Third Destination Earth User eXchange

MindEarth SOLENIX CITYNEXUS

CityNexus: an advanced urban digital twin use case for high-resolution mobility and air quality "what if" scenario simulations on the DestinE platform

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CityNexus: an overview

CityNexus is an **innovative urban digital twin** designed for the Local Council of Amager Vest in **Copenhagen**. It serves as a comprehensive decision-making tool, enabling policymakers and urban planners to analyze the impacts of various urban development strategies on **mobility patterns**, **air quality**, and **population distribution**.

As Copenhagen works toward its ambitious goal of becoming carbon neutral by 2025, CityNexus plays a critical role in aligning local policies with these objectives, contributing to a more sustainable urban future.

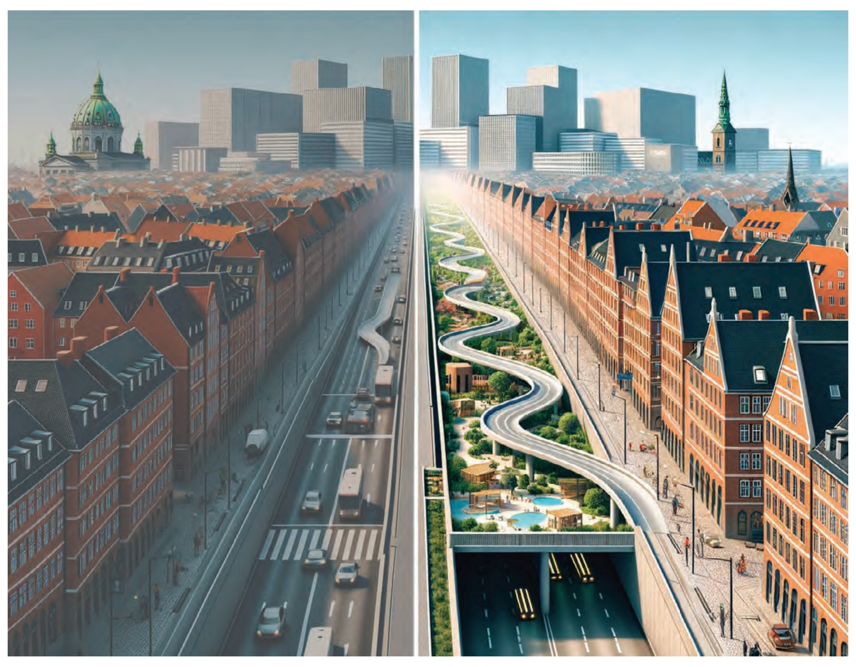
Indeed, by leveraging CityNexus, **stakeholders can explore how changes in road networks, land use, and urban infrastructure affect the functionality and livability of the city.**

The platform not only helps visualize the immediate impacts of policy decisions but also considers long-term trends, making it an indispensable tool for cities aiming to evolve into smarter, greener, and more liveable spaces.

