D5.1 Achievements, Synergies, and Coupled Simulations

HiDALGO2
CENTRE OF EXCELLENCE

Date: June 30, 2024

EuroHPC
Joint Undertaking

Document Identification			
Status	Final	Due Date	30/06/2024
Version	1.0	Submission Date	30/06/2024

Related WP	WP5	Document Reference	D5.1
Related Deliverables	D4.1, D5.2, D5.3,D5.4,D5.6,D5.7, D5.8	Dissemination Level (*)	PU
Lead Participant	UNISTRA	Lead Author	Christophe Prud'homme
Contributors	FAU, MTG, PSNC, SZE	Reviewers	Angeliki Dimitriou (ICCS)
			Jesús Gorroñogoitia (ATOS)

Keywords:
Pilot applications, Achievements, Synergies, Coupling Simulations

Document Information

List of Contributors	
Name	Partner
Christophe Prud'homme	UNISTRA
Vincent Chabannes	UNISTRA
Philippe Pinçon	UNISTRA
Javier Cladellas	UNISTRA
Maryam Maslek	UNISTRA
Zoltán Horváth	SZE
László Környei	SZE
Michał Kulczewski	PSNC
Wojciech Szeliga	PSNC
Krzysztof Kotecki	PSNC
David Caballero	MTG
Luis Torres	MTG
Harald Koestler	FAU

Document History			
Version	Date	Change editors	Changes
0.1	03/05/2024	UNISTRA	Table of Contents
0.15	08/05/2024	Marcin Lawenda (PSNC) Harald Koestler (FAU)	ToC, timeline and responsibilities approved
0.2	23/05/2024	UNISTRA, MTG, SZE, PSNC	Update Table of Contents Write content
0.3	26/05/2024	UNISTRA, FAU	Write MTW-WRF coupling Update English wording in WRF section
0.4	27/06/2024	UNISTRA	Take into account reviewer 2 feedback Added subsection 3.5 on MTW and UAP synergy which needs now to be written

			Added subsection 2.5.6 and 3.6 on status and roadmaps tables for the technological and coupling synergies respectively which now need to be completed New References up reviewer 2 request have been added and need now to be completed by partners.
0.5	29/06/2024	FAU,MTG,PSNC, SZE,UNISTRA	Complete status and roadmaps tables Answer Reviewer2 remarks and questions Complete References Version submitted to QA manager and PC
0.6	29/06/2024	Harald Koestler (FAU)	Quality assurance check
1.0	30/06/2024	Marcin Lawenda (PSNC)	Final check and corrections

Quality Control		
Role	Who (Partner short name)	Approval Date
Deliverable Leader	Christophe Prud'homme (UNISTRA)	29/06/2024
Quality Manager	Harald Koestler (FAU)	29/06/2024
Project Coordinator	Marcin Lawenda (PSNC)	30/06/2024

Table of Contents

List of Acronyms

Insert here all the acronyms appearing along the deliverable in alphabetical order.

Abbreviation / acronym	Description
AI	Artificial Intelligence
BOD	Biochemical Oxygen Demand
CD	Continuous Delivery or Continuous Deployment
CI	Continuous integration
CI/CD/CD	Continuous integration/Continuous Delivery/Continuous Deployment
CS	Coupling Synergy
DMS	Data Management Synergy
DSO	Distribution System Operators
Dx.y	Deliverable number y belonging to WP x
ETS	Educational and Training Synergy
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
Feel++	Finite Element Embedded Library in C++
HPDA	High Performance Data Analytics
GHG	Green House Gases
MTW	Material Transport in Water
MS	Methodological Synergy
ML	Machine Learning
OS	Operational Synergy
RES	Renewable Energy Source

Abbreviation / acronym	Description
TS	Technology Synergy
UAP	Urban Air Pollution
UB	Urban Building
UBEM	Urban Building Energy Modeling
UBM	Urban Building Model
UHI	Urban Heat Island
WF	WildFires
WRF	Weather Research and Forecast
WP	Work Package

Executive Summary

This deliverable documents the initial outcomes of synergies and coupling scenarios identified between the pilots, extending the capabilities of HiDALGO2 use cases.

The discussion started initially with the work in deliverables D4.1 and D5.3. Covering the period up to Month 18, D5.1 encapsulates the progress made in enhancing the capabilities and integration of our pilot applications, namely Material Transport in Water(MTW), Urban Air Pollution (UAP), Urban Buildings (UB), Renewable Energy Sources (RES), and Wildfires (WF).

Each pilot has successfully implemented initial scenarios demonstrating the potential of integrated simulation tools in supporting city policymakers, energy producers, and disaster management authorities. Implementation achievements are explicitly documented in D5.6.

