Enhanced cellular automata model for the simulation of electricity demand at the urban scale

Study case: Guadalajara, Mexico

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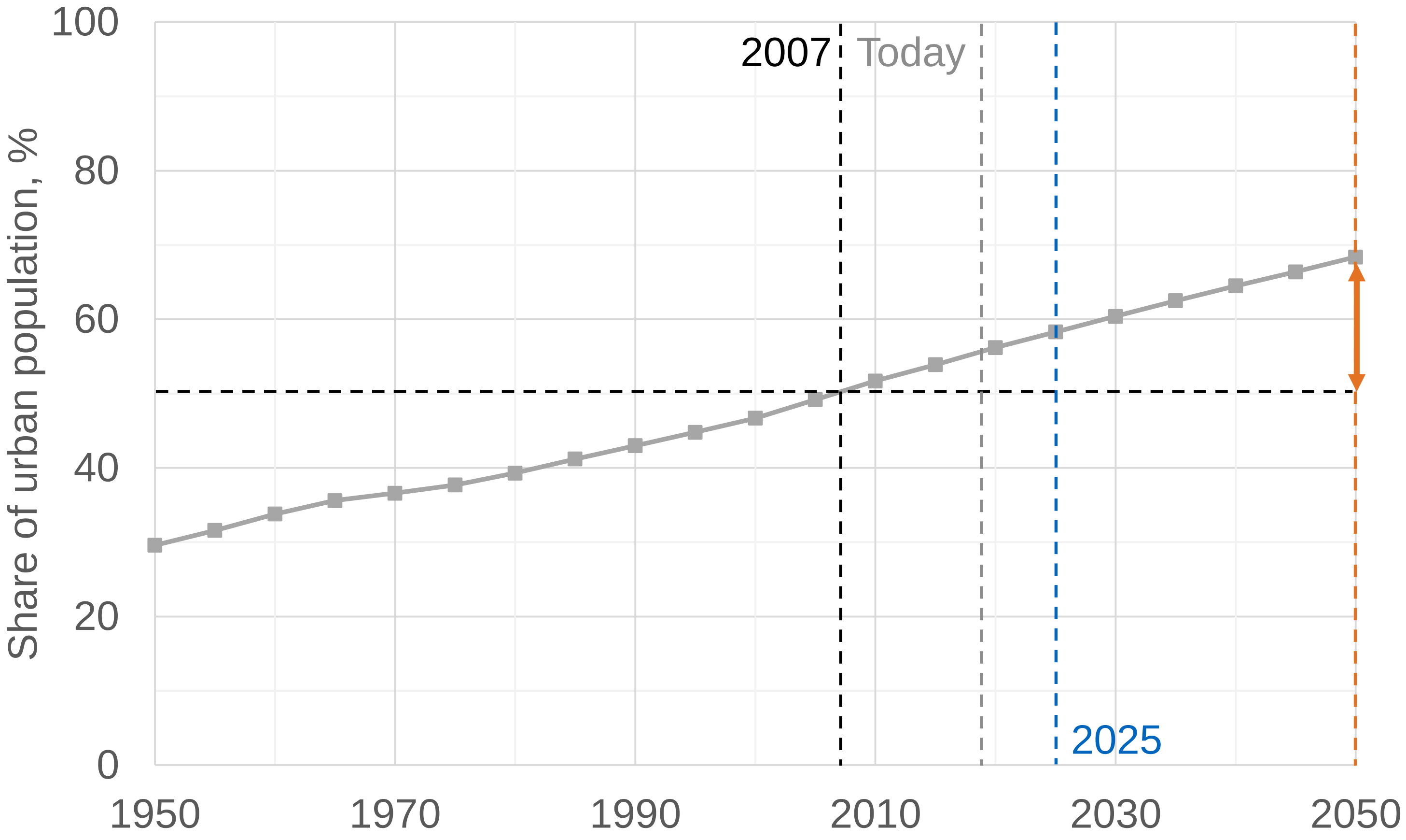
Our urban world

UN Urbanization prospects (2018)



Cities are responsible of 75% of the global **primary energy** consumption and 50-60% of the total **GHG emissions**.

