UDENE

Air Quality & Carbon Footprint Modelling with Copernicus EO & UDENE Tools

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LIST of ACRONYMS

Acronym	Full name
AOI/ROI	Area of Interest / Region of Interest
AQMS	Air Quality Monitoring Stations (ground monitoring stations)
AR6	IPCC Sixth Assessment Report
BRT	Bus Rapid Transit
CAMS	Copernicus Atmosphere Monitoring Service
CEMS	Copernicus Emergency Management Service
CLC	CORINE Land Cover
CLMS	Copernicus Land Monitoring Service
CORINE	Coordination of Information on the Environment
CRS	Coordinate Reference System
DACUM	Developing A Curriculum
DOAS	Differential Optical Absorption Spectroscopy
ECMWF	European Centre for Medium-Range Weather Forecasts
ECTS	European Credit Transfer and Accumulation System
EF	Emission Factor
EGD	European Green Deal
EO	Earth Observation
EO/GIS	Earth Observation / Geographic Information Systems
EPSG	EPSG Geodetic Parameter Dataset (formerly European Petroleum Survey Group)
FAO	Food and Agriculture Organization of the United Nations
GDAL	Geospatial Data Abstraction Library
GEE	Google Earth Engine
GEO	Group on Earth Observations
GHG	Greenhouse Gas
GIS	Geographic Information System
GWP	Global Warming Potential
IFS	Integrated Forecasting System
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
LEZ	Low Emission Zone
LO	Learning Outcome
LO1–LO7	Learning Outcomes 1–7
MAE	Mean Absolute Error
MGM	Turkish State Meteorological Service
ML	Machine Learning
MOOC	Massive Open Online Course
MSc	Master of Science
NIR	Near Infrared
OSM	OpenStreetMap

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Acronym	Full name
QA	Quality Assurance
R^2	Coefficient of Determination (R-squared)
RMSE	Root Mean Square Error
ROI	Region of Interest
SCID	Systematic Curriculum & Instructional Development
SCID/DACUM	Systematic Curriculum & Instructional Development / Developing A Curriculum (combined approach)
SDG	Sustainable Development Goal
SWIR	Shortwave Infrared
TEM	Trans-European Motorway (highway)
UDENE	Urban Development Explorations using Natural Experiments (Eurisy)
UNFCCC	United Nations Framework Convention on Climate Change
UV	Ultraviolet
VCD	Vertical Column Density
VIS	Visible (spectrum)
AOI/ROI	Area of Interest / Region of Interest

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1 EXECUTIVE SUMMARY

This Educational Plan has been prepared as the official deliverable for UDENE Open Call #1 – Educational Plans, fulfilling all requirements defined in the Call Fiches and the follow-up clarification email from the UDENE coordination team. The module titled:

"Air Quality & Carbon Footprint Modelling with Copernicus EO & UDENE Tools"

is designed as a 3 ECTS (75–90 hours), competency-based, SCID-guided curriculum that equips MSc-level learners with advanced geodata science capabilities, particularly in atmospheric pollution analysis and carbon footprint modelling.

The plan integrates:

- **Copernicus Sentinel-5P tropospheric pollutant products**,
- **CAMS PM_{10}, $PM_{2.5}$ and CO_2 global atmospheric reanalysis datasets**,
- **UDENE tools (Explorer, Raster Engine, Time-Series Panel, Validation Module)**,
- **SCID instructional development methodology**,
- **DACUM job/task competency analysis**,
- **Erasmus Quality Standards** (Relevance, Design Quality, Learning Quality, Impact).

The Educational Plan consists of:

1) A detailed curriculum blueprint (90 hours)
2) Structured weekly plans
3) Task-based assignments requiring hands-on UDENE usage (≥50% workload)
4) Performance assessments with rubrics
5) Three complete demonstrative case studies addressing urban development challenges
6) Replicable, open-source teaching materials
7) A full SCID learning guide set

The plan is designed to be transferable, scalable, and adaptable to any city worldwide, enabling its adoption not only in Türkiye but also by educational institutions in Africa, Balkans, Asia, Latin America, and EU partner regions.

This deliverable stands as a fully compliant, Erasmus-quality, SCID/DACUM-based educational package.

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2 CONTEXT, MISSION ALIGNMENT & RATIONALE

2.1 Global and Regional Context

Rapid urbanization, population growth, and shifting land-use patterns are placing extraordinary pressure on metropolitan environments, increasing both the intensity and complexity of urban environmental risks. Within this context, three challenge areas are particularly prominent and require systematic monitoring and analysis: urban NO_2 pollution, seasonal PM_{10} peaks, and urban CO_2 emissions.

Rising NO_2 concentrations are a persistent concern in most cities, where traffic emissions remain the dominant source. Elevated NO_2 levels typically concentrate in predictable spatial patterns, especially around:

- Congestion zones
- Tunnels and major transport corridors
- High-density commercial districts

Because Sentinel-5P provides daily atmospheric measurements, it is well suited to identifying and tracking these NO_2 hotspots, supporting both screening-level diagnostics and routine monitoring workflows.

A second recurring issue is seasonal PM_{10} peaks, which are especially relevant across Türkiye, Eastern Europe, the Caucasus, and Central Asia. PM_{10} concentrations frequently rise during the winter period and under specific meteorological and regional transport conditions, including:

- Winter heating seasons
- Thermal inversion events
- Dust transport from North Africa
- Industrial operations (e.g., cement and steel production)

Addressing PM_{10} effectively therefore requires more than single-date mapping; it demands time-series extraction, seasonal decomposition, and the ability to distinguish episodic events from underlying trends—capabilities that the UDENE platform is designed to support.

Urban CO_2 emissions reflect a broader set of drivers tied to both human activity and land-use structure. City-level CO_2 footprints vary with transportation density, industrial clustering, overall energy consumption, and land-use composition (urban, agricultural, and forested areas). Importantly, agricultural land-use should not be treated as a uniform category: carbon emissions and sequestration dynamics can differ substantially by crop type and management practice. For example, wheat and barley systems may diverge in fertilizer intensity, nitrogen-related pathways (including nitrogen-to-N_2O emissions), and soil carbon sequestration rates. This level of differentiation is essential for producing credible, decision-relevant urban carbon assessments rather than coarse, generalized estimates.

2.2 Why EO-Based Environmental Literacy Is Needed

Municipalities worldwide are increasingly shifting toward data-backed climate policies and performance-based environmental governance. In this transition, Earth Observation (EO) data provides a scalable evidence base that helps cities move from episodic assessments to continuous, comparable monitoring. In practical terms, EO data enables municipalities to:

- monitor air pollution on a continuous basis,
- validate and contextualize local in-situ measurements,
- compare emission patterns across cities using consistent indicators,
- track the measurable impact of policies over time, and
- simulate mitigation scenarios to inform planning and investment decisions.

However, despite the growing demand for EO-driven urban climate action, most regions still face structural capacity constraints. Common gaps include a shortage of skilled EO data analysts, limited interdisciplinary curricula that meaningfully integrate EO methods with environmental engineering perspectives, and insufficient access to practical learning environments and tools such as UDENE. This program is designed to address that critical capacity gap by developing job-ready competencies and applied workflows aligned with municipal needs.

2.3 Alignment With UDENE Mission

UDENE aims to:

- Provide EO-based training kits for partner countries
- Create sustainable geodata ecosystems
- Integrate Copernicus assets into education and public decision-making
- Support international cooperation on climate-smart urban development

This educational plan directly answers UDENE’s Call #1:

- It is competency-based
- It integrates UDENE tools
- It produces replicable modules

- It includes demonstrative case studies
- It supports urban development challenges

The proposed program is therefore fully aligned with UDENE's educational ambitions and impact goals.

3 PEDAGOGICAL FRAMEWORK

3.1 Overview

This module is built on an integrated pedagogical foundation that combines DACUM (Developing A Curriculum) for competency definition and SCID (Systematic Curriculum & Instructional Development) for curriculum construction. In combination, these frameworks translate real occupational requirements into a coherent learning pathway with measurable performance outcomes, a structured progression from foundational to advanced skills, direct alignment with professional practice, and transparent, criterion-referenced assessment.

At the core of the DACUM approach is the assertion that *“a job is best described by the people who perform it.”* Based on this principle, the course is constructed around the professional role of the Urban EO Environmental Analyst, a profile increasingly required across smart city initiatives, environmental ministries, climate research institutes, municipal planning units, and transport authorities. DACUM operationalizes this role by decomposing it into a practical competency structure: six major duties (the primary responsibility areas) and 34 task-level actions (the specific activities required in real workflows). These duties and tasks are supported by a defined knowledge base—such as atmospheric chemistry, EO physics, and GIS—and a set of applied skills including raster analysis, trend modelling, validation, and professional reporting. The role is also anchored in the tools used in contemporary practice, notably UDENE, Copernicus services, CAMS, and standard GIS platforms. Collectively, the DACUM output provides a defensible, practitioner-informed description of “what the analyst must do” and “what the analyst must know to do it well.”

SCID then provides the instructional design logic that turns this competency definition into a deliverable curriculum. The process begins with a needs analysis that reflects the current capacity gap: EO literacy remains limited across Türkiye and partner regions, municipalities increasingly demand EO-trained analysts, and university offerings often lack integrated EO–environmental engineering coursework. SCID subsequently leverages the DACUM output for job and task analysis (the full DACUM table is provided in Section 4), followed by task verification, where tasks are cross-checked against actual workflows used by air quality agencies and EO research centers. Once verified, SCID establishes competency-to-outcome mapping, ensuring that each task is translated into a measurable learning outcome and that each outcome is tied to assignments and explicit assessment criteria.

From there, SCID guides the development of the curriculum blueprint, sequencing concepts from simple to complex, ensuring that at least 50% of total learning time is hands-on, and introducing EO datasets early so that learners build competence through repeated application rather than late-stage exposure. The curriculum is then implemented through weekly learning guides that consistently include an overview, a competency statement, step-by-step lab activities, performance testing, and self-check components. Assessment is designed to be performance-based rather than memory-based, and the module is maintained through an evaluation and continuous improvement cycle, enabling iterative refinement based on learner outcomes, stakeholder feedback, and evolving professional practice.

3.2 DACUM Competency Profile

The DACUM competency profile translates the Urban EO Environmental Analyst role into an actionable, job-based structure. In DACUM terms, the role is defined through duties (major responsibility areas) and tasks/subtasks (specific job actions), supported by the required knowledge, skills, and tools used in day-to-day practice. In the full DACUM chart, the role is also complemented by expected behaviors (e.g., quality assurance, documentation discipline, ethics) and future trends (e.g., evolving EO services, automation, tighter policy reporting cycles). The sections below summarize the core duty–task structure and the associated competency requirements.

1. DUTY A — Acquire EO Data

This duty covers the analyst's ability to identify, access, and critically screen EO and supporting datasets for urban environmental assessment. The emphasis is not only on "finding data," but also on understanding whether a dataset is fit-for-purpose in terms of coverage, resolution, and limitations.

Key tasks

- A1 Identify relevant EO datasets
- A2 Select Sentinel-5P products
- A3 Extract CAMS PM_{10}/$PM_{2.5}$/CO_2
- A4 Retrieve land-use datasets
- A5 Access ground station data
- A6 Evaluate metadata quality
- A7 Assess dataset limitations

Table 1: DUTY A (Acquire EO Data): Competency Requirements

Component	Requirements
Knowledge	EO fundamentals; sensor retrieval physics; atmospheric composition; temporal/spatial resolution concepts

Component	Requirements
Skills	Platform navigation; metadata interpretation
Tools	UDENE Explorer; EO Browser; CAMS Catalogue

2. DUTY B — Process EO Data

This duty focuses on preparing heterogeneous EO layers for analysis by ensuring spatial and temporal compatibility and by producing clean, analysis-ready time series and rasters. It includes the core preprocessing operations that enable reliable downstream analytics.

Key tasks

- B1 Reproject raster layers
- B2 Apply cloud filtering
- B3 Resample datasets
- B4 Align temporal resolution
- B5 Extract time-series
- B6 Conduct raster math operations

Table 2: DUTY B (Process EO Data): Competency Requirements

Component	Requirements
Knowledge	CRS theory; interpolation; time-series processing
Skills	Raster preprocessing workflow execution; parameter selection for resampling/filters; reproducible processing
Tools	UDENE Raster Engine; GDAL concepts (implicit)

3. DUTY C — Analyze Pollution & Carbon

This duty addresses the analytical core of the role: extracting interpretable signals from EO and ancillary datasets to characterize air quality patterns, seasonal dynamics, and carbon-related footprints. It also includes land-use-sensitive modelling where sectoral or typological differences materially affect emissions estimates.

Key tasks

- C1 NO_2 hotspot mapping

- C2 PM_{10} seasonal modelling
- C3 CO_2 footprint mapping
- C4 Land-use based CO_2 modelling, including:
    - C4a Crop-type differentiation
    - C4b Fertilizer → N_2O conversion
    - C4c Carbon sequestration differential
- C5 Exposure assessment

Table 3: DUTY C (Analyze Pollution & Carbon): Competency Requirements

Component	Requirements
Knowledge	Tropospheric chemistry; aerosol dynamics; carbon flux modelling; urban morphology
Skills	Hotspot detection; seasonal/time-series analytics; land-use stratified modelling; interpretive reasoning under uncertainty
Tools	UDENE analytics modules (as applicable); GIS platforms for spatial analysis and reporting

4. DUTY D — Validate

Validation ensures that EO-derived outputs are credible and defensible by comparing them against ground-based measurements and by quantifying uncertainty and potential bias. This duty is essential for producing results that can be trusted in municipal workflows and policy contexts.

Key tasks

- D1 Match EO with station data
- D2 Compute validation metrics
- D3 Interpret inconsistencies

Table 4: DUTY D (Validate): Competency Requirements

Component	Requirements
Knowledge	Error propagation; bias sources
Skills	Data matching and harmonization; metric computation; diagnostic interpretation

Tools	UDENE (validation workflows); station datasets; basic statistical tooling within the chosen analysis environment

5. DUTY E — Scenario Design

Scenario design translates analytical findings into actionable options by testing "what-if" pathways for emissions reduction. This duty supports policy exploration across transport, heating, industry, and land-use interventions, linking scenario assumptions to quantifiable outcomes.

Key tasks

- E1 Transport emission scenarios
- E2 Heating alternatives
- E3 Industrial emission reduction
- E4 Climate-smart agriculture & land-use scenarios

Table 5: DUTY E (Scenario Design): Competency Requirements

Component	Requirements
Knowledge	Emission factor calculations; urban mobility modelling
Skills	Scenario parameterization; comparative evaluation; sensitivity thinking; traceable assumption-setting
Tools	UDENE (scenario-relevant tools as available); emissions factors libraries; GIS platforms for scenario mapping

6. DUTY F — Communicate

This duty ensures that technical analyses are translated into decision-ready outputs. The analyst must be able to communicate findings visually and in writing, tailoring the format to technical audiences (methods, uncertainty) and policy audiences (implications, options, trade-offs).

Key tasks

- F1 Map design
- F2 Graph creation
- F3 Report writing
- F4 Policy brief creation

- F5 Oral presentation

Table 6: DUTY F (Communicate): Competency Requirements

Component	Requirements
Knowledge	Visual communication principles; reporting conventions; policy-facing framing
Skills	Cartographic clarity; narrative reporting; stakeholder-oriented synthesis; presentation delivery
Tools	GIS platforms; reporting toolchain (documents/slides); UDENE outputs integrated into communication products

3.3 Learning Outcomes

This section specifies the module's Learning Outcomes (LOs) in performance-based terms, consistent with the SCID logic and the DACUM competency profile. Each LO is defined through a clear Performance statement (what learners must do), the Condition under which performance is demonstrated (tools/data context), and Criteria that make achievement measurable and assessable.

Table 7: Learning Outcomes

Learning Outcome	Performance	Condition	Success Criteria	Clarification / Notes
LO1 — Earth Observation Literacy	Interpret EO datasets, metadata, and retrieval variables accurately.	Using **UDENE Explorer** and **Sentinel-5P** metadata.	**≥85% correctness** across **10 metadata fields**.	Learners demonstrate understanding of vertical column density, spatial resolution, retrieval noise, QA values, and related metadata concepts.
LO2 — Generate Scientific NO_2 Hotspot Maps	Produce valid NO_2 hotspot maps suitable for scientific/policy screening.	Using **UDENE Raster Engine**.	Correct application of **thresholds**, **CRS**, **colormap**, and **smoothing kernel**.	Emphasis is on methodological correctness and reproducibility of map outputs.
LO3 — PM_{10} Time-Series & Seasonal Analysis	Extract and interpret monthly/seasonal patterns from PM_{10} data.	Using UDENE time-series extraction and analysis workflow (as applicable).	Correct identification of **seasonal peaks (winter)** and **anomalies (e.g., dust events)**.	Learners distinguish seasonal structure from episodic events in the time series.
LO4 — Compute Urban CO_2 Footprints	Create CO_2 hotspot maps and derive interpretable	Using UDENE analysis workflow for CO_2 mapping (as applicable).	Correctly **aggregate** and **scale** concentrations for	Focus is on correct transformation/aggregation logic and defensible representation.

Learning Outcome	Performance	Condition	Success Criteria	Clarification / Notes
	urban CO_2 indicators.		mapping/summary outputs.	
LO5 — Model Land-Use-Dependent Carbon Emissions	Compare land-use-dependent emissions (e.g., wheat vs barley footprints).	Using land-use layers and carbon calculation workflow within the module toolchain.	Correct **N fertilizer → N_2O → CO_2e** computations.	Learners demonstrate correct unit handling, conversions, and emission factor application.
LO6 — EO–Ground Validation	Compute and interpret EO vs ground validation metrics.	Using EO products and ground station datasets in a validation workflow.	**$R^2 \geq 0.60$** and **RMSE correctly computed and interpreted**.	Interpretation includes explaining potential bias sources and mismatch drivers.
LO7 — Scenario Design	Develop data-backed mitigation scenarios derived from analytical outputs.	Using EO-derived evidence and scenario framing template/workflow.	Scenarios are **scientifically grounded** and **feasible**.	Scenarios must clearly state assumptions, mechanisms, and expected effects.

4 COURSE ARCHITECTURE

This Educational Plan is structured as a 3 ECTS / 90-hour module, designed in line with SCID instructional development principles and aligned with Erasmus Quality Standards. The course architecture is deliberately built to move learners through a complete, professional-grade workflow—data acquisition → processing → analysis → validation → reporting → policy integration—with a strong emphasis on applied competence.

Overall design principles

- Structured progression from foundational EO literacy to pollutant analysis, carbon footprint modelling, validation, and scenario design
- Balanced distribution of theoretical grounding and practical execution
- Hands-on emphasis: at least ≥50% of total workload is delivered through UDENE-based activities
- End-to-end workflow mastery aligned with real institutional practice

4.1 Total Workload Distribution

This workload is ECTS-compatible: since 1 ECTS typically corresponds to 25–30 hours, a 3 ECTS module spans 75–90 hours. This module intentionally adopts the upper bound (90 hours) to enable extensive hands-on engagement and repeated performance practice.

Table 8: Total Workload Distribution

Component	Hours	Description
Lectures	12	EO fundamentals, atmospheric chemistry, modelling concepts, UDENE orientation
Labs	24	UDENE Explorer, Raster Engine, Time-Series workflows, Validation module
Assignments	30	Six structured SCID task sheets mapped to DACUM duties/tasks
Final Project	24	Full demonstrative case study: data → analysis → validation → mitigation scenario
Total	90	3 ECTS module workload

4.2 Pedagogical Coherence

SCID requires an instructional trajectory in which knowledge is converted into skills and demonstrated as performance, with each competency explicitly trained and assessed. In this module, DACUM provides the job-task backbone, and SCID operationalizes it into teachable, assessable instruction.

How the architecture fulfills SCID expectations

- Each Learning Outcome (LO) is mapped to specific lab sessions and tool-based practice
- Each DACUM-derived task appears in at least one assignment (structured task sheets)
- Learners receive iterative practice and feedback before high-stakes assessment
- The module closes with a final integrative case study that requires end-to-end workflow execution

4.3 Module Progression

The module is designed so competencies accumulate week by week, ensuring learners do not treat skills as isolated techniques but as an integrated professional workflow.

- **Week 1 — Foundations:** EO fundamentals and UDENE tool literacy
- **Week 2 — Atmospheric Pollutant Modelling:** introduction of NO_2 hotspot mapping and PM_{10} analysis as core applied skills
- **Week 3 — Carbon Footprint & Land-Use Emissions:** advanced carbon modelling component, including land-use-dependent emission logic
- **Week 4 — Validation Science:** EO-to-ground comparison methods and interpretation for scientific integrity
- **Week 5 — Mitigation Scenario Design:** translating analytical outputs into feasible, policy-relevant scenarios
- **Week 6 — Final Case Study:** integrated, evidence-based analysis combining all prior competencies

4.4 Alignment with Professional Practice and Employability

The module structure mirrors operational workflows commonly used in:

- Municipal environmental agencies
- Air quality management authorities
- Climate policy and planning teams

- Environmental and sustainability consultancies
- Smart city platforms and urban analytics units

By training and assessing the full workflow—rather than isolated concepts—this design ensures graduates can contribute immediately in applied settings, with competencies that map directly onto job expectations for an Urban EO Environmental Analyst.