"What if" scenarios in CityNexus

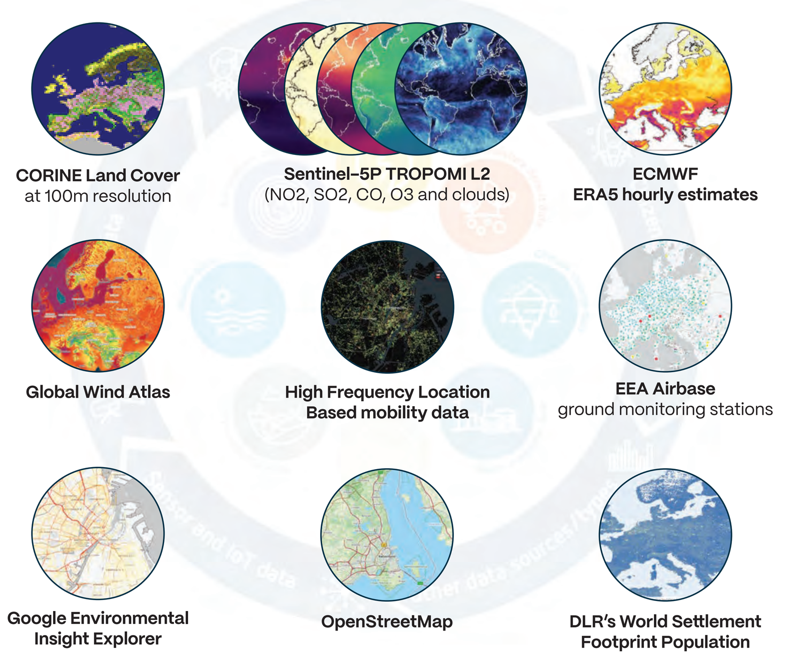
A core feature of CityNexus is its ability to **run interactive "what-if" scenarios** that allow users to test in a risk-free environment how different strategies affect key urban indicators linked to **mobility and air quality.** CityNexus currently supports four primary "what-if" scenario parameters:

- **High-speed Road Redesign:** This parameter allow tunnelling high-speed roads to see how this could influence traffic flows and help reduce pollution sources.
- **Promoting Electric Vehicles:** This parameter allows to increase the share of electric vehicles adoption, therefore leading to reductions in harmful pollutants.
- **Restricted traffic zones:** This parameter allows to prohibit motorized circulation on specific roads, areas, or category of roads.
- **Speed Limit adjustment:** This parameter allows to modify speed limits and evaluate the impact on congestio and air quality.



Input Data

In CityNexus, diverse datasets are curated for simulating urban scenarios. This includes data from the DestinE Data Portfolio, publicly available datasets, OpenStreetMap data, authoritative datasets and commercial human mobility records.



Local mobility & pollutant concentraton model

The key steps for developing the engine to simulate mobility patterns and pollutant concentrations are:

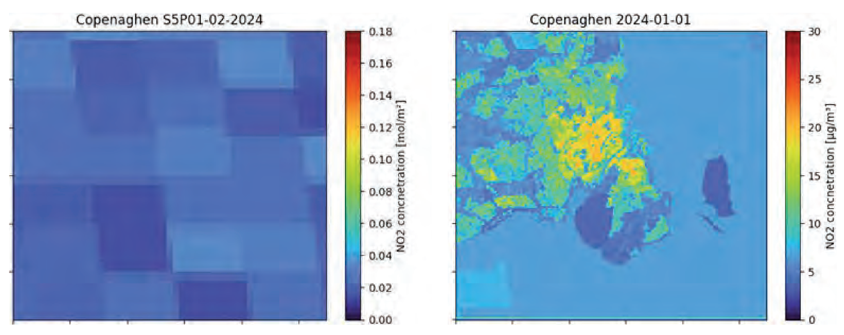
- **Data cleaning and filtering:** Raw mobility data is filtered to remove single pings and low-accuracy entries, identifying stops where users stay within a 30m area for over 5 minutes.
- **O/D Trajectories:** Trips are generated from these stops, aggregated into 3-hour intervals, and mapped into H3 cells for origin and destination points, with in-flows and out-flows calculated.
- **Street Network & Spatial Features:** The OpenStreetMap (OSM) street network is edited to fulfill graph constraints, while land use, population, and POI data is associated to H3 cells.
- **Mode of Transport Detection:** Travel modes are distinguished by speed, identifying pedestrians, cyclists, and vehicles.
- **Deep Gravity Model:** Simulates mobility patterns and predicts changes as new OD metrices, obtained as result of network modifications.
- **Traffic Simulation:** SUMO simulates traffic flows, accounting for factors like congestion and road signs, and vehicle types (e.g., Euro 5, Euro 4), and estimates associated emissions (CO_2, NOx, PM).
- **Pollutant Concentration Estimation:** SUMO emissions are combined with **Google EIE data** to estimate pollutant concentrations per cubic meter, also accounting for general environmental pollution.