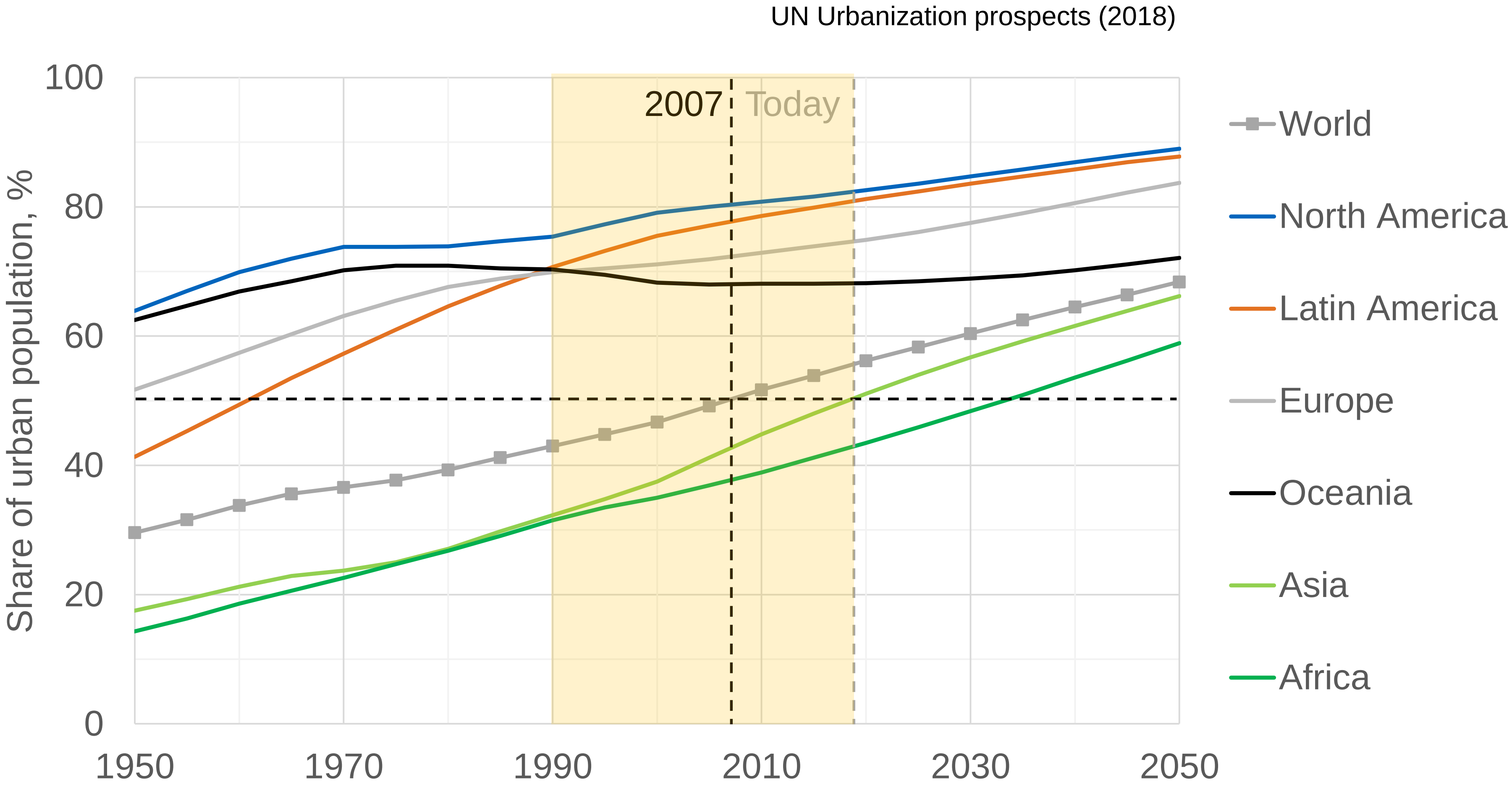
1 billion new inh. in the „**consuming class**“

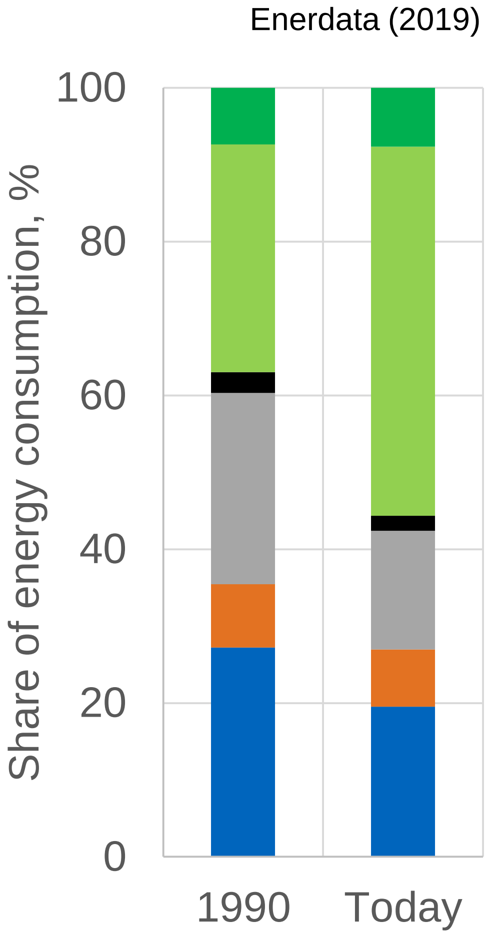
1 in 8 people will live in one of the 43 **megacities**

