50**	**9.88**	**12.24**	**1.58**

In Moldova, air pollution varies much more across the time than across the districts. Figure below presents the analysis of air pollution levels depending on the time of day and days of the week.

Figure 42: **Average weekday (right) and hourly (left) concentrations of CO (A), NO$_2$ (B), O3 (C.), PM$_{2.5}$ (D), PM$_{10}$ (E), and SO$_2$ (F) within the 3 largest cities of Moldova by population between August 2017 and July 2020 obtained from the Copernicus Atmosphere Monitoring Service data. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

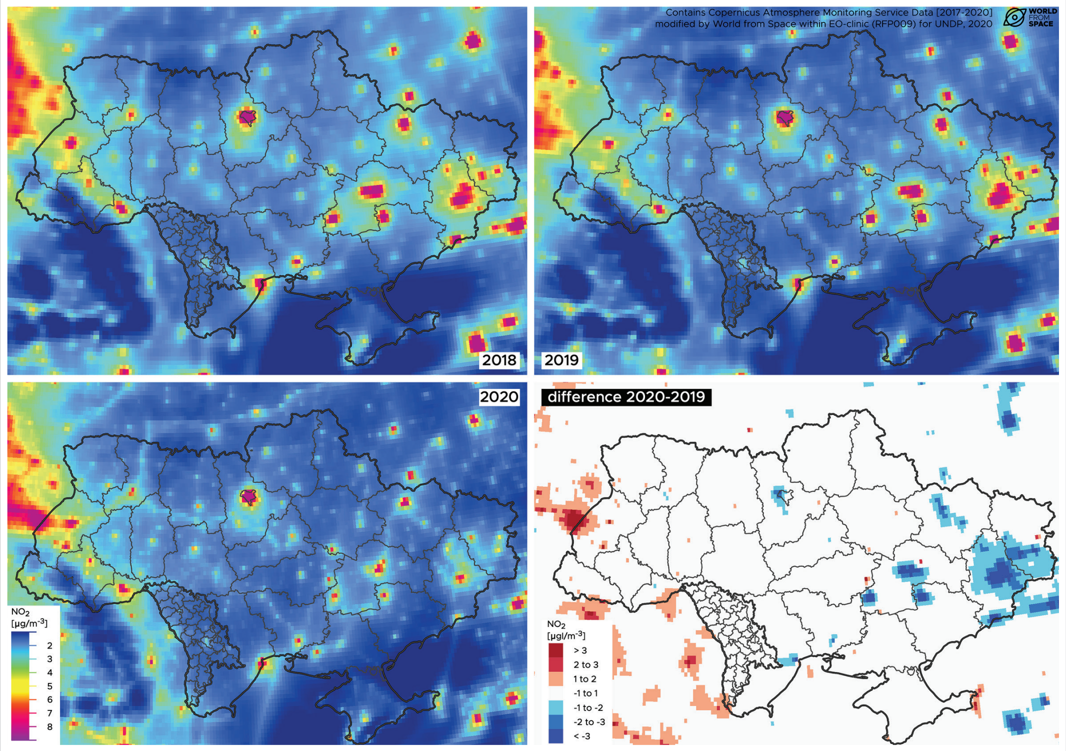
3.3.3 Report on COVID-19 era anomalies

3.3.3.1 Nitrogen dioxide NO2

Among other data resulting from the NO2 concentration over Ukraine and Moldova during COVID-19 lockdown era (defined as 17 March 2020 - 15 May 2020). Also, a comparison for the same period in 2019. Compared to the previous year, from where a significant decline can be observed over larger cities and industrial areas in Ukraine, such as Kiev city and Donetsk, Zaporizhzhia, Kharkiv and Dnipropetrovsk regions.

Figure below displays the average concentrations of NO_2 over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 periods, obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. Despite of the fact these are modelled data and do not necessarily reflect a significant suspension of economic activities, a decline of nitrogen dioxide concentration can be observed particularly over the largest cities located in the southeast part of Ukraine. Decrease in values can be as well as observed in the Kiev city.

Figure 43: **Average concentrations of nitrogen dioxide over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



Contains Copernicus Atmosphere Monitoring Service Data [2017-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