D5.1 introduces initial coupling workflows between identified scenarios to handle complex simulations, and data flows effectively. Establishing integration workflows within each pilot is instrumental for these coupled scenarios between different pilots. For instance, the workflows specify how the Urban Buildings pilot interacts with the Urban Air Quality pilot, allowing for combined environmental and building energy simulations that enhance urban planning and policy-making. This cross-pilot synergy is essential in developing holistic solutions to the complex challenges addressed by the HiDALGO2 project.

This deliverable also outlines a strategic roadmap for the ongoing research and development activities. It sets the stage for the next steps in simulation enhancements, including introducing advanced modelling techniques, integrating new physics into simulations, and improving and extending computational workflows.

1 Introduction

1.1 Purpose of the document

The document is essential for recording the achievements with respect to synergies in WP5. In the context of the HiDALGO2 project, synergies can be realized in several forms, which are instrumental in enhancing the project's output and impact. Here are the key forms of synergies that might be expected:

1. **Technological Synergies [TS]**:
   a. Shared Tools and Platforms: Different use cases might utilize common computational tools, libraries, and frameworks, which can improve the resource utilization and reduce the developmental redundancies.
2. **Methodological Synergies [MS]:**
   a. Cross-Disciplinary Approaches: Combining diverse scientific and engineering disciplines to solve complex problems can foster innovative solutions that would not emerge from a single field.
   b. Best Practices and Standards: Developing and adopting industry-wide best practices and standards can enhance the compatibility and scalability of solutions across different domains.
3. **Coupling Synergies [CS]:**
   a. Model Coupling: Integrating different simulation models (e.g., coupling urban air quality models with energy consumption models) allows for more comprehensive analyses and predictions.
   b. Data Fusion: Combining data from various sources enhances the accuracy and reliability of the models, providing a richer dataset for simulations and analyses.
4. **Data Management Synergies [DMS]:**
   a. Shared Data Repositories: Creating unified platforms for data sharing among different pilots can streamline data access and promote consistency in data usage.
   b. Advanced Data Analytics: Leveraging collective insights from multiple data streams can improve decision-making and process optimization.
5. **Operational Synergies [OS]:**
   a. Workflow Optimization: Streamlining processes across different project components to reduce time and cost while improving the quality of outputs.
   b. Resource Sharing: Pooling computational resources, such as HPC clusters, to ensure that they are used efficiently across various project tasks.

6. **Educational and Training Synergies [ETS]:**
    a. Training Programs: Develop training materials and workshops based on the collective findings and technologies developed in the project.
    b. Knowledge Transfer: Encouraging cross-pilot training and internships can facilitate a deeper understanding and broader application of the project's outcomes.

We focus on this deliverable on technological synergies (Item 1) and coupling scenarios (item 3). The other items are dealt with in other aspects of the project, specifically:

- [MS] are discussed in the scientific committee and also shared in technical discussions or conferences and workshops,
- [DMS] is taken care of by the use of CKAN as a common platform to share data. Data analytics aspects are taken care of at the level of WP4 of HiDALGO2 on HPDA and AI, and coupling technologies.
- [OS] is taken care of by WP2, which deals with HiDALGO2 operations
- [ETS] is taken care of by WP6 regarding the training activities and WP2 regarding the pooling of compute resources.

Regarding technological synergies [TS], we have identified the use of a meteorological prediction tool, i.e. Weather Research and Forecast tool (WRF) [1], in the pilots. Indeed, the analysis of the high spatial resolution parameterization needed for the Wildfires pilot can be exploited in other use cases, namely MTW, UAP, UB, RES, and WF.

Regarding the coupling synergies [CS], we detail the strategic interactions between the Urban Air Pollution (UAP) and Urban Buildings (UB), the coupling of UAP with Wildfires (WF), and the integration of Urban Buildings with Renewable Energy Sources (RES) as well as Material Transport in Water and Wildfires. These scenarios demonstrate the practical application of combining simulation models to address complex challenges in urban planning and environmental management.

1.2 Relation to other project work

D5.1 is related to D5.6 (M18), which describes the pilots' implementation achievements, and builds upon and extends the work done in D5.3 (M10), which describes the pilots' research which also led to D5.1 and D4.1(M11) which describes the data management and coupling technologies in HiDALGO2.

D5.1 will be updated by D5.2 (M48).

D5.1 work also feeds D5.4 (M23) and D5.6 (M36) research advancements as well as D5.7 (M29) and D5.8 (M46) regarding pilot implementation.