2.5 billion **new urban** inhabitants

50% of the population are expected to live in **medium-sized cities**

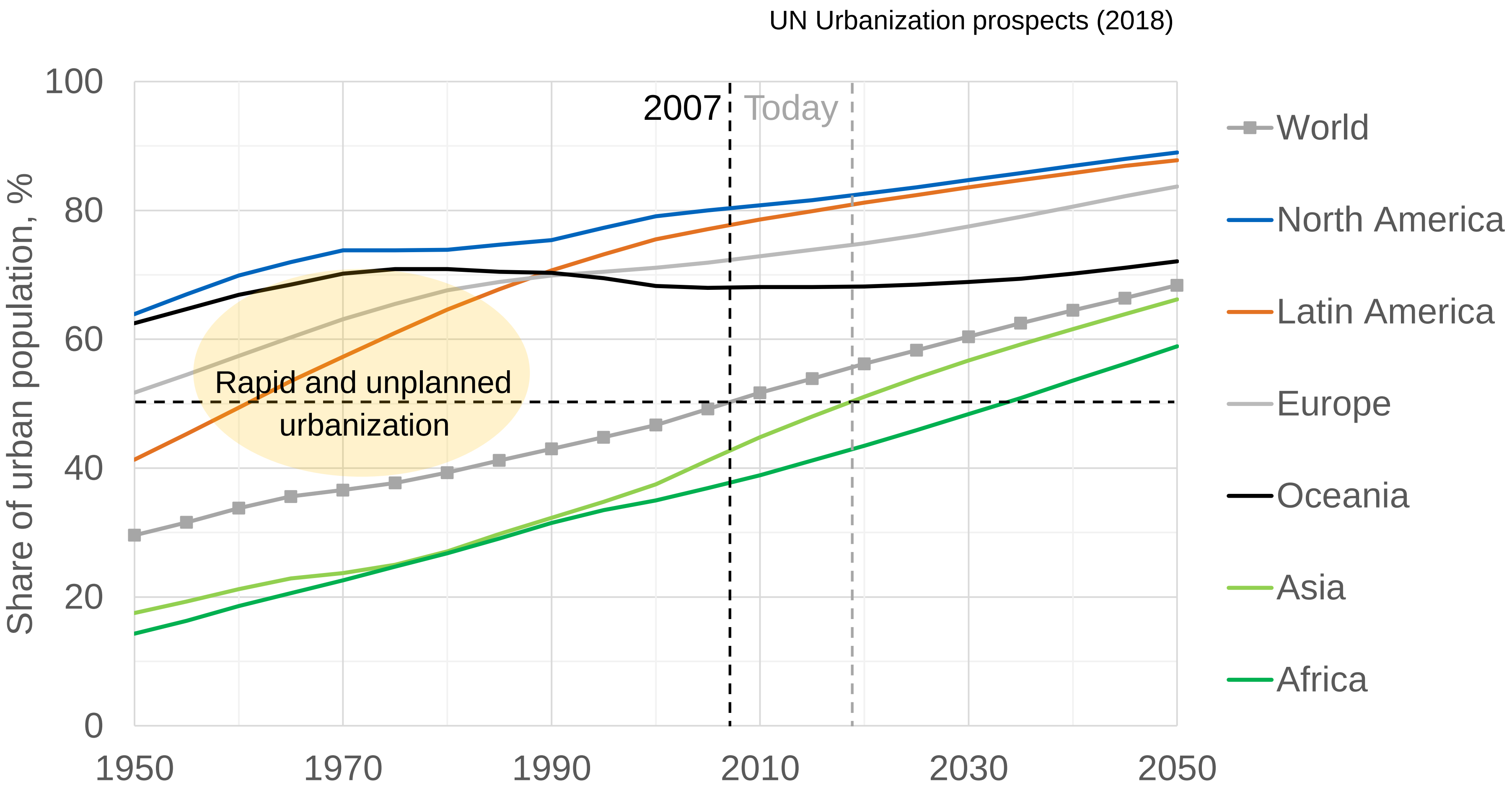
Our urban world





$$\boldsymbol{E = f(P, K, I, C)}$$

Our urban world



Urban expansion in slums

Inefficient use of resources

Poor urban infrastructure

Social segregation

Systemic poverty

Study case

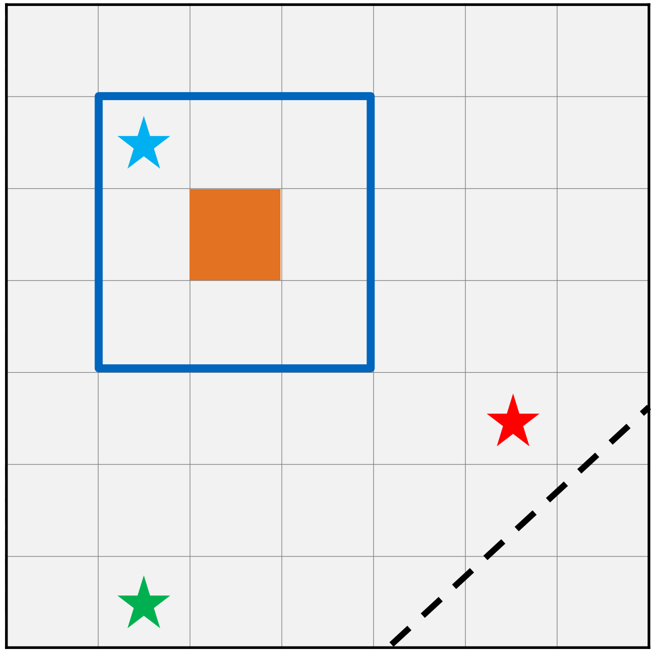
- Second largest urban area in Mexico
- Population: ~ 5 mio.
- 70% of the state population is projected to live in Guadalajara by 2030

Cities as complex systems: urban growth

Cellular automata + agent-based simulation

Guadalajara, Mexico

Source: Google Earth (2016)



Cells

Environment

$$C_t = \sum c_{i,j,t} \qquad c_i \in \mathrm{N_i}$$

$$c_{i,j,t} = [c_{i,j,t}^{\mathrm{D_1}}, c_{i,j,t}^{\mathrm{D_2}}, \dots, c_{i,j,t}^{\mathrm{D_n}}]$$

$$D_x = [d_1, d_2, \dots, d_m]$$

- Geographic features
- Urban infrastructure

Agents

Drivers of urbanization

- ★ Industry
- ★ Commerce
- ★ High-income residential

Modeling urban energy demand

Growth cycle, g_i

$$\boldsymbol{E = f(P, K, I, C)}$$

1. - Accessibility matrices
     (land value) for agents and cells
2. - ABM
     Location of key urbanization drivers
3. - CA
     Local urban growth rules
4. - Distribution of wealth
5. - Energy demand

1. Accessibility matrices: learning the value of land

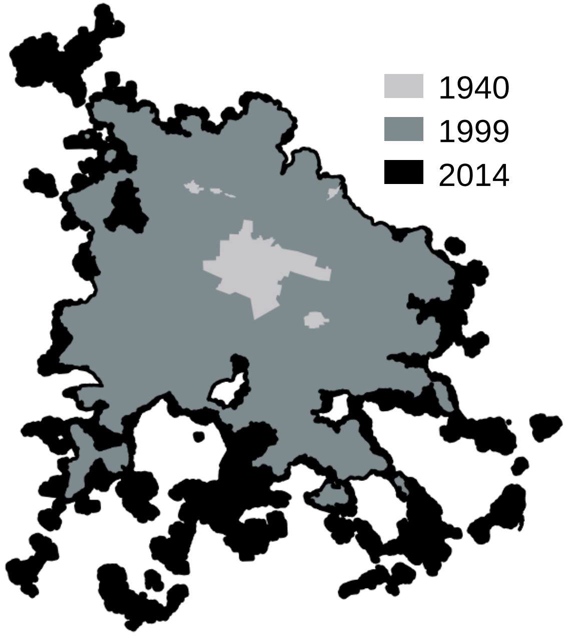
Urbanization (residential)