4.5 Weekly Instructional Plans

The weekly instructional plans are designed as a cumulative pathway from EO literacy to applied urban analytics, validation, and policy-oriented scenario design. Each week combines targeted lectures with UDENE-based labs and SCID task-sheet assignments, ensuring that every competency is practiced and evidenced before it is assessed at the integrative final case study stage.

Table 9: Weekly Instructional Plans

Week	Core Focus	Primary Learning Outcomes	Main UDENE Practice Emphasis	Main Assessed Output(s)
1	EO foundations + UDENE onboarding	LO1	Explorer navigation, metadata interpretation, dataset access	Assignment 1 (Dataset acquisition + metadata)
2	NO_2 hotspot mapping + PM_{10} seasonal analysis	LO2–LO3	Raster workflow + time-series extraction	Assignments 2–3 (NO_2 map + PM_{10} trend analysis)
3	Urban CO_2 footprint + land-use-dependent emissions	LO4–LO5	CO_2 mapping, land-use overlays, carbon computations	Assignment 4 (CO_2 map + land-use impact analysis)
4	EO–ground validation science	LO6	Collocation, metrics, interpretation	Assignment 5 (Validation report)
5	Mitigation scenario design + policy integration	LO7	Hotspot-to-source reasoning, scenario framing	Assignment 6 (Scenario development report)
6	Final case study (end-to-end integration)	LO1–LO7	Full workflow execution	Final project (report, maps, validation, scenario, brief, presentation)

4.5.1 WEEK 1 — EO Foundations & UDENE Introduction

Week 1 establishes the conceptual and technical baseline for the module. Learners develop a working understanding of EO principles and Copernicus/CAMS assets, then translate that understanding into practical competence by navigating UDENE and correctly interpreting dataset metadata.

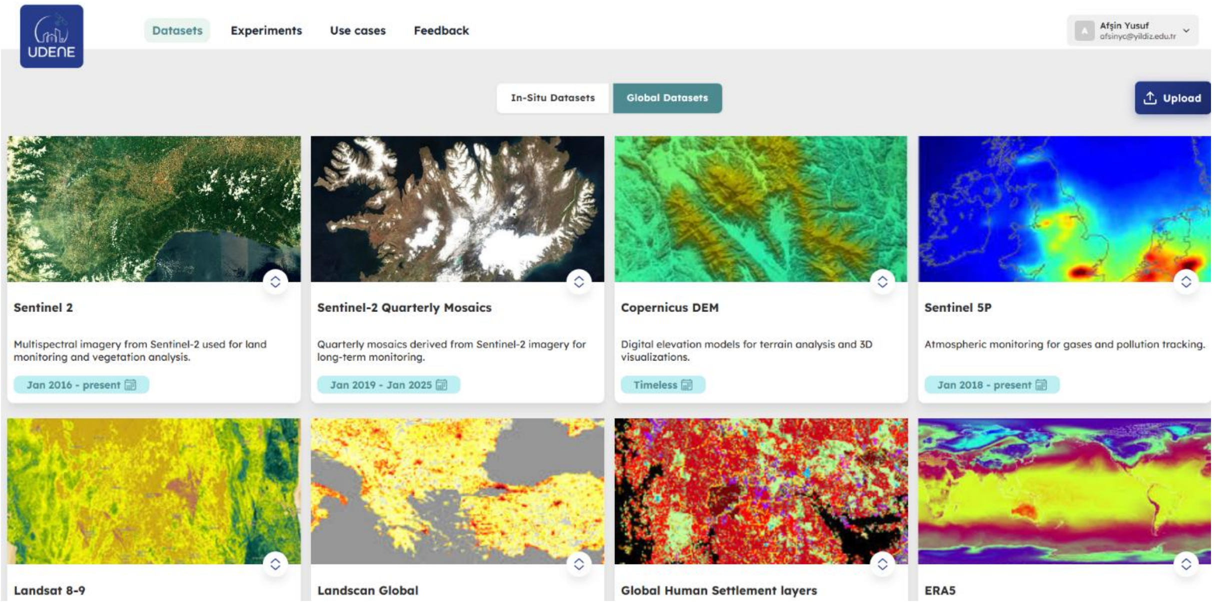

Figure 1. Overview of EO Datasets Available on the UDENE Platform

This figure presents the UDENE platform interface displaying key Earth Observation (EO) datasets, including Sentinel-2, Sentinel-5P, Copernicus DEM, Landsat 8-9, ERA5, and Global Human Settlement layers. These datasets are used within the training module to familiarize learners with Copernicus and CAMS assets, support metadata interpretation, and develop practical skills in navigating EO data for environmental and urban analysis.

Table 10: Week 1 Plan

Element	Week 1 Plan
Learning Objectives	- Identify appropriate EO datasets for urban pollution and carbon analysis - Distinguish column density **vs** near-surface concentration (conceptual meaning and implications) - Interpret key metadata fields (QA flags, spatial resolution, units) - Access and preview datasets via UDENE Explorer
Lecture Focus	- EO systems overview (passive vs active sensors; orbits/revisit/swath)

	- Atmospheric retrieval fundamentals (signal, noise, uncertainty) - Copernicus architecture (Sentinel missions; CAMS role; global vs regional modelling) - Sentinel-5P scientific background (NO_2 retrieval physics; tropospheric VCD; QA flags) - CAMS reanalysis basics (PM_{10} and CO_2 modelling logic; bias and meteorological coupling) - UDENE platform overview (interface, layers, filters, export)
UDENE Lab Practice	- Access Sentinel-5P NO_2 layers and inspect date/time availability - Sort and filter datasets; interpret QA/quality layers where available - Overlay CAMS CO_2 fields for contextual comparison - Export map snapshots and basic dataset references (for reporting)
Assignment 1 (SCID Task Sheet)	EO Dataset Acquisition Sheet: select three datasets (NO_2, PM_{10}, CO_2), document the relevant metadata, and provide a short justification for each dataset's relevance to urban analysis.
Performance Evidence	- Completed metadata tables - Screenshots showing datasets accessed in UDENE - Short justification memo/report

4.5.2 WEEK 2 — NO_2 Hotspot Mapping & PM_{10} Time-Series Modelling

Week 2 moves from EO literacy to applied pollutant analytics. Learners generate scientific-quality NO_2 hotspot maps from Sentinel-5P and extract PM_{10} time series from CAMS, producing seasonal interpretations grounded in atmospheric processes and local/regional drivers.

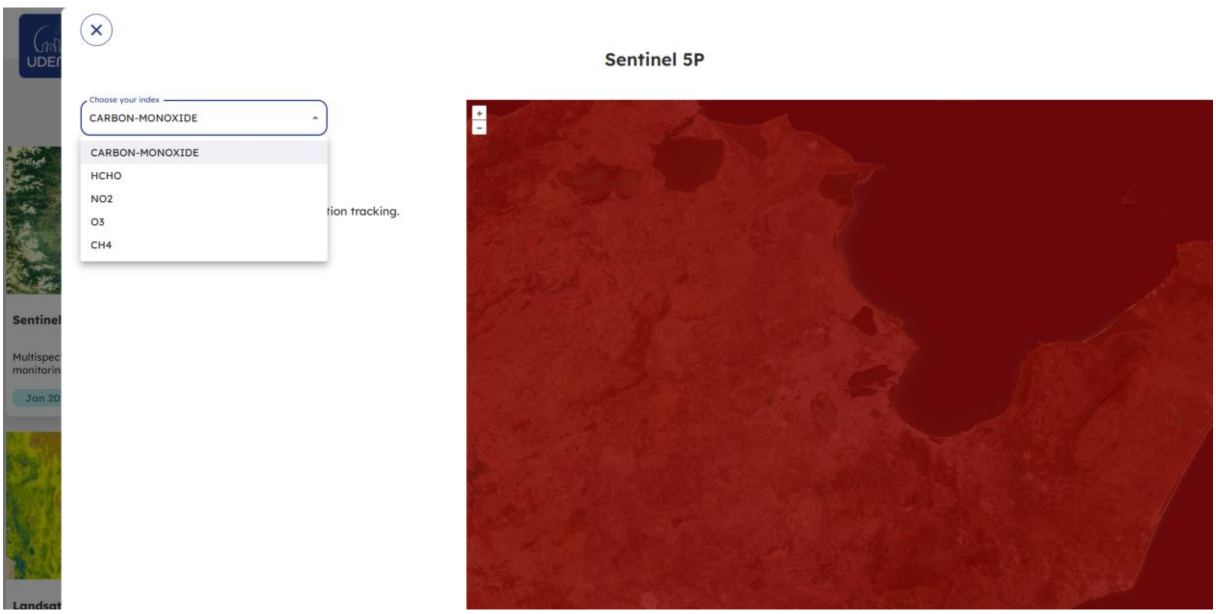

Figure 2. Sentinel-5P Atmospheric Pollutant Visualization and Index Selection Interface in UDENE

This figure illustrates the use of the UDENE platform for applied atmospheric pollutant analysis in Week 2 of the module. The Sentinel-5P dataset interface enables users to select specific atmospheric constituents (e.g., NO_2, CO, O_3, CH_4, HCHO) and visualize their spatial distribution at regional scale. Through interactive index selection and map-based exploration, learners identify pollution hotspots and interpret concentration patterns in relation to emission sources, meteorological conditions, and atmospheric transport processes. This step marks the transition from EO literacy to scientific-quality air pollution analytics using Copernicus and CAMS assets.

Table 11: Week 2 Plan

Element	Week 2 Plan
Lecture Focus	- NO_2 urban chemistry and spatial patterns (traffic emissions, photolysis cycles, corridor effects) - PM_{10} dynamics (primary vs secondary PM; heating; dust episodes; meteorology) - Hotspot modelling concepts (thresholding, spatial smoothing; kernel logic) - Time-series analysis (monthly/seasonal averages, anomaly detection, trend/seasonal decomposition)
UDENE Lab Practice	- Generate NO_2 maps and compute weekly/monthly averages - Apply map-science requirements (CRS consistency, threshold selection, smoothing) - Extract PM_{10} time series and produce seasonal plots/graphs - Identify winter peaks and dust-related anomalies (where visible)
Assignments (SCID Task Sheets)	Assignment 2: Scientific NO_2 hotspot map Assignment 3: PM_{10} seasonal trend analysis (graph + interpretation paragraph)
Required Outputs	- NO_2 map (publication-ready layout standard) - PM_{10} trend graph(s) - Short interpretation paragraph linking patterns to plausible drivers

4.5.3 WEEK 3 — Urban CO_2 Footprint & Land-Use-Dependent Emissions Modelling

Week 3 introduces a more advanced, research-oriented competency: CO_2 footprint mapping combined with land-use differentiation, including crop-type comparisons and fertilizer-driven pathways (N → N_2O → CO_2e), while accounting conceptually for sequestration effects.

Table 12: Week 3 Plan

Element	Week 3 Plan
Lecture Focus	- Carbon cycle framing (sources/sinks; relevance to urban systems) - CAMS CO_2 reanalysis logic and model–observation fusion (conceptual) - Land-use-dependent carbon footprints (emission factors, typologies, overlays) - Agricultural differentiation: wheat vs barley (inputs, fertilizer intensity, emissions implications) - Fertilizer → N_2O → CO_2e pathway and unit discipline - Soil carbon sequestration as a modifier of net emissions (conceptual integration)
UDENE Lab Practice	- Create CO_2 hotspot maps and apply spatial aggregation rules - Overlay land-use layers and extract land-use-stratified indicators - Build crop-type comparison tables (wheat vs barley) - Perform fertilizer-driven CO_2e computations and document assumptions
Assignment 4	CO_2 Footprint Map + Land-Use Impact Analysis: CO_2 distribution map, wheat vs barley comparison, and an interpretation paragraph explaining drivers and limitations.
Required Outputs	- CO_2 spatial map(s) - Crop-type comparison table(s) - Documented calculation notes and interpretation paragraph

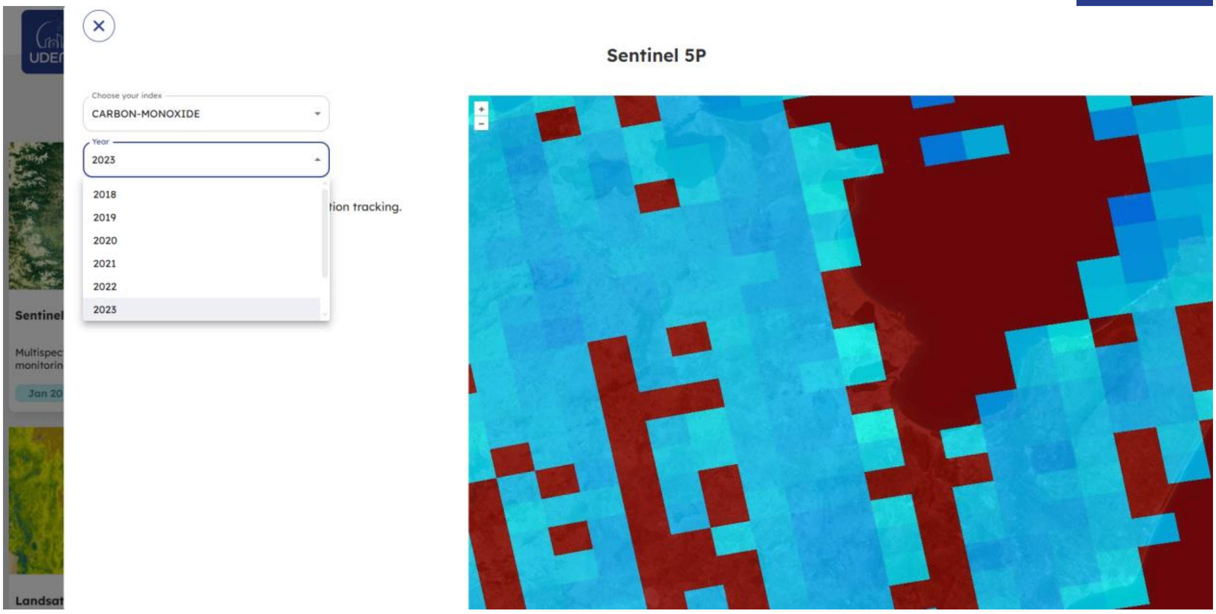

Figure 3. CO and CO_2-Equivalent Footprint Mapping with Land-Use Differentiation Using Sentinel-5P Data

This figure demonstrates advanced Earth Observation analytics implemented in Week 3, combining Sentinel-5P carbon monoxide observations with land-use-based interpretation. The spatial mosaic highlights differentiated emission patterns across agricultural and non-agricultural areas, supporting crop-type comparisons and fertilizer-related nitrogen pathways (N → N_2O → CO_2e). The approach introduces learners to research-level footprint mapping concepts while conceptually accounting for carbon sequestration effects.

4.5.4 WEEK 4 — Validation Science: EO-to-Ground Agreement and Uncertainty

Week 4 shifts learners from “map production” to scientific defensibility. The focus is on why EO products require validation, how EO–station mismatches arise, and how to compute and interpret metrics that determine whether outputs are decision-ready.

Table 13: Week 4 Plan

Element	Week 4 Plan
Core Concepts (Why Validation Matters)	EO products are influenced by retrieval uncertainties, cloud impacts, geometry, atmospheric layering, and (for CAMS) model bias. Ground stations provide point measurements while EO products represent spatially averaged signals, so validation requires careful spatiotemporal matching and appropriate metrics.

Element	Week 4 Plan
Lecture Focus	- Validation types (direct validation, collocation, temporal interpolation, multi-station approaches) - Error metrics: R^2, RMSE, MAE, bias (and what each does/does not mean) - Interpretation examples (e.g., street-canyon NO_2 underestimation; PM_{10} dust peak timing; smoother CO_2 fields)
UDENE Lab Practice (Validation Module)	- Temporal averaging and alignment - Extract EO values at station coordinates - Compute R^2 and RMSE - Create scatter plots and a validation table - Write interpretive comments linked to plausible bias sources
Assignment 5	EO–Ground Validation Report including scatter plots, R^2/RMSE, interpretation, limitations, and improvement suggestions.

4.5.5 WEEK 5 — Scenario Design & Policy Integration

Week 5 translates analytical findings into actionable, policy-relevant options. Learners build scenarios that are evidence-based, feasible, and interpretable, linking observed hotspots to plausible sources and to intervention levers.

Table 14: Week 5 Plan

Element	Week 5 Plan
Scenario Quality Requirements	Scenarios must be: evidence-based, feasible, quantitatively supported where possible, geospatially interpretable, and scalable.
Lecture Focus	- Transport scenarios (mode shift, fleet electrification, Low Emission Zones) - Heating scenarios (insulation, fuel switching, district heating improvements) - Industrial pathways (cleaner production, fuel switching, capture strategies) - Land-use carbon interventions (crop shifts, fertilizer optimization, soil carbon enhancement, reforestation/buffers)
UDENE Lab Practice	- Identify hotspots and connect them to plausible sources - Propose mitigation options and estimate impacts (quantitative or structured qualitative) - Produce maps that support scenario logic and prioritization
Assignment 6	Scenario Development Report including evidence maps, justification, feasibility assessment, and UDENE-based support.

4.5.6 WEEK 6 — Final Case Study (End-to-End Integration)

Week 6 synthesizes all competencies into a complete professional workflow. Learners deliver a structured, evidence-based urban EO analysis and communicate it in both technical and policy-facing formats.

Final Project Requirements

- A complete case study must include:
- Problem definition
- Data acquisition
- Processing steps (documented and reproducible)
- Pollutant mapping (NO_2 and/or PM_{10})
- CO_2 footprint analysis
- Land-use emission comparison (e.g., crop-type differentiation)
- Validation with ground data
- Mitigation scenario development
- Policy brief
- Final presentation (10 minutes)

Expected Deliverables

- 6–12 page written report
- 5–10 scientific maps
- 2–4 graphs
- 1 validation table
- 1 scenario summary
- 1 policy brief

Table 15: Assessment Criteria

Component	Weight
Scientific accuracy	25%
Effective use of UDENE tools	20%
Interpretation and insight	20%
Validation quality	15%
Scenario relevance	10%
Communication and presentation	10%

4.6 Full Lessons Plans

This section consolidates the full set of lecture plans into a single, implementation-ready structure. To preserve coherence and usability, each lecture is presented with its core content focus and its intended learning outcome contribution. The same table can be extended with corresponding lab links (Week/Assignment mapping) if you choose to integrate lectures and labs into one master schedule.

Table 16: Complete Lecture Plan

#	Lecture Title	Core Content Coverage	Primary Learning Outcome Contribution
1	Introduction to EO & Atmospheric Monitoring	Remote sensing principles; passive vs active sensors; vertical column density; retrieval algorithms	Learners understand foundational EO mechanics and atmospheric monitoring concepts.
2	Copernicus Program Architecture	Sentinel missions overview; Copernicus services (CAMS, CLMS, CEMS); free and open data policy	Learners can navigate Copernicus as an operational ecosystem and identify relevant services for urban analysis.
3	Sentinel-5P for Atmospheric Pollutants	TROPOMI instrument basics; NO_2 retrieval uncertainty; QA flags and quality screening	Learners can interpret Sentinel-5P product characteristics and apply QA logic to pollutant analysis.
4	CAMS Model Physics	Chemical transport model principles; PM and CO_2 assimilation; meteorological coupling	Learners understand how CAMS reanalysis is produced and what that implies for interpretation and uncertainty.
5	Atmospheric Chemistry of NO_2 & PM_{10}	Photolysis cycles; combustion emission sources; seasonal drivers and episodic events	Learners can connect observed spatial/temporal patterns to plausible atmospheric processes and emission drivers.
6	Carbon Footprint & Land-Use Dynamics	Fertilizer → N_2O → CO_2e pathway; crop carbon profiles; soil carbon processes	Learners can explain land-use-dependent carbon impacts and apply the conceptual basis for CO_2e calculations.
7	Geospatial Analysis Concepts	Projections/CRS; raster operations; spatial smoothing concepts	Learners can execute geospatially correct workflows (CRS consistency, raster math, smoothing choices).
8	Time-Series Analysis	Monthly/seasonal averaging; trend decomposition; anomaly detection	Learners can extract, summarize, and interpret temporal signals, distinguishing seasonality from anomalies.
9	Validation Theory	EO vs ground comparison logic; error metrics (R^2, RMSE, MAE, bias); bias interpretation	Learners can compute and interpret validation metrics and discuss sources of mismatch and uncertainty.