1.3 Structure of the document

This document, D5.1 "Achievements, Synergies, and Coupled Simulations," is structured to provide a comprehensive overview of the progress, synergies, and integration efforts within the HiDALGO2 project up to Month 18. The following sections are included to guide readers and reviewers through the document:

1. Introduction:

- **Purpose of the document**: Explains the objectives and significance of this deliverable in the context of the HiDALGO2 project.
- **Relation to other project work:** Describes the connection of this document to the overall project roadmap, Description of Action (DoA), and other related deliverables.
- **Structure of the document**: This subsection provides an outline of the document's organization, offering insight into each section's contents.

2. Technological Synergies:

- **Using Weather Research and Forecasting (WRF)**: Discusses the shared technological tools and platforms across different pilots, emphasizing the use of WRF in enhancing weather prediction for various applications. This section covers:
    - Material Transport in Water (MTW)
    - Renewable Energy Sources (RES)
    - Urban Air Pollution (UAP)
    - Urban Building (UB)
    - Wildfires (WF)

3. Coupling Synergies:

- **Urban Air Pollution & Urban Building**: Details the strategic integration between UAP and UB pilots, focusing on air quality assessment, boundary condition improvements, urban heat island effect, and holistic urban planning.
- **Urban Building & Renewable Energy Source**: Explores the synergies between UB and RES pilots, particularly in solar mask computation and energy production forecasting.

- **Urban Air Pollution & Wildfires**: Examines the interaction between UAP and WF pilots, addressing the air quality impact assessment and the boundary condition enhancements.
- **Material Transport in Water & Wildfires**: Describes the coupling of WF with MTW, focusing on the hydrological impact of wildfires and the subsequent water transport modelling.

4. Conclusions:

Summarizes the key achievements, identified synergies, and developed coupled scenarios. This section also outlines future research directions and next steps in the HiDALGO2 project.

By following this structure, the document aims to present a clear and detailed account of the HiDALGO2 project's progress, highlighting the collaborative efforts and technological advancements achieved so far.

2 Technological Synergies

2.1 [TS] Using Weather Research and Forecasting

All pilots require, to some extent, access to meteorological prediction. As such, this is a technological synergy. The WRF model supports nested domain configurations, allowing for runs with varying resolutions in nested areas. The high resolution needed for wildfire simulations can be exploited by other pilots who can benefit from high-resolution weather forecasts. In this sense, and to increase the quality of the meteorological information as well as to facilitate the downscaling to high resolution, 1km or hundreds of meters, the inclusion of boundary conditions coming from the ECMWF model [4] is foreseen instead of those used so far in the project ERA5 [5].

During the project's first year, a thorough parameterization study was performed. This has shown the dependence of the lower atmosphere and other physical processes that are not resolved by the common equations with the input parameters. Considering that the wind is one of the main contributors to wildfire behaviour, a key objective of this analysis was to optimize it. Additionally, the interaction between wildfire and the atmosphere has also been analysed, and this has yielded the best parameterizations to determine atmospheric stability and its influence on the formation of pyro convective movements and smoke dispersion. This work can be used on other pilot cases to determine the wind fluxes and atmospheric stability that influence air fluxes and particle concentrations in urban environments or the boundary conditions in windmills and solar farms.

Although it has not been one of the study's main objectives, the high resolution of the model offers the possibility of obtaining precipitation and runoff that may prove useful for Material Transport in Water.

2.1.1 Material Transport in Water

The usage of weather forecasting data in MTW is yet to be exploited. However, data such as average rainfall per year and average temperatures recorded per year could be helpful to datasets that, for example, can be used to further our knowledge about how it affects the transport of sediments. The temperature data can be beneficial, especially considering temperature effects coupled to our simulations. Also, for problems with free surfaces, the average surface temperatures of the oceans in a year can be a good starting point for determining the surface boundary conditions in problems involving temperature transport.

2.1.2 Renewable Energy Sources

The computational core of RES are two independent weather forecasting applications, each providing results for different scale ranges. The first, WRF, is a mesoscale solver capable of providing a spatial resolution of the forecast up to the scale of ca. 1000 meters, considering its internal model applicability. The second one, EULAG [6], is an all-scale geophysical flow solver that can be applied to more fine-grained scenarios, and therefore it can provide a forecast of finer resolution and including multiple local factors, such as city buildings, forests, detailed topography, etc. In RES, both models are already loosely coupled: the output of WRF is automatically passed as input data to EULAG, as reported in deliverable D5.3. The combination of both allows for receiving results that are detailed and, on the other hand, take into account the bigger image. Moreover, while a single pipeline includes a single WRF simulation based on received results, multiple instances of EULAG can be run in parallel during the same instance of RES and enhance multiple areas of the domain covered by WRF simulation.