Machine learning (Random Forest Regressor)

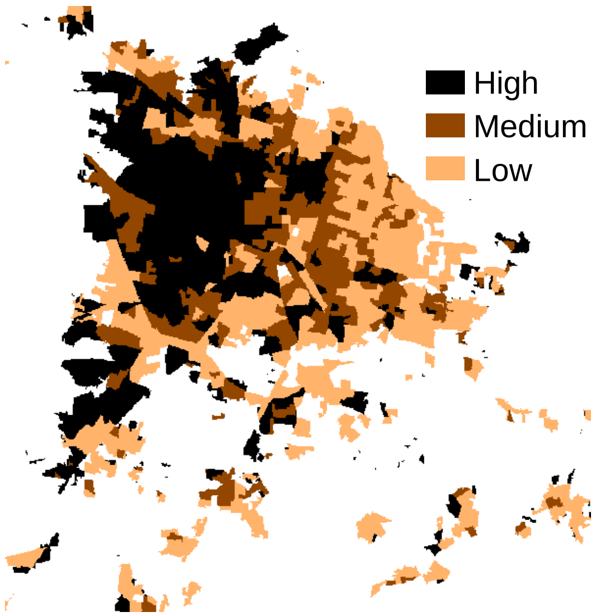
$$\boldsymbol{Y} = \boldsymbol{f}(\boldsymbol{X}) + \boldsymbol{\varepsilon}$$