Sentinel-5P TROPOMI-based regional NO2 concentration model

To assess total near-surface pollutant concentrations, an integrated model, based on a **CatBoost decision tree**, is trained to generate daily NO2 maps at 100m resolution using **Sentinel-5P TROPOMI** satellite data along with key inputs such as S5P cloud cover as well as ERA5 surface temperature, solar radiation and total precipitation.

Additional inputs include Planetary Boundary Layer Height (PBLH), land cover data (CORINE), elevation data (NASADEM), population density (WSF), slope, and wind data (Global Wind Atlas). Ground-level data from European Environmental Agency (EEA) AirBase monitoring stations are used as reference data to train the model.

Given Denmark's limited ground monitoring stations, the model is trained with data from Poland and Germany, which share similar climate conditions.

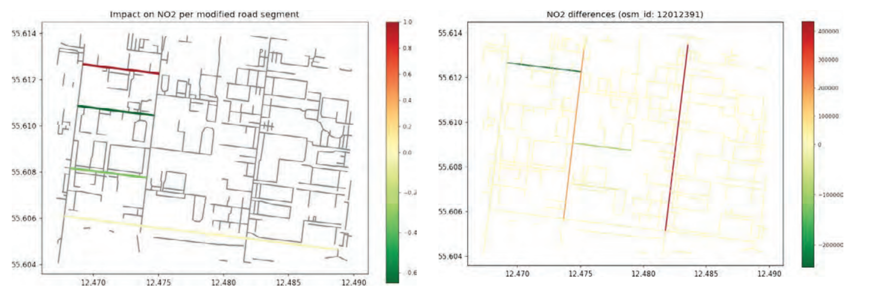


Explainable AI: impact & suggestion

CityNexus' XAI module is organised in **two stages** and helps explains the **environmental impact** of road changes and provides **recommendations** to mitigate negative effects. In particular:

- **Stage 1 – Explaining Environmental Impact:** multiple simulations with varied inputs are run to assess the environmental impact of road modifications, comparing results with the baseline. This process highlights per-road-segment effects and offers mobility trajectories to explain traffic flow changes.
- **Stage 2 – Suggesting Actions:** In the second stage, XAI goes beyond explanation by suggesting specific actions to mitigate the negative environmental impacts identified in the first stage and proposing alternative modifications that optimize environmental outcomes.

When key parameters are added to a simulation, the module runs additional simulations to generate explainable outputs. which are accessible via REST endpoints for analysis.



High performance "What if" senario simulation linking mobility to traffic-induced air pollution

Exploring the City Map and Initial Data

When users first access the platform, they are presented with an interactive city map divided into a 100x100 meter hexagonal grid, along with the full street network of Copenhagen.

The hexagonal grid displays essential details such as land use types (residential, commercial, industrial, etc.), points of interest (POIs) (schools, shops, health facilities), and the population associated with each cell. The street network shows all roads, with segments labeled by street type, traffic restrictions, and maximum speed limits.

Configuring the Simulation Parameters

Next, users define the parameters for the simulation. They can customize the simulation by selecting specific road segments or areas and adjusting:

- **Road properties:** Whether the road is open or closed to vehicular traffic, speed limits, and whether it is underground or above ground.
- **Zone properties:** Adjust the land use ratio (residential, commercial, etc.), the number and types of POIs, and the population in each area.

Additionally, users set broader simulation parameters, such as:

- The **percentage of bicycles** and electric vehicles on the roads.
- The type of day (weekday or weekend).
- The targeted **3-hour time slot** for which the simulation will run.

