Imperial College London

Introduction of EPSRC project: Hybrid AI and multiscale physical modelling for optimal urban decarbonisation combating climate change

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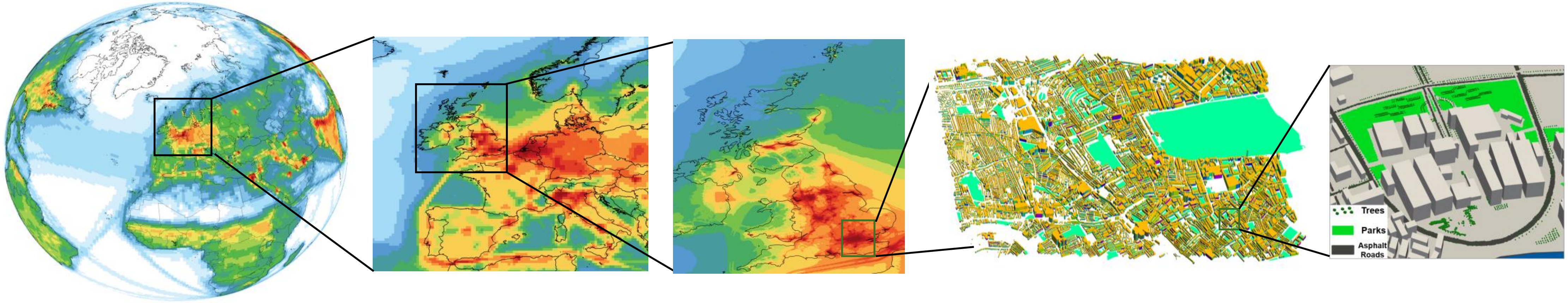
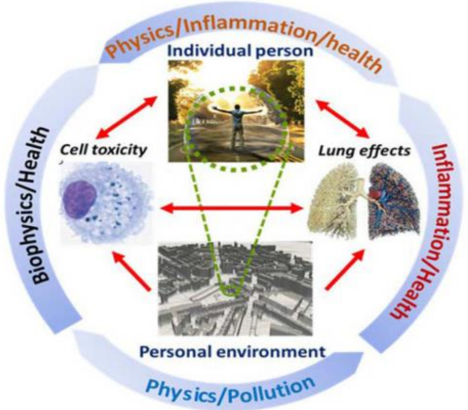
Digital tools for Urban Environment Management

Decarbonisation combating climate change– NetZero by 2050

Global scale | Regional scale | City scale | Neighbourhood scale | Building scale



Understanding of relationship between health, economics, environment and climate change



Digital-twin operational tools for environment and energy management, which enable the urban population (as well as policy makers) to make both strategic and everyday decisions that help generate a zero pollution environment by 2050

Digital tools for Urban Environment Management

Aim to develop develop a hybrid AI-physics framework for optimal city design and management for decarbonisation

- Allow critical assessment of UK existing and drive new policy options on decarbonisation to achieve net zero by 2050
- Improve the existing regulations for decarbonization by providing valuable insights, optimising energy efficiency, and empowering decision-making processes with increased knowledge and awareness.

Existing Cities

London

Singapore

Ningbo

Future Smart Cities

Neom city (smart city) construction in Saudia Arabia – to demonstrate the AI approach

Government and Regulation

Department for Environment Food & Rural Affairs

Department of Health & Social Care

Department for Business, Energy & Industrial Strategy

Department for Transport

Environment Agency

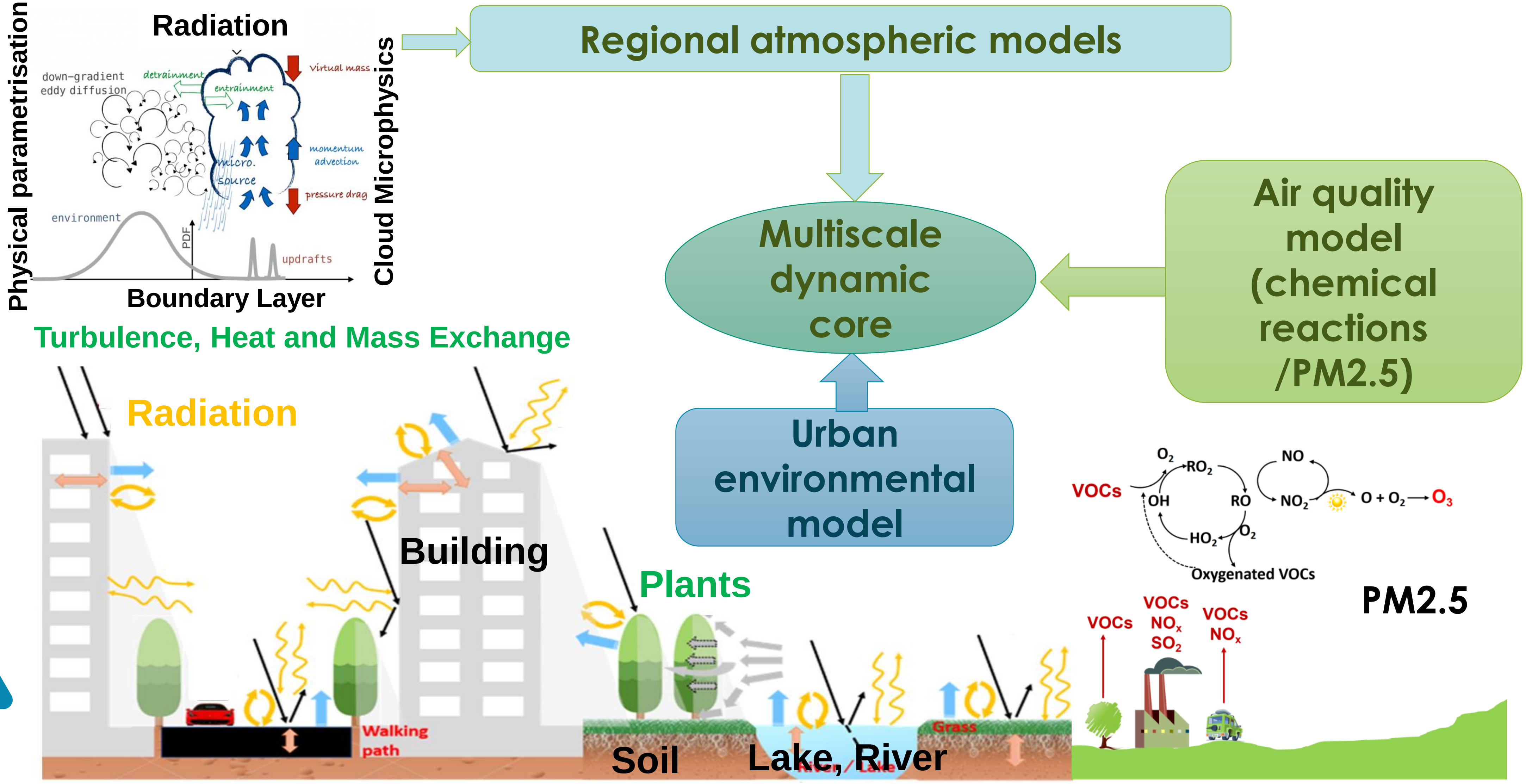
Digital tools for Urban Environment Management:

Questions to be addressed

- How do anthropogenic carbon emissions affect local urban and global climate change?
- Which optimal GI-BI, buildings, transportation, and sustainable city designs provide maximum mitigation of carbon emissions & climate change?
- What is the trade-off between carbon reduction, energy use and economics?
- What are the feedbacks of the urban carbon contribution to global climate?
- How can detailed multi-scale models provide efficient and accurate prediction of carbon emissions and their impact on climate change?