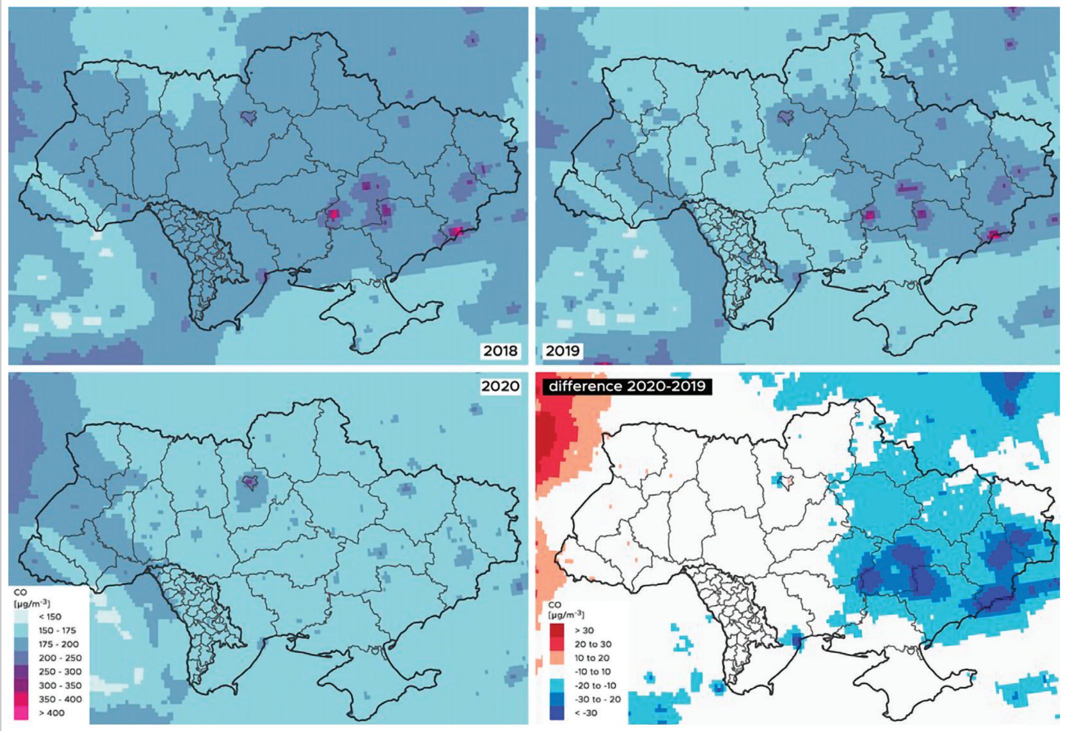
3.3.3.2 Carbon monoxide

The distribution of carbon monoxide concentration over Ukraine and Moldova during COVID-19 lockdown era was analysed. To determine the effects of lockdown on air quality related to decrease of economic activities, a comparison with the same period in 2019 was used. In general, natural sources of CO come from volcanic activity, forest fires, degradation of vegetation and its distribution is also affected by elevation and temperature. To exclude the impact of natural resources on increasing concentration, comparison with temperature data and forest fires emission data was performed.

Figure below displays the average concentrations of carbon monoxide over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 periods, obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. Despite the fact these are modelled data and do not necessarily reflect a significant suspension of economic activities, a decline of carbon monoxide concentration can be observed in the southeast part of Ukraine. Particular decline in values can be seen over the area where the major steel production centers are located (Mariupol, Zaporizhzhia, Kryvyi Rih and Kamianske).

There are no significant observable declines of carbon monoxide concentrations over Moldova between 2019 and 2020 from the Copernicus Atmosphere Monitoring Service.

Figure 44: **Average concentrations of carbon monoxide over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

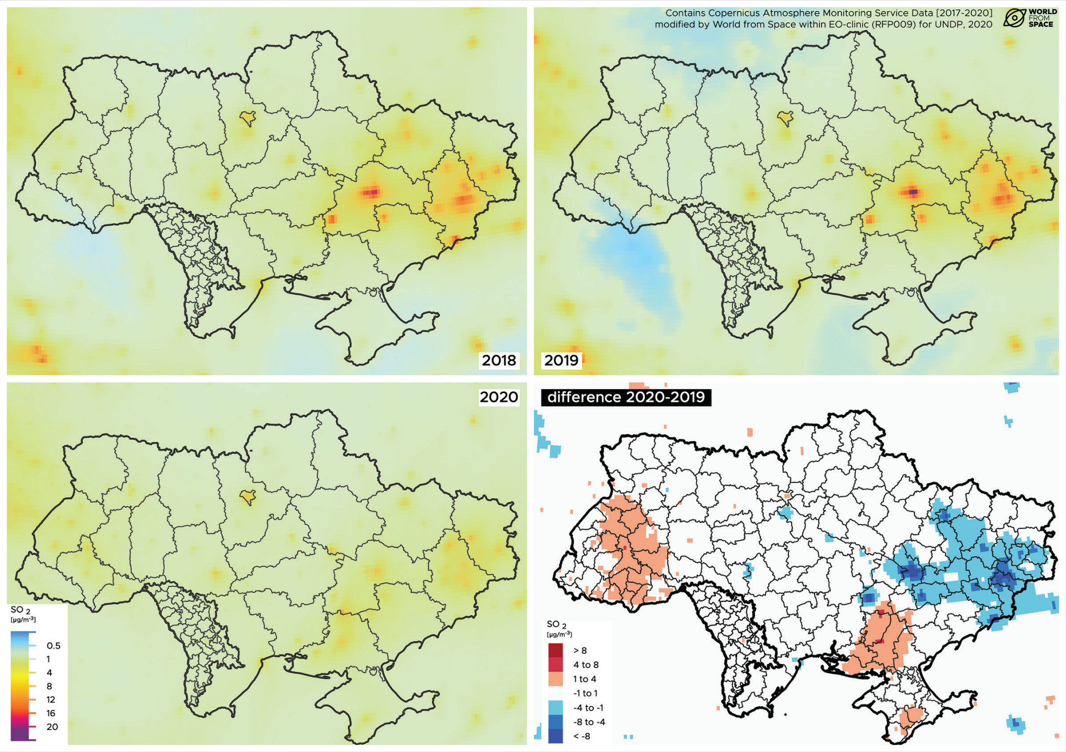


3.3.3.3 Sulfur dioxide SO2

Figure below displays the average concentrations of sulfur dioxide over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 periods, obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. The sulfur dioxide concentration for 2018 and 2019 is evenly distributed. The highest values reach industrial cities located in the southeast part of Ukraine. In contrast, in the same period of 2020, when significant decrease in sulfur dioxide concentration in the industrial spots can be observed.