Y response or dependent

X causative factors or features

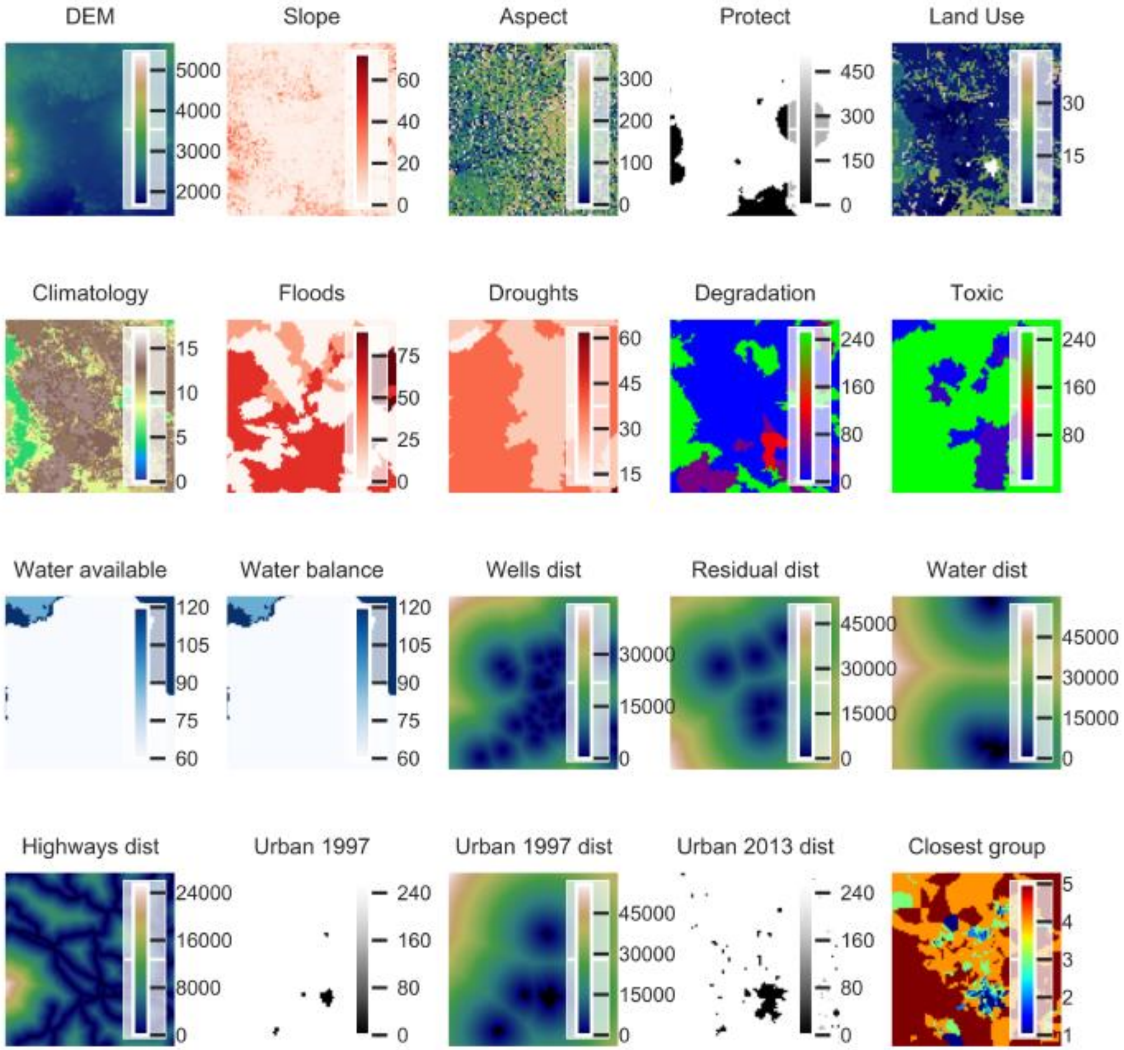


Urban cells



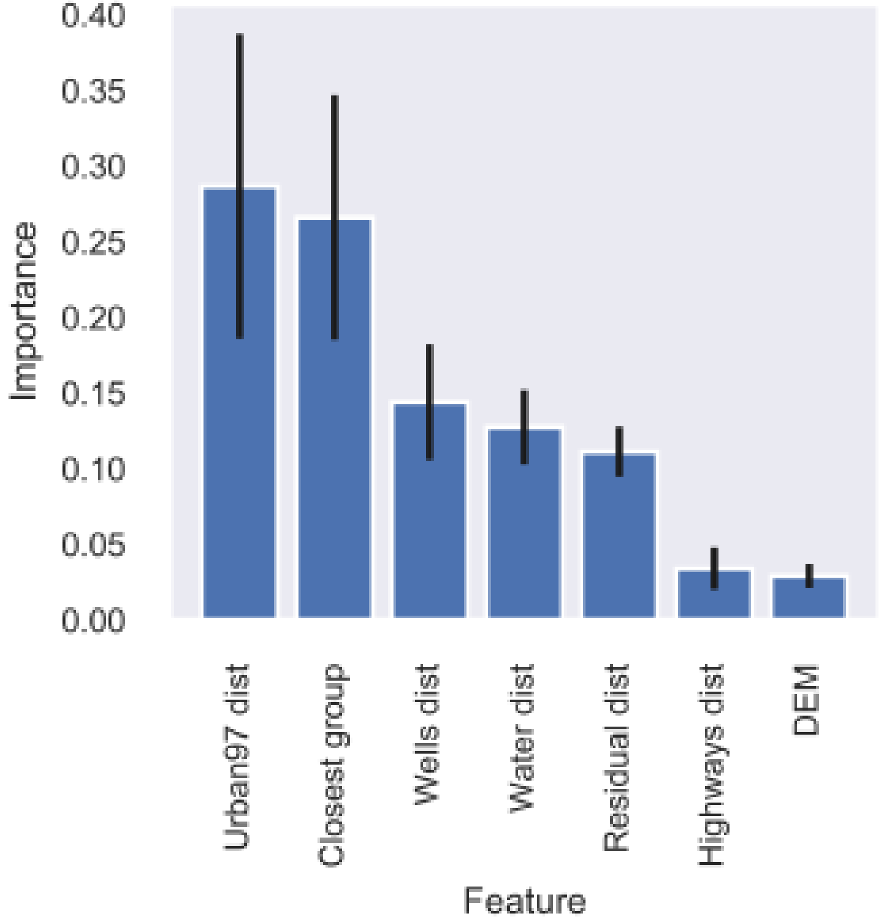
Socioeconomic level

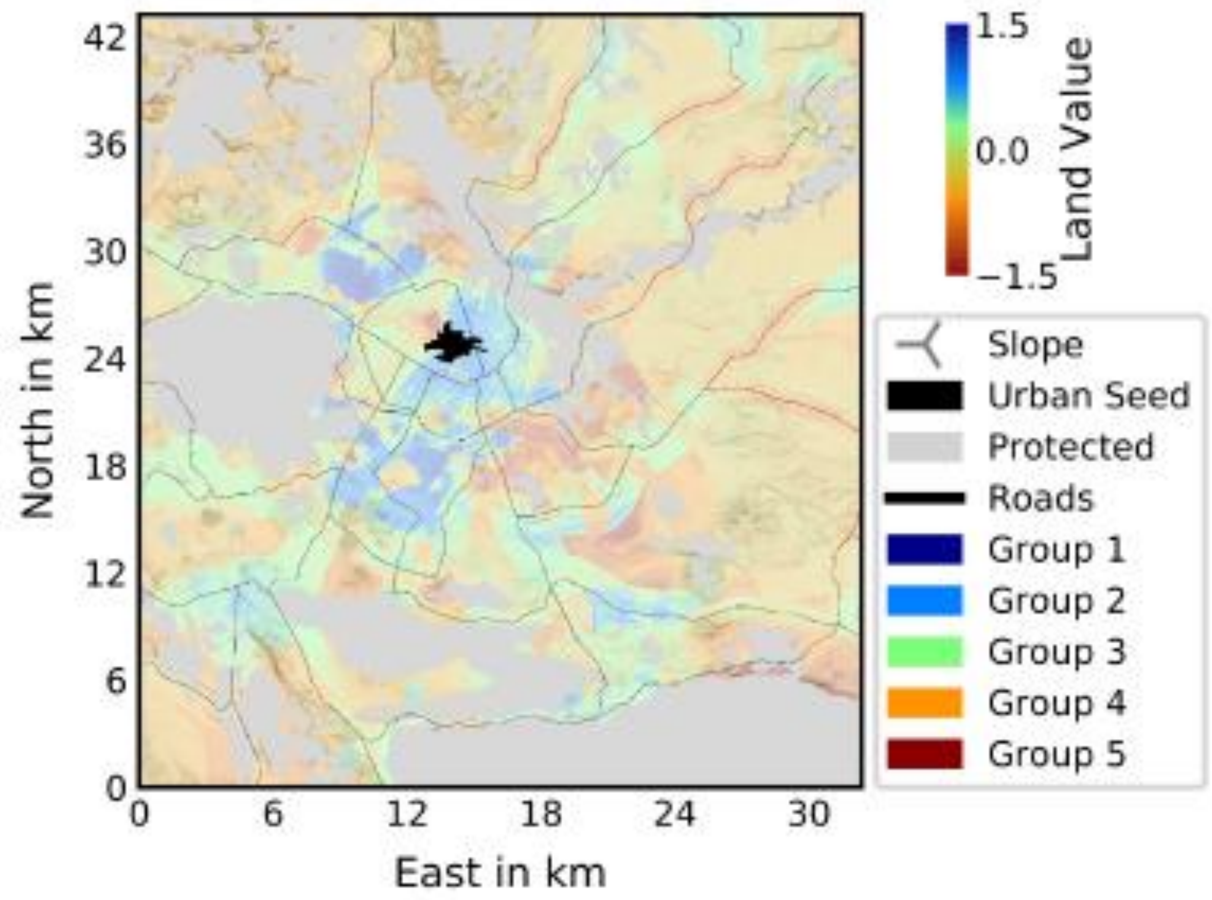
$\boldsymbol{X}$



1. Accessibility matrices: learning the value of land
Urbanization (residential)

$$Y = f(X) + \varepsilon$$

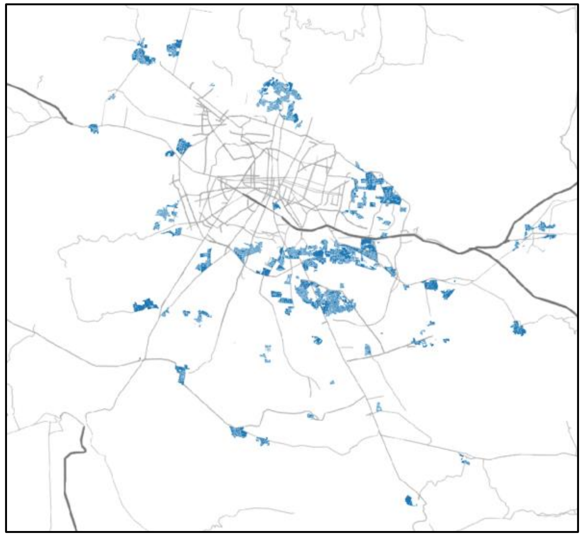




2. ABM: Location of key urbanization drivers

High-income residential

(-) Distance to high-income residential
(-) Distance to main roads
(+) Urban infrastructure