Complex physical processes

In Atmosphere and Urban Environments



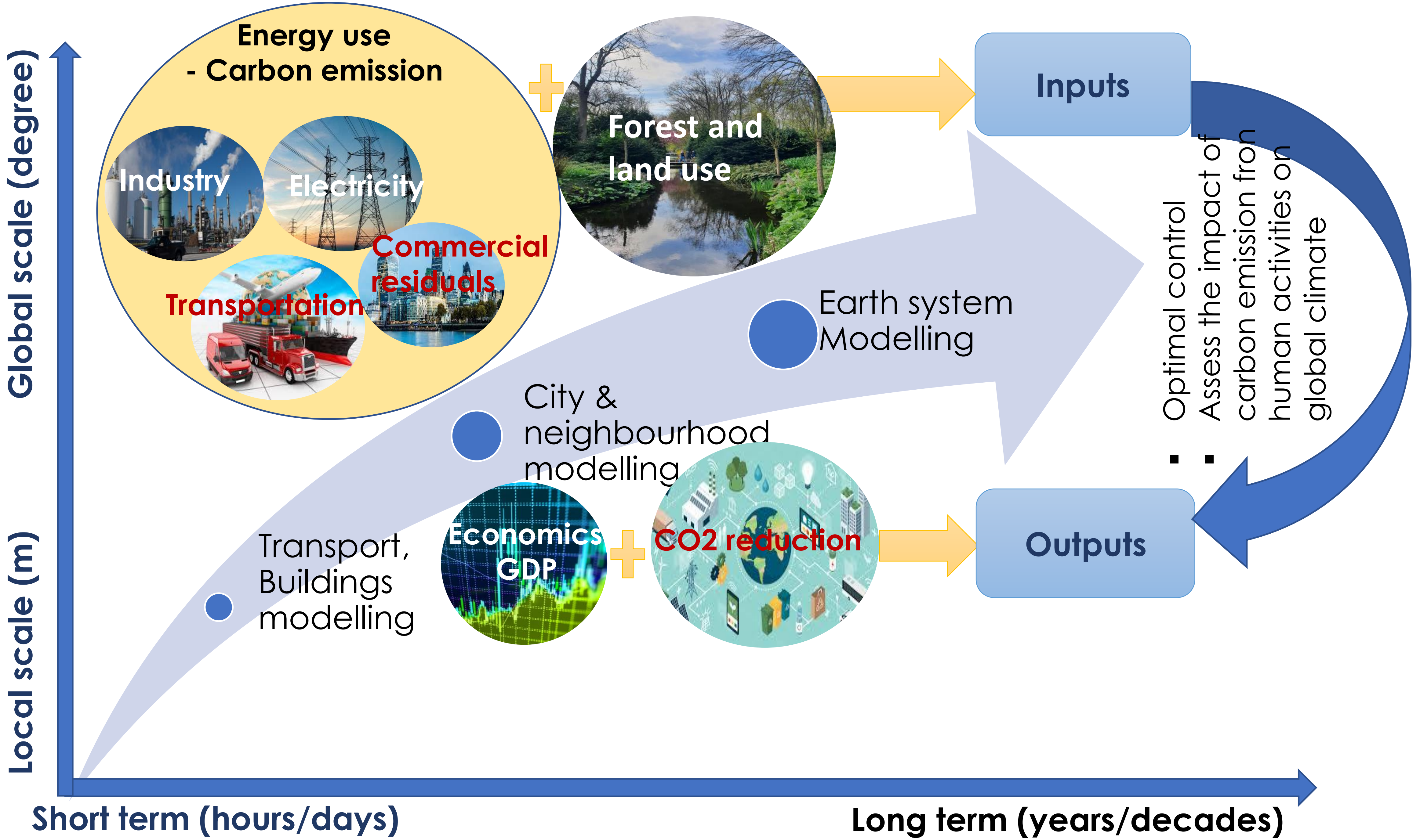
Digital tools for Urban Environment Management –
Challenges and objectives:

- Accurately assess carbon emissions;
  - Providing detailed spatial distribution of carbon/pollutants and reali-time forecast
  - Integrated assessment of the environment and human development
  - The complex carbon cycle and atmospheric physical processes over a wide range of spatial and temporal scales

- Help design and manage cities so that the carbon footprint is reduced;
  - Infrastructure Transition: Upgrading or replacing existing infrastructure to be more energy-efficient and environmentally friendly
  - Transportation Emissions: transportation routes, use of public transportation, bycycle etc.
  - Urban Planning and Design: Design urban layouts to accommodate green spaces, promote walkability, and reduce reliance on cars
  - Energy Generation and Consumption: Transitioning to renewable energy sources for both residential and industrial needs

- Quantify the impact of urban carbon emissions on global climate change:

  An Integrated modelling across neighbourhood, city and global scales which can be used for exploring the complex relationship between carbon emissions associated with human activities and global climate change



Energy use
- Carbon emission
Industry
Electricity
Commercial residuals
Transportation
Forest and land use
Inputs
Outputs
Optimal control
Assess the impact of carbon emission from human activities on global climate
Earth system Modelling
City & neighbourhood modelling
Transport, Buildings modelling
Economics GDP
CO2 reduction
Global scale (degree)
Local scale (m)
Short term (hours/days)
Long term (years/decades)

Physical image
“As Is”

Hybrid data generation approach

- Collecting data from sensors (e.g. drones, mobiles) and satellites;
- Physical modelling solutions

Hourly/daily physical nowcast/forecast

- Traffic emission spatial map
- Carbon/pollutant spatial map
- People map – linked to mobiles – people trace app
- Energy use/distribution map
- Extreme weather forecast (flooding, hurricane)

Digital Twin
(IoT)