There are no notable observable declines of sulfur dioxide concentrations over Moldova between 2019 and 2020 from the Copernicus Atmosphere Monitoring Service.

Figure 45: **Average concentrations of sulfur dioxide over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

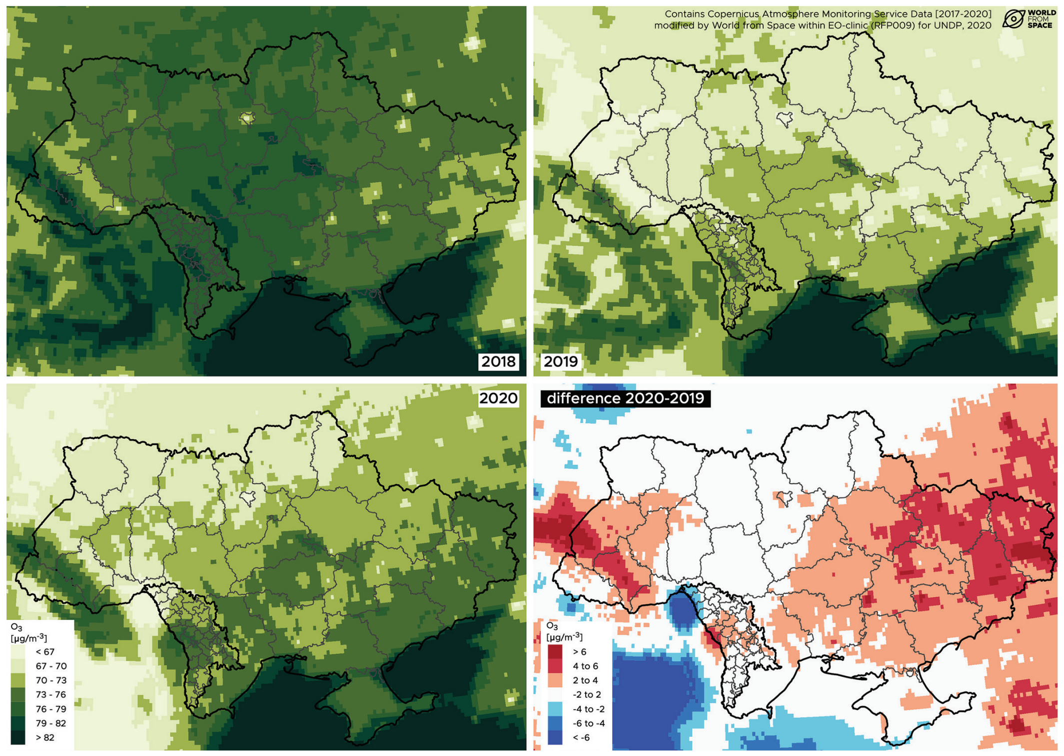

Contains Copernicus Atmosphere Monitoring Service Data [2017-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

3.3.3.4 Ozone O3

Figure below displays the average concentrations of ozone over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 periods, obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. Significant differences can be observed between 2018 and 2019. Due to the fact that ozone concentrations in the Northern Hemisphere reaches maximum values in spring, the increase in concentrations during the COVID-19 period is related to another number of factors. Regional distribution of concentration is sensitive to the spring peak. In 2018, the maximum values have reached high values between March and April, while in 2019, the ozone concentration peaked only in April. Due to the fact that the distribution of ozone negatively correlates with the distribution of nitrogen dioxide and despite the different range of values in 2018 and 2019, a pattern of reduced values can be observed over the areas with increased nitrogen dioxide concentration (urban and industrial areas) in 2018 and 2019. While in 2020 (lockdown period), when nitrogen dioxide concentrations declined, the pattern is not observable as clearly.

Ozone concentrations in Moldova follow the general trend of its distribution in the region.

Figure 46: **Average concentrations of ozone over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**