(-) Distance to green areas



Industry

(+) Area
(-) Distance to transport infrastructure

Commerce

(-) Distance to main roads
(-) Distance to high-income residential
(+) Area

3. CA: local urban growth rules

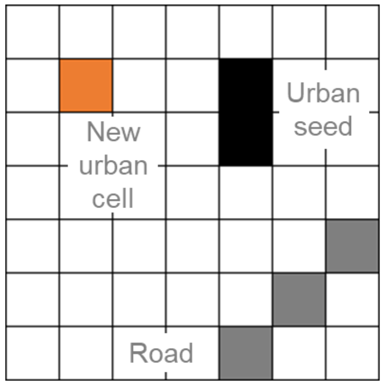
Probabilistic cellular automata model

Dimensions:

- Land use [urban, not urban]
- Land value (-1.5, 1.5)
- Infrastructure [with road, without road]
- Urbanization driver [high-income, industry, commerce)

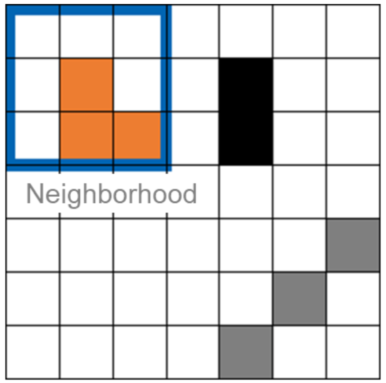
SLEUTH model (Clark et al, 1997)