Internet of things

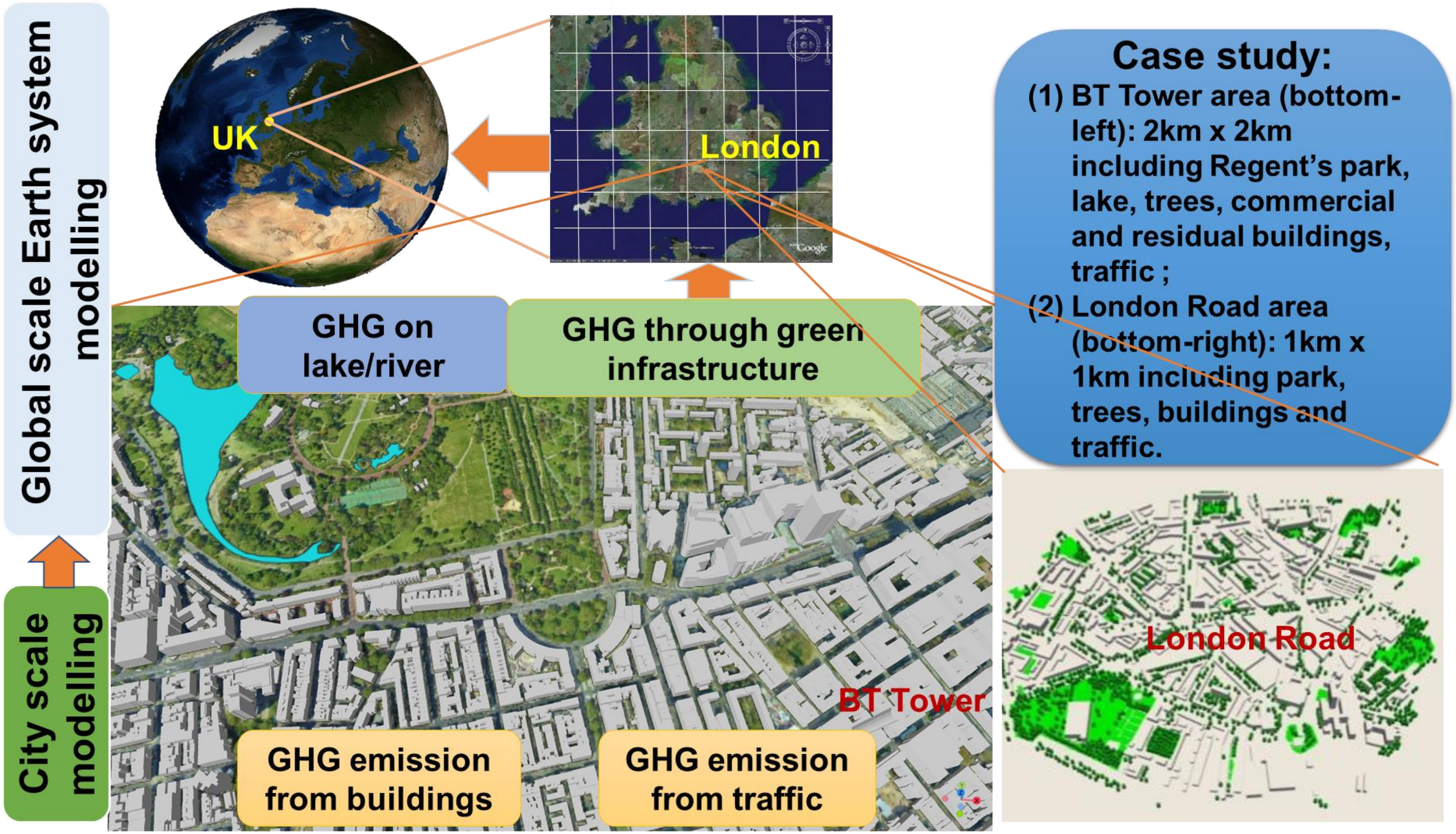
Virtual image
“To Be”

AI-enabling decision support system

- Autonomous carbon/pollutant monitoring and control
- Optimal traffic flow system
- Building environment control system (indoor and outdoor)
- Green and Blue infrastructures
- Efficient energy system
- Assessment of socio-economic & health impact

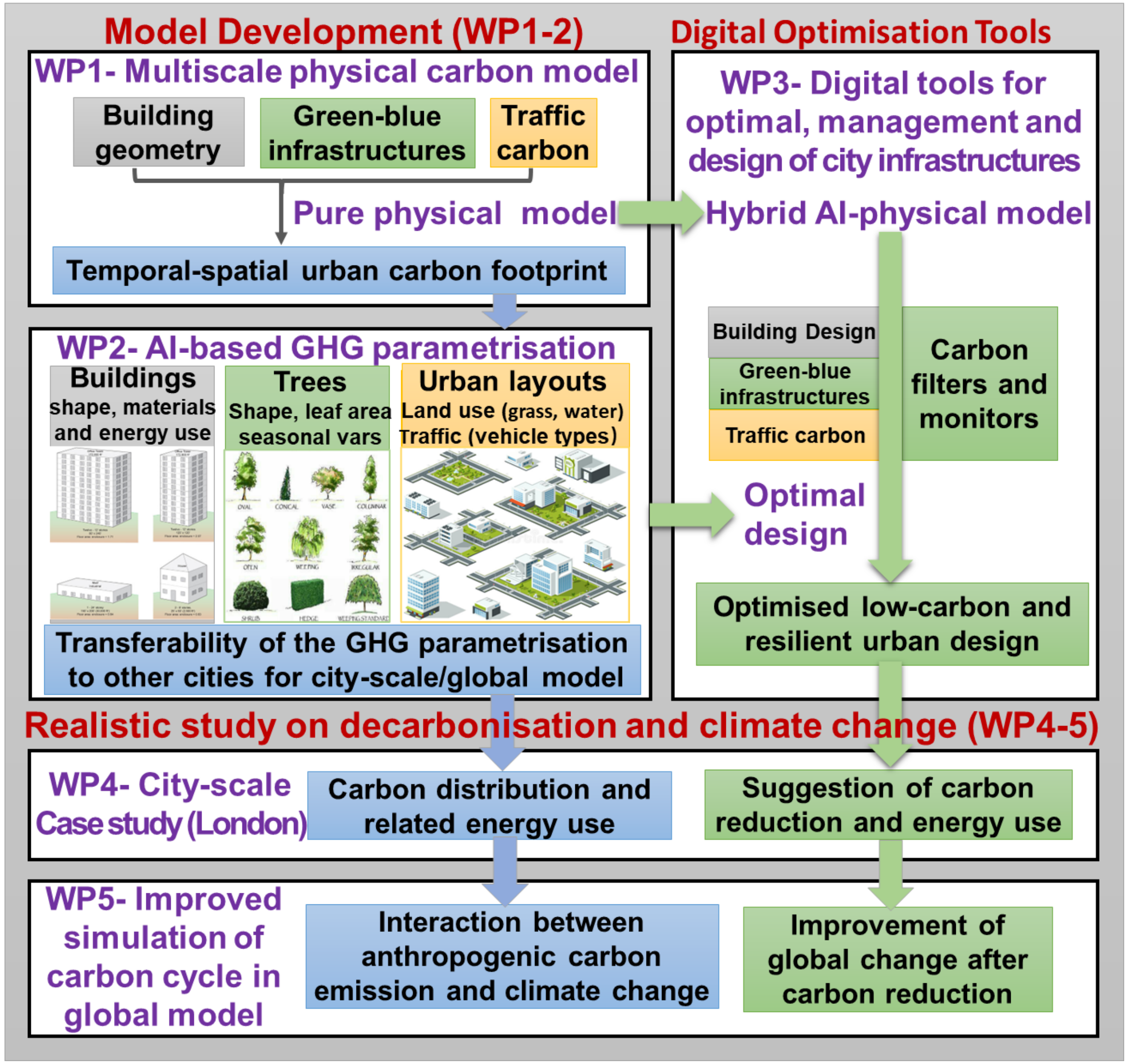
Digital tools for Urban Environment Management:

Integrated modelling from the neighbourhood, city to global scales showing the city GI-BI and human activities on local and global climate



Digital tools for Urban Environment Management:

Schematic diagram showing the linkages across workpages:



- Optimal ratio the areas of green-blue (G-B) infrastructures and buildings
- Incorporation of trees and greener roofs and walls
- Materials for buildings (low carbon emissions, cooling in Summer and heating isolation in Winter)
- Efficient energy use, and natural ventilation
- Advanced traffic and transportation monitoring and management systems for optimizing flow in densely populated areas
- Incorporate trees (types) along roadsides and medians for cooling and carbon absorption.
- Interaction of **health**, **economics**, **society**, and **environment -** a significant role in designing and managing a greener built environment, especially within limited spaces.
- Engagement of policy-maker, stakeholders, urban planers
- Use IoT, AI, and data analytics to monitor and optimize energy and traffic systems, thus reducing pollutant and carbon emissions

Digital tools for Urban Environment Management:

WP 1: Develop an advanced multiscale physical model for improved accuracy of urban carbon modelling.

- Develop the urban biogenic and anthropogenic tree and land surface model

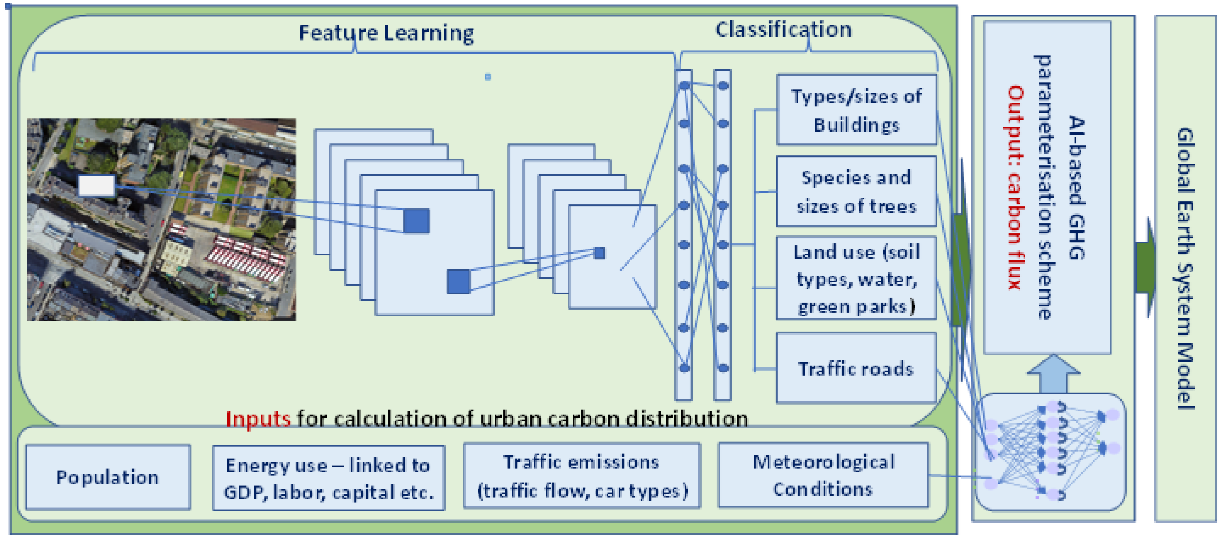
- Develop multiscale urban carbon model
  - the detailed city geometries G-BI, traffic emission etc) - including the details of buildings, street canyon) and identifying the land types (water, tree, roof, wall, greening etc
  - Traffic modelling
  - Modelling validation using in-situ measurement

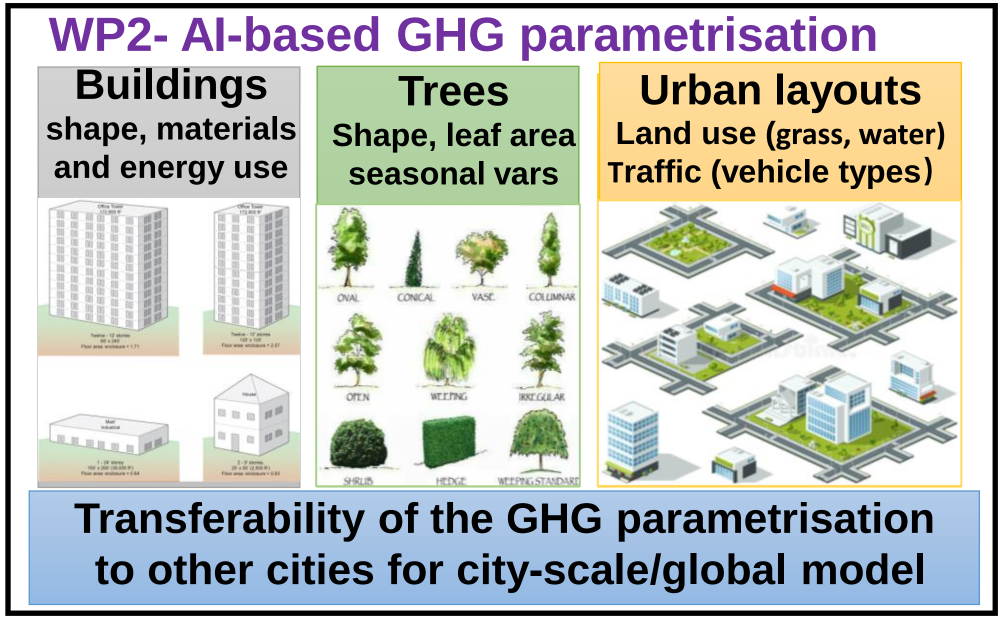
- Generate datasets of CO_2 from the new urban carbon model for training and validation of AI models in WP2.