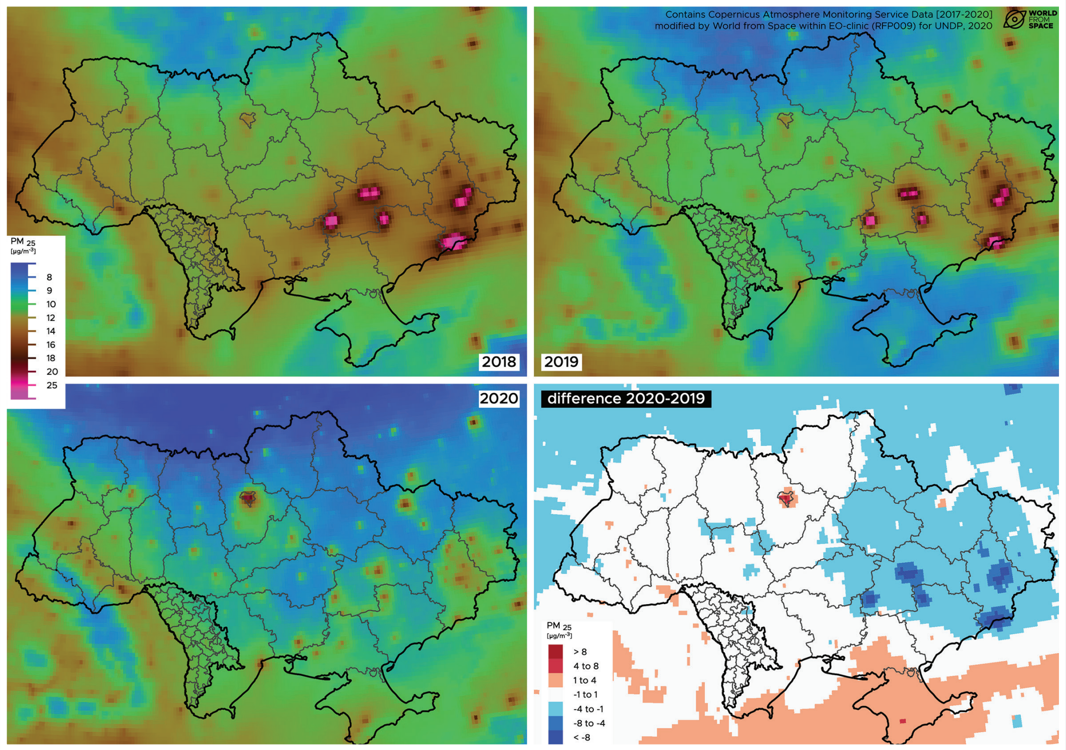


Contains Copernicus Atmosphere Monitoring Service Data [2017-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

3.3.3.5 Particulate Matter 2.5

Figure below displays the amount of particulate matter smaller than 2.5 μm ($PM_{2.5}$) over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 period, obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. Despite of the fact that this data is modelled data (from CAMS), it does not reflect a significant suspension of economic activities can be seen over Ukraine. While for the years 2018 and 2019 a significant part of Ukraine and Moldova reached the WHO air quality guideline's annual-mean value of 10 µg/m^3, in the same period in 2020, there was a significant reduction below the limit value. At the same time, a notable decrease below the WHO 24-hour mean limit (25 µg/m^3) can be observed in the largest industrial cities in the southeast part of Ukraine.

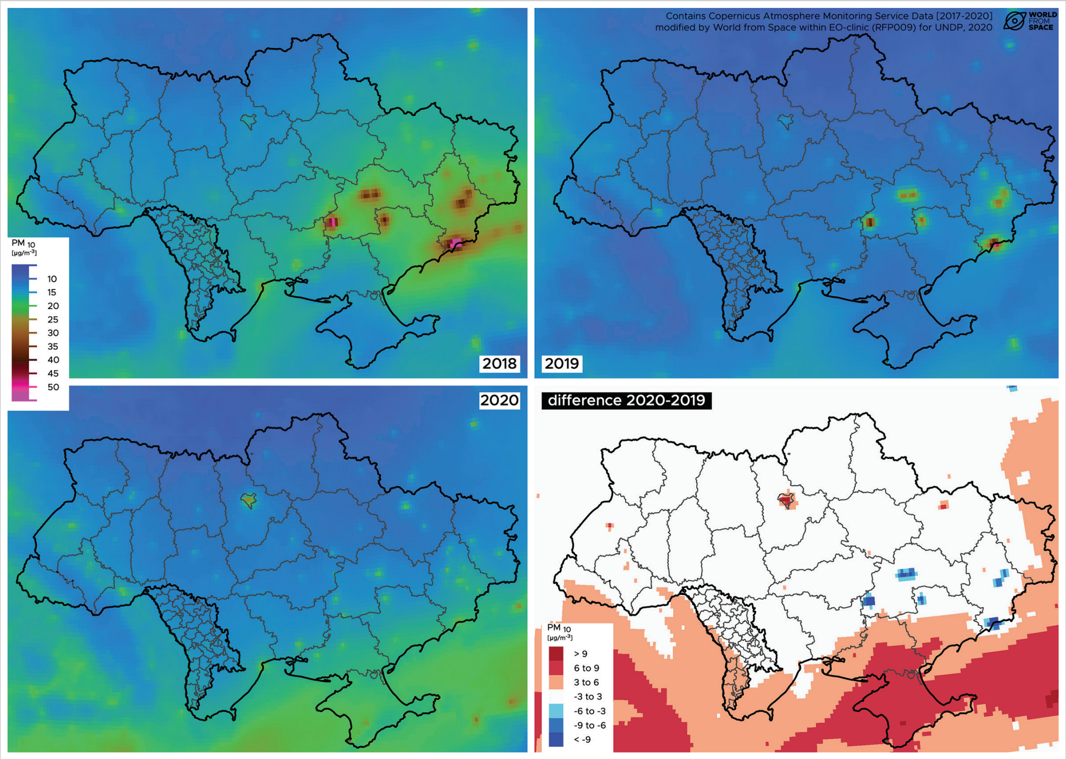
Figure 47: **Average concentrations of parti-cles smaller than 2.5 µm ($PM_{2.5}$) over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Information [2020])**