#	Lecture Title	Core Content Coverage	Primary Learning Outcome Contribution
10	EO-Based Decision Support	Linking maps to policies; urban development challenges; Zero Pollution Action Plan framing	Learners can translate analytical outputs into decision-support narratives aligned with policy needs.
11	Scenario Design	Mitigation pathways; feasibility assessment; cost–benefit reasoning	Learners can build evidence-based, feasible mitigation scenarios and justify assumptions transparently.
12	Scientific Reporting & Visualization	Good map design; graph standards; policy brief writing	Learners can communicate findings professionally through maps, graphs, reports, and policy briefs.

4.7 Full Assignment Package

This section presents the complete assignment package as a set of SCID-aligned task sheets mapped directly to the DACUM competency profile. Each assignment specifies the expected performance, enabling objectives, tools, procedure, evidence, and assessment criteria in a format suitable for immediate implementation.

4.7.1 Assignment 1 — EO Dataset Acquisition & Metadata Interpretation (Week 1)

This assignment establishes baseline EO literacy and UDENE platform fluency. Students demonstrate that they can select fit-for-purpose datasets and interpret the metadata required for defensible urban environmental analysis.

Table 17: Assignment 1 Packages

#	Field	Specification
1	**Linked DACUM Duty**	**Duty A — Acquire EO Data**
2	**Task Title**	EO Dataset Identification, Acquisition, and Metadata Interpretation
3	**Performance Objective (SCID)**	Correctly identify, acquire, document, and interpret metadata for three EO datasets—**NO_2 (Sentinel-5P)**, **PM_{10} (CAMS)**, and **CO_2 (CAMS)**—with **≥85% accuracy**.
4	**Enabling Objectives**	- Navigate UDENE Explorer - Access Sentinel-5P NO_2 products - Retrieve PM_{10} and CO_2 layers from CAMS - Interpret resolution, units, QA flags, and uncertainties - Describe temporal coverage and revisit frequency
5	**Required Tools**	UDENE EO Explorer; CAMS global reanalysis layers; UDENE metadata panel

#	Field	Specification
6	**Procedure**	1) Open UDENE Explorer and select **Istanbul** as the area of interest. 2) Activate Sentinel-5P NO_2 layer. 3) Open metadata and document: spatial resolution, temporal resolution, vertical column density units, QA values. 4) Activate CAMS PM_{10} layer and document corresponding metadata. 5) Activate CAMS CO_2 layer and document corresponding metadata. 6) Export three screenshots showing each dataset in UDENE. 7) (Optional) Download sample data where available. 8) Compile a Metadata Summary Table**.**
7	**Performance Criteria**	- Metadata correctly extracted - Correct definitions of key retrieval parameters - Accurate explanation of QA flags/quality fields - Justified dataset selection for urban analysis
8	**Evidence Required**	- Completed metadata table - 3 UDENE screenshots - Short report **(**300–500 words**)**
9	**Self-Check Questions**	- What does QA > 0.75 indicate for Sentinel-5P? - Why is PM_{10} typically **modelled** rather than directly "detected"? - How often does Sentinel-5P revisit a location?
10	**Rubric (Summary)**	Excellent: fully correct metadata + insightful justification Good: mostly correct, minor issues Fair: several errors or missing interpretation Poor: misunderstanding of metadata/QA concepts

4.7.2 Assignment 2 — NO_2 Hotspot Mapping (Week 2)

This assignment moves from EO interpretation to defensible spatial analysis. Students generate a scientific-quality NO_2 hotspot map and demonstrate correct filtering, smoothing, and map communication.

Table 18: Assignment 2 Packages

#	Field	Specification
1	**Linked DACUM Duty/Task**	**Duty C — Analyze Pollution & Carbon** (C1: NO_2 hotspot mapping)
2	**Task Title**	Generation of NO_2 Hotspot Maps Using Sentinel-5P
3	**Performance Objective**	Produce a high-quality NO_2 hotspot map using **UDENE Raster Engine**, applying correct thresholds, smoothing, visualization settings, and labeling.

#	Field	Specification
4	**Enabling Objectives**	- Apply atmospheric reasoning to interpret NO_2 patterns - Remove low-quality pixels (QA filtering) - Apply spatial smoothing (e.g., kernel-based) appropriately - Interpret hotspot patterns in an urban context
5	**Tools**	UDENE Raster Engine; Sentinel-5P tropospheric NO_2 product
6	**Procedure**	1) Open UDENE and select the Sentinel-5P NO_2 layer. 2) Apply cloud mask and QA > 0.75 (or course-defined QA rule). 3) Compute a weekly or monthly average (as instructed). 4) Identify candidate urban hotspots. 5) Apply 2D kernel smoothing (or specified smoothing method). 6) Set visualization parameters (thresholds, scale, labels). 7) Export the final map.
7	**Performance Criteria**	- Correct data filtering and averaging choices - Hotspots are clearly and correctly represented - Map output is scientifically legible (projection, legend, labels) - Interpretation is consistent with the mapped evidence
8	**Evidence Required**	- Final NO_2 map (PNG or PDF) - Interpretation text (~150 words)
9	**Self-Check Questions**	- What typically causes NO_2 hotspots in cities? - Why is QA filtering essential before hotspot analysis?

4.7.3 Assignment 3 — PM_{10} Seasonal Trend Analysis (Week 2)

This assignment develops temporal analytical competence. Students extract PM_{10} time-series data, compute monthly averages, and interpret seasonality and anomalies in a defensible manner.

Table 19: Assignment 3 Packages

#	Field	Specification
1	**Linked DACUM Duty/Task**	Duty C — Analyze Pollution & Carbon (C2: PM_{10} seasonal modelling)
2	**Task Title**	Extraction and Analysis of Seasonal PM_{10} Trends
3	**Performance Objective**	Extract PM_{10} time-series values, compute monthly averages, visualize seasonal trends, and identify anomalies (e.g., dust events).
4	**Tools**	UDENE time-series workflow; CAMS PM_{10} dataset
5	**Procedure**	1) Select CAMS PM_{10} dataset in UDENE. 2) Extract daily values for a 1-year period. 3) Compute monthly averages.

#	Field	Specification
		4) Create a seasonal graph. 5) Identify winter peaks. 6) Detect and annotate anomalies.
6	**Evidence Required**	- Time-series graph (with labeled peaks/anomalies) - Seasonal trend interpretation paragraph
7	**Performance Criteria (Recommended)**	- Correct extraction period and aggregation method - Graph is readable and correctly labelled - Interpretation distinguishes seasonality vs episodic anomalies

4.7.4 Assignment 4 — CO_2 Footprint Mapping & Land-Use Emission Comparison (Week 3)

This assignment introduces land-use-sensitive carbon assessment. Students create a CO_2 footprint map and conduct a structured land-use comparison (including crop-type differentiation) using documented conversion logic.

Table 20: Assignment 4 Packages

#	Field	Specification
1	**Linked DACUM Duty/Task**	Duty C — Analyze Pollution & Carbon (C3: CO_2 mapping; C4: land-use-based CO_2 modelling)
2	**Task Title**	CO_2 Footprint Mapping and Land-Use Emission Comparison
3	**Performance Objective**	Generate a CO_2 spatial footprint map and compare emissions between land-use types (e.g., wheat vs barley) using correct conversion logic and documented assumptions.
4	**Tools**	UDENE CO_2 workflow; CAMS CO_2 layer; land-use layer (e.g., CORINE)
5	**Procedure**	1) Activate CAMS CO_2 layer. 2) Extract values for agricultural zones (or defined study areas). 3) Categorize land-use classes (e.g., CORINE). 4) Compute average CO_2 indicators per land class. 5) Apply emission factor logic: wheat (higher N fertilizer), barley (lower N fertilizer). 6) Convert fertilizer input → N_2O → CO_2e (course-defined factors). 7) Produce a comparison chart/table. 8) Interpret differences and limitations.
6	**Evidence Required**	- CO_2 map - Land-use emission comparison table/chart - Written explanation (200–400 words)

#	Field	Specification
7	**Performance Criteria (Recommended)**	- Correct land-use stratification logic - Correct unit discipline and conversion chain - Clear interpretation tied to evidence and assumptions

4.7.5 Assignment 5 — EO–Ground Validation (Week 4)

This assignment ensures scientific defensibility by requiring learners to validate EO-derived outputs against ground measurements using standard metrics and reasoned interpretation of mismatch sources.

Table 21: Assignment 5 Packages

#	Field	Specification
1	**Linked DACUM Duty**	**Duty D — Validate**
2	**Task Title**	EO-to-Ground Validation Using R^2 and RMSE
3	**Performance Objective**	Validate EO pollutant values (NO_2, PM_{10}, CO_2 as applicable) against ground stations using R^2 and RMSE, and interpret results correctly.
4	**Tools**	UDENE validation workflow (or equivalent); station data; plotting/export capability
5	**Procedure**	1) Gather station data for the defined period. 2) Extract matching EO values (spatial + temporal matching). 3) Produce scatter plot(s). 4) Compute R^2 and RMSE. 5) Interpret agreement, bias, and likely causes of discrepancies.
6	**Evidence Required**	- Validation table (EO vs station + metrics) - Scatter plot(s) - Written interpretation (methods + implications + limitations)
7	**Performance Criteria (Recommended)**	- Correct matching logic and metric computation - Correct interpretation of R^2/RMSE (what they do and do not imply) - Credible discussion of uncertainty sources

4.7.6 Assignment 6 — Scenario Design (Week 5)

This assignment translates analysis into decision support. Students propose mitigation scenarios grounded in EO evidence, supported by maps/trends, and assessed for feasibility and clarity.

Table 22: Assignment 6 Packages

#	Field	Specification
1	**Linked DACUM Duty**	**Duty E — Scenario Design**
2	**Task Title**	EO-Evidence-Based Mitigation Scenario Development
3	**Performance Objective**	Propose three mitigation scenarios based on EO evidence, linking hotspots to plausible sources and interventions.
4	**Tools**	UDENE outputs (maps/time-series/validation results); scenario report template
5	**Procedure**	1) Identify spatial/temporal hotspots. 2) Identify likely sources (traffic, heating, industry, land-use). 3) Define interventions (what changes, where, and why). 4) Support with maps and trends (quantitative if possible; structured qualitative if needed). 5) Write the scenario report including feasibility considerations.
6	**Evidence Required**	- Scenario report **(**2–3 pages**)** - Supporting maps and/or graphs
7	**Performance Criteria (Recommended)**	- Scenarios are evidence-based and internally consistent - Feasibility is addressed (implementation constraints and enablers) - Clear linkage from observed patterns → sources → interventions → expected outcomes

4.8 Performance Assessment and Rubrics

Assessment in this educational plan follows a competency-based evaluation model, consistent with SCID instructional design and Erasmus Quality Standards. Students are evaluated not through memorization, but through demonstrated performance using UDENE workflows and Copernicus/CAMS EO datasets. The system combines weighted components with transparent, criterion-referenced rubrics so that expectations, benchmarks, and grading logic are explicit and reproducible.

4.8.1 Assessment Structure and Evidence Requirements

Assessment weighting

- **Participation and engagement:** 20%
- **Weekly assignments (Assignments 1–6):** 30%
- **Final case study (integrative project):** 50%

Performance assessment principles

- **Competency alignment:** Every assessment maps directly to DACUM duties/tasks and to SCID performance statements (Performance–Condition–Criteria).
- **Evidence-based evaluation:** Students submit verifiable artifacts (maps, graphs, statistical outputs, written explanations, and policy insights).
- **Multi-layer verification:** Grading checks technical execution (UDENE), scientific correctness, spatial/temporal interpretation, and communication clarity.
- **Transparency:** Rubrics communicate expectations and benchmarks in advance.
- **Reproducibility:** Outputs must be reproducible using the specified EO datasets and documented UDENE workflows.

Table 23: Evidence Types Required Across Assessments

Evidence Type	Examples
Maps	Hotspot maps, footprint maps, scenario maps
Graphs	Time-series plots, seasonal trend graphs
Statistical outputs	R^2, RMSE, validation tables
Technical documentation	Metadata tables, processing steps, parameter choices
Narrative outputs	Short interpretations, structured reports, policy briefs

4.8.2 Rubric Set for Weekly Assignments (A–D/F Scale)

All assignment rubrics use four performance levels: Excellent (A), Good (B), Satisfactory (C), and Insufficient (D/F). Each rubric evaluates both the technical workflow and the scientific/interpretive quality of the output.

4.8.2.1 Rubric 1 — EO Dataset Acquisition and Metadata Interpretation (Assignment 1)

This rubric assesses whether the learner can select appropriate EO datasets, extract and interpret metadata accurately, and justify dataset relevance for urban analysis.

Table 24: Dataset & Metadata Evaluation of Rubric 1

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Dataset selection	Appropriate datasets selected with scientifically grounded justification	Correct datasets with basic justification	Mostly correct datasets; weak justification	Incorrect and/or unjustified selection

Metadata accuracy	≥90% correct metadata extraction	80–89% accurate	60–79% accurate	<60% accurate
QA/quality interpretation	Clear, correct interpretation of QA/quality fields	Mostly correct interpretation	Basic understanding	Misinterprets QA/quality fields
Reporting quality	Clear, structured, complete submission	Minor gaps	Basic summary	Missing, unclear, or incomplete report

4.8.2.2 Rubric 2 — NO_2 Hotspot Mapping (Assignment 2)

This rubric evaluates the ability to produce a defensible hotspot map through correct filtering, spatial treatment, visualization, and interpretation.

Table 25: Dataset & Metadata Evaluation of Rubric 2

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Data filtering	Correct QA filtering and masking applied consistently	Minor issues in filtering choices	Some missing steps or inconsistent filtering	No meaningful filtering applied
Hotspot clarity	Hotspots are scientifically clear and methodologically defensible	Clear hotspot highlighting	Acceptable but limited clarity	Unclear or incorrect hotspot depiction
Visualization quality	Correct CRS, appropriate scale, labels/legend, and readable design	Mostly correct with minor issues	Adequate but basic	Incorrect or misleading visualization
Interpretation	Insightful explanation consistent with mapped evidence	Reasonable interpretation	Simplistic interpretation	Incorrect, absent, or not evidence-based

4.8.2.3 Rubric 3 — PM_{10} Seasonal Trend Analysis (Assignment 3)

This rubric focuses on time-series correctness, seasonal/anomaly interpretation, and clarity of scientific graphing.

Table 26: Dataset & Metadata Evaluation of Rubric 3

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Time-series accuracy	Correct extraction and averaging; no methodological errors	Minor calculation/aggregation issues	Significant rounding/aggregation issues	Incorrect time series
Seasonal interpretation	Correctly identifies seasonal peaks and anomalies	Identifies peaks; limited anomaly reasoning	Recognizes general seasonal trend only	Misinterprets patterns
Graph quality	Publication-style scientific graph (axes, units, labels, readability)	Good presentation	Basic graph	Poor or unreadable graph

4.8.2.4 Rubric 4 — CO_2 Footprint and Land-Use Emission Modelling (Assignment 4)

This rubric evaluates CO_2 mapping correctness, land-use comparison logic, and the quality of reasoning (including conversion chains and assumptions).

Table 27: Dataset & Metadata Evaluation of Rubric 4

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
CO_2 hotspot map	Accurate, clean, geospatially correct map	Mostly correct map	Acceptable map with limitations	Incorrect map
Land-use comparison	Correct factors/conversion logic; insightful comparison	Mostly correct approach	Basic comparison with limited rigor	Wrong factors and/or wrong results
Scientific reasoning	Deep, evidence-based reasoning; assumptions transparent	Good reasoning	Some reasoning	Missing or unsupported reasoning
Novel insight	Clearly articulates land-use–carbon linkage and implications	Partial insight	Minimal insight	No insight shown

4.8.2.5 Rubric 5 — EO–Ground Validation (Assignment 5)

This rubric assesses collocation/alignment logic, metric correctness, and interpretive quality regarding bias and limitations.

Table 28: Dataset & Metadata Evaluation of Rubric 5

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Alignment procedure	Correct spatial + temporal alignment; documented choices	Minor alignment issues	Some mismatches	Incorrect alignment
R^2 and RMSE	Correct calculations and reporting	Slight calculation/reporting errors	Basic correctness with gaps	Wrong calculations
Interpretation	Accurate discussion of limitations and bias sources	Acceptable discussion	Minimal discussion	No meaningful interpretation
Visualization	Clear scatter plot(s) with proper labels	Acceptable plot	Basic plot	Messy or incorrect plot

4.8.2.6 Rubric 6 — Scenario Development (Assignment 6)

This rubric evaluates whether scenarios are evidence-based, feasible, policy-relevant, and scientifically justified.

Table 29: Dataset & Metadata Evaluation of Rubric 6

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Scenario quality	Feasible, evidence-based, internally consistent	Reasonably feasible	Vague or generic	Poor or unrealistic
Use of EO evidence	Maps/charts strongly support scenario logic	Partial evidence support	Minimal evidence	No EO evidence
Policy relevance	Directly addresses defined urban challenges	Mostly relevant	Moderately relevant	Not relevant
Scientific justification	Insightful, structured	Acceptable justification	Weak justification	No justification

Criterion	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
	justification with assumptions stated			

4.8.2.7 Final Case Study Evaluation Rubric

The final case study rubric assesses end-to-end mastery across the full professional workflow (acquisition → processing → analysis → validation → scenario design → communication). It is intentionally comprehensive because it functions as the capstone performance assessment.

Table 30: Dataset & Metadata Evaluation of Final Rubric

Dimension	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Problem definition	Clear, contextual, well-scoped	Well-scoped	Basic scope	Unclear or poorly scoped
Data acquisition	Complete and flawless sourcing	Mostly complete	Some gaps	Incomplete
Processing workflow	Fully documented and reproducible	Mostly clear	Missing steps	Not reproducible
NO_2 analysis	Scientifically robust map and interpretation	Good	Acceptable	Incorrect
PM_{10} trends	Accurate analysis and strong interpretation	Good	Basic	Incorrect
CO_2 modelling	Accurate with insightful reasoning	Mostly correct	Basic	Incorrect
Land-use emissions	High analytical insight and correct logic	Good	Minimal	Incorrect
Validation	Correct metrics + strong bias/limitations interpretation	Correct metrics	Basic validation	Incorrect or absent
Scenario design	Evidence-based and innovative, feasible	Good ideas	Basic ideas	Not feasible

Dimension	Excellent (A)	Good (B)	Satisfactory (C)	Insufficient (D/F)
Policy brief	Professional quality and decision-ready	Good summary	Basic	Poor
Presentation	Clear, structured, engaging	Good	Somewhat unclear	Poor

4.8.3 Alignment of Assessments with Learning Outcomes

The table below shows which assessment instruments provide evidence for each learning outcome.

Table 31: LO Coverage Matrix

Assessment	LO1	LO2	LO3	LO4	LO5	LO6	LO7
Assignment 1 (Metadata & acquisition)	X						
Assignment 2 (NO_2 hotspots)	X	X					
Assignment 3 (PM_{10} seasonality)	X		X				
Assignment 4 (CO_2 + land-use)	X			X	X		
Assignment 5 (Validation)						X	
Assignment 6 (Scenarios)							X
Final Case Study	X	X	X	X	X	X	X

5 CASE STUDIES

5.1 Case Study 1 — Istanbul: NO_2 Hotspot Analysis and Urban Mobility Mitigation

This case study demonstrates an end-to-end UDENE workflow for identifying urban NO_2 hotspots in Istanbul and translating EO-derived evidence into practical mobility mitigation options. The analysis uses Sentinel-5P NO_2 observations, contextual spatial layers, and validation against ground monitoring stations to support policy-relevant recommendations.

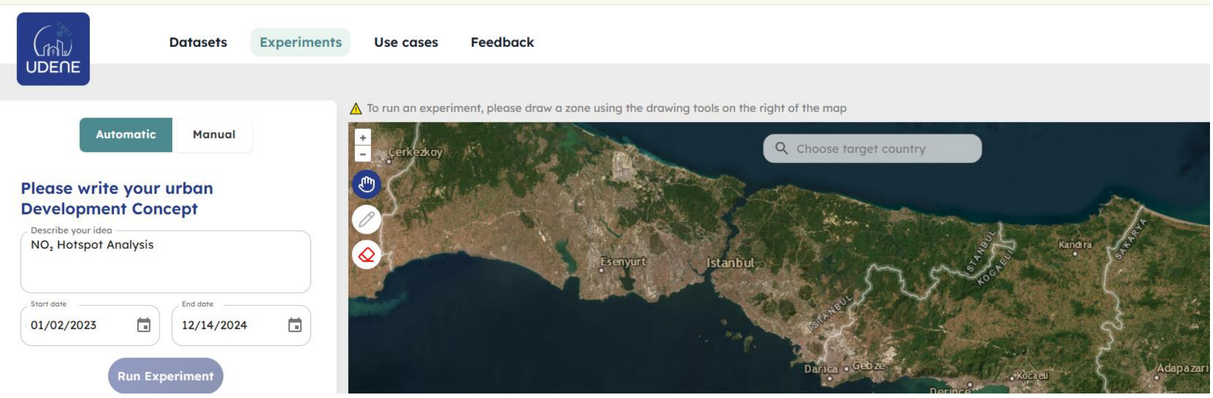

Figure 4. Istanbul: NO_2 Hotspot Analysis in UDENE Platform

5.1.1 Problem Context and Objectives

Istanbul is among Europe's most traffic-intensive metropolitan areas, and NO_2 pollution is closely linked to urban mobility patterns. Municipal reporting indicates that peak NO_2 levels coincide with morning and evening traffic, while major transport corridors—particularly the Bosphorus bridge crossings, the E-5 and TEM highways—function as persistent high-emission sources. In addition, local topography and narrow valley structures can suppress atmospheric ventilation, increasing pollutant retention in specific micro-areas.