Digital tools for Urban Environment Management:

WP 2:Develop AI-based GHG parameterisation scheme.

- **Effect of trees on decarbonisation** depending on the factors: the tree species, tree age, the amount of land reforested, and where they are planted (locations)
- **Effect of land use on decarbonisation.** The ratio of green and water areas and locations (as carbon storage) in the total city area is crucial on carbon reduction
- **AI GHG parameterisation tool** which will be coupled with the global model for improved assessment of the impact of carbon emission on global climate





Digital tools for Urban Environment Management:

WP 3: Develop an advanced AI-based tool for smart city management

- Hybrid AI and physical modelling for providing an interactive map of CO_2 concentrations at a high spatial resolution

- Digital tools for optimal control for *low-carbon* and resilient *urban* development
  - *Optimal locations of carbon filters and monitors within the city area*
  - Optimal design of urban infrastructures using the integrated AI-based GHG and physical modelling framework (Building design, optimal configuration of G-BI surrounding buildings, Optimal traffic management based on carbon emission indicators)

Digital tools for Urban Environment Management:

WP 4: Case studies: London, Singapore etc

- Assessment of carbon distribution and related energy use

- Providing suggestion of carbon reduction via optimal infrastructure management and efficient use of energy

- Regression analysis of carbon distribution/emission and layout of city infrastructures

Digital tools for Urban Environment Management:

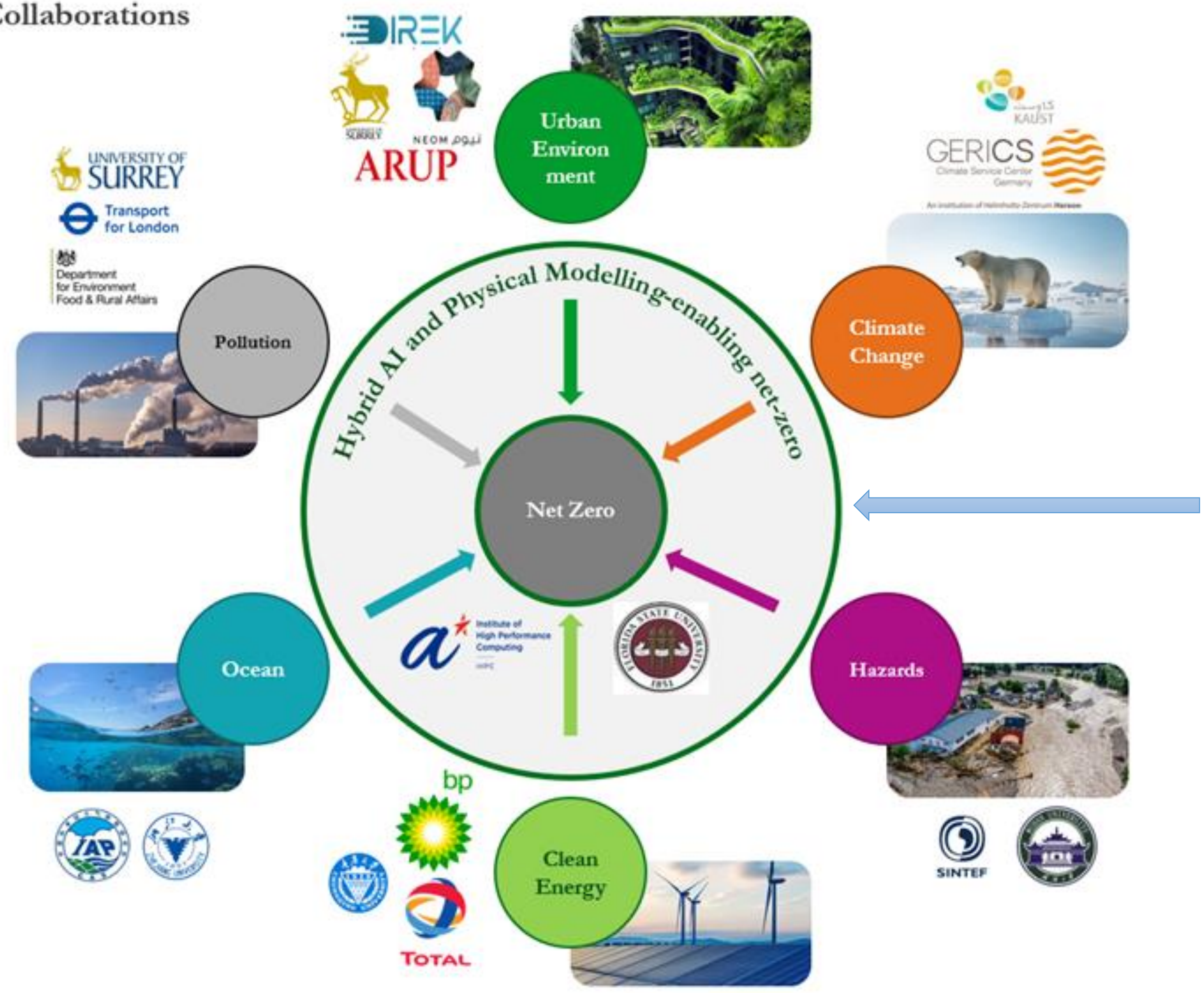
WP 5: Develop an interface tool for coupling the AI-based GHG sub-model with the existing Community Earth System Model (CESM)

- Improve the understanding of the interaction between anthropogenic carbon emission and climate change
- Assess the improvement of global climate change after carbon reduction through improving/optimising the existing/future infrastructures
- Recommendations of optimal city infrastructures for carbon reduction

Generally, the hybrid AI and multiscale physical modelling framework will facilitate a comprehensive evaluation of the existing conditions in the UK and enable the exploration of new policy options for decarbonization. These powerful tools possess the potential to significantly impact and improve current regulations related to decarbonization by providing valuable insights, optimizing energy efficiency, and empowering decision-making processes through increased knowledge and awareness.

- **Infrastructure Optimization**: Enable us to optimise existing infrastructures for energy efficiency and reduction of carbon emission and environment impact
- **Transportation planning**: Allow us to optimise the transportation routes and control the traffic flow, thus reduce the carbon/pollutant emission;
- **Urban planning and design**: Enable urban planners to visualize and plan for a sustainable city layout with green/blue spaces and efficient energy buidlings;
- **Efficient and resilience energy system**: Simulate energy consumption patterns in buildings and entire city systems. AI algorithms can then identify opportunities for energy efficiency and provide resilient energy plan in response to extreme climate;
- **Financial planning**: Provide cost-benefit analysis for different carbon reduction strategies, thus maximising its impact.
- **Real-time monitoring and data analysis**: Provide real-time data allowing us to monitor and measure the effectiveness of decarbonization efforts continuously;
- **Policy and regulation support**: Assess the impact of different policies and regulations on the city’s footprint, thus providing new regulations for decarbonisaton.