3.3.3.6 Particulate Matter 10

Figure below displays the amount of particulate matter smaller than 10 µm (PM_{10}) over Ukraine and Moldova between 17 May to 15 March for 2018, 2019 and 2020 period obtained from the Copernicus Atmosphere Monitoring Service. The figure is supplemented with a difference in concentration between lockdown period and the same period in 2019. Notable changes in PM_{10} concentrations occurred between 2018 and 2019 as can be seen. Likewise, a decrease in the values can be seen over industrial cities in eastern Ukraine between 2019 and 2020 for the same period.

Figure 48: **Average concentrations of particles smaller than 10 µm (PM_{10}) over Ukraine and Moldova between 17 March 2020 and 15 May 2020 compared with the same period of 2019 and 2018 obtained from the Copernicus Atmosphere Monitoring Service. (Contains modified Copernicus Atmosphere Monitoring Service Infor-mation [2020])**



3.3.4 Report on links between air quality and socioeconomic data

Various datasets were collected by partners and investigated for the links between air pollution. In general, several phenomenons are expected to have some link to air pollution: human activities, transport, industrial production and natural sources of pollutants.

Figure 49: **Average concentrations of nitrogen dioxide over Ukraine between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. Supplemented with population density 2019 data provided by UNDP Ukraine (Contains modified Copernicus Sentinel data and [2020])**

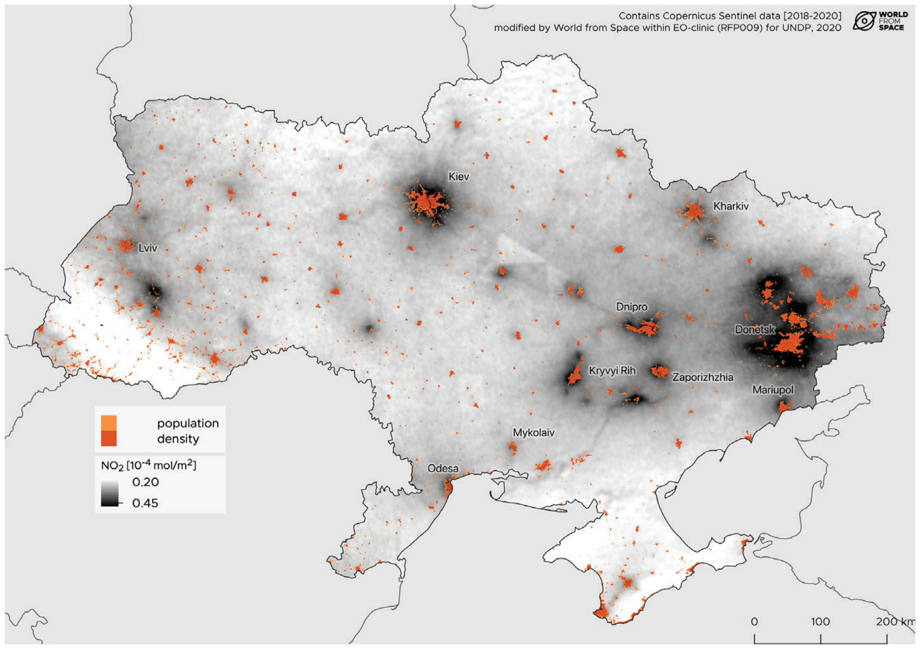
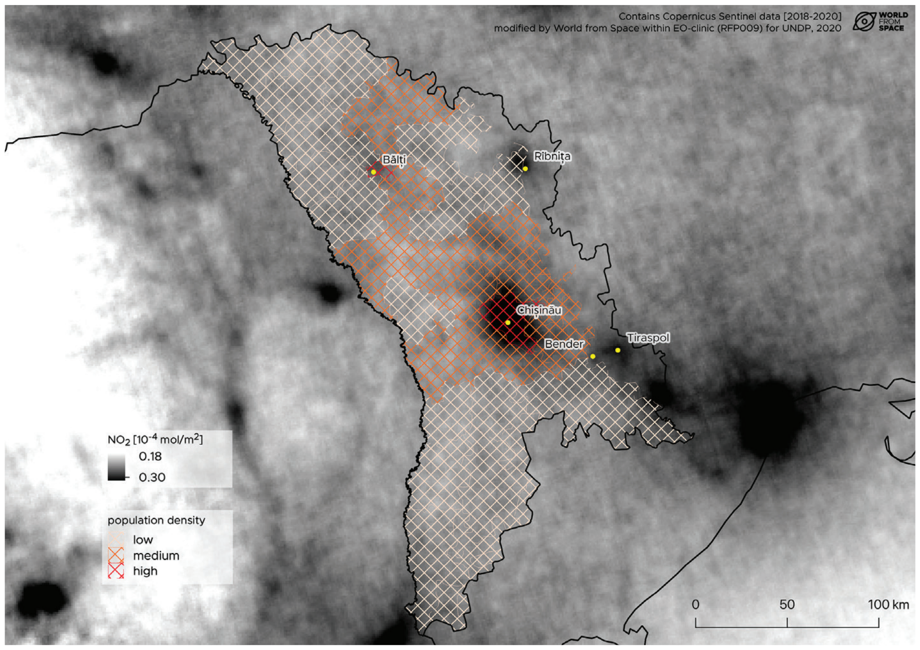