k_1



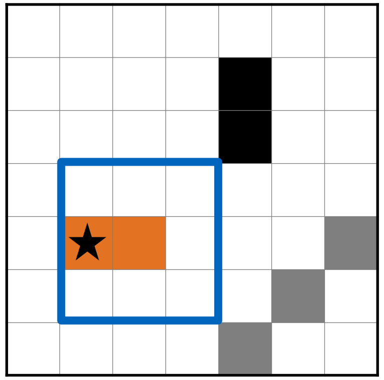
1. Spontaneous growth

k_2



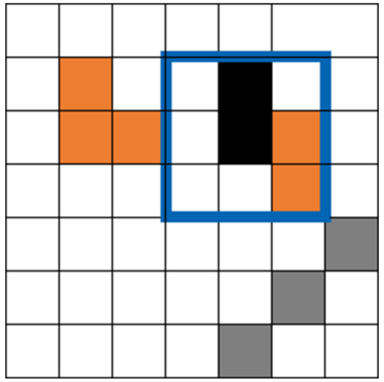
2. Growth of new spreading center

k_5



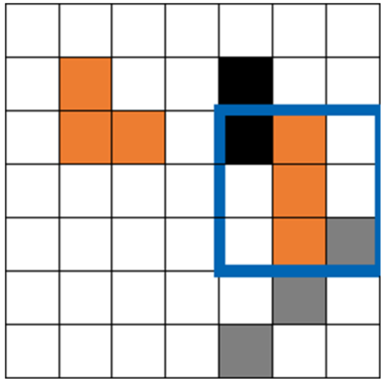
5. Key driver-influenced growth

k_3