Collaborations

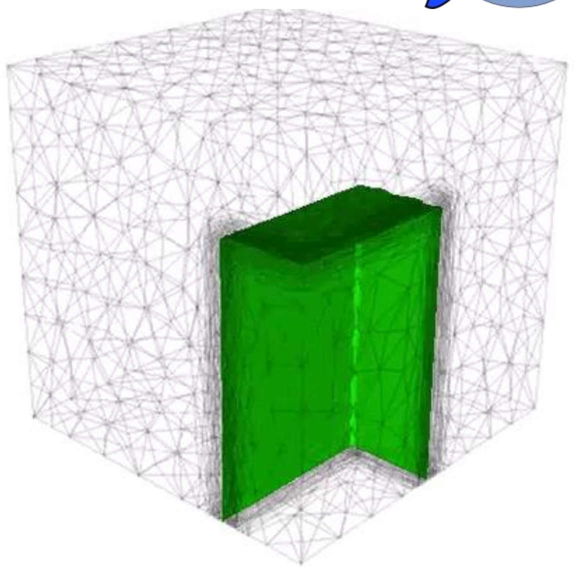


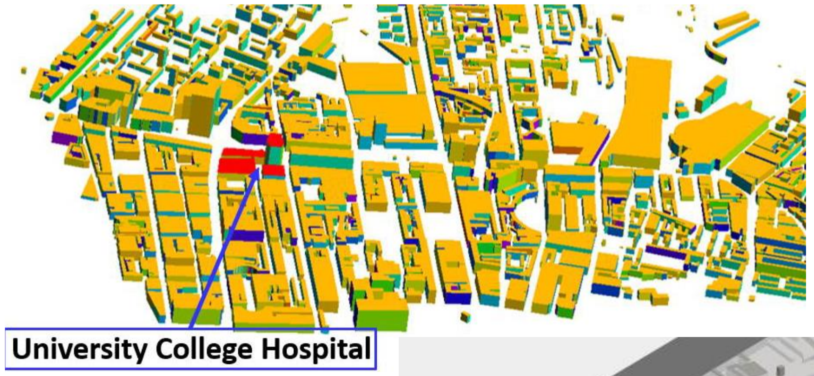
Internal collaboration

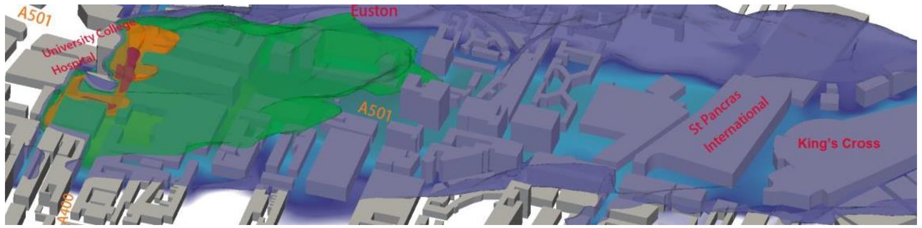
ESE;
Environmental research group;
Centre for environmental policy;
Transport and the Environment in the Department of Civil and Environmental Engineering;
Data Science Engineering;
I-X;
Grantham institute;
ICT

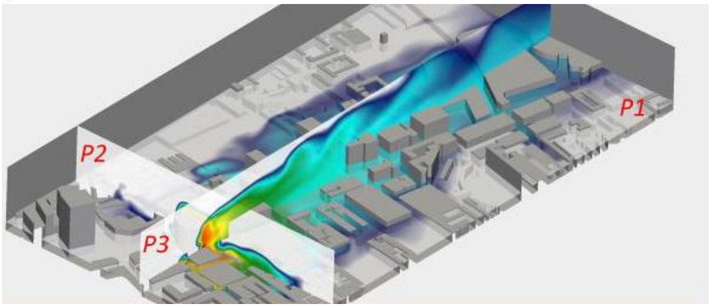
Introduction of an adaptive unstructured mesh fluid model – Fluidity-urban

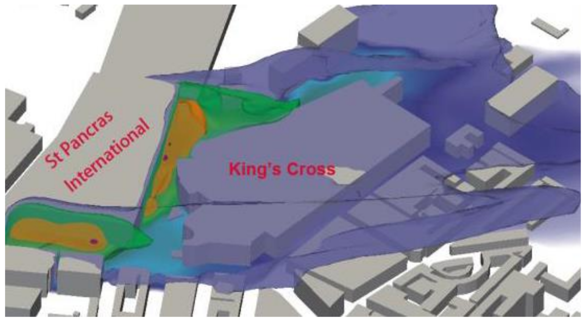
- ❖ Open Source Model Software for Multiphysics Problems
- ❖ Unstructured FEM Meshes
- ❖ Large Eddy Simulation (LES)
- ❖ Anisotropic Adaptive Mesh technology
- ❖ User-friendly GUI
- ❖ Python interface to calculate diagnostic fields, to set prescribed fields and user-defined boundary conditions