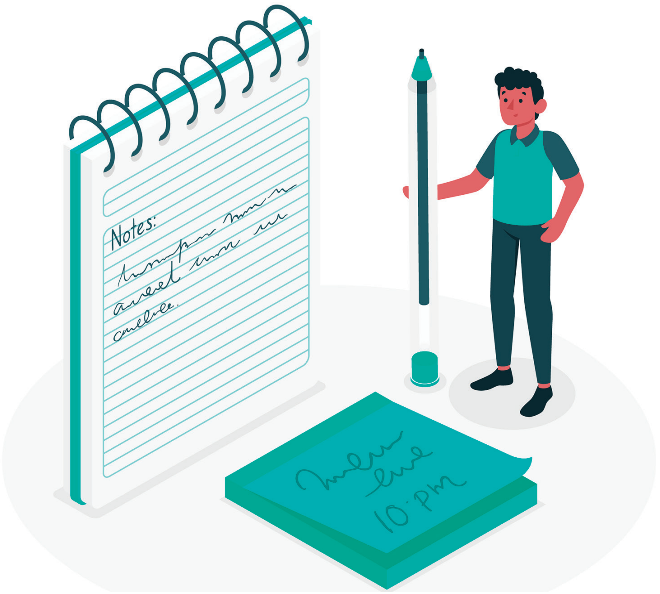
Figure 50: **Average concentrations of nitrogen dioxide over Moldova between May 2018 and July 2020 obtained from the Copernicus S-5p satellite data. Supplemented with population density 2019 data provided by UNDP Moldova (Contains modified Copernicus Sentinel data and [2020])**



4. Deliveries

The outcomes from the project is:

- Technical Note 1 containing the explanatory results of WP1 and WP2
- Files containing all images and data from the work performed
- The Web-based platform, accessible for 1 years where the results can be seen visually in the Map (**http://air.worldfrom.space/**).
- Four visually appealing and content-rich web stories showcasing results of the analysis.:
    - **Urban pulse - air pollution in Kyiv and Chernivtsi (Ukraine)** – (http://stories.worldfrom.space/urban_pulse_ua)
    - **Tracking down major industrial polluters (Ukraine)** – (http://stories.worldfrom.space/poluters_ua)
    - **Urban pulse - air pollution in Chisinau and Balti (Moldova)** – (http://stories.worldfrom.space/urban_pulse_md)
    - **Air pollution in Moldova from space (Moldova)** – (http://stories.worldfrom.space/air_pollution_md)
- **Final Report**: this document compiling the objectives and achievements of the Project together with the conclusions and findings. It presents the potential of the methodology applied during the project is described, but also its limitations, for UNDP and other stakeholders to be aware of the working flow and it's potential.



5. Summary and Future Actions

Air pollution has a significant impact on the health of the European population, particularly in urban areas. The United Nations Development Programme (UNDP) works with Ukraine and Moldova on their own solutions to global and national development challenges, including the air pollution as well as the recent pandemic of the SARS-CoV-2 or coronavirus causing the COVID-19 illness.

This study provides decision makers in Ukraine and Moldova with tools for improving situational awareness, enabling early warning systems (EWS), and supporting planning of mitigation measures in the air quality domain. Analysis is based on the data from the Copernicus Sentinel-5p satellite as well as on the quality-controlled reanalysis data provided by the Copernicus Atmosphere Monitoring Service.

This study includes:

- Air quality assessment for Ukraine and Moldova for NO2, SO2, CO, O3, PM10 and PM2,5
- Analysis of air pollution distribution in regional and urban areas in Ukraine and Republic of Moldova
- Identification of COVID-19 related specifics in air quality and their socio economic links
- Promotion of the results by web-based platform and 4 web stories
- Suggestion on tools for decision makers