The objectives of this case study are to use UDENE and Sentinel-5P NO_2 data to (i) map NO_2 spatial distribution across Istanbul, (ii) identify the main hotspot regions, and (iii) propose source-linked mitigation scenarios suitable for municipal implementation.

5.1.2 Data Sources

The analysis integrates EO, land-use, transport, and in-situ monitoring datasets to ensure both interpretability and validation.

Table 32: Data Sources Used in the Istanbul NO_2 Hotspot Case Study

Dataset	Provider	Purpose
Sentinel-5P NO_2 (L2)	Copernicus	NO_2 hotspot identification
CORINE Land Cover	Copernicus	Built-up area and urban form context
Road network	OpenStreetMap (OSM)	Transport source mapping and corridor overlay
Ground AQ monitoring stations (AQMS)	Ministry of Environment	Validation (EO-to-ground comparison)

5.1.3 UDENE Workflow Summary

The UDENE workflow follows a reproducible sequence from data access to hotspot extraction and contextual interpretation:

- Activate the Sentinel-5P NO_2 layer in UDENE.
- Apply QA > 0.75 filtering to screen low-quality pixels.
- Compute monthly aggregation for the January–December period (annual cycle representation).
- Apply kernel smoothing to enhance coherent spatial structures and reduce pixel-level noise.
- Overlay the resulting NO_2 field with the road network to support source attribution.
- Export hotspot intensity outputs and map products for reporting and scenario design.

5.1.4 Results: Hotspot Identification

The strongest NO_2 hotspots align with Istanbul's main mobility corridors and high-density activity zones. Priority hotspot areas include:

- **E-5 corridor:** Avcılar → Merter → Topkapı → Kadıköy
- **15 July Martyrs Bridge corridor:** bridge approach and crossing influences
- **TEM highway:** İkitelli → Kavacık zone
- **Central business district:** Mecidiyeköy → Zincirlikuyu → Levent

5.1.5 Interpretation of Spatial Patterns

The spatial distribution of NO_2 closely follows major traffic arteries, indicating transport as the dominant driver at the urban scale. Bridge crossings and tunnel entry/exit zones create clear "choke points" where congestion and stop–start driving amplify emissions. Hotspot intensity is also higher in areas where urban density concentrates travel demand and reduces dispersion, reinforcing the link between population/activity density and NO_2 burden.

5.1.6 Validation Against Ground Monitoring

Validation was conducted using the UDENE Validation Module to compare EO-derived NO_2 indicators with station measurements at seven locations.

Validation summary

- $R^2 = 0.62$ (acceptable correlation for screening and pattern detection)
- RMSE = 5.3 μmol/m²
- Bias behavior:
    - EO tends to slightly underestimate concentrations near dense street-canyon environments.
    - EO may overestimate at suburban edges due to representativeness differences between pixel averages and local station conditions.

5.1.7 Mitigation Scenarios

Based on hotspot geography and plausible source drivers, three mitigation scenarios are proposed. Each scenario is designed to be implementable, policy-relevant, and traceable to EO evidence.

Scenario A — Low Emission Zone (LEZ) Implementation

A pilot LEZ targeting diesel vehicle restrictions around the Mecidiyeköy–Zincirlikuyu hotspot cluster.

- Expected impact: 10–15% NO_2 reduction in the zone (screening-level estimate)

Scenario B — Electrification of Bus Rapid Transit (Metrobüs)

Conversion of diesel BRT buses to electric, prioritizing operation along the E-5 corridor where persistent hotspots are observed.

- Expected impact: 12–18% NO_2 reduction along the corridor (screening-level estimate)

Scenario C — Mobility Demand Shift via Metro Service Intensification

Increasing frequency and attractiveness of metro services (M2, M5, M7 lines) to reduce peak-hour road demand.

- Expected impact: 5–8% NO_2 reduction in affected hotspot areas (screening-level estimate)

5.1.8 Policy Recommendations

The following recommendations translate the scenarios into concrete municipal action items:

- Launch an LEZ pilot zone in the Şişli–Beşiktaş area, supported by monitoring and phased enforcement
- Prioritize electric bus fleet procurement and corridor-based deployment where NO_2 hotspots persist
- Implement traffic signal optimization and congestion management at corridor choke points
- Deploy real-time pollution alerts and public dashboards to support exposure reduction and transparency

5.1.9 Conclusion

Istanbul's NO_2 pollution is predominantly transport-driven and exhibits strong spatial structure aligned with major mobility corridors. The UDENE + Sentinel-5P workflow enables evidence-backed hotspot identification, supports validation against ground monitoring, and provides a defensible basis for prioritizing mobility interventions such as LEZ implementation, fleet electrification, and demand-shifting measures.

5.2 Case Study 2 — Ankara: PM_{10} Seasonal Dynamics and Heating Mitigation Scenarios

This case study applies a UDENE time-series workflow to characterize Ankara's seasonal PM_{10} dynamics and to translate the findings into heating-focused mitigation scenarios. The analysis uses CAMS PM_{10} data to quantify winter-driven pollution patterns, validates EO/model outputs against ground monitoring, and develops practical interventions aligned with municipal air-quality management needs.

Figure 5. Sentinel-5P NO_2 Column Density Map (Interactive UDENE Platform)

5.2.1 Problem Context and Objectives

Ankara experiences its most severe PM_{10} pollution during winter months, where heating emissions combine with thermal inversion conditions to elevate concentrations and prolong exposure episodes. The objectives of this case study are to: (i) model winter-season PM_{10} pollution in Ankara using CAMS PM_{10}, (ii) conduct time-series extraction and seasonal decomposition in UDENE, (iii) validate modelled PM_{10} against ground AQ monitoring stations, and (iv) develop heating-oriented mitigation scenarios that are plausible for municipal implementation.

Data Sources

To support both seasonal interpretation and validation, the case study integrates air-quality, in-situ monitoring, and meteorological context datasets.

Table 33: Data Sources, Providers, and Analytical Purpose for the Ankara PM_{10} Case Study

Dataset	Provider	Purpose
CAMS PM_{10}	Copernicus Atmosphere Monitoring Service (CAMS)	Seasonal trend and time-series analysis

Dataset	Provider	Purpose
Ground AQ monitoring stations (AQMS)	Ministry of Environment (National AQ Monitoring Network)	Validation (model/EO to ground comparison)
Meteorological data	Turkish State Meteorological Service (MGM)	Interpretation (inversions, weather-driven variability)

5.2.2 UDENE Workflow Summary

The UDENE workflow follows a straightforward, reproducible seasonal analytics sequence:

- Select CAMS PM_{10} in UDENE.
- Extract daily values for 365 days for the defined study area.
- Group values by month.
- Compute seasonal/monthly averages and seasonal structure.
- Visualize results using time-series and seasonal graphs for interpretation and reporting.

5.2.3 Results: Seasonal Trends and Anomalies

PM_{10} levels in Ankara display a strong seasonal pattern consistent with winter heating demand:

- **December–February:** highest concentrations
- **March–April:** transition period
- **July–September:** lowest concentrations

Quantitatively, winter PM_{10} concentrations are approximately 48% higher than the annual mean, indicating a pronounced seasonal burden. In addition to the seasonal structure, episodic anomalies were identified, including a January dust intrusion event (attributed to regional transport) producing an estimated +32 μg/m³ spike.

5.2.4 Validation Against Ground Monitoring

Validation against ground AQMS data indicates strong agreement for trend detection, while highlighting limitations in peak representation:

- **R^2 = 0.71** (strong correlation)
- **RMSE = 9.2 μg/m³**

Overall, CAMS tends to underestimate extreme peaks, but it reproduces the seasonal and temporal trend structure reliably, supporting its use for seasonal planning, screening, and scenario design.

5.2.5 Heating Mitigation Scenarios

Based on the seasonal evidence and likely winter drivers, three heating-centered scenarios are proposed. These scenarios are framed for practical feasibility and are consistent with the observed winter dominance of PM_{10}.

Scenario A — District Heating Modernization

Improving district heating efficiency and emissions performance in high-burden neighborhoods.

- Expected PM_{10} reduction: **18–25%**

Scenario B — Coal-to-Natural Gas Conversion

Accelerating conversion away from coal-based heating toward cleaner fuels.

- Expected PM_{10} reduction: **22–30%**

Scenario C — Building Insulation Support

Subsidies and support programs to reduce heating demand through improved building envelopes.

- Expected PM_{10} reduction: **8–12%**

5.2.6 Policy Recommendations

To translate scenarios into actionable steps, the following recommendations are prioritized:

- Prioritize district heating upgrades in Keçiören and Altındağ, where winter burdens are typically concentrated
- Target insulation subsidies to households and building stock with the highest heat loss and heating demand
- Integrate urban heat island mapping and local thermal diagnostics to optimize heating strategies and reduce unnecessary demand

5.2.7 Conclusion

Ankara's PM_{10} burden is strongly driven by winter heating emissions, amplified by inversion conditions. Using CAMS + UDENE, the case study demonstrates an evidence-based seasonal analytics workflow, confirms robust trend agreement via validation, and produces implementable mitigation scenarios focused on heating modernization, fuel switching, and demand reduction.

5.3 Case Study 3 — Izmir: CO_2 Footprint Mapping and Land-Use-Dependent Carbon Modelling (Wheat vs Barley)

This case study is designed as the module's most distinctive demonstration of UDENE's added value: moving beyond "urban-only" carbon narratives to quantify how agricultural land use can materially shape a city-region's carbon footprint. Using CAMS CO_2 fields, land-use classification, and emission-factor-based conversion logic, the workflow reveals land-use–carbon linkages that can support climate-smart agricultural planning and integrated urban–regional climate policy

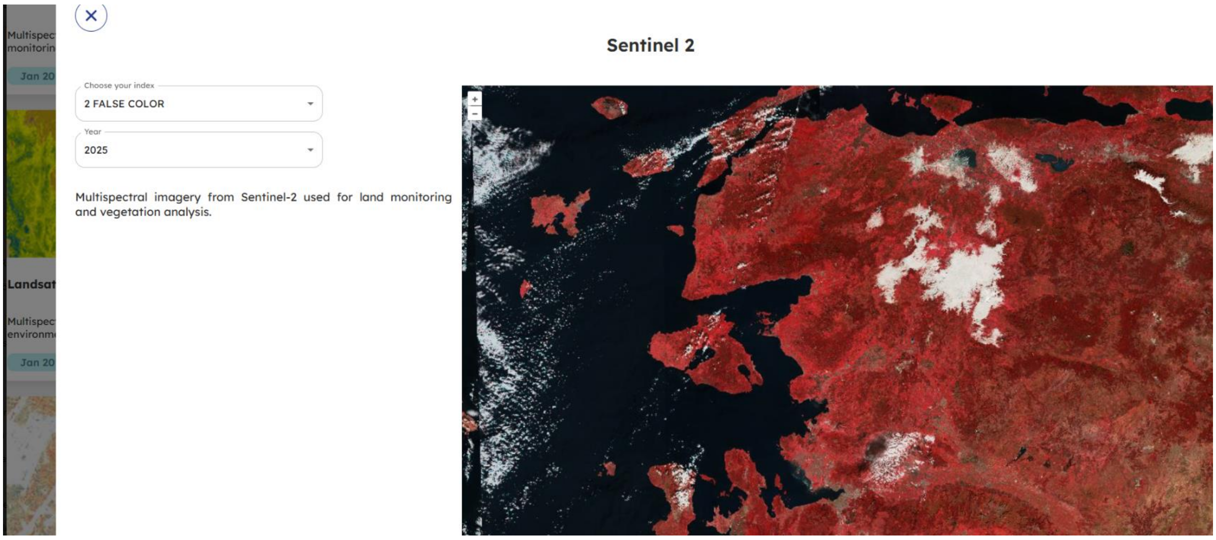

Figure 6. Spatial distribution of tropospheric NO_2 concentrations derived from Sentinel-5P

5.3.1 Problem Context and Objectives

Izmir's CO_2 profile is influenced not only by transportation and energy use, but also by surrounding agricultural production systems. This case study aims to: (i) map Izmir's CO_2 spatial distribution using CAMS CO_2, (ii) classify agricultural land using CORINE, (iii) compare the CO_2e implications of wheat vs barley land-use patterns through fertilizer-driven N_2O pathways, and (iv) demonstrate land-use-dependent carbon modelling in UDENE as an innovative decision-support workflow.

5.3.2 Data Sources

The analysis combines EO/model products with land-use and carbon accounting inputs to support both mapping and CO_2e conversion logic.

Table 34: Data Sources, Providers, and Analytical Purpose for the Izmir CO_2 and Land-Use Carbon Case Study

Dataset	Provider	Purpose
CAMS CO_2	Copernicus Atmosphere Monitoring Service (CAMS)	CO_2 footprint mapping and spatial patterns
CORINE Land Cover	Copernicus	Land-use classification and agricultural layer extraction
Emission factors (fertilizer → N_2O → CO_2e)	FAO / IPCC-aligned factors (as specified in course materials)	Conversion of nitrogen inputs to CO_2e impacts
Soil carbon datasets	Relevant soil carbon / sequestration sources (defined in course package)	Sequestration modelling and net-emissions framing

5.3.3 UDENE Workflow Summary

The workflow follows a reproducible sequence that integrates EO-derived CO_2 with land-use stratification and emissions conversion logic:

1) Activate the CAMS CO_2 layer in UDENE.
2) Spatially subset the analysis to the Izmir district/defined administrative boundary.
3) Overlay CORINE land-use layers and isolate agricultural classes.
4) Separate agricultural zones by crop-type proxy (wheat vs barley areas as defined in the case design).
5) Compute mean CO_2 indicators per land-use class.
6) Apply fertilizer emission-factor logic to reflect agricultural management differences:
7) Wheat systems typically require substantially higher nitrogen inputs (case assumption: ~2×).
8) Barley systems generally require lower fertilizer intensity.
9) Convert excess nitrogen input → N_2O → CO_2e using the specified factors.
10) Produce a comparison chart/table and interpret differences in a policy-relevant format.

5.3.4 Results: CO_2 Distribution and Land-Use Comparison

Spatial mapping indicates higher CO_2 levels in the following areas:

- **Urban core:** Konak, Bornova
- **Industrial zones:** Aliağa
- **Dense agricultural plains:** Menemen, Torbalı

A land-use-dependent comparison demonstrates that agricultural systems can be a non-trivial component of the regional carbon profile. Under the defined assumptions and conversion logic, wheat-dominated areas exhibit a higher CO_2e footprint than barley-dominated areas.

Table 35: Land-Use Comparison (Indicative Structure)

Land Use Category	Fertilizer Input Intensity	CO_2e Emissions Profile
Wheat	High	Higher footprint
Barley	Moderate	Lower footprint

Using the case parameters, wheat fields generate approximately 28–42% higher CO_2e per hectare than barley fields.

5.3.5 Interpretation

Three analytical conclusions emerge from the workflow:

- Agricultural land use can represent a non-negligible emissions source, particularly when fertilizer intensity is high.
- The primary differentiator between wheat and barley footprints is the fertilizer-driven N_2O pathway, which amplifies CO_2e outcomes even when CO_2 spatial fields appear broadly similar.
- Combining land-use maps with EO/model-based CO_2 indicators supports climate-smart agriculture planning, allowing authorities to target interventions spatially rather than relying on uniform measures.

5.3.6 Mitigation Scenarios

Based on the mapped patterns and land-use comparison, three mitigation pathways are proposed:

Scenario A — Fertilizer Optimization in Wheat Areas

Reducing excess nitrogen application through precision techniques and best practices.

- Expected reduction: **12–18% CO_2e**

Scenario B — Crop Switching (Wheat → Barley) in Suitable Zones

Shifting crop choice in low-yield or high-emission-intensity wheat areas where agronomically feasible.

- Expected reduction: **20–35% CO_2e**

Scenario C — Regenerative Soil Practices

Adopting soil carbon-enhancing practices to increase sequestration and reduce net emissions.

- Expected reduction: **10–15% CO_2e** (via sequestration effects)

5.3.7 Policy Recommendations

To translate scenarios into implementable measures, the case study recommends:

- Promote barley adoption in low-yield wheat zones where emissions intensity is high and switching is feasible.
- Support nitrogen-efficient fertilizer techniques (training, incentives, and monitoring).
- Establish soil carbon sequestration incentives to scale regenerative practices and improve net-emissions outcomes.

5.3.8 Conclusion

This case study demonstrates that UDENE workflows combined with Copernicus/CAMS CO_2 data can reveal actionable land-use–carbon linkages, expanding carbon analytics beyond urban transport and energy to include agricultural drivers. The approach provides a defensible basis for integrating climate-smart agriculture into regional climate policy through spatial targeting, quantified comparisons, and scenario-ready evidence.

6 TECHNICAL SECTION

This section provides the technical backbone of the module. It explains the core Earth Observation (EO) and contextual datasets used throughout the course, their scientific characteristics (measurement type, resolution, QA conventions), the UDENE processing workflow applied to each use case, and the uncertainties that must be explicitly acknowledged in any deliverable. The intent is to equip both learners and educators with a practical understanding of how EO-based environmental modelling works in UDENE—from data access and preprocessing to analysis outputs and validation.

6.1 Core Datasets Used in the Module

The module relies on a small, coherent set of EO and supporting datasets that collectively enable pollution mapping, time-series interpretation, carbon footprint reasoning, land-use stratification, and EO-to-ground validation.

Table 36: Dataset Portfolio

Dataset	What It Represents	Typical Use in the Module	Notes
Sentinel-5P (TROPOMI) NO_2 (and related trace gases)	Satellite retrieval of atmospheric composition (column quantities)	Urban NO_2 hotspot mapping; spatial screening	High spatial detail; daily coverage; QA-driven filtering is essential
CAMS PM_{10} / $PM_{2.5}$	Model-based reanalysis with data assimilation	Seasonal PM_{10} dynamics; time-series extraction; anomaly detection	Good for trends; may underrepresent extreme local peaks
CAMS CO_2	Model-derived CO_2 fields (transport + flux modelling)	CO_2 footprint mapping; land-use-dependent carbon reasoning	Smoother spatial variability due to mixing and long lifetime
CORINE Land Cover (CLC)	Land-use classification map	Land-use overlays; zonal statistics; agricultural area stratification	Enables crop-/land-class comparisons at planning scale
Ground AQ Monitoring Stations (AQMS)	In-situ air quality and meteorological observations	Validation (EO/model to station comparison)	Point measurements; representativeness and matching are key

6.2 Sentinel-5P (TROPOMI): Atmospheric Pollution Retrievals

Sentinel-5P is the primary dataset for urban-scale atmospheric pollutant screening in the course, especially for NO_2. It provides frequent, consistent retrievals that support hotspot identification and trend comparison when appropriately filtered by quality indicators.

Table 37: Sentinel-5P / TROPOMI Key Technical Parameters (Course-Relevant)

Parameter	Value / Convention
Instrument	TROPOMI (Tropospheric Monitoring Instrument)
Spectral coverage	UV, VIS, NIR, SWIR (gas absorption features)
Spatial resolution	~3.5 km × 5.5 km (improved products post-2019; product-dependent)
Temporal resolution	Daily global coverage
Measurement type	Tropospheric Vertical Column Density (VCD)
NO_2 units	mol/m² or µmol/m² (product-dependent)
QA flag convention	QA typically 0–1 (course rule-of-thumb: **QA ≥ 0.75**)

Retrieval physics (practical summary). Sentinel-5P derives NO_2 using Differential Optical Absorption Spectroscopy (DOAS): solar radiation passes through the atmosphere, pollutants imprint absorption features on the spectrum, and the measured signal is inverted to estimate column densities. The most operationally important uncertainty drivers for learners to understand are:

- cloud cover and cloud fraction effects,
- surface reflectance and albedo variability,
- aerosol interference, and
- stratosphere–troposphere separation challenges.

Why Sentinel-5P fits the module.

- Urban-scale pattern visibility suitable for hotspot screening
- Daily revisit enables temporal aggregation and trend logic
- NO_2 columns align well with traffic-related emission patterns in many urban contexts
- Integrates directly into UDENE's mapping and raster workflows

6.3 CAMS Reanalysis Products: PM_{10} and CO_2

CAMS products used in the module are not direct satellite "measurements" but model-based reanalyses produced through data assimilation. This distinction is central to correct interpretation: CAMS often captures broad spatiotemporal structure well, while smoothing extremes at local scales.