Running and Interpreting the Simulation Results

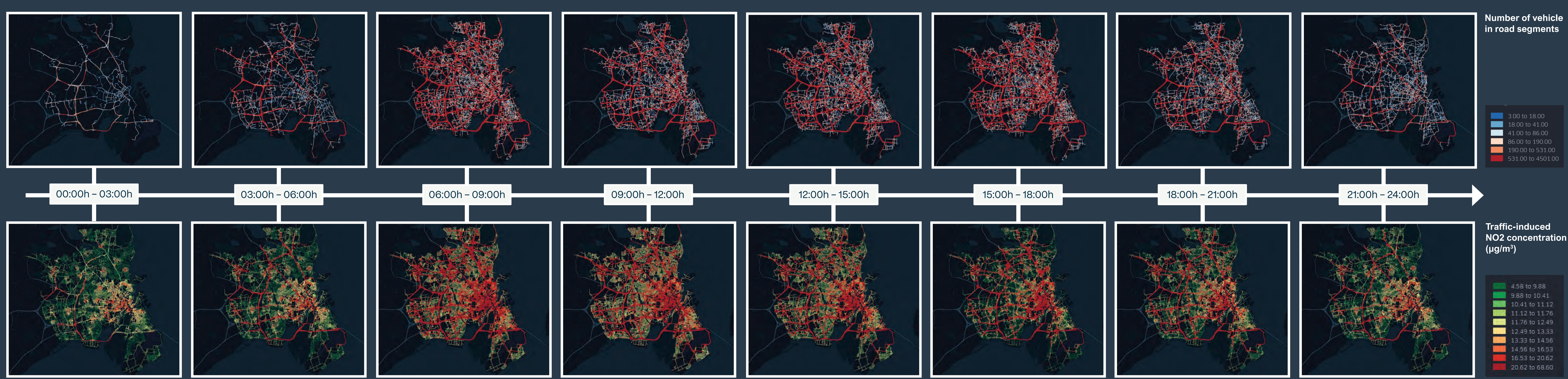
After setting up the parameters, users run the simulation. The platform provides detailed outputs on the map, including:

- **Pollutant concentrations** for CO2, CO, NO2, hydrocarbons (HC), and particulate matter (PMx).
- **Traffic statistics** such as average speed and congestion levels.

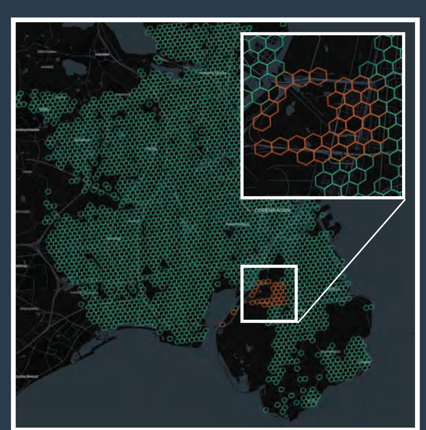
The results are visually displayed on the map, showing road occupancy and other relevant data for the selected time period.

Users can explore detailed data for each road segment or zone and save their simulation results for future comparisons.

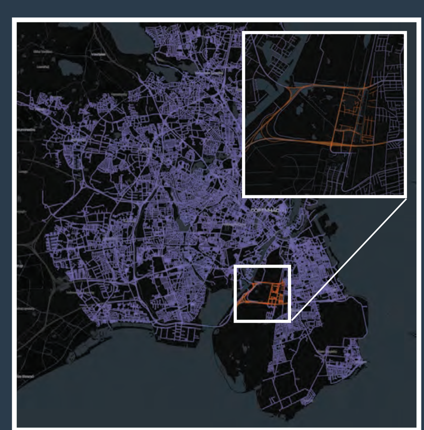
Baseline conditions: mobility VS NO_2 concentration



Input of user-defined scenario parameters



Commercial land use	1
Residential land use:	10
Healthcare POIs	1
Education POIs	1
Shopping POIs	5
Sport POIs	2
Population	50



Motorways & Juncions	tunnel
Tertiary roads	30km/h
Residential roads	30km/h
e-vehicles	+ 20%
bycicles	+ 30%
Day type:	weekday
Timeslots	all

What if scenario simulation results: mobility VS NO_2 concentration

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