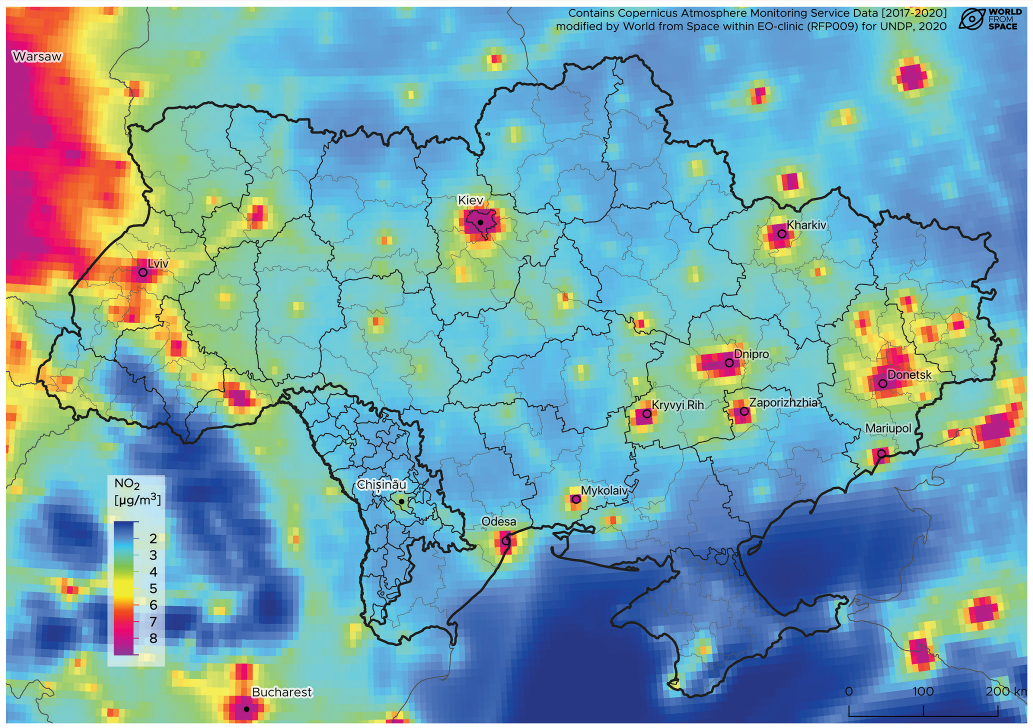
Key findings:

Current air quality situation is diverse in **Ukraine** and it reflects the distribution of densely populated places as well as industrial areas (including major industrial polluters). The lowest average concentrations can be spotted over the sparsely populated areas, including Carpathian mountain range and the Crimean mountains.

The overall situation of air pollution in **Moldova** is favourable, specifically when compared to other European countries. Higher concentration of pollutants is observable only in the capital city and near large power plants.

Concentrations of **nitrogen dioxide** are relatively even in Ukraine, with several regions having significantly higher concentrations than the rest of the country. These regions mainly comprise the vicinity of the capital city Kyiv and regions in the eastern and southeast part of the country, including the Donetsk, Zaporizhzhia, Kharkiv and Dnipropetrovsk regions.

Figure 51: **Concentrations of nitrogen dioxide.**


Contains Copernicus Atmosphere Monitoring Service Data [2017-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

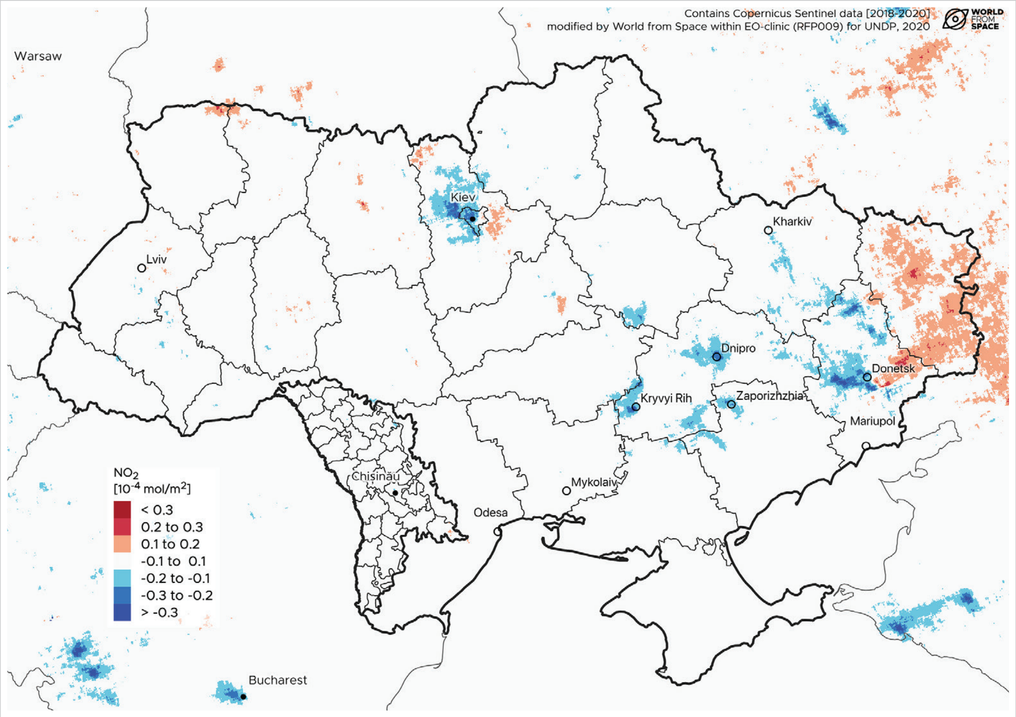
In Moldova, concentrations are generally low. Elevated values were observed in and around the capital city Chișinău, around the border with Ukraine, especially where the Kuchurgan power plant is located, and around the cities of Tiraspol and Rîbnița. WHO limits on nitrogen dioxide concentrations were not exceeded during the studied period.

Natural variations have a main effect on distribution of **carbon monoxide** within the region. However, several hotspots caused by human activity were recognized in Kyiv, Mariupol, Kryvyi Rih, Zaporizhzhia and Kamianske. Recommended limits by the WHO were not exceeded during the studied period.