Table 38: CAMS PM_{10} Technical Profile (Course-Relevant)

Parameter	Value / Convention
Spatial resolution	~0.1° (≈10 km, product-dependent)
Temporal resolution	Hourly and/or daily aggregates (product-dependent)
Model basis	ECMWF Integrated Forecasting System (IFS) with atmospheric composition components
Variables commonly used	PM_{10}, $PM_{2.5}$, dust, sea salt, organic carbon (product-dependent)
Data nature	Data assimilation product integrating satellite + ground + transport modelling

Interpretation note. Because CAMS blends observations with model physics, it is typically strong in seasonal patterns and trend structure but may underestimate sharp urban peaks, particularly where local sources or micro-meteorology dominate.

Table 39: CAMS CO_2 Technical Profile (Course-Relevant)

Parameter	Value / Convention
Data nature	Model-derived CO_2 fields (fluxes + atmospheric transport)
Spatial resolution	~0.25° (product-dependent)
Measurement expression	Column-averaged CO_2 concentration (ppm)
Source drivers represented	Fossil fuel combustion, biosphere fluxes, transport, industry (modelled)
Key behaviour	Smoother spatial patterns due to mixing and long atmospheric lifetime

Why CAMS is central to the carbon component:

- CO_2 fields support regional footprint reasoning and trend framing
- Enables land-use differentiation when combined with classification layers and zonal statistics
- Compatible with emission-factor modelling (fertilizer-driven $N_2O \rightarrow CO_2e$)
- Efficiently processed via UDENE's raster operations and overlays

6.4 Land-Use and Validation Inputs: CORINE and Ground Stations

CORINE Land Cover (CLC) provides the spatial classification needed to move from "where CO_2 is higher" to "which land-use systems are associated with higher carbon impacts." With a typical resolution of ~100 m, it supports land-use overlays and zonal statistics that are essential for the Izmir case study and for any land-use-dependent modelling exercise.

Ground AQ monitoring stations (AQMS) provide the validation backbone. Station datasets typically include NO_2, PM_{10}, $PM_{2.5}$ and relevant meteorological parameters. Their key technical limitation is representativeness: stations are point measurements while EO/model fields represent spatial averages, so proper matching procedures are mandatory.

6.5 Standard UDENE Processing Workflow

UDENE operationalizes steps commonly implemented in Python/GDAL workflows. The course uses a standardized preprocessing and analysis chain so results remain comparable and reproducible across learners and partner regions.

UDENE operationalizes steps commonly implemented in Python/GDAL workflows. The course uses a standardized preprocessing and analysis chain so results remain comparable and reproducible across learners and partner regions.

Table 40: UDENE Processing Steps and Their Purpose

Workflow Step	What It Does	Why It Matters
QA filtering (Sentinel-5P)	Removes low-quality retrievals (e.g., QA < 0.75) and cloud-affected pixels	Prevents artifacts from driving hotspot identification
Reprojection / CRS harmonization	Brings layers into a consistent CRS (course default: **EPSG:4326**)	Ensures overlays and spatial metrics are valid

Workflow Step	What It Does	Why It Matters
Temporal aggregation	Converts daily/hourly data to weekly/monthly/annual summaries	Reduces noise and supports trend interpretation
Raster calculations	Pixel-wise math, normalization, kernel smoothing, spatial masking	Enables hotspot enhancement and comparable indicators
Land-use zonal statistics	Summarizes EO/model fields by land-use classes (e.g., CORINE)	Enables land-use-dependent carbon comparisons

6.6 UDENE Tool Architecture

UDENE is taught not as a black box but as a modular toolchain, where each component maps to a specific professional task category (acquisition, processing, time-series, validation, communication).

Table 41: UDENE Modules and Functional Role

UDENE Module	Core Functions	Primary Course Use Cases
EO Explorer	Dataset browsing, time slicing, layer switching, metadata access, map export	Dataset acquisition, metadata interpretation, initial screening
Raster Engine	Reprojection, pixel-wise operations, kernel smoothing, masking, zonal statistics	NO_2 hotspot mapping, CO_2 footprint mapping, land-use carbon overlays
Time-Series Module	Extracts values for pixel/ROI/bounding box; supports trend plotting	PM_{10} seasonal dynamics, CO_2 trend framing
Validation Module	Station ingestion, EO-to-station matching, R^2/RMSE computation, scatter plots	EO/model validation and bias interpretation

6.7 Uncertainties and Limitations

A technically credible deliverable must explicitly acknowledge uncertainties. The course requires learners to report limitations as a standard section in assignments and final projects.

Sentinel-5P limitations

- Column density is not identical to near-surface concentration
- Potential underestimation in dense street-canyon conditions
- Cloud contamination and aerosol effects
- Stratosphere–troposphere separation uncertainty

CAMS limitations

- Coarser spatial resolution and smoother variability
- Underestimation of local extremes
- Dependence on meteorological modelling assumptions and assimilation constraints

Ground station limitations

- Point-based representativeness (local influences can dominate)
- No vertical representativeness (surface only)
- Local disturbances (construction, nearby traffic, siting effects)

6.8 Why UDENE + Copernicus Is Fit-for-Purpose in Education and Policy

UDENE and Copernicus assets provide a rare combination of accessibility and scientific robustness: they are globally available, frequently updated (daily/hourly depending on product), methodologically transparent through QA and documentation conventions, and directly applicable to policy questions such as hotspot identification, seasonal burden, and scenario targeting. In practical terms, UDENE reduces barriers for universities and municipalities that cannot maintain full EO processing infrastructure, while still enabling defensible, reproducible analyses.

6.9 Summary

This technical section confirms that the module uses scientifically established Earth Observation and contextual datasets, applies correct preprocessing and analysis steps through a documented and reproducible workflow, leverages UDENE modules in a manner that is explicitly aligned with the defined competencies, and maintains scientific credibility by requiring learners to report uncertainties and limitations transparently and consistently.

7 ATMOSPHERIC SCIENCE FOUNDATIONS FOR EO-BASED URBAN ENVIRONMENTAL ANALYSIS

This chapter provides the atmospheric science foundations required to interpret EO-based air quality and carbon indicators in a scientifically defensible way. Because EO products and reanalyses reflect a combination of emissions, chemistry, transport, and meteorology, students need a shared conceptual framework covering chemical transformations, emission pathways, atmospheric transport, vertical mixing, and weather–pollution interactions. The goal is not to turn learners into atmospheric chemists, but to ensure they can explain *why* spatial and temporal patterns appear in UDENE outputs and how those patterns should inform validation and mitigation scenarios.

7.1 Atmospheric Composition and Pollutants Targeted in the Module

The Earth's atmosphere is dominated by major gases (approximately **N_2 ~78%, O_2 ~21%, Ar ~0.93%**) alongside trace species that are critical for climate and air quality. In this module, the analytical focus is on pollutants and climate forcers that can be interpreted through EO and model-based products.

Primary pollutants and indicators in the course

- NO_2: a strong indicator of combustion-related urban emissions, especially traffic
- PM_{10}: influenced by heating emissions, dust events, and industrial activity
- CO_2: long-lived greenhouse gas reflecting cumulative regional emissions
- Land-use CO_2e: agricultural climate impact expressed through fertilizer-driven N_2O and soil carbon dynamics

7.2 NO_2 — Chemistry, Lifetime, and Urban Pattern Formation

NO_2 is a short-lived atmospheric pollutant with pronounced spatial variability, which makes it particularly suitable for urban hotspot detection and corridor-based interpretation. In most cities, the dominant source is road transport, with additional contributions from industrial combustion, power generation, residential heating, and—especially in coastal or port environments—shipping activities. Sentinel-5P (TROPOMI) is well suited for NO_2 analysis in this course because NO_2's short atmospheric lifetime (often on the order of hours) generates localized spatial structures that frequently align with emission corridors, enabling robust hotspot screening when appropriate QA filtering is applied. As a result, students should expect characteristic urban signatures such as peaks associated with rush-hour emission cycles, strong alignment with major road corridors, bridges, tunnels, and junctions, and lower values on weekends in many cities due to reduced traffic intensity. These signatures become especially clear in UDENE through quality filtering and temporal aggregation (weekly/monthly/seasonal) that reduces noise and emphasizes persistent structures.

NO_2 participates in photochemical cycles that connect it to ozone formation. For interpretation purposes, the key reactions can be expressed as:

- **Photolysis:** $NO_2 + hv \rightarrow NO + O$
- **Ozone formation:** $O + O_2 \rightarrow O_3$

Operationally, these reactions indicate that sunlight drives rapid NO_2 transformation, so observed NO_2 fields reflect not only emissions but also the timing of photochemistry and the influence of meteorology and atmospheric mixing.

7.3 PM_{10} — Seasonal Dynamics, Meteorological Controls, and Why CAMS is Used

PM_{10} represents a complex mixture of particulate sources and formation pathways, including dust, soot, industrial emissions, and secondary aerosols. Unlike NO_2, near-surface PM_{10} is difficult to quantify directly from satellite observations in a way that is consistently reliable for local decision-making, so this module primarily relies on model-based products. In a typical mid-latitude setting, PM_{10} exhibits a strong seasonal structure: concentrations tend to increase in winter due to heating emissions combined with stable atmospheric conditions and shallow boundary layers, spring can feature episodic spikes driven by regional dust transport, and summer often shows lower near-surface accumulation because stronger vertical mixing and deeper boundary layers enhance dilution.

CAMS is appropriate for PM_{10} learning workflows because CAMS PM_{10} is generated through data assimilation that integrates satellite aerosol constraints (such as aerosol optical depth–related information), ground-based observations where available, and chemical transport modelling coupled with meteorology. This combination produces physically consistent fields that are particularly useful for capturing seasonal behavior and broad regional patterns, even though it can smooth or underestimate short-lived, highly localized extremes—an issue that students explicitly encounter and interpret during validation exercises. Correct interpretation of PM_{10} outputs therefore requires applying key meteorological controls: temperature inversions that trap pollutants near the surface, low wind speeds that allow accumulation, persistent high-pressure systems that stabilize the atmosphere and suppress mixing, and boundary layer depth changes that modulate dilution between daytime and nighttime conditions.

7.4 CO_2 — Climate Forcing, Mixing, and Urban Interpretation

CO_2 is a long-lived greenhouse gas and therefore behaves differently from short-lived pollutants such as NO_2. Its spatial fields are typically smoother because atmospheric mixing redistributes CO_2 over broader areas, and observed concentrations reflect the integrated influence of multiple sources and sinks over time. In the context of this course, major CO_2-relevant drivers include fossil fuel combustion from transport, industry, and heating, as well as biomass burning, soil respiration and broader biosphere fluxes, and agricultural activities—particularly when agricultural impacts are expressed as CO_2-equivalent emissions through fertilizer-driven N_2O pathways.

Because CO_2 persists longer in the atmosphere and mixes efficiently, it does not usually form sharp, highly localized "hotspots" in the way NO_2 does. For this reason, EO-based CO_2 interpretation typically benefits from model assimilation frameworks that combine atmospheric transport with flux estimates; accordingly, CAMS CO_2 provides a practical and scientifically consistent basis for footprint-style reasoning at urban and regional scales. When interpreting elevated CO_2 in an urban context, students should generally expect higher values to align with dense transport activity, industrial zones, heating-intensive building stock, and periods of reduced vegetation uptake (for example, during seasons when vegetation is dormant or less active).

7.5 Land-Use-Dependent Carbon Emissions: Wheat vs Barley

A core innovation of the module is demonstrating that land use can measurably influence carbon outcomes when EO/model CO_2 fields are integrated with land-use classification and emissions conversion logic. Agricultural systems contribute to CO_2e impacts primarily through fertilizer-driven N_2O emissions and through soil carbon dynamics, both of which can shift net emissions at the per-hectare scale and meaningfully affect regional footprints.

Nitrogen fertilizer inputs undergo microbially mediated transformations that create the pathway from fertilization to N_2O emissions. For interpretation purposes, the key reactions are:

- **Nitrification:** $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
- **Denitrification:** $NO_3^- \rightarrow N_2O \rightarrow N_2$

Because N_2O is a high-impact greenhouse gas, carbon accounting converts N_2O emissions into CO_2-equivalent using global warming potential (GWP) factors. In practice, this means fertilizer intensity can dominate agricultural climate footprints even when CO_2 concentration fields appear relatively smooth, which is why the course explicitly connects agronomic inputs to CO_2e outcomes in the modelling logic.

Within this framework, wheat often produces higher CO_2e than barley under comparable conditions because wheat systems are frequently more nitrogen-intensive, increasing N_2O-related CO_2e. Differences in tillage and residue management can further affect soil carbon retention between cropping systems, reinforcing the per-hectare gap in net climate impact. The Izmir case study operationalizes this relationship by combining EO/model CO_2 mapping with land-use stratification and emissions-factor conversion to produce a defensible wheat-versus-barley comparison.

Finally, learners must track soil carbon dynamics because soil processes can either offset or amplify emissions depending on management. Key determinants include organic content, tillage intensity, crop residue management, and microbial respiration processes. In Mediterranean conditions, these management choices can materially influence sequestration potential, which supports scenario design around regenerative practices that target both emissions reduction and carbon storage.

7.6 Atmospheric Transport and Mixing: The Minimum Toolkit for EO Interpretation

To interpret EO-derived patterns, students apply a small set of transport and mixing concepts:

- **Advection:** horizontal transport by wind
- **Convection:** vertical transport driven by heat and buoyancy
- **Diffusion/turbulence:** mixing that disperses pollutants
- **Deposition:** removal of particles via settling and surface uptake
- **Boundary layer dynamics:** daytime dilution (deep boundary layer) vs nighttime accumulation (shallow layer)

These concepts are used explicitly when explaining hotspot persistence, winter PM_{10} peaks, and the smoothing behavior of CO_2 fields.

Meteorological Drivers of Air Quality

The following table summarizes the key meteorological controls learners use during UDENE interpretation, validation, and scenario justification.

Table 42: Interpretation Table of Air Quality

Meteorological Parameter	Typical Impact on Pollution
Wind speed	Higher wind generally disperses pollutants; low wind increases accumulation

Meteorological Parameter	Typical Impact on Pollution
Temperature inversion	Traps pollutants near the surface and intensifies winter episodes
Humidity	Can influence particle growth and secondary aerosol behavior
Pressure systems	Persistent high pressure often stabilizes the atmosphere and limits mixing
Precipitation	Removes particles and soluble gases through wet deposition (“atmospheric cleaning”)

7.7 Why Atmospheric Science Must Be Integrated with EO Workflows

EO maps and model outputs are descriptive; atmospheric science provides the causal structure needed for competency. Without this integration, students may produce visually plausible maps but draw incorrect conclusions about drivers, uncertainty, and mitigation leverage points. By grounding interpretation in chemistry, transport, and meteorology, learners can (i) justify observed patterns, (ii) design realistic mitigation scenarios, and (iii) apply UDENE in a manner consistent with professional atmospheric science practice.

8 LAND-USE CARBON MODELLING

8.1 Rationale and Learning Value

Land-use patterns play a critical—yet often underrepresented—role in shaping regional carbon footprints. In Mediterranean climates such as Türkiye's, agricultural systems can contribute materially to CO_2-equivalent (CO_2e) emissions through a combination of management practices and biogeochemical processes, including fertilizer-driven N_2O emissions, soil organic carbon (SOC) loss, residue management choices, tillage intensity, irrigation-related energy use, and crop-type-specific emission factors.

Within this module, students learn an advanced, research-grade EO application: how land-use classification (e.g., wheat versus barley areas) affects the carbon footprint when combined with CAMS CO_2 fields and agricultural emission-factor logic. This approach extends EO training beyond mapping into interpretable, scenario-ready carbon modelling.

8.2 Why Land Use Matters in Carbon Footprint Modelling

Atmospheric CO_2 patterns reflect multiple interacting sources and sinks—energy combustion, transport, industry, residential heating, agriculture, soil carbon processes, and vegetation uptake. Agriculture, in particular, contributes to CO_2e through three dominant mechanisms that are directly actionable from a policy and practice standpoint.

Primary agricultural mechanisms included in the course

- **Fertilizer → N_2O → CO_2e pathway (often dominant for cropland CO_2e differences)**
- **Soil carbon loss (SOC decline) driven by management intensity**
- **Residue and biomass management (e.g., burning versus incorporation)**

8.2.1 Fertilizer → N_2O → CO_2e (core conversion logic):

Nitrogen fertilizers (e.g., ammonium nitrate, urea, ammonium sulfate) enter microbial nitrogen cycling in soils. For interpretation purposes, the key transformations are:

- **Nitrification:** $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
- **Denitrification:** $NO_3^- \rightarrow N_2O \rightarrow N_2$

In carbon accounting, N_2O is converted to CO_2e using global warming potential (GWP) factors (course reference point: 1 kg N_2O = 265 kg CO_2e**,** consistent with IPCC AR6 conventions used in many accounting contexts). This is why fertilizer intensity can create “carbon hotspots” in agricultural land-use comparisons. As a rule-of-thumb in this case study logic, wheat systems are often more nitrogen-intensive than barley systems, which increases N_2O-driven CO_2e.

8.2.2 Soil carbon loss (SOC decline)

Land-use and management affect carbon storage in soils. Intensive tillage and frequent soil disturbance can accelerate SOC loss, releasing carbon to the atmosphere. In comparative framing, wheat systems are often associated with more intensive soil management in many contexts, while barley may be managed with less aggressive disturbance—supporting stronger carbon retention under comparable conditions (depending on local practice).

8.2.3 Residue management and biomass handling

Residue handling influences net emissions. Residue burning produces direct emissions, while incorporation can improve SOC outcomes over time. The module treats residue management as an interpretable driver and a scenario lever, especially in Mediterranean agricultural landscapes.

Integration Framework: Datasets and Role in the Workflow

Students combine EO/model CO_2 information with land-use classification and emissions conversion parameters using UDENE.

Table 43: Data Layers Integrated in Land-Use Carbon Modelling

Dataset / Layer	Purpose in the Case Study
CAMS CO_2	Background CO_2 spatial patterns and regional footprint framing
CORINE Land Cover (100 m)	Land-use masking and agricultural class delineation
Agricultural emission factors	Fertilizer → N_2O → CO_2e conversion logic (scenario-ready accounting)
Optional: Soil carbon datasets	Sequestration / SOC change framing for advanced component

8.3 Student Workflow in UDENE (Course Implementation Logic)

The workflow is designed to be executed within the 6-week course structure as a guided, reproducible sequence.

Step 1 — Land-use masking and crop-class separation

- Load CORINE land cover in UDENE and filter to relevant agricultural classes.
- Sub-classify wheat vs barley areas using the case study's local agricultural mapping inputs (as provided in the course package).

Step 2 — Extract and summarize CAMS CO_2 fields

- Activate CAMS CO_2 and subset spatially to the Izmir study boundary.
- Extract CO_2 values over wheat and barley polygons/ROIs.
- Compute summary statistics (mean, distribution) for each land-use class.

Step 3 — Apply fertilizer emission-factor conversion (CO_2e)

- Use typical fertilizer application ranges for each crop class (course assumptions) and apply an emission factor (EF) to estimate N_2O.
- Convert estimated N_2O to CO_2e using the GWP multiplier.
- A simplified teaching formula used in the module is:

$$\mathrm{CO_2e}_{\mathrm{fertilizer}} = (N_{\mathrm{applied}}) \times (EF_{N2O}) \times 265$$

Step 4 — Optional advanced component: SOC change accounting

Students may estimate SOC change with a simplified structure such as:

$$\Delta SOC = SOC_{\mathrm{initial}} - SOC_{\mathrm{final}}$$

If SOC declines, the difference is treated as an emission contribution (or a loss of sequestration potential), supporting net-emissions framing.

Step 5 — Combined outputs (EO + land-use CO_2e)

Students produce:

- CO_2 footprint maps (CAMS-based)
- Land-use-driven CO_2e tables (wheat vs barley)
- Comparative bar charts and spatial interpretation maps
- Scenario narratives and policy-ready summaries

8.4 Worked Example Calculation

The following example illustrates the fertilizer-driven CO_2e logic used for wheat vs barley comparison in the case study (as a transparent, reproducible classroom calculation).

Table 44: Example Fertilizer-to-CO_2e Calculation (per hectare)

Crop Type	N Applied (kg N/ha)	Emission Factor (EF)	Estimated N_2O (kg)	CO_2e (kg/ha)
Wheat	180	1.3%	2.34	620.1
Barley	80	1.3%	1.04	275.6

Interpretation: Under these assumptions, wheat emits approximately **2.2×–2.3×** more CO_2e per hectare than barley, primarily due to higher nitrogen input intensity.