The next step is to use the same coupling approach to run RES with WRF-Wildfires (more detailed prediction) and WRF-Solar [7] (for photovoltaic systems).

2.1.3 Urban Air Pollution

UAP-FOAM [8] is currently coupled with the ECMWF interface polytope to incorporate global-scale (with ca. 10 km resolution) weather forecasts to be used as boundary conditions in urban scale. However, to improve the forecasting qualities of the UAP codes on simulating microscale urban climate down to one meter resolution, WRF can be coupled to provide mesoscale (200 to 1000 meter resolution) refinement of the global-scale data.

Several climate variables, including temperature, wind speed, cloud coverage, planetary boundary layer height, and pressure, can be used in the coupling. The spatial and temporal resolution of these physical parameters can vary, but fluctuations and uncertainties can be addressed and analysed this way.

Coupling can be done in two steps. First, the results of the WRF simulations are used as boundary conditions for the UAP simulations in a one-way coupled mode, where the results of the mesoscale simulations influence the boundary conditions of the microscale model. However, there is no feedback from the microscale to the mesoscale.

As a second step, a tight coupling of the two simulations could be implemented so that WRF results could also influence behaviour within the domain, and microscale behaviour could react to mesoscale behaviour, too.

Both implementations require validation and analysis of improvement, which is planned to be done based on the Antwerp validation study published in 2024 based on measurements in 2016 [9].

2.1.4 Urban Building

The Urban building model uses weather data to simulate building energy through heat exchanges throughout buildings (walls, windows, roof, etc.) and outdoor environments. UB uses historical observations recorded from the Open-meteo API archive [11] for historical simulations. Observations refer to measured weather quantities using meteorological instruments. Currently, UB simulations include 1-year (for example 2023) of historical data with an hourly temporal resolution. For spatial resolution, the UB model employs averaged data from measurements recorded across all meteorological stations on a city scale. Implied weather parameters are 2 meters temperature, surface pressure, 10 meters wind speed, 10 meters wind direction, 2 meters relative humidity, total cloud cover, direct solar radiation, and diffuse solar radiation. Simulations have been run for several European cities, particularly cities with HiDALGO2 partners.

Within the objective of predictive building energy simulations, the UB model must update weather data by including forecasts. The technology synergy between WRF and UB allows the enriching of the input datasets of predictive UB with city-scale weather forecasts in an hourly resolution from mid-range forecasts (several days) to long-term climate forecasts (several months to several years). The WRF model will supply the UB model with the following input forecast parameters: 2 meters temperature, surface pressure, 10 meters wind speed, 10 meters wind direction, 2 meters relative humidity, and total cloud cover. The coupling with WRF-Solar [7] will provide direct and diffuse solar radiation forecasts for the UB model. The forecast datasets are required for European cities. The spatial resolution is still under discussion.

2.1.5 Wild Fires

The simulation of wildfires and fire-atmosphere interaction is carried out at different scales according to the objective pursued:

- At the landscape scale (several tens of kilometres), the goal is to obtain the expansion of a flame front and the production and dispersion of generated smoke, identifying which populated areas may be affected.
- At the urban core scale (city, town, residential area, several hundred meters), the goal is to identify the potential pattern of fire propagation in the vicinity and within the urbanization, and the potential impact on homes from

flames and on the population from smoke due to the combustion of forest vegetation, garden vegetation, and residential fuels.

This multi-scale approach requires using and coupling two simulation schemes with different models, data, and spatial and temporal resolutions.

- WRF-SFIRE [11] is used for wildfire simulation at the landscape scale.
- OpenFOAM-FireFOAM [12] is used for combustion and fire propagation simulation in the vicinity and within urban areas.

The results of WRF-SFIRE are delivered in the form of grids with variable resolution, but in HiDALGO2, horizontal resolutions of 200 m or less are proposed for the atmospheric grid. These include a number of vertical levels in the Z dimension, in this case 45 levels are considered following sigma co-ordinates. The results of the simulations are the 3D wind vector field, including the feedback due to the fire, the 2D flame front position, the amount of heat emitted (heat flux), and the smoke density at each point in 3D space. Additionally, fire propagation is calculated on grids 10 times finer, that is, with a resolution of 20 m.

In the OpenFOAM-fireFOAM fluid dynamics model, much finer three-dimensional adaptive grids are used, on the order of centimetres or sometimes smaller. The coupling of the WRF-SFIRE and OpenFOAM-fireFOAM models requires careful selection of the grids and their exact referencing so that the results of one can be resampled in the matrix of the other as boundary conditions.