Sulphur dioxide hotspots were recognized in the industrial region of eastern Ukraine and some urban areas, including Ukrainan cities Kyiv, Mykolaiv and Odesa. The distribution of values within Moldova shows no definite trend. Values are generally low throughout the country, with only modest increase around the capital city. Similarly to previous cases, WHO limits were not exceeded during the studied period.

The highest concentrations of **ozone** can be found over the coastal areas of Ukraine and over Crimea. In Moldova, concentrations rise from northwest to the southeast of the country, with the highest concentrations over the Moldavian Plateau. WHO limits on ozone were exceeded between 10 to 100 days across the region within the last three years.

Figure 52: **Concentrations of particulate matter.**


Contains Copernicus Sentinel data [2018-2020] modified by World from Space within EO-clinic (RFP009) for UNDP, 2020

Concentrations of **particulate matter** (PM) show significant pollution in the studied area, often exceeding WHO levels. Daily limits for PM2.5 were exceeded in industrial cities of Donetsk, Dnipro, Mariupol, Kryvyi Rih and Zaporizhznia more than 200 times in 3 years. In Mariupol, PM10 concentrations were exceeded once in every 3 days. Concentrations of PM2.5 are relatively high in other industrial cities of Ukraine and Moldova, while concentrations of PM10 are high only in several hotspots.

Observable reduction of air pollution concentrations was detected in Ukraine during the **COVID-19 lockdown**, while there were no significant changes to be related to Moldova when the country was locked down.

Compared to the previous year, a significant decline was observed in all studied pollutants over larger cities and industrial areas in Ukraine, such as Kiev city, Donetsk, Zaporizhzhia, Kharkiv and Dnipropetrovsk regions.

Low decrease in concentrations was observed in the northern regions of Moldova and around the capital Chisinau. Comparison between economic activity change during COVID-19 period and NO_2 concentration change did not show any direct link.

A new simple **web application** available on the site **air.worldfrom.space** illustrates available data on air pollution and enables comparison between pollutants, data sources and time periods. While using it, the different nature of the data should be taken into consideration.

Four **web stories** showcasing the potential of air quality data to the general public are also available online.

Consistent, stable, equally dense and controlled **in-situ measurement network** would benefit to overall assessment of air pollution. Saveecobot initiative is an interesting and promising achievement in that respect. To assess this dataset additional time is needed for quality checks and data harmonisation.

Further cooperation can be explored based on this study including:

- setting up operational monitoring of air pollution from S-5p data and CAMS for its availability to any public (extension of the web application for automatically adding new/actual data)
- setting up an operational EWS for air quality monitoring
- processing of saveecobot data for whole country, quality checks and harmonisation
- methodology for combination all the country-scale in-situ data and satellite observations
- creation of additional web stories
- extension of the use of web application and web stories after 1 year
- extension of the analysis to other countries and areas world-wide.

Appendix **A**: References

The following table shows references of our consortium which apply to the current RFP:

Table 12: **References**

Company		
EVERIS	General cartographic repository of Unnamed Traffic Management Demostrator for SESAR JSU (DOMUS)	Spain, 2019
	Small Infrastructure Study, associated with public transport services and urban and rural terminals	Regional Government of La Araucanía, Chile, 2018
	Technological specialized consultancy about Corporative GIS of the Metropolitan Transport of Barcelona	Barcelona, Spain, 2018
	Madrid Digital, GIS applications maintenance: urban planning, official street name, property and real estate valuation system	Madrid, Spain, 2018
	Framework GIS of Autonomous Community of Madrid	Madrid, Spain, 2018
	Spatial Data Infrastructure (IDE) of the Spanish Directorate General of Cadastre of National Institute of Statistics	Madrid, Spain, 2018
WORLD FROM SPACE	DynaCROP - ready-to-use satellite API for agricultural applications & AI	proprietary SaaS product, 2020 **https://dynacrop.worldfromspace.cz/**
	Crop damage assessment after hail storm for insurance company	2019
	Analysis of urban vegetation dynamics and green areas	different projects in Prague, Brno, SLavkov and Pilsen Czech Republic, 2018, 2019
	Urban heat island methodology	Prague, 2019
	Vegetation detection and classification	Liberty Steel, 2019
	Copernicus data and services consulting	Alpha Consult, 2019-2020

Appendix **B**: List of Acronyms

Table 13: **List of Acronyms**

Acronym	Meaning
AOI	Area of interest
AQG	Air Quality Guideline
CAMS	Copernicus Atmosphere Monitoring Service
CO	Carbon monoxide
EO	Earth Observation
ESA	European Space Agency
EWS	Early warning system
MD	Moldova
NO_2	Nitrogen dioxide
O_3	Ozone
PM	Particulate matter (PM2.5 and PM10)
RFP	Request for Proposal
S-5p	Sentinel-5p satellite
SO_2	Sulfur dioxide
IT	Interim Target
IT-2	Interim Target 2
IT-3	Interim Target 3
UA	Ukraine
WHO	World Health Organization
WO	Work Order
WOR	Work Order Report
WP	Work Package