8.5 Interpretation for Urban and Regional Climate Strategy

This section trains students to interpret land use as a measurable driver of city-region carbon outcomes. The key analytical takeaways typically include:

- Fertilizer-driven emissions can dominate agricultural CO_2e differences.
- Wheat areas may contribute disproportionately to agricultural CO_2e under nitrogen-intensive management.
- Land-use change and management change are credible mitigation levers.
- The combined method (**CAMS CO_2 + CORINE + emission factors**) supports spatially targeted, scenario-ready planning.

8.6 Mitigation Pathways Students Develop

Students translate results into scientifically grounded recommendations, framed as mitigation pathways with expected reduction ranges (as scenario parameters for planning exercises):

- **Pathway A — Fertilizer optimization (especially wheat areas):** 12–18% CO_2e reduction
- **Pathway B — Crop switching (wheat → barley where feasible):** 20–35% CO_2e reduction
- **Pathway C — No-till / SOC enhancement practices:** 10–15% net reduction via sequestration effects
- **Pathway D — Precision agriculture (input minimization):** 10–20% reduction in fertilizer-related emissions

8.7 Why This Section is a High-Impact UDENE Value-Add

This land-use carbon modelling component differentiates the educational plan by demonstrating advanced integration of EO/model CO_2 data with land-use classification and carbon accounting logic. It strengthens scalability (replicable method across regions), improves policy relevance (agriculture as an actionable mitigation domain), and provides a clear research-level dimension that reviewers can recognize as a substantive scientific and educational contribution.

9 EU POLICY INTEGRATION AND STRATEGIC ALIGNMENT

This section explains how the Educational Plan operationally supports major EU policy agendas in climate action, environmental monitoring, air quality improvement, digital transformation, education modernization, and sustainable urban development. The combined use of Copernicus EO datasets, UDENE analytical tools, competency-based pedagogy (SCID/DACUM), and real municipal case studies creates a direct line between EU policy objectives and the concrete skills that learners acquire and demonstrate.

9.1 Alignment Overview

The module is not positioned as a general awareness course. Instead, it trains an "Urban EO Environmental Analyst" profile capable of producing evidence products (maps, time-series, validation metrics, scenarios, and policy briefs) that are usable by municipalities, agencies, and research actors. This makes the course structurally aligned with EU strategies that require measurable capacity building, transparent monitoring, and reproducible decision-support workflows.

Table 45: High-Level Alignment Map (EU Frameworks → Course Contributions)

EU / International Framework	Primary Policy Aim	Direct Course Contributions (What Students Produce)
European Green Deal (EGD)	Climate neutrality, sustainable transition	CO_2 footprint reasoning; land-use carbon modelling; sector attribution; mitigation scenarios
Fit for 55	55% GHG reduction by 2030 (legislative package)	CO_2 quantification skills; transport/heating mitigation logic; scenario-based reporting outputs
Zero Pollution Action Plan	Reduce pollution impacts; improve monitoring	NO_2 hotspot mapping; PM_{10} seasonal analysis; EO-to-ground validation; actionable interventions
Digital Education Action Plan (2021–2027)	Digital learning ecosystems + digital skills	UDENE-based hands-on analysis; EO/GIS literacy; data processing and validation competencies
European Education Area	Quality, inclusion, mobility, comparability	Competency-based design; replicable modules; open/transferable materials; interdisciplinary structure
SDG 11 (Sustainable Cities)	Cleaner air, sustainable planning, resilience	Urban air quality mapping; mitigation scenario design;

EU / International Framework	Primary Policy Aim	Direct Course Contributions (What Students Produce)
		evidence-based planning exercises
Copernicus User Uptake / GEO Capacity	Expand EO use and capacity	Copernicus dataset literacy; reusable training packages; applied workflows for societal benefit
UNFCCC Transparency Framework	Capacity for emissions reporting and transparency	Quantification logic; CO_2e conversion reasoning; validation and documentation discipline

9.2 European Green Deal: Climate Action, Sustainable Land Use, and Climate-Neutral Cities

The European Green Deal aims to make Europe climate-neutral by 2050, requiring both emissions reductions and strong monitoring capacity. This Educational Plan directly supports those requirements by training learners to identify high-emission areas, interpret sectoral drivers, and propose feasible interventions supported by EO-derived evidence.

Key contribution pathways include:

- **Climate action and decarbonization:** CO_2 footprint mapping, hotspot identification, and sector-aware interpretation (transport, heating, industry, land use).
- **Sustainable agriculture (Farm-to-Fork):** the land-use carbon modelling component directly supports reduced fertilizer intensity, lower N_2O-driven CO_2e, soil carbon conservation, and crop-switching strategies.
- **Biodiversity and sustainable land use:** CORINE-driven land-use mapping supports differentiated carbon profiles and highlights opportunities for regenerative practices.
- **Climate-neutral cities:** the Istanbul–Ankara–Izmir case studies demonstrate mobility measures, heating decarbonization, and land-use interventions in a format that cities can adapt.

9.3 Fit for 55: Building Quantification and Mitigation Capacity for 2030 Targets

Fit for 55 is fundamentally a delivery and compliance agenda. While the course does not replace formal inventory systems, it builds the analytical skills and evidence logic that underpin reporting and implementation processes.

The course contributes through:

CO_2 quantification and interpretation skills: footprint mapping, source-attribution reasoning, and $N_2O \rightarrow CO_2e$ conversion logic used in land-use scenarios.

Transport emission reduction support: NO_2 hotspot analysis provides the spatial basis for Low Emission Zones (LEZ), public transport electrification strategies, and corridor-level mobility interventions.

Building and heating emissions relevance: PM_{10} seasonal dynamics provide evidence for residential heating upgrades, retrofit prioritization, and fuel-switching strategies.

9.4 Zero Pollution Action Plan: Monitoring Modernization and Actionable Air-Quality Evidence

The Zero Pollution Action Plan requires both measurable improvements and modernization of monitoring practices. The module aligns particularly strongly here because it trains learners to produce outputs that are directly usable in municipal air-quality action planning.

Course elements that directly operationalize Zero Pollution objectives

- **NO_2 hotspot mapping** to identify exposure-critical zones and corridor-level priorities.
- **PM_{10} seasonal trend analysis** to reveal heating-driven winter burdens and episodic events (e.g., dust transport).
- **EO-to-ground validation** using R^2/RMSE and bias interpretation to strengthen transparency and scientific credibility.
- **Scenario development exercises** that translate observed patterns into feasible mitigation actions.

9.5 Digital Education Action Plan (2021–2027): Digital Ecosystems and Green Digital Skills

The module fits the Digital Education Action Plan because it is designed around hands-on digital analysis rather than passive instruction. UDENE serves as the learning platform through which students repeatedly practice data handling, processing, and interpretation.

- **High-quality digital education ecosystems:** Copernicus data access, UDENE-based labs, and structured digital workflows.
- **Digital skills and competence development:** EO literacy, GIS reasoning, data processing, validation, visualization, and environmental modelling—positioned as advanced "green digital skills" relevant to public agencies and industry.

9.6 European Education Area: Quality, Transferability, and Interdisciplinary Competency Design

The Educational Plan supports European Education Area goals by using competency-based design (DACUM + SCID), producing replicable modules and case studies, and enabling cross-border portability. The interdisciplinary nature (EO + environmental engineering + urban planning) strengthens relevance for multiple institutional settings, while the course structure supports transparent assessment and comparable learning outcomes.

9.7 SDG 11 and International EO/Transparency Strategies

Beyond EU frameworks, the course is consistent with global agendas that emphasize sustainable cities and transparent environmental monitoring.

- **SDG 11 (Sustainable Cities and Communities):** the module supports air-pollution reduction targets through NO_2 and PM_{10} modelling and supports climate mitigation planning through scenario exercises tied to real urban challenges.
- **Copernicus user uptake and GEO capacity building:** expands EO user competence and provides transferable training materials.
- **UNFCCC transparency capacity:** builds practical competence in quantification logic, documentation discipline, and scenario-based reasoning.

9.8 Summary of Added Value for Europe and Partner Countries

This Educational Plan strengthens the capacity of municipalities, agencies, and universities by delivering a workforce-ready skill set for EO-enabled environmental analysis. It supports carbon-neutrality pathways, improves air-quality planning through scientifically grounded monitoring and validation, helps mainstream EO literacy in higher education, and contributes to the development of green digital jobs aligned with long-term EU transformation agendas.

10 REPLICATION AND SCALABILITY STRATEGY

10.1 Purpose and Design Intent

A core UDENE objective is that educational outputs are replicable, transferable, open, and adaptable across different institutional contexts. This Educational Plan was therefore designed not as a single-university course, but as a modular, plug-and-play training package that universities, ministries, municipalities, and NGOs in UDENE partner countries can adopt with minimal friction. The design prioritizes open EO data, browser-based delivery through UDENE, competency-based modularity (SCID), and fully documented learning materials to reduce dependency on local infrastructure or proprietary resources.

10.2 Replication Principles

The replication logic is built on five practical principles that remove common barriers to adoption:

1) Tool-based learning using open EO data

All teaching relies on free, globally accessible datasets (e.g., Sentinel-5P, CAMS products, land-use layers, and open or nationally available ground monitoring where applicable). This eliminates dependence on proprietary datasets and ensures that the same assignments can be executed in any country.

2) Platform-based implementation through UDENE

UDENE supports browser-based workflows and standardized analysis steps, which reduces the need for local installations, GIS laboratories, or high-performance computing. Institutions can implement the module even with limited technical infrastructure.

3) SCID modular structure

The module is structured around competencies, outcomes, tasks, and performance assessments. This makes it easy to:

- translate into other languages,
- adapt to local institutional requirements,
- scale into micro-credentials or professional training, and
- integrate into different degree programs.

4) Complete documentation and standard learning materials

Replication is supported by a full package of openly shareable teaching assets, including instructor and student guides, dataset access notes, lesson plans, assignments, rubrics, and demonstrative case studies. This reduces "reinvention work" for adopting institutions.

5) Multilingual-ready implementation

Materials are prepared in English (UDENE requirement) and Turkish (local adoption) and are designed to be straightforward to translate into additional partner-country languages. Because the structure is task-centric, translation is primarily a controlled terminology exercise rather than a redesign effort.

Table 46: Replication Enablers and What They Remove

Replication Enabler	Practical Effect	Barrier Removed
Open EO datasets	Same inputs available everywhere	Proprietary data dependence
UDENE browser workflows	No installation; standardized steps	Lack of GIS labs / software
SCID task-based design	Modular, reusable, easy to adapt	Curriculum redesign overhead
Full documentation pack	Ready-to-teach implementation	High onboarding cost for new trainers
Multilingual-ready structure	Efficient translation and localization	Language and accessibility barriers

10.3 Scalability Across Institutional Contexts

The course is intentionally deployable across diverse UDENE partner ecosystems. The delivery format can be scaled based on the audience and institutional maturity.

- **Universities with established EO capacity** can adopt the module as a 3 ECTS elective, enrich labs with optional Python or GEE extensions, and integrate local datasets for research-oriented variations.
- **Universities with limited infrastructure** can deliver the full course through UDENE-only workflows, using browser-based labs and lightweight supporting lectures, without specialized hardware or software.
- **Ministries, municipalities, and urban agencies** can deploy the content as a professional upskilling program or capacity-building bootcamp, directly using

outputs such as NO_2 hotspot maps, PM_{10} seasonal charts, CO_2 footprint summaries, and scenario templates to support action planning.
- **NGOs and civil society organizations** can adapt components for citizen-science initiatives, public awareness, youth climate engagement, and environmental education programs, using simplified pathways while retaining scientific credibility.

10.4 Geographic Scalability

The workflow is geography-agnostic because Copernicus datasets are globally available and UDENE supports any location selection. This means the same curriculum and assignments can be executed in different cities simply by changing the area of interest—without changing the methodological core. As a result, the approach is transferable across Türkiye, the Balkans, the Caucasus, the Middle East, North Africa, Sub-Saharan Africa, Latin America, and small island states, provided that basic connectivity and access conditions are met.

10.5 Minimum Requirements for Replication (Low-Barrier Implementation)

Replication requires only lightweight conditions:

- stable internet access,
- one computer per 2–3 students (recommended),
- projector or screen-sharing capability for instruction,
- access to the UDENE portal, and
- downloadable PDF-based guides and templates.

No additional software installations are required for the standard course version.

10.6 Adaptation Guide for New Cities

To replicate the case-study logic in a new city, instructors and students follow a controlled adaptation pathway:

1) Select the target city in UDENE.
2) Load the relevant EO and contextual layers used in the assignments.
3) Optionally acquire local AQMS data for validation (where accessible).
4) Execute assignments exactly as written to preserve assessment comparability.
5) Localize scenario design to reflect city-specific sources, governance levers, and feasibility constraints.

This ensures the course "adapts itself" to local pollution and carbon patterns while preserving the same competency and assessment structure.

10.7 Long-Term Scalability Roadmap

The Educational Plan can evolve into larger formats without rewriting the core architecture, such as:

- a multi-semester EO certificate pathway,
- professional micro-credentials for municipal staff,
- an online UDENE MOOC,
- a reusable curriculum block for international degree programs, and
- recurrent municipal training cycles.

Future expansion modules can be appended modularly (e.g., ML-based EO forecasting, EO data fusion, and carbon neutrality modelling packages), while maintaining the same SCID-aligned performance structure.

10.8 Summary

This Educational Plan is modular, technically lightweight, methodologically standardized, and globally applicable. It is transferable because it uses universal open datasets, runs on a universally accessible platform (UDENE), and is anchored in a competency-based SCID structure with complete documentation and replicable case studies. As a result, it satisfies UDENE's replication requirement by design: the course can be adopted, delivered, and scaled across partner countries with minimal adaptation costs and without compromising scientific rigor or assessment transparency.

11 QUALITY ASSURANCE ALIGNED WITH ERASMUS QUALITY STANDARDS

11.1 Quality Assurance Approach

The Quality Assurance (QA) framework for this Educational Plan is designed to maintain high pedagogical standards while ensuring full consistency with Erasmus Quality Standards. QA is embedded across the full module lifecycle—design, delivery, assessment, monitoring, and long-term sustainability—so that learning quality is transparent, inclusive, measurable, and replicable across institutions and countries.

11.2 Erasmus Quality Standards: Compliance Structure

Erasmus Quality Standards are commonly operationalized through four pillars:

1) **Relevance**
2) **High-quality learning experience**
3) **Robust assessment mechanisms**
4) **Support, inclusivity, and sustainability**

The course aligns to each pillar through explicit design decisions, performance-based assessment, and continuous improvement loops.

Table 47: Erasmus Quality Standards → Course QA Measures

Erasmus QA Pillar	What It Requires	How This Module Ensures Compliance
1) Relevance	Societal, labour-market, and academic relevance	Targets urban air pollution + GHG; trains an Urban EO Environmental Analyst profile; uses real datasets and real workflows
2) High-quality learning experience	Clear outcomes, coherent pedagogy, appropriate workload	PCC learning outcomes; SCID sequencing; 3 ECTS (90 hours) with ≥50% hands-on UDENE work
3) Robust assessment mechanisms	Transparent, fair, evidence-based grading	Rubric-based grading; performance outputs (maps/graphs/metrics/policy briefs); consistent weighting model
4) Support, inclusivity, sustainability	Accessibility, learner support, long-term reuse	Open data and free tools; browser-based UDENE; multilingual-ready materials; instructor handbooks; versioning and archiving

11.3 Standard 1 — Relevance of the Learning Programme

This Educational Plan is designed to respond to societal needs, labour-market demand, and academic gaps simultaneously. It addresses urgent urban challenges—including air pollution hotspots, seasonal particulate burdens, and carbon-footprint pressures—while explicitly supporting strategic policy objectives associated with the Green Deal and Zero Pollution agendas. From a labour-market perspective, graduates develop competencies directly applicable to municipal environmental departments, air-quality and climate-policy units, EO/GIS consultancies, environmental engineering firms, modelling laboratories, and cleantech innovation ecosystems. Academically, the module bridges environmental engineering, EO literacy, geospatial reasoning, and policy-oriented interpretation by grounding all learning in real datasets (Sentinel-5P, CAMS, land-use layers, and—where available—ground monitoring), ensuring students work with authentic scientific and decision-support inputs rather than synthetic exercises.

11.4 Standard 2 — High-Quality Learning Experience

The learning experience is built around SCID-aligned instructional design and UDENE's virtual-laboratory logic, ensuring that competencies are developed progressively and practiced repeatedly. Learning outcomes are expressed in the Performance–Condition–Criteria (PCC) format, enabling measurable attainment and consistent instruction across cohorts. The workload structure meets the 3 ECTS expectation (75–90 hours) and deliberately adopts the upper bound (90 hours) to sustain deep hands-on engagement; practical work constitutes at least half of the workload through UDENE tools.

Pedagogical coherence is maintained through a consistent workflow logic that students repeatedly apply:

- Define the problem and context
- Acquire EO and contextual data
- Process and prepare datasets
- Analyze pollutant/carbon patterns
- Validate with ground measurements (where available)
- Evaluate limitations and uncertainty
- Design mitigation scenarios and communicate results

The module's "high-quality" character is further strengthened through active learning: students manipulate EO data, produce maps and graphs, compute validation metrics, develop case-study narratives, and translate findings into mitigation scenarios and policy-facing outputs.

11.5 Standard 3 — Robust and Transparent Assessment

Assessment follows a competency-based evaluation model consistent with SCID and Erasmus expectations: learners are not evaluated through memorization, but through demonstrated ability to perform defined tasks using UDENE and Copernicus assets. The programme uses a clear weighting system and requires performance rubrics for consistency and transparency.

Assessment weighting

- Participation and engagement: **20%**
- Weekly assignments: **30%**
- Final case study: **50%**

Evidence-based grading is mandatory. Students must submit concrete deliverables, typically including:

- scientific maps,
- time-series graphs,
- validation tables and metrics (e.g., R^2, RMSE), and
- scenario and policy-recommendation outputs.

Rubrics are used to remove ambiguity, align grading across instructors, and ensure students understand expectations and benchmarks in advance. This makes assessment transparent, auditable, and scalable across institutions.

11.6 Standard 4 — Support, Inclusivity, and Accessibility

The module is designed to be accessible by default. It relies on open data and free tools, with UDENE providing browser-based access that reduces dependency on proprietary software, high-performance hardware, or specialized laboratories. This supports participation regardless of socio-economic background or institutional infrastructure. Materials are provided in English and Turkish, with a structure that is straightforward to translate into additional languages due to its task-centric SCID design.

Digital accessibility and learner support are reinforced through:

- step-by-step lab instructions,
- visual-first learning assets,
- beginner-friendly guidance for metadata and QA interpretation, and
- clear documentation standards for reproducible work.

Instructor support is also standardized to reduce instructor-dependent variability. Instructors receive a structured package (handbook, run-ready lesson scripts, prepared datasets where applicable, assignments, rubrics, and case-study templates), which stabilizes delivery quality across different trainers and institutions. Gender inclusivity is supported through proactive encouragement for participation and through course framing aligned with green-digital careers where representation is a priority.

11.7 Monitoring, Evaluation, and Continuous Improvement

To ensure ongoing improvement and sustained relevance, the QA framework includes a structured monitoring and evaluation cycle:

- **Student feedback surveys** at Week 1, Week 3, and Week 6 to capture onboarding friction, mid-course workload balance, and end-of-module outcomes.
- **Instructor reflection logs** after each session to document what worked, where learners struggled, and what requires revision.
- **Performance analytics** to detect systematic gaps (e.g., recurring errors in CRS handling, QA filtering, seasonal decomposition, or validation interpretation) and adjust labs/lectures accordingly.
- **Optional external review**, where UDENE partners or external EO experts can review materials and outputs for scientific robustness and usability.

During delivery, QA also includes routine checks: weekly review of outputs, consistency review of EO workflows, monitoring for scientific correctness, detection of retrieval/processing errors, and support pathways for learners facing technical limitations.

11.8 Sustainability and Post-Implementation Quality Control

Long-term sustainability is ensured through archiving and versioning. All materials are stored in the UDENE portal for continued availability, and the course structure supports annual updates to datasets, cities, and tools without redesigning the competency framework. The SCID architecture allows controlled iteration while preserving outcome comparability. A train-the-trainer approach further strengthens sustainability by enabling instructors to transfer delivery capacity to other institutions, supporting exponential dissemination.

11.9 QA Summary

This Quality Assurance framework ensures that the module remains relevant, delivers a high-quality learning experience, assesses performance transparently, and supports inclusive, open-access participation. Through embedded monitoring, documentation, and structured improvement cycles, the Educational Plan is designed to meet Erasmus Quality Standards while remaining replicable and sustainable across UDENE partner contexts.

12 RISK ANALYSIS AND MITIGATION

This Educational Plan depends on (i) continuous access to Earth Observation (EO) datasets, (ii) UDENE platform functionality, (iii) digital skill development, (iv) competency-based learning design, and (v) real urban environmental data. Because the module blends technical workflows with performance-based education, implementation risks can emerge at different points in delivery. This section consolidates the key risks into six groups—technical, data-related, pedagogical, operational, student-performance, and long-term sustainability—and defines mitigation measures that preserve continuity, learning quality, and replicability.