The method of coupling both models is through their files via resampling. The workflow would be as follows:

1. Simulation of fire propagation and smoke with WRF-SFIRE,
2. Extraction of the variables of interest at time intervals:
   a. Wind vector components (3D),
   b. Smoke column density (3D),
   c. Fraction of burned area (flame front position) (2D),
   d. Heat flux (2D),
3. Description of the OpenFOAM computational domain and mesh resolution,
4. Resampling of WRF-SFIRE variables onto the OpenFOAM mesh,
5. Description of the geometry in the OpenFOAM scenario,
6. Parameterization of the OpenFOAM simulations,

7. Incorporation of the resampled grids into the OpenFOAM simulation at time intervals as boundary conditions (e.g., wind, smoke concentration, combustion points).
8. Execution of the OpenFOAM-fireFOAM simulations

2.1.6 Status and Roadmaps

This section displays a table showing the coupling status with WRF as a technology synergy and the implementation roadmap.

Technology Synergies	Current Status	Roadmap
MTW-WRF	Early design stage due to recent inclusion of the pilot. Requirements and specifications phase	To be decided internally after discussion within the pilot
RES-WRF	WRF is already loosely coupled with RES.	M30 - coupling with WRF-solar M36 - coupling with WRF-MG
UAP-WRF	Requirements and specifications phase. Currently, macroscale meteorological data is obtained from ECMWF.	M24 - Initial coupling. M36 - Benchmark and validation.
UB-WRF	Requirements and specifications phase. Currently, meteorological data is obtained by OpenMeteo. Up to 16 days forecast are available.	M18-requirements and specifications M21-workflow definition M23-initial coupling and results M24-first release of UB-WRF coupling M26-second release of UB-WRF coupling
WF-WRF	Requirements and specifications phase completed. C++ module to extract variables of interest and resampling WRF-SFIRE	M23 - initial coupling and results / First simulations M36 - Benchmark with reframe and validation

Technology Synergies	Current Status	Roadmap
	data onto the OPENFOAM mesh on going.	

3 Coupling Synergies

The section on coupled scenarios in the HiDALGO2 project focuses on integrating different simulation models across our pilot projects. This approach facilitates a deeper understanding of urban and environmental issues by leveraging the strengths of each pilot to produce more comprehensive solutions.

This section describes these coupled scenarios, identifies the challenges faced, and discusses the solutions adopted.

In section 3.6, we present a table with the current status of each coupling synergy and a roadmap for each.

3.1 [CS] Urban Air Pollution & Urban Building

3.1.1 Urban Air Pollution

The Urban Air Pollution (UAP) within HiDALGO2 addresses several key urban challenges critical to improving the quality of life in rapidly growing urban areas. With the United Nations projecting that 68% of the world's population will live in urban areas by 2050 [13], these challenges are increasingly important.

Challenge 1: Air Quality: Air pollution is a significant issue, with the World Health Organization attributing 6.7 million deaths annually to exposure to ambient and household air pollution [14]. Many cities experience air quality levels above health-critical values, leading to public protests and prompting stricter regulations by policymakers.

Challenge 2: Wind Comfort and Safety: Urban wind patterns can cause discomfort for pedestrians and, in some cases, create safety hazards, particularly around high-rise buildings. Ensuring wind comfort and safety is essential for creating liveable urban environments.

Challenge 3: Urban Planning: Urban policymakers face the challenge of mitigating the negative effects of these urban issues. Effective urban planning is crucial for addressing air quality concerns, managing wind comfort, and ensuring sustainable city development.

The UAP pilot aims to provide computational solutions to assist city policymakers in planning and regulation, contributing to healthier and safer urban environments.

3.1.2 Urban Building

The Urban Building pilot within the HiDALGO2 project aims to address the significant energy consumption and greenhouse gas (GHG) emissions attributed to the building sector in the European Union (EU). The EU's Horizon 2050 objectives include doubling the annual energy renovation rates over the next decade, with an ambitious goal of approximately 700,000 renovations per year in France alone [15].

Key objectives of the Urban Building pilot include:

- **Assessing energy performance** of existing buildings
- **Identifying sources of energy savings**, focusing on anomalies and areas for improvement.
- **Comparing and evaluating renovation** and energy management strategies.
- **Ensuring the optimal management** of buildings.

The pilot employs advanced building energy simulations to predict energy consumption, thermal comfort, and indoor air quality at both building and urban scales. Integrating building stock within its environment involves coupling with the Urban Air Pollution (UAP) model to:

- Assess the contribution of the building stock (heat, GHG, NOx) to outdoor air quality.
- Improve boundary conditions of the building model, such as wind speed and outdoor temperature.
- Enhance radiative heat transfer on building envelopes through better estimation of solar shading.