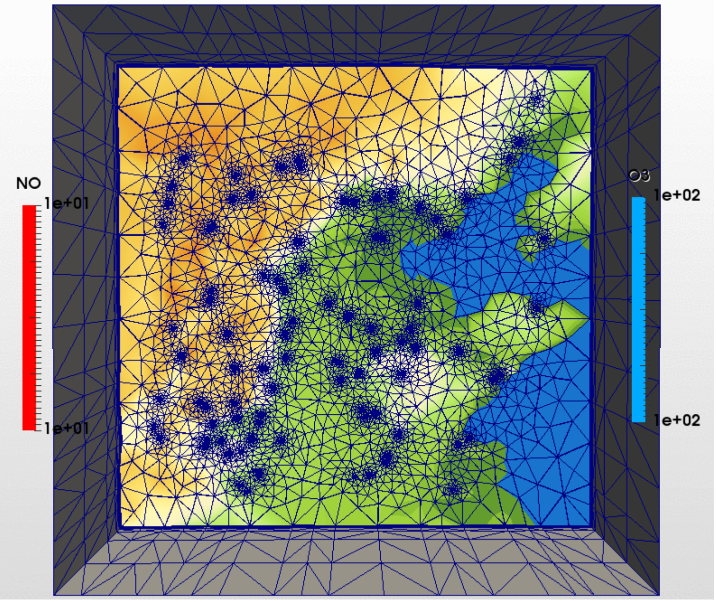








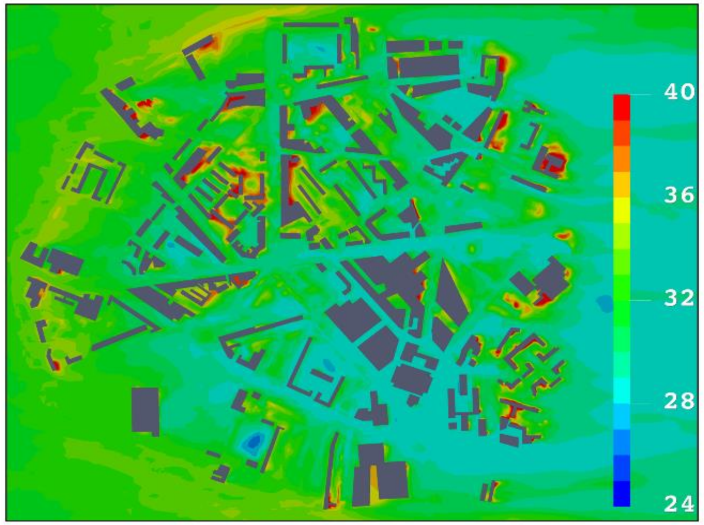




Physical green thermal-dynamical simulation Examples (Dr Wu)

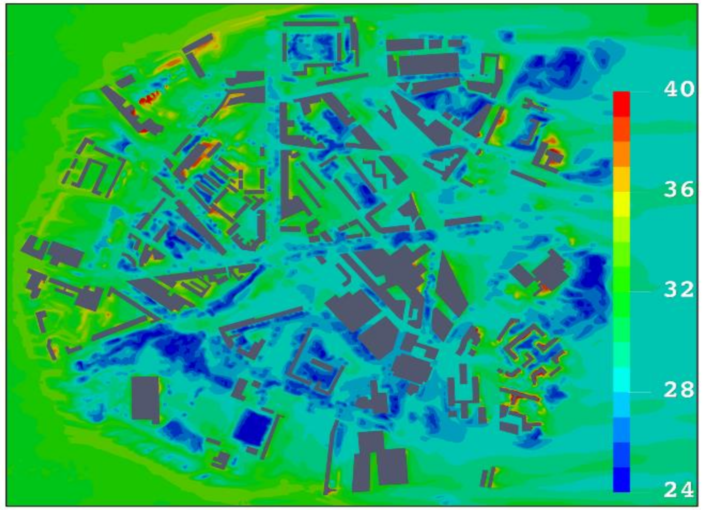
INHALE

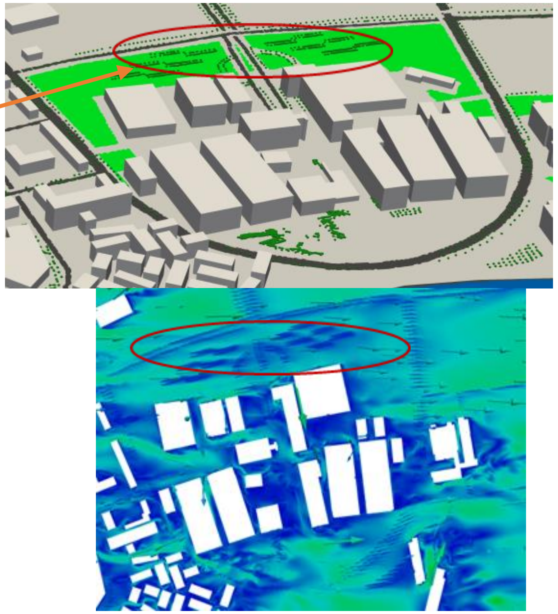
(a) Temperature without trees [°C]



London Road, Elephant and castle, UK

(b) Temperature with trees [°C]