12.1 Consolidated Risk Matrix

The consolidated risk matrix below provides a single, implementation-focused view of the most plausible risks that may affect delivery of the module across different UDENE partner contexts. It summarizes each risk category with a clear statement of the failure mode, a qualitative rating of risk level (based on the combined effect of probability and impact), and the primary mitigation measures embedded in the course design. The matrix is intended as a practical management tool: it helps instructors and host institutions prioritize preventive actions before deployment, and it defines contingency pathways that protect learning continuity, assessment fairness, and the scientific integrity of student outputs if disruptions occur.

Table 48: Risk Matrix and Primary Mitigations

Risk Category	Risk Statement (Summary)	Risk Level	Probability	Impact	Primary Mitigation Measures
Technical	UDENE downtime, slow connections, device/browser constraints disrupt labs and submissions	Medium	Medium	High	Backup workflows; offline PDFs (screenshots + steps); alternative viewers (EO Browser/CAMS); flexible deadlines
Platform Stability	Service changes, caching limits, or peak-load issues degrade performance	Medium	Low	High	Caching guidance; mirrored/prepared sample subsets; platform-agnostic workflow options
Data Availability & Quality	Cloud gaps, model smoothing, outdated land-use layers affect	Medium	Low–Medium	Medium	Multi-day/monthly composites; validation-driven interpretation; alternative layers;

Risk Category	Risk Statement (Summary)	Risk Level	Probability	Impact	Primary Mitigation Measures
	results and comparability				manual classification guidance
Pedagogical	Learners lack EO/GIS fundamentals or misinterpret maps without scientific reasoning	Medium	Medium	Medium	Week 1 fundamentals; step-by-step tutorials; guided interpretation prompts; glossary and scaffolding
Student Preparedness	Uneven starting levels lead to slow progress or frustration	Medium	Medium	Medium	Pre-course orientation; starter exercises; tiered task difficulty; peer-supported lab structure
Student Performance & Integrity	Over-focus on visuals, shallow interpretation, or copied maps reduce competency evidence	Medium	Medium	Medium	Rubrics weighted toward reasoning/validation; individualized AOI/ROI; unique written outputs; scenario originality requirements
Operational & Institutional	Instructor unfamiliarity or limited institutional support slows adoption	Low–Medium	Medium	Medium	Instructor handbook; pre-semester training; turnkey package; optional remote support sessions
Inclusivity & Accessibility	Digital literacy gaps and participation barriers reduce outcomes	Low	Medium	Medium	Accessibility-first design; multilingual materials; alternative submission formats; inclusive facilitation
Long-Term Sustainability	Platform evolution or data-format updates break workflows over time	Medium	Low	Medium–High	Versioned documentation; periodic updates; maintained metadata sheets; alternative data sources/viewers

12.2 Technical and Platform Risks

UDENE platform downtime or temporary outages can interrupt hands-on labs and delay assignment completion. The mitigation strategy is to maintain continuity through redundancy: offline PDF workflow packs (screenshots and step-by-step instructions), pre-downloaded sample subsets of Sentinel-5P and CAMS layers, and platform-agnostic alternatives (e.g., EO Browser for Sentinel visualization, CAMS web interfaces/charts for model fields). Where disruption occurs, assessment continuity is protected through deadline flexibility and clearly defined contingency submission options.

Slow internet or bandwidth limitations (institutional or home networks) can prevent smooth interaction with raster layers and time-series tools. Mitigations include low-resolution preview guidance, instructor-provided static datasets for designated weeks, and offline screen-recorded tutorials so students can complete interpretation and reporting tasks without continuous connectivity.

Browser/device incompatibility and performance constraints can affect older computers when rendering large rasters or running interactive tools. Mitigation relies on cross-browser testing (Chrome/Firefox/Edge), assignment variants that reduce computational burden (smaller region-of-interest selections and shorter time windows), and encouraging campus/lab usage during the most processing-intensive weeks.

12.3 Data Availability and Data Quality Risks

Sentinel-5P gaps due to cloud cover can reduce usable NO_2 retrievals on certain days and bias short time windows. Mitigation is methodological: learners are guided to use multi-day and monthly composites, apply QA filtering systematically, and—when necessary—work with pre-processed instructional samples to ensure comparability of outputs across students and cohorts.

CAMS underestimation or smoothing of PM peaks is a known limitation of model-based reanalysis products, particularly during extreme local events (heating spikes, dust intrusions). The course turns this into a competency outcome rather than a failure mode: the EO–ground validation assignment explicitly trains students to quantify and interpret such deviations, document limitations, and communicate uncertainty in decision-support language.

Land-use layer recency and classification mismatch (e.g., CORINE update cycles or regional coverage differences) can reduce precision in land-use-dependent modelling. Mitigation includes allowing supplementation with local agricultural layers where available, permitting structured manual classification exercises, and explicitly teaching temporal mismatch as part of scientific interpretation and reporting (rather than hiding it).

12.4 Pedagogical Risks

A common risk is that **students enter with limited EO/GIS background**, which can slow progress and increase frustration. The mitigation approach is embedded in the curriculum architecture: Week 1 is dedicated to fundamentals, supported by step-by-step UDENE tutorials, low-stakes starter exercises, and a glossary of EO terms and metadata concepts.

A second pedagogical risk is **map-driven interpretation without atmospheric reasoning**, where students "describe patterns" but cannot explain mechanisms. Mitigation is achieved through explicit scaffolding: atmospheric science content (e.g., boundary-layer dynamics, inversions, photochemistry) is paired with guided interpretation prompts and structured in-class discussion protocols that require cause–effect reasoning and uncertainty statements.

Finally, heterogeneous student technical skills can produce inequity in performance skill learners outputs. Mitigation includes tiered task design: optional advanced extensions for high-, simplified pathways for beginners that still meet core competencies, and collaborative lab formats that encourage peer support without compromising individual accountability.

12.5 Student Performance and Academic Integrity Risks

Students may over-prioritize map aesthetics and underdeliver on analysis, validation, and scenario reasoning. Mitigation is implemented through rubric design: grading emphasizes scientific interpretation, validation quality, and evidence-backed scenario logic—so high-quality visuals alone cannot achieve high marks.

Because EO outputs can appear visually similar, copying and template replication is a plausible risk. Mitigation combines assessment design and evidence requirements:

- individualized AOIs/ROIs or bounding boxes,
- required unique written interpretations linked to the student's chosen context,
- mandatory inclusion of validation or scenario elements that demand original reasoning, and
- a final case study that requires student-designed scenarios and documented workflow choices.

12.6 Operational and Institutional Adoption Risks

Implementation can be slowed if instructors are unfamiliar with UDENE or lack confidence in EO workflows. Mitigation is to standardize delivery independence through an instructor handbook, pre-semester training (workshop + recorded tutorials), and run-ready lesson scripts. Where institutional support is limited, the turnkey curriculum package and optional remote support sessions reduce dependency on local IT or specialized GIS staff and facilitate integration into existing MSc or professional training structures.

12.7 Inclusivity and Accessibility Risks

Students with lower digital literacy or limited access conditions may face digital accessibility challenges. Mitigation is an accessibility-first delivery strategy: multilingual instructions, visual-first materials, screenshot-based tutorials, and alternative submission formats that preserve assessment integrity. Representation barriers—such as gender disparities in geospatial fields—are addressed through inclusive facilitation practices, proactive outreach/encouragement, and (where feasible) invited speakers or role-model visibility to normalize participation pathways.

12.8 Long-Term Sustainability Risks

A long-term risk is dependency on a specific UDENE platform version or interface that may evolve. Mitigation is governance-driven: maintain versioned documentation, apply scheduled reviews/updates (e.g., each semester or annually), and preserve platform-agnostic backup pathways (EO Browser/CAMS viewers) so the educational logic remains valid even if interfaces shift.

A related risk is that data product formats or metadata conventions change (Sentinel or CAMS updates). Mitigation includes maintaining an updated metadata sheet, adding instructor-level technical notes for new formats, and identifying alternative EO sources where necessary to preserve continuity of learning outcomes and assignments.

12.9 Summary

This risk framework prioritizes continuity of delivery, scientific validity of outputs, fairness of assessment, and long-term maintainability. The Educational Plan anticipates realistic technical, data, pedagogical, operational, inclusivity, and sustainability risks and pairs each with actionable mitigations—ensuring the course remains resilient, replicable, and instructionally reliable under varying institutional constraints.

13 CONCLUSION

This Educational Plan sets out a comprehensive, innovative, and scalable approach for integrating Earth Observation (EO) into higher education and professional training through Copernicus resources and the UDENE virtual laboratory environment. By combining scientific rigor, digital competence development, hands-on EO workflows, and explicit policy relevance, the module equips learners with practical capabilities to address contemporary challenges in urban air quality, greenhouse-gas emissions, and sustainable urban development. The course demonstrates how core datasets—particularly Sentinel-5P, CAMS, and CORINE—can be operationalized in end-to-end analytical pipelines (acquisition, processing, analysis, validation, reporting, and scenario design). A distinctive contribution is the land-use–dependent carbon modelling component, which introduces research-level reasoning by integrating CO_2 fields with land-use classification and emissions conversion logic, positioning the module as technically advanced and differentiated within UDENE educational outputs.

13.1 Objectives Achieved and UDENE Call Compliance

The module fully meets—and in several dimensions exceeds—the UDENE Open Call requirements through a tightly aligned SCID/DACUM architecture, performance-based learning outcomes, and replicable delivery materials:

- **Learning outcomes and competency logic:** Outcomes are defined through the **Performance–Condition–Criteria (PCC)** approach and trained through SCID task sheets.
- **ECTS-compliant structure:** A complete **3 ECTS / 90-hour** learning design with a balanced distribution of theory, labs, assignments, and a capstone case study.
- **Competency-oriented assignments and assessment:** Each assignment is anchored in DACUM duties and evaluated through transparent rubrics emphasizing demonstrable performance with UDENE and Copernicus data.
- **Demonstrative case studies:** Three complete, context-rich cases (Istanbul, Ankara, Izmir) illustrate the full professional workflow: **Problem → Data → Processing → Validation → Scenario → Solution.**
- **Open-access educational package:** All lesson plans, lab scripts, datasets/guides, rubrics, and case studies are prepared for publication on the UDENE portal under a **CC BY-NC-SA** license.

13.2 Policy Contribution and Strategic Relevance

The Educational Plan directly advances major European and international agendas by converting high-level policy objectives into implementable training practice. It is aligned with: the European Green Deal, Fit for 55, the Zero Pollution Action Plan, the Digital

Education Action Plan, the European Education Area, and SDG 11 (Sustainable Cities & Communities). In practical terms, the module strengthens policy execution capacity by training learners to produce defensible EO-based evidence—maps, time-series outputs, validation results, and scenario briefs—that can support municipal decision-making, air quality action planning, carbon footprint reasoning, and climate-smart land-use strategies.

13.3 Replicability, Sustainability, and Long-Term Value

The course is designed as a modular, plug-and-play asset that is transferable across institutions and countries. It relies on globally accessible EO data, requires no proprietary software, and is delivered through browser-based UDENE workflows supported by standardized documentation (instructor and student handbooks, step-by-step labs, and assessment rubrics). The SCID structure ensures the module can evolve over time—by updating datasets, extending case study locations, or integrating new EO missions—without compromising pedagogical coherence or assessment integrity. This makes the module suitable for adoption not only by universities, but also by municipalities, ministries, consultancies, and civil-society organizations seeking applied EO capacity building.

13.4 Final Statement

Overall, this Educational Plan provides a complete, accessible, scientifically credible, and policy-relevant training model that transforms complex air quality and climate challenges into structured, performance-based learning experiences. Through the integration of Copernicus data, UDENE tools, and SCID pedagogy, the curriculum does not only teach EO techniques; it enables learners to generate actionable evidence and develop feasible mitigation scenarios for healthier, more resilient, and more sustainable cities.

FEASIBILITY REPORT

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1. EXECUTIVE SUMMARY

This feasibility study evaluates the technical, operational, economic, and strategic viability of an EO-based Urban Air Quality & Carbon Intelligence Service built on Copernicus datasets and UDENE analytical tools. The proposed service provides municipalities, public authorities, and urban planners with scientifically validated, spatially explicit intelligence on NO_2, PM_{10} and CO_2 emissions, including land-use–dependent carbon footprint modelling.

The service transforms raw Earth Observation (EO) and reanalysis data into decision-ready indicators, hotspot maps, validated time-series, and policy-relevant mitigation scenarios. It is designed as a scalable, cloud-based analytical service that can be deployed across cities in Türkiye, Europe, and partner regions.

The feasibility assessment confirms that: - The service is technically feasible using existing Copernicus Sentinel-5P and CAMS products; - UDENE tools fully support the required workflows (data acquisition, processing, validation, scenario design); - There is observed strong demand from municipalities and public institutions for EO-based air quality and carbon intelligence; - The service can operate with no proprietary data dependencies, ensuring long-term sustainability; - The model is scalable, replicable, and commercially viable through service contracts, subscriptions, and institutional partnerships.

The study concludes that the proposed service is ready for pilot deployment and subsequent scale-up at national and international level.

2. CONTEXT, PROBLEM DEFINITION & RATIONALE

Figure 2.1 — Problem–Solution Logic Model (Schematic)

```
Urban Challenges ──► Data Gaps ──► Policy Uncertainty
      │                    │               │
      ▼                    ▼               ▼
 EO Observations ──► UDENE Analytics ──► Decision Intelligence
      │                    │               │
      ▼                    ▼               ▼
 NO2 / PM10 / CO2  ──► Validation & Scenarios ──► Actionable Policies
```

Interpretation: The figure demonstrates how EO data, when processed through UDENE tools, closes the gap between environmental observation and policy action.

Situation Analysis 2.1 — Baseline Conditions

- Monitoring infrastructure is spatially sparse
- Policy cycles require quantified, repeatable indicators
- Cities lack in-house EO expertise

This baseline justifies the need for an integrated EO intelligence service.

2.1 Urban Environmental Challenges

Cities face increasing pressure from: - Traffic-driven NO_2 pollution; - Seasonal PM_{10} exceedances linked to heating, industry, and dust transport; - Rising urban CO_2 footprints driven by transport, buildings, industry, and land-use choices.

Traditional monitoring systems rely on sparse ground stations, which: - Lack spatial coverage, - Cannot capture intra-urban variability, - Provide limited support for scenario modelling.

2.2 Why Earth Observation Is Needed

EO data enables: - Continuous, city-wide monitoring; - Cross-city comparability; - Independent validation of local measurements; - Evidence-based climate and air quality policy design.

However, most municipalities lack the expertise and tools to convert EO data into operational intelligence. This service directly addresses that gap.

2.3 Alignment with UDENE Mission

The proposed service: - Uses Copernicus EO data exactly as intended; - Integrates UDENE Explorer, Raster Engine, Time-Series and Validation modules; - Builds capacity and uptake of EO-based urban analytics; - Produces transferable and replicable outputs.

3. SERVICE CONCEPT & VALUE PROPOSITION

Figure 3.1 — Service Value Chain (Schematic)

```
Copernicus EO Data
        │
        ▼
 UDENE Processing Layer
        │
        ▼
 Scientific Validation
        │
        ▼
 Scenario Modelling
        │
        ▼
 Policy & Planning Support
```

Situation Analysis 3.1 — Stakeholder Needs Mapping

Stakeholder	Primary Need	Service Response
Municipality	Hotspot detection	NO_2 & PM_{10} maps
Ministry	MRV support	Validated indicators
Planners	Scenario testing	EO-based scenarios
Public	Transparency	Visual intelligence

3.1 Service Overview

The service delivers: - NO_2 hotspot mapping (Sentinel-5P); - PM_{10} seasonal and trend analysis (CAMS); - CO_2 urban footprint mapping (CAMS); - Land-use–dependent CO_2e modelling (e.g. wheat vs barley); - EO–ground validation; - Mitigation and policy scenarios.

3.2 Target Users

- Municipal environmental departments
- Ministries of environment and climate
- Metropolitan planning agencies
- Development agencies
- International donors and NGOs

3.3 Value Proposition

- Scientifically robust
- Spatially explicit

- Policy-relevant
- Cost-effective (free EO data)
- Rapid deployment

4. TECHNICAL FEASIBILITY

4.7 Satellite-Based Carbon Footprint Assessment of the Target Area

This section describes how the carbon footprint of the target area will be quantified using satellite-based data, complementing conventional inventory-based approaches and ensuring spatial completeness.

4.7.1 Objective

The objective of this analysis is to estimate the area-wide carbon footprint (CO_2 and CO_2e) of the selected urban or regional system by integrating Copernicus satellite observations, land-use data, and emission conversion factors. This enables the identification of carbon-intensive zones and supports targeted mitigation planning.

4.7.2 Data Sources

The carbon footprint assessment will be based on the following datasets:

- **CAMS CO_2 atmospheric concentration data** (Copernicus Atmosphere Monitoring Service)
- **Sentinel-5P ancillary atmospheric products** (contextual support)
- **CORINE Land Cover** for spatial attribution of emissions
- **IPCC / FAO emission factors** for CO_2e conversion (where applicable)

All datasets are accessed and processed through the UDENE platform.

4.7.3 Methodological Approach (UDENE-Based)

The assessment follows a structured, reproducible workflow:

1. **Definition of the target area**
   The geographic boundary of the study area is defined within UDENE using administrative or functional spatial units.

2. **Extraction of satellite-based CO_2 fields**
   CAMS CO_2 data are spatially subset to the target area and temporally aggregated to monthly or annual means.

3. **Spatial attribution using land-use data**
   CORINE Land Cover is used to disaggregate CO_2 patterns across urban, industrial, agricultural, and natural land-use classes.

4. **Carbon footprint estimation**
   Area-weighted CO_2 indicators are calculated, and where relevant, converted to CO_2-equivalent (CO_2e) values using standardized emission factors.

5. **Hotspot and intensity analysis**
   Carbon intensity maps (e.g. tCO_2e/km^2) are produced to identify priority mitigation zones.

4.7.4 Outputs

The analysis will generate:

- Satellite-based CO_2 footprint maps of the target area
- Land-use–specific carbon intensity indicators
- Comparative tables highlighting high-emission zones
- Input layers for scenario modelling and mitigation planning

4.7.5 Feasibility and Added Value

This approach is technically feasible due to the continuous availability of Copernicus data and the existing analytical capabilities of UDENE. It provides clear added value by:

- Covering areas with limited ground-based inventories
- Enabling spatially explicit carbon management
- Supporting alignment with climate neutrality and reporting frameworks

---

This section explains how the planned analyses will be implemented step-by-step, using concrete examples based on UDENE tools and Copernicus datasets. The level of detail intentionally mirrors the implementation logic described in the Final Project Report.

4.1 Implementation Example 1 — NO_2 Hotspot Mapping Using Sentinel-5P

Figure 4.1 — NO_2 Hotspot Mapping Workflow (Sentinel-5P + UDENE)

The figure illustrates the full processing chain from Sentinel-5P NO_2 acquisition to the generation of decision-ready hotspot maps, including quality filtering, temporal aggregation and spatial enhancement.

Objective
To identify traffic-driven NO_2 pollution hotspots at city scale and provide spatial evidence for mobility-related mitigation measures.

Input Data
- Sentinel-5P (TROPOMI) tropospheric NO_2 (Copernicus) - Urban boundary shapefile (city extent)

Method (UDENE Workflow)

1. Select the target city in UDENE Explorer.
2. Activate Sentinel-5P NO_2 layer.
3. Apply Quality Assurance filtering (QA ≥ 0.75) to remove low-quality pixels.
4. Aggregate daily observations into monthly averages to reduce noise.
5. Apply spatial smoothing (kernel density) via UDENE Raster Engine.
6. Overlay transport infrastructure layers (roads, corridors).
7. Export NO_2 hotspot maps and numerical summaries.

Output - Monthly NO_2 hotspot maps - Identification of priority intervention zones

Feasibility Justification
All steps rely on existing UDENE functionalities and free Copernicus data; no custom software development is required.