3.1.3 Synergies

The integration of building energy simulations with the UAP model presents significant synergies that enhance both pilots' capabilities:

1. **Environmental Impact Assessment**
   - The UAP model benefits from detailed energy consumption and emission data from the building simulations, leading to more accurate air quality predictions.
   - Incorporating data on building heat emissions and thermal behaviour can improve simulations of urban heat islands and local microclimates.

2. **Improved Boundary Conditions**:
   - Coupling the UAP and Urban Building models enables more accurate boundary conditions for both simulations. For instance, real-time wind speed,

temperature, and solar radiation data can refine the accuracy of building energy models.
- Enhanced boundary conditions contribute to more precise simulations of both air quality and energy performance.

3. **Holistic Urban Planning**:
   - Integrated models support city policymakers in making informed decisions regarding urban planning, regulation, and renovation strategies.
   - Combining the insights from energy and air quality models helps identify and mitigate adverse effects of urbanization on health and the environment.

4. **Urban Heat Island (UHI) effect:**
   - The UHI effect occurs when urban areas become significantly warmer than their rural surroundings due to human activities and alterations in land surfaces. Coupling UB and UAP models allows for a detailed analysis of UHI by combining building energy consumption data with environmental factors such as air temperature, wind speed, and pollution levels.
   - Understanding the UHI effect at a granular level enables the development of targeted mitigation strategies, such as increasing green spaces, optimizing building layouts, and using materials with better thermal properties. These strategies can be simulated and tested within the integrated UB and UAP framework to assess their effectiveness before implementation.

5. **Data Sharing and Fusion**:
   - Sharing data between UAP and Urban Building models allows for a comprehensive understanding of the urban environment.
   - Data fusion techniques can merge energy consumption patterns with air quality metrics, providing a richer dataset for further analysis and optimization.

The proposed workflow is as follows:

- Select a common region to simulate,
- Generate a watertight surface mesh of the building terrain and vegetation that will be used for the data exchange between UAP and UB,
- Exchange temperature, wind velocity, and pollutant concentrations through the surface mesh, while the simulations run
- UAP will dictate the time resolution for coupling UAP and UB.

In conclusion, the synergies between the Urban Building pilot and the UAP model create a more integrated approach to urban sustainability. This collaboration enhances the accuracy and efficiency of individual models and contributes to a more comprehensive understanding of urban dynamics, supporting the HiDALGO2 project's overarching goals.

3.2 [CS] Urban Building & Renewable Energy Source

3.2.1 Renewable Energy Source

The Renewable Energy Sources (RES) pilot aims to provide accurate predictions of energy produced by wind farms and photovoltaic systems, taking into account forecasted weather conditions. Both open and dense urban areas are taken into consideration. With forecasts dedicated to RES, further scenarios will be created to support distribution system operators at the operational level. Thus, key objectives of the RES pilot include:

- **Forecasting energy production** for wind farms and photovoltaic systems,
- **Identifying the best spots** for new installations of photovoltaic panels and wind farms,
- **Predict damages** to RES installations due to extreme weather events,
- **Support DSOs** in stabilizing the grid.

The RES pilot employs a mesoscale weather prediction model with a detailed all-scale geophysical flow solver to accurately model wind flows over complex terrain and other obstacles, such as buildings. Providing accurate predictions for photovoltaic systems requires solvers and data related to solar radiation. The integration with these requires, among other things, computing a solar mask to quantify the exposition to the sun. The effectiveness of photovoltaic systems depends on the angle between sun rays and solar infrastructure.

3.2.2 Urban Building

UB provides distributed computation of solar masks for buildings, which will include the building environment, such as vegetation, terrain, and urban furniture in the forthcoming releases. The actual computation is very flexible and can be enabled for any identified system. The requirement is to have access to marked soups of triangles.

3.2.3 Synergies

UB flexible computation of solar masks can be used by RES.

The proposed workflow is as follows:

- Select a common region to simulate.

- Generate a common geometric representation of the region as a surface mesh, e.g., a soup of marked triangles. The marked triangles identify the RES components and the urban environment.
- UB provides the solar masks for RES as a one way coupling using the time resolution required by RES.

3.3 [CS] Urban Air Pollution & WildFires

3.3.1 Urban Air Pollution

Urban areas may be affected by smoke generated from nearby wildfires. In the case of large fires the smoke generated may affect distant areas as well, as in the case of New York during the fires in Canada in 2023 [16]. Air quality levels may vary on the microscale level, even if the source of pollution is outside the city: smoke particles may concentrate on the street side or may be absorbed by urban vegetation.