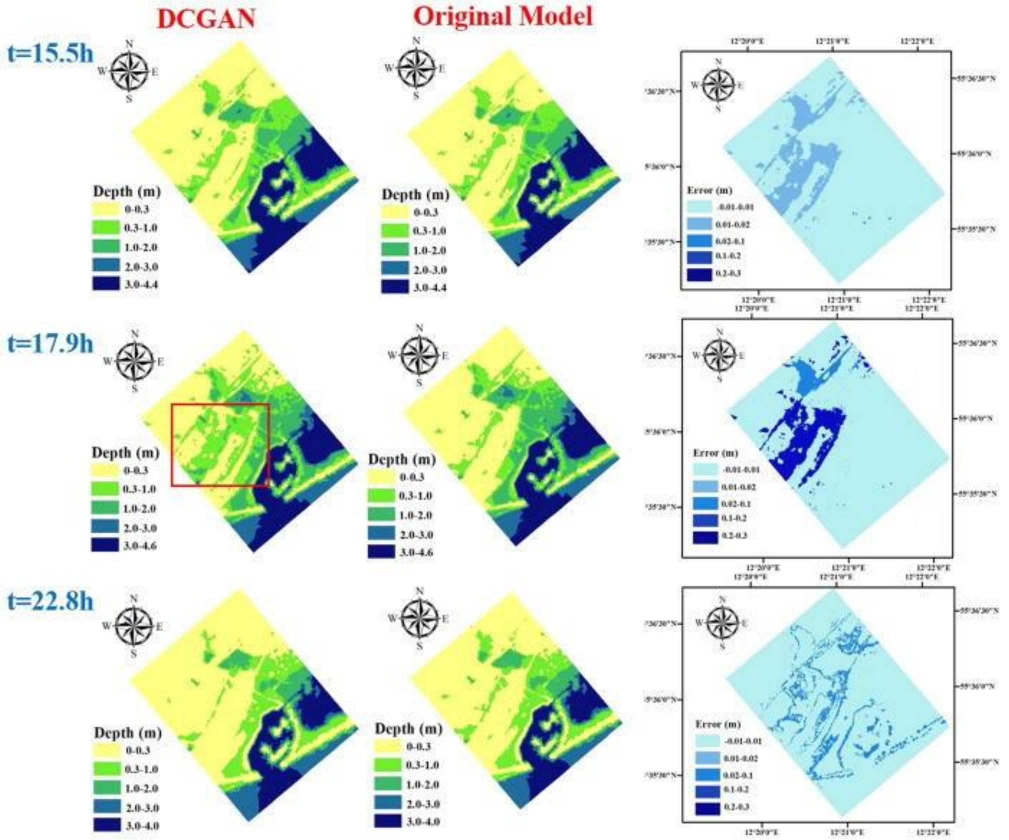
KAUST, Saudi Arabia

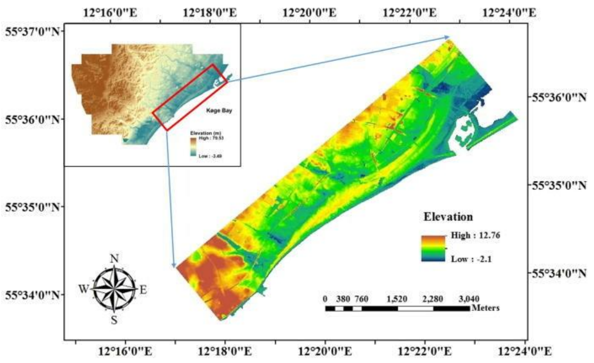
MAGIC

Envisaging a world with greener cities

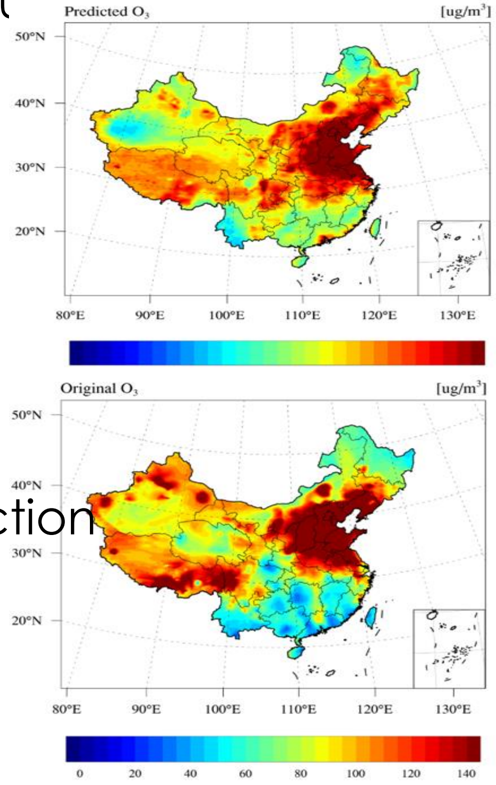
Spatial-temporal prediction using hybrid-machine learning and physical informed modelling & data assimilation (Dr. Cheng)

- Machine learning based rapid response tools for real-time operation prediction and uncertain analysis
- Sub-grid physical parameterization schemes in atmospheric modelling
- Real time air pollution forecasting at high spatial and temporal scales
- Machine learning-based coupling of multiple scale models from large (national/region), city to street sales
- Real-time operational tools for urban environment (traffic, green/blu





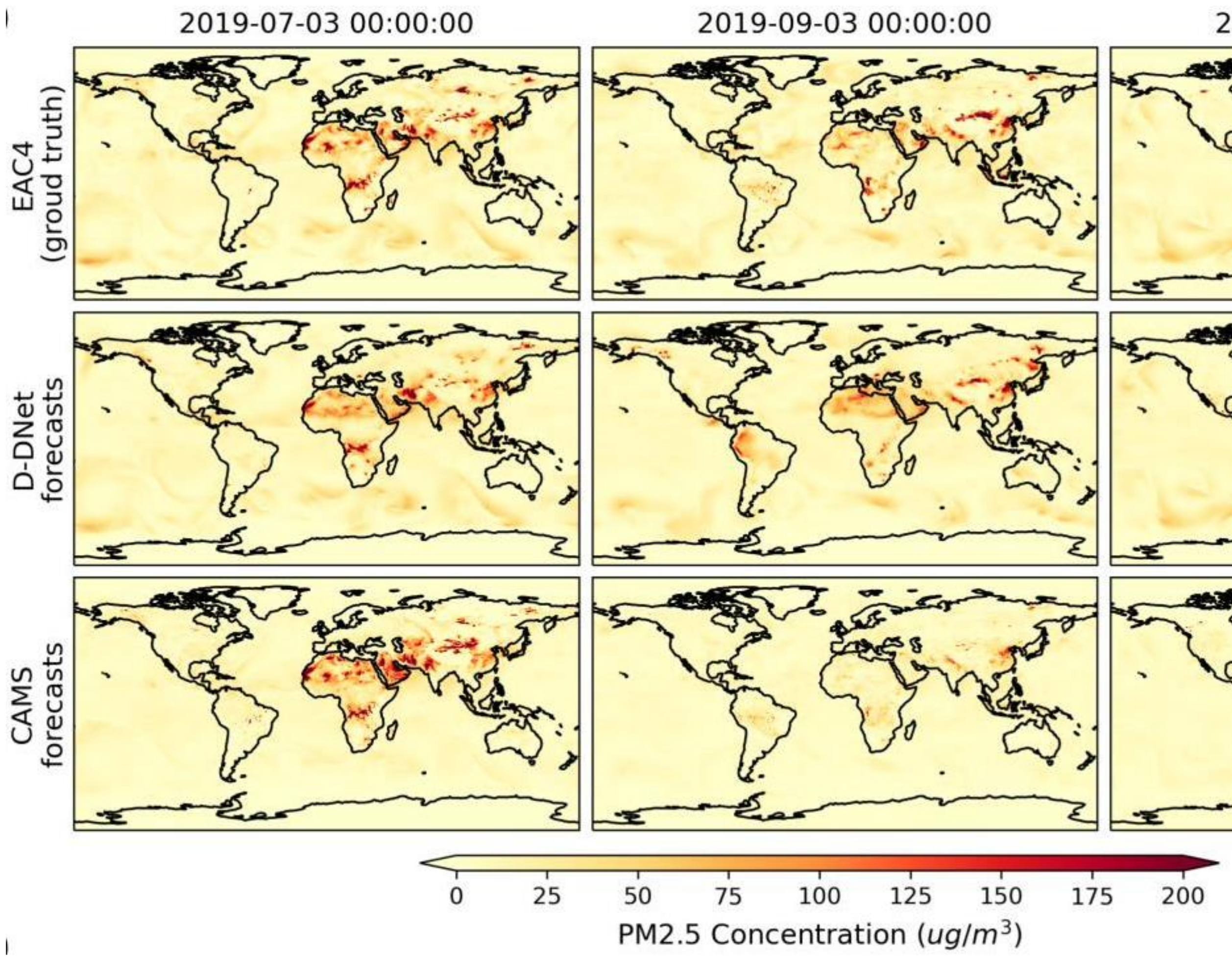
Real-time flooding prediction



Real-time ozone spatial distribution map in China

Global PM2.5 forecasting–Case Study (Ms. Cai)

ML & DA model – sparse observations



ECMWF Atmospheric Composition Reanalysis

- Reanalysis data = Integrating surface observations and physical simulation - advanced Copernicus Atmosphere Monitoring Service (CAMS), operated by the European Centre for Medium-Range Weather Forecasts (ECMWF).
- High spatial resolution: 80km x 80km (60000 nodes)
- High temporal resolution: 3h
- Data assimilation frequency: 6h.

Sparse data: 3258.

Training (90%) + validation (10%) : 2013-2018

Predicting: 2019

Thanks!

SCAN ME

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Senior Research Fellow