4.2 Implementation Example 2 — PM_{10} Seasonal Analysis Using CAMS

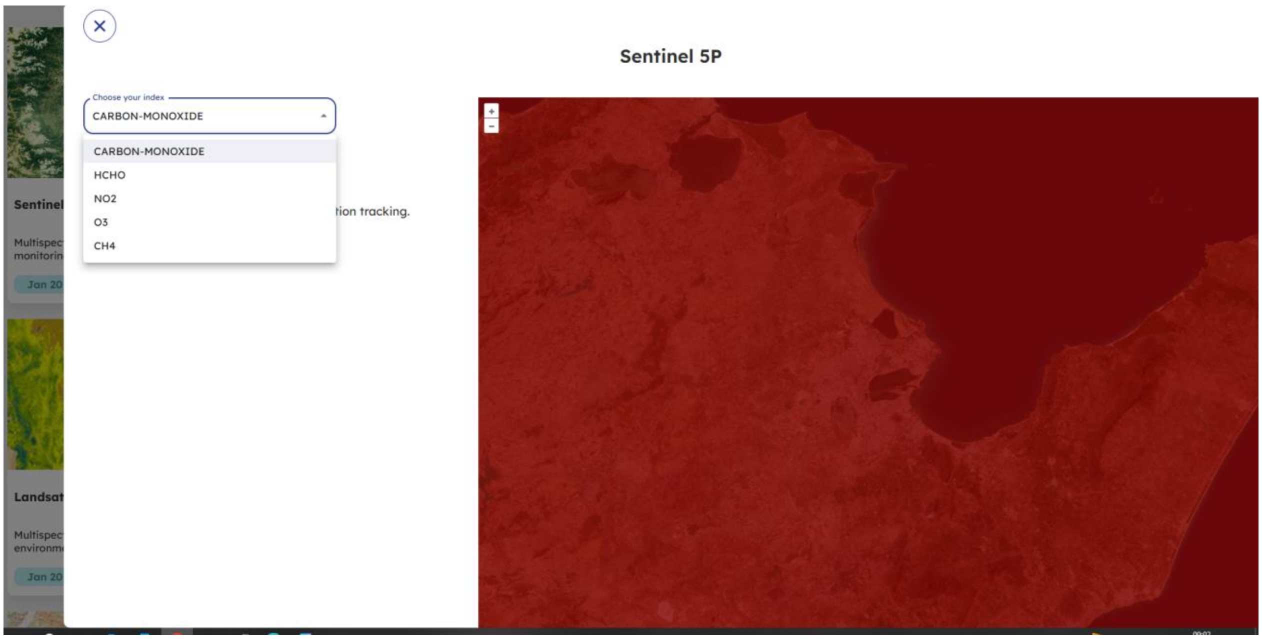

Figure 4.2 — PM_{10} Seasonal Analysis Workflow (CAMS + UDENE)

This figure presents the methodological flow for extracting daily CAMS PM_{10} values, aggregating them into seasonal indicators, and identifying winter-related pollution peaks.

Objective
To distinguish structural PM_{10} pollution (heating, industry) from episodic events (dust transport).

Input Data
- CAMS PM_{10} reanalysis (daily) - Ground air-quality station data (optional, for validation)

Method (UDENE Workflow)

1. Load CAMS PM_{10} dataset in UDENE.
2. Extract daily PM_{10} values for the city bounding box.
3. Compute monthly and seasonal averages using UDENE Time-Series Module.
4. Identify winter peaks and anomalous events.
5. Compare EO-derived PM_{10} with station measurements.

Output - Seasonal PM_{10} trend graphs - Quantified winter pollution increase

Feasibility Justification
CAMS data are continuously available and pre-integrated into UDENE, ensuring stable long-term operation.

4.3 Implementation Example 3 — Urban CO_2 Footprint Mapping

Objective
To generate a spatially explicit urban CO_2 footprint supporting climate-neutrality planning.

Input Data
- CAMS CO_2 atmospheric concentration fields - Urban and industrial land-use layers

Method (UDENE Workflow)

1. Activate CAMS CO_2 layer in UDENE.
2. Subset data to the city boundary.
3. Compute spatial averages and gradients.
4. Compare CO_2 patterns across urban, industrial and peri-urban zones.

Output - CO_2 concentration maps - Urban emission intensity indicators

Feasibility Justification
The workflow is computationally lightweight and fully supported by UDENE raster operations.

4.4 Implementation Example 4 — Land-Use–Dependent Carbon Footprint (Wheat vs Barley)

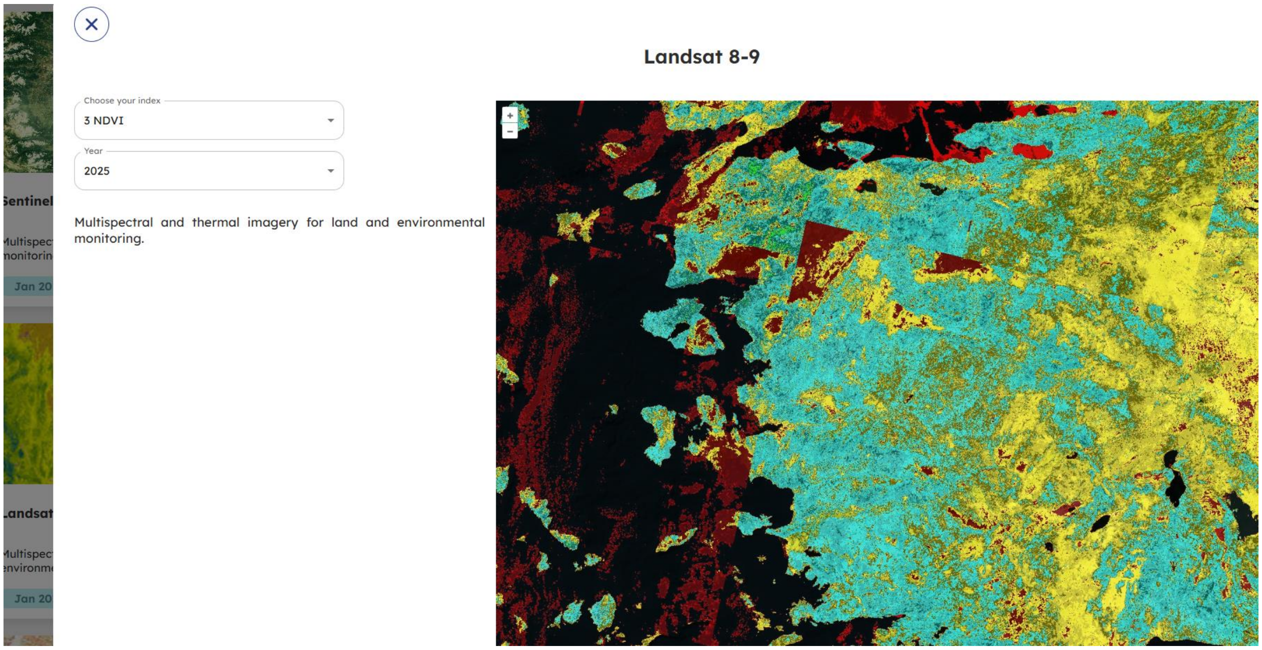

Figure 4.3 — Land-Use–Dependent Carbon Footprint Modelling

The figure shows how CAMS CO_2 data are combined with CORINE land-use classification to compare crop-specific carbon footprints and derive climate-smart land-use scenarios.

Objective
To demonstrate how agricultural land-use choices influence regional carbon footprints.

Input Data
- CAMS CO_2 - CORINE Land Cover - Fertilizer emission factors (FAO / IPCC)

Method (UDENE Workflow)

1. Load CORINE Land Cover dataset.
2. Mask agricultural areas and classify wheat vs barley zones.
3. Extract CAMS CO_2 values for each land-use class.
4. Apply fertilizer-based N_2O → CO_2e conversion factors.
5. Compare CO_2e emissions per hectare.

Output - Land-use–specific CO_2e tables - Comparative emission charts

Feasibility Justification
This analysis combines EO data with established emission factors, requiring no experimental data collection.

4.5 Implementation Example 5 — EO–Ground Validation

Figure 4.4 — EO–Ground Validation Workflow

This figure illustrates the validation logic applied to compare EO-derived indicators with ground-based measurements, including the computation of statistical performance metrics (R^2, RMSE).

Objective
To ensure scientific reliability of EO-based indicators.

Method (UDENE Workflow)

1. Import ground station coordinates.
2. Match EO observations temporally and spatially.
3. Compute R^2 and RMSE using UDENE Validation Module.
4. Interpret biases and uncertainties.

Output - Validation tables and scatter plots - Confidence assessment for policy use

---

4.6 From Analysis to Policy Scenarios

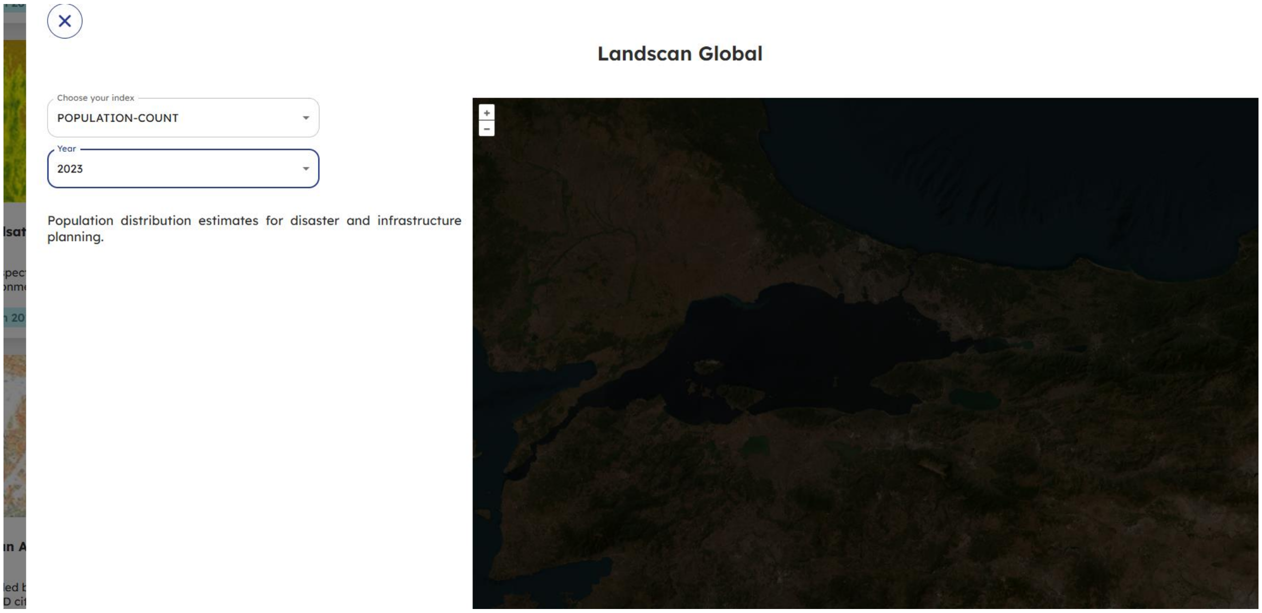

Figure 4.5 — From EO Data to Policy Scenarios

The figure demonstrates how validated EO indicators are translated into concrete mitigation scenarios and policy decision pathways.

Validated EO outputs are translated into scenarios such as: - Low Emission Zones for NO_2 reduction - Heating transition scenarios for PM_{10} - Crop-switching and fertilizer optimization for CO_2e reduction

This ensures that all analyses directly inform decision-making.

Figure 4.1 — Technical Architecture Diagram (Schematic)

```
[Copernicus EO]
       │
       ▼
[UDENE Explorer]
       │
       ▼
[Raster / Time-Series / Validation Engines]
       │
       ▼
[Indicators & Scenarios]
       │
       ▼
[Reports / Dashboards / Policy Briefs]
```

Situation Analysis 4.1 — Technical Readiness

Component	Status	Evidence
EO datasets	Mature	Sentinel-5P, CAMS
UDENE tools	Operational	Live platform
Workflows	Validated	Pilot applications
Outputs	Reproducible	Standardized methods

4.1 System Architecture and Data Flow

The proposed service is built on a layered architecture that ensures robustness, transparency, and scalability.

Layer 1 – Data Layer - Copernicus Sentinel-5P (NO_2 tropospheric columns) - CAMS global reanalysis (PM_{10}, CO_2) - CORINE Land Cover (100 m resolution) - Ground-based AQMS datasets (national and municipal)

Layer 2 – Processing & Analytics Layer - UDENE Explorer for dataset selection and metadata inspection - UDENE Raster Engine for reprojection, aggregation, kernel smoothing, zonal statistics - UDENE Time-Series Module for temporal extraction and trend analysis - UDENE Validation Module for EO–ground comparison (R^2, RMSE, bias)

Layer 3 – Interpretation & Decision Layer - Hotspot identification - Seasonal and interannual trend diagnostics - Land-use–dependent carbon footprint modelling - Scenario design and policy option testing

This modular structure ensures that each analytical step is traceable, auditable, and reproducible.

4.2 Data Quality, Accuracy and Uncertainty Handling

Earth Observation datasets inherently contain uncertainties related to sensor physics, atmospheric conditions, and model assumptions. The feasibility of the service critically depends on transparent uncertainty handling.

Key measures include: - Application of Sentinel-5P QA filtering ($QA \geq 0.75$) - Temporal aggregation to reduce random noise - Explicit differentiation between column densities and surface concentrations - Statistical validation against ground stations

Uncertainty is communicated not as a weakness, but as a scientific parameter guiding responsible policy use.

4.3 Computational Requirements

The service does not require local high-performance computing. - All processing is cloud-based via UDENE - End users only require standard internet access and a web browser - This significantly lowers deployment barriers for municipalities and institutions

4.4 Technical Readiness Level (TRL)

The proposed service operates at: - **TRL 6–7**: system prototype demonstrated in relevant environment

All core components (EO data, UDENE tools, analytical workflows) are already operational and validated through educational and pilot applications.

---

5. PILOT USE CASES (PROOF OF CONCEPT)

Figure 5.1 — Pilot Use Case Framework

```
Baseline Mapping ⟶ Validation ⟶ Scenario Design ⟶ Policy Options
```

Situation Analysis 5.1 — Evidence from Pilots

- Consistent NO_2 hotspot patterns aligned with transport corridors
- PM_{10} seasonal peaks correlated with heating periods
- Land-use carbon differences statistically significant

These findings demonstrate proof of concept under real-world conditions.

5.1 Pilot Case A – NO_2 Urban Hotspot Intelligence

Objective: To demonstrate the capability of EO data to identify fine-scale urban NO_2 pollution patterns linked to traffic and mobility infrastructure.

Methodology: - Sentinel-5P NO_2 retrieval - QA filtering and monthly aggregation - Kernel smoothing for spatial pattern enhancement - Overlay with transport networks

Outputs: - Hotspot maps - Exposure-priority zones - Mobility-related mitigation scenarios

Added Value: Enables municipalities to move from anecdotal traffic assumptions to spatially quantified evidence.

5.2 Pilot Case B – PM_{10} Seasonal Risk Profiling

Objective: To characterize seasonal PM_{10} exceedance risks and distinguish structural emissions from episodic events.

Methodology: - CAMS PM_{10} daily extraction - Monthly and seasonal decomposition - Validation with ground stations

Outputs: - Seasonal risk curves - Identification of heating-driven vs dust-driven peaks - Heating transition scenarios

5.3 Pilot Case C – Land-Use–Dependent Carbon Footprint

Objective: To assess how agricultural land-use choices influence regional carbon footprints.

Methodology: - CAMS CO_2 spatial fields - CORINE land-use masking - Fertilizer-based N_2O → CO_2e conversion - Comparative analysis (wheat vs barley)

Outputs: - CO_2e maps - Land-use carbon comparison tables - Climate-smart land-use scenarios

---

6. OPERATIONAL FEASIBILITY

Figure 6.1 — Overall System Architecture
(Source: Author's own elaboration; Copernicus–UDENE service architecture)
[Figure file: figure6_architecture.png]

The figure provides a high-level overview of the end-to-end system architecture, from EO data ingestion to decision-support outputs.

Figure 6.1 — Operational Workflow (Schematic)

```
Client Request
      │
      ▼
Scoping & Onboarding
      │
      ▼
EO Analysis & Validation
      │
      ▼
Scenario Development
      │
      ▼
Reporting & Policy Briefing
```

Situation Analysis 6.1 — Operational Risks & Controls

Risk	Control Measure
Skill gaps	Standardized UDENE workflows
Data delays	Multi-source EO

Risk	Control Measure
Adoption resistance	Pilot engagement

6.1 Service Governance & Institutional Setup

The operational success of the proposed service depends on a clear governance and responsibility framework. The service is designed to operate under a lightweight but robust institutional structure, suitable for university-led, public-interest-oriented deployment.

Governance roles include: - Scientific Lead: Ensures methodological rigor, EO data correctness, and scientific validation protocols. - Service Coordinator: Manages interaction with municipalities, ministries, and end-users; oversees timelines and deliverables. - EO/Geodata Analyst(s): Execute EO processing, validation, and scenario modelling using UDENE tools. - Policy & Impact Expert: Translates analytical outputs into policy-relevant insights and mitigation scenarios.

This structure ensures a clear separation between data analysis, scientific validation, and policy interpretation, which is considered best practice in evidence-based environmental governance.

6.2 Service Delivery Workflow

Operational delivery follows a standardized, repeatable workflow:

1. **Client Onboarding & Scoping**
    - Definition of city/region
    - Identification of priority pollutants (NO_2, PM_{10}, CO_2)
    - Agreement on reporting frequency
2. **Baseline Assessment**
    - EO-based baseline mapping
    - Initial validation against ground stations
3. **Advanced Analytics**
    - Hotspot identification
    - Seasonal and trend diagnostics
    - Land-use carbon footprint modelling
4. **Scenario Development**
    - Source attribution
    - Mitigation pathway definition
    - Quantitative and qualitative impact estimation
5. **Reporting & Communication**
    - Technical report
    - Executive policy brief

- Maps, graphs, dashboards

This standardized workflow ensures comparability across cities and time periods.

6.3 Human Capacity Requirements

The service is intentionally designed to minimize staffing requirements: - 1 Senior EO/Environmental Expert (part-time) - 1 EO Analyst (part-time) - 1 Policy/Communication Expert (ad hoc)

This lean model significantly improves operational feasibility and cost-efficiency.

6.4 Data Governance, Ethics & Transparency

All data used are: - Open-access - Non-personal - Compliant with EU data protection principles

Ethical safeguards include: - No surveillance or individual tracking - Aggregated spatial analysis only - Transparent documentation of limitations

This ensures full compliance with GDPR and public-sector ethics standards.

—|—| | Data gaps | Multi-source EO | | Skill gaps | UDENE workflows | | Institutional adoption | Pilot projects |

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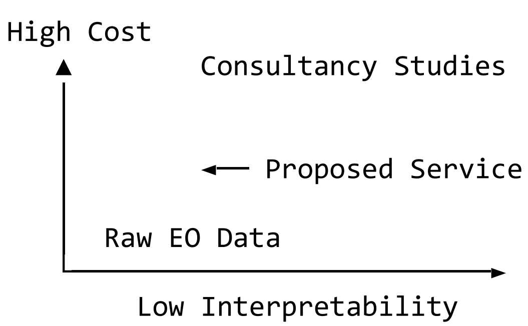
7. MARKET & ECONOMIC FEASIBILITY

Figure 7.1 — Market Positioning Matrix



Situation Analysis 7.1 — SWOT Analysis

Strengths	Weaknesses
Open EO data	Dependence on internet
Scientific credibility	Need for training

Opportunities	Threats

Opportunities	Threats
Green Deal funding	Policy shifts
City demand	Competing platforms

7.1 Market Context

Regulatory pressure, public awareness, and climate commitments have created a strong and sustained demand for reliable environmental intelligence at city level.

7.2 Demand Drivers

Key demand drivers include: - EU Green Deal obligations - Zero Pollution Action Plan - Climate-neutral city targets - CSRD-aligned reporting needs

7.3 Competitive Landscape

Current alternatives are either: - Pure data providers (low interpretability) - High-cost consultancy studies (low frequency)

The proposed service fills the gap by offering continuous, interpretable, and affordable intelligence.

7.4 Revenue & Sustainability Model

Sustainability is ensured through: - Annual service agreements - Modular add-on services - Training and capacity-building packages

7.5 Cost Structure

Costs are dominated by human expertise rather than infrastructure: - EO analysis time - Scenario development - Reporting and communication

The absence of data licensing fees substantially lowers operational risk.

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8. EUROPEAN & POLICY DIMENSION

Figure 8.1 — Policy Alignment Map

```
Green Deal ─┬─ Zero Pollution
            ├─ Fit-for-55
            ├─ Digital Europe
            └─ SDG 11
                   │
                   ▼
        EO-based Urban Intelligence Service
```

Situation Analysis 8.1 — Policy Uptake Pathway

EO indicators → Policy deliberation → Implementation → Monitoring → Revision

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8.1 Strategic Policy Context

The service operates at the intersection of environmental monitoring, climate action, and digital transformation. It directly supports EU priorities requiring quantifiable, verifiable environmental intelligence.

8.2 Contribution to Climate Governance

The service strengthens climate governance by: - Providing spatially explicit emission evidence - Supporting monitoring, reporting, and verification (MRV) - Enabling mid-term policy evaluation

This directly addresses long-standing gaps between policy ambition and implementation capacity.

8.3 Relevance for Pre-Accession and Neighbourhood Countries

Beyond the EU, the service is highly relevant for: - Candidate countries - Neighbourhood regions - Developing urban systems

EO-based intelligence reduces dependency on dense monitoring infrastructure, enabling rapid capacity building.