If implemented, the applications of UAP may efficiently and reliably simulate fluctuations and changes in the microscale urban climate, including chemical reactions of pollutants.

3.3.2 Wildfires

The main objective of WF is to provide simulations of wildfire progression, energy released, and coupled atmosphere-fire interactions. It uses a high-resolution meteorological model coupled with the fire simulation model to evaluate the disturbance of wind fields due to the energy released, the generation of pyro-convective movements, and the release and dispersion of smoke.

WRF-SFIRE [11] allows the generation and dispersion of incandescent particles (sparks) as well as the simulation of the emission of different smoke components and their subsequent dispersion over large areas that can include urban areas and entire cities.

WRF-CHEM [17] can be coupled with WRF-SFIRE [11] for more detailed information on the evolution of different pollutants in the smoke.

3.3.3 Synergies

1. **Air Quality Impact Assessment:** The UAP model benefits from detailed smoke dispersion over the urban area

2. **Improved Boundary Conditions**: Coupling the UAP and WF models enables more accurate boundary conditions (smoke, wind speed, temperature, and solar radiation data) and can allow the analysis of pollutants behaviour.

The proposed workflow is as follows

- Simulation of meteorological local conditions using WRF,
- Wildfire propagation using WRF-SFIRE under various meteorological assumptions (wind, humidity, temperature, etc.),
- Estimation of concentrations of different pollutants over the urban area using tracers in WRF-SFIRE (boundary conditions),
- Simulation with UAP solver.

3.4 [CS] Material Transport in Water & Wildfires

Wildfires have a direct effect on a watershed's hydrological behaviour. On the one hand, they remove vegetation that participates in the capture and regulation of runoff; on the other hand, high temperatures can lead to the formation of hydrophobic layers on the surface, which prevent water percolation to deeper soil horizons and facilitate surface runoff.

Both phenomena occur immediately and are significant during subsequent rain episodes. In this regard, the curve number of the portion of the watershed affected by the wildfire is altered, and thus the hydrological response is changed. Since rainwater runoff occurs more efficiently, it is very common for the erosion of surface soil particles to be significantly higher, along with the addition of ash left after the fire.

All these particles, whether coarse, medium, or fine, end up in the river and stream channels of the watershed, altering the physics of transport and chemistry mainly due to increased turbidity, which has an immediate effect on BOD (Biochemical Oxygen Demand).

The proposed workflow is as follows:

- Simulation of wildfire propagation using WRF-SFIRE under various meteorological assumptions (wind, humidity, temperature, etc.).
- Determination of severity of vegetation based on linear intensity and residence time.
- Determination of hydrophobic effect on soil.
- Calculation of the altered curve number.

- Simulation of the altered hydrological response under prescribed rainfall.
- Estimation of runoff and sediment transport.
- Incorporation of sediments into the network of streams and rivers.
- Simulation with MTW.

MTG carried out similar developments within the European project MEDIGRID [3]. In this project, the FSE [2] wildfire propagation model was coupled with the SHETRAN hydrological model [18]. A similar task is proposed but includes fire-atmosphere interaction and coupling solid transport modelling in water (MTW).

3.5 [CS] Status and Roadmaps

In this section, we provide an overview of the advancement of the different coupling synergies and a roadmap

Coupling Synergies	Current Status	Roadmap
MTW-WF	Initial discussion stage Workflow designed for initial coupling	To be done after internal analysis between Pilot's Teams.
RES-UB	Workflow designed for initial coupling Method for initial coupling one way from UB to RES agreed upon Data for one way coupling provided by UB	M18 - initial data exchange and code provided to read the dataset M24 - initial coupling result M27 - initial coupling implementation M36 - second release of coupling implementation
UAP-UB	Workflow designed for initial coupling Method for initial coupling one way from UB to UAP agreed upon Data for one way coupling provided by UB	M17 - initial data exchange M21 - initial one way coupling results M26 - initial two way coupling
UAP-WF	Workflow designed for initial coupling	M20 - initial data exchange and code provided to read the dataset M24 - initial coupling result M27 - initial coupling implementation

4 Conclusions

This deliverable, D5.1 “Achievements, Synergies, and Coupled Simulations,” highlights the progress made in the HiDALGO2 project up to Month 18: it outlines the technological synergies and initial coupling scenarios among the pilot applications, including Material Transport in Water (MTW), Urban Air Pollution (UAP), Urban Buildings (UB), Renewable Energy Sources (RES), and Wildfires (WF).

Key achievements include initial or planned implementation of WRF in all pilots, demonstrating their potential in supporting city policymakers, energy producers, and disaster management authorities. The document also establishes initial integration workflows for the coupling scenarios, which are crucial for enabling effective simulations and data exchanges between pilots.

The synergies identified, such as integrating the meteorological prediction tool WRF and coupling pilot simulations, highlight the project’s collaborative efforts to address complex urban and environmental challenges. These advancements pave the way for more comprehensive and accurate simulations, enhancing the decision-making process in urban planning and environmental management.

Looking ahead, the deliverable sets the stage for further research and development activities, see sections 2.5.6 and 3.6. Future steps include introducing advanced modelling techniques, integrating new physical processes into simulations, and improving computational workflows. These efforts will be continued and expanded in subsequent deliverables, such as D5.2, to ensure the HiDALGO2 project achieves its goals of developing holistic and sustainable solutions for urban and environmental issues.

References

[1] Weather Research and Forecasting (WRF) [Online]. https://www.mmm.ucar.edu/models/wrf

[2] Caballero, D. "Taxicab geometry: Some problems and solutions for square grid-based fire spread simulation". Forest Ecology and Management (234), 2006

[3] Bovolo, C.I., Abele, S.J; Bathurst, J.C., Caballero, D.; Ciglan, M., Eftichidis, G., Simo, B. A distributed framework for multi-risk assessment of natural hazards used to model the effects of forest fire on hydrology and sediment yield. Ed. Computers & Geosciences, 2007

[4] ECMWF Model https://www.ecmwf.int/en/research/modelling-and-prediction

[5] ERA5 model ERA5 hourly data on single levels from 1940 to present (copernicus.eu) Complete ERA5 global atmospheric reanalysis (copernicus.eu)

[6] M. Z. Ziemiański, M.J. Kurowski, Z.P. Piotrowski, B. Rosa, O. Fuhrer, "Toward very high horizontal resolution NWP over the Alps: Influence of increasing model resolution on the flow pattern", Acta Geophysica, 59, 2011, 1205 – 1235

[7] Jiménez, P. A., J. P. Hacker, J. Dudhia, S. E. Haupt, J. A. Ruiz-Arias, C. A. Gueymard, G. Thompson, T. Eidhammer and A. Deng, 2016: WRF-Solar: Description and clear-sky assessment of an augmented NWP model for solar power prediction. Bull. Amer. Meteor. Soc., 97, 1249-1264, https://doi.org/10.1175/BAMS-D-14-00279.1.

[8] Kornyei, Laszlo ; Horvath, Zoltan ; Ruopp, Andreas ; Kovacs, Akos ; Liszkai, Bence *"Multi-scale Modelling of Urban Air Pollution with Coupled Weather Forecast and Traffic Simulation on HPC Architecture"* In: The International Conference on High Performance Computing in Asia-Pacific Region Companion (2021) pp. 9-10. , 2 p.

[9] Martín F., Janssen S., Rodrigues V., Sousa J., Santiago J.L., Rivas E., Stocker J., Jackson R., Russo F., Villani M.G., Tinarelli G., Barbero D., José R. San, Pérez-Camanyo J.L., Santos G. Sousa, Bartzis J., Sakellaris I., Horváth Z., Környei L., Liszkai B., Kovács Á., Jurado X., Reiminger N., Thunis P., Cuvelier C. "*Using dispersion models at microscale to assess long-term air pollution in urban hot spots: A FAIRMODE joint intercomparison exercise for a case study in Antwerp"* SCIENCE OF THE TOTAL ENVIRONMENT 925 Paper: 171761 (2024)

[10] Open Meteo API (OM API) [Online] https://open-meteo.com/en/docs

[11] WRF-SFIRE J. Mandel, S. Amram, J.D. Beezley, G. Kelman, A.K. Kochanski, V. Y.Kondratenko, B.H. Lynn, B. Regev , and M. Vejmelka. (2014) Recent advances and applications of WRF-SFIRE. Manuscript prepared for Nat. Hazards Earth Syst. Sci. Discuss. September.

WRF-SFIRE user guide - openwfm

[12] OpenFOAM-FireFOAM [Online] https://www.openfoam.com/

[13] United Nations [Online] https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

[14] World Health Organization [Online] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

[15] European Commission - Renovation Wave [Online] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

[16] Yale School of Public Health - Canadian wildfire smoke associated with increase asthma cases in New York City https://ysph.yale.edu/news-article/canadian-wildfire-smoke-associated-with-increased-asthma-cases-in-nyc/

[17] WRF-CHEM [Online] WRF-Chem | Atmospheric Chemistry Observations & Modeling (ucar.edu)

[18] SHETRAN hydrological model [Online] SHETRAN hydrological model (ncl.ac.uk)