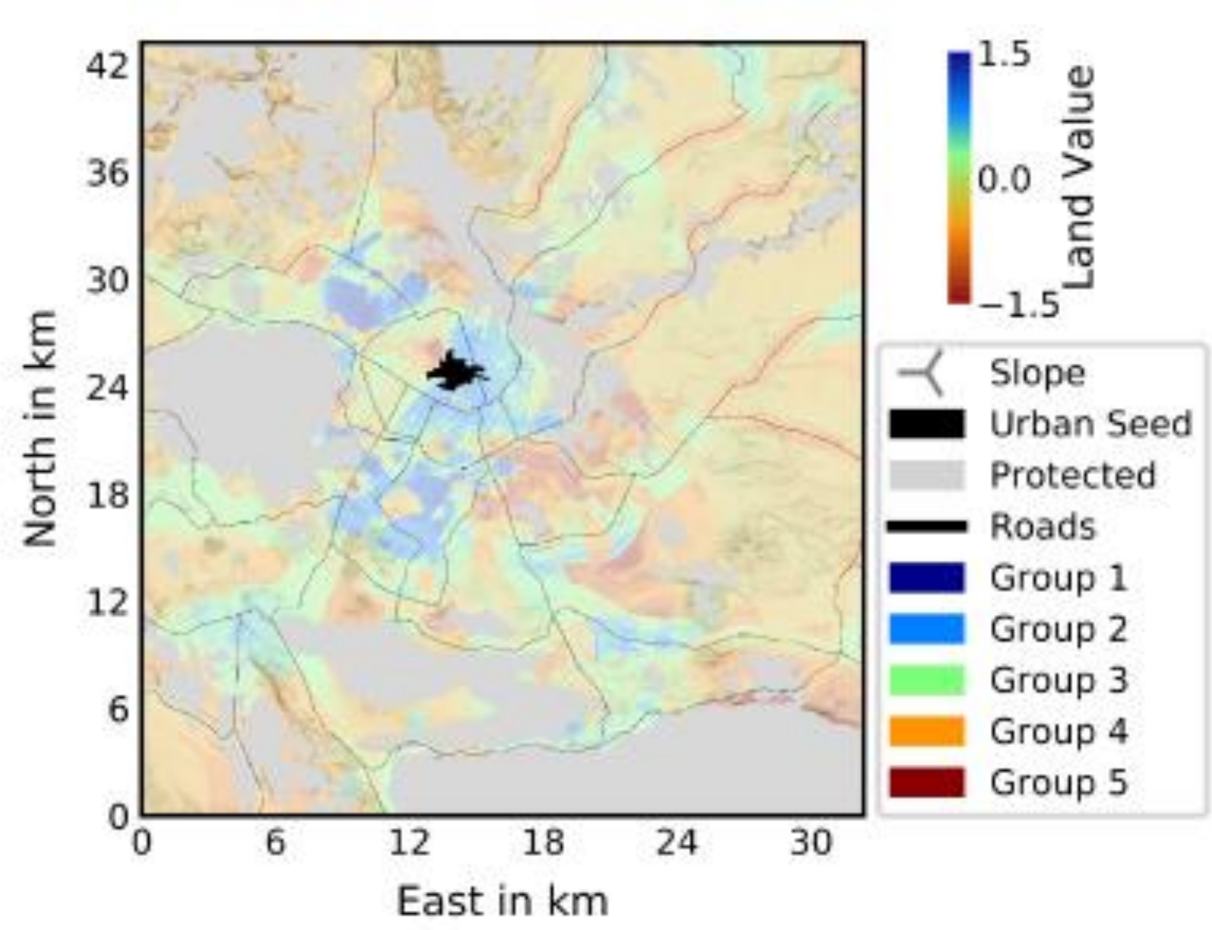
3. Edge growth

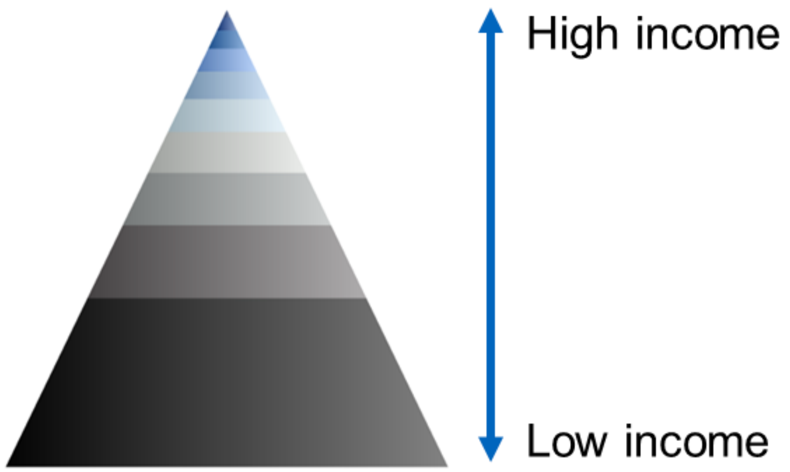
k_4



4. Road-influenced growth

4. Distribution of wealth

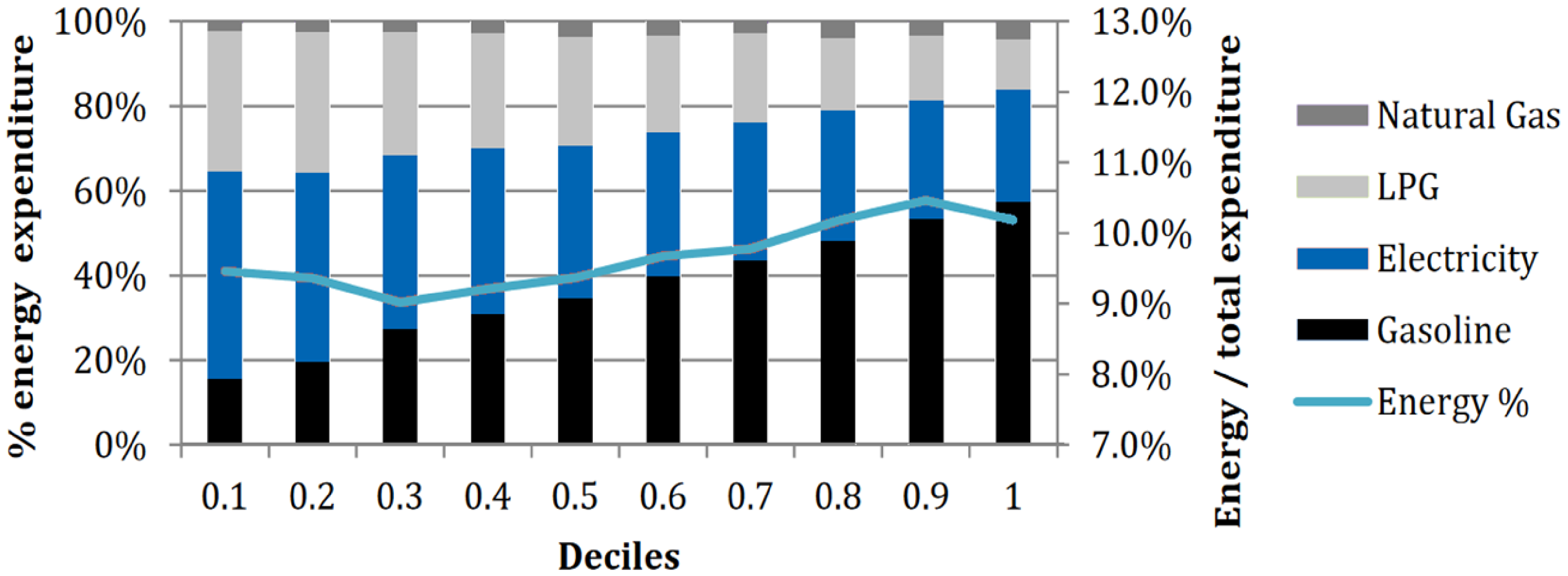




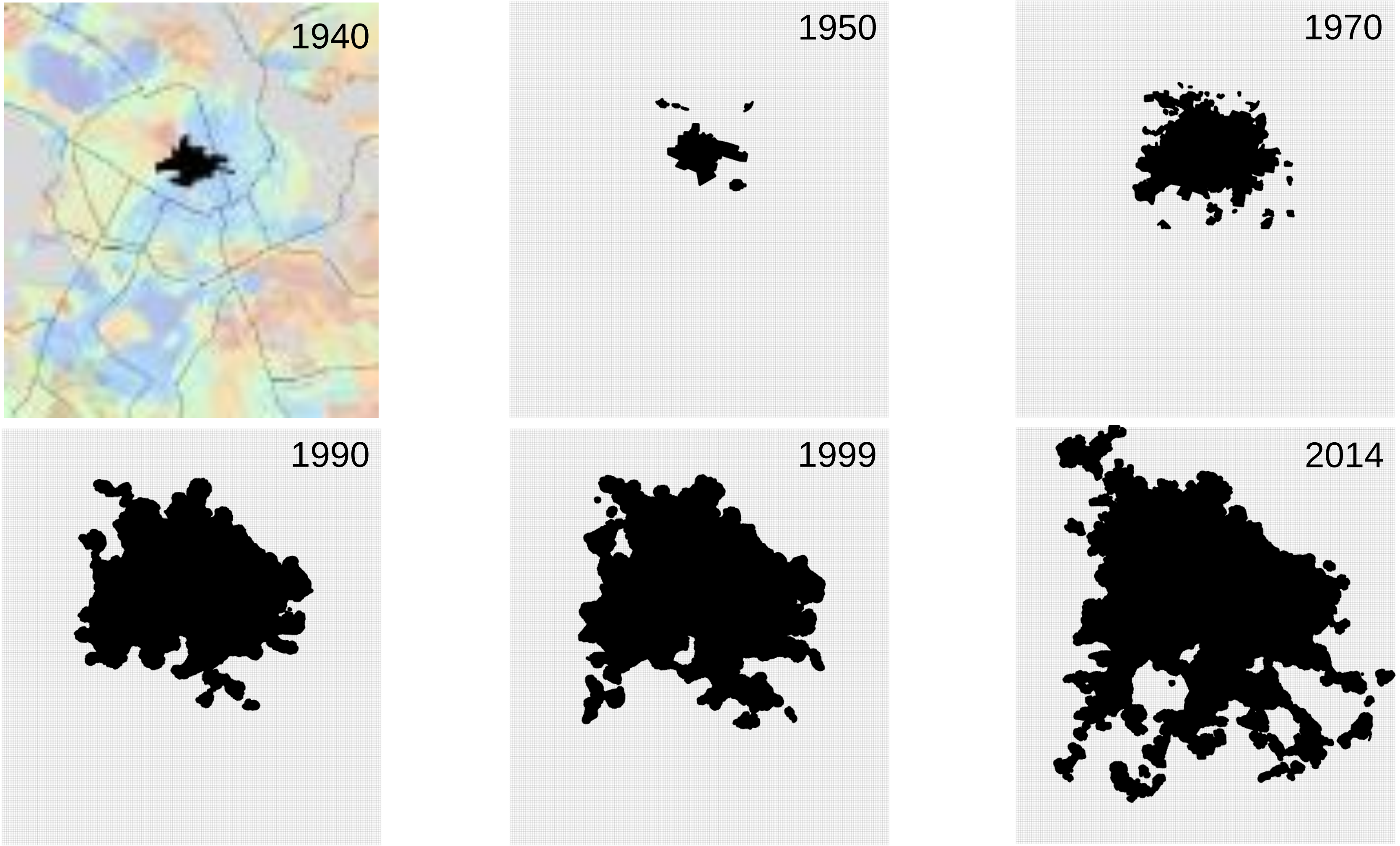
5. Urban energy demand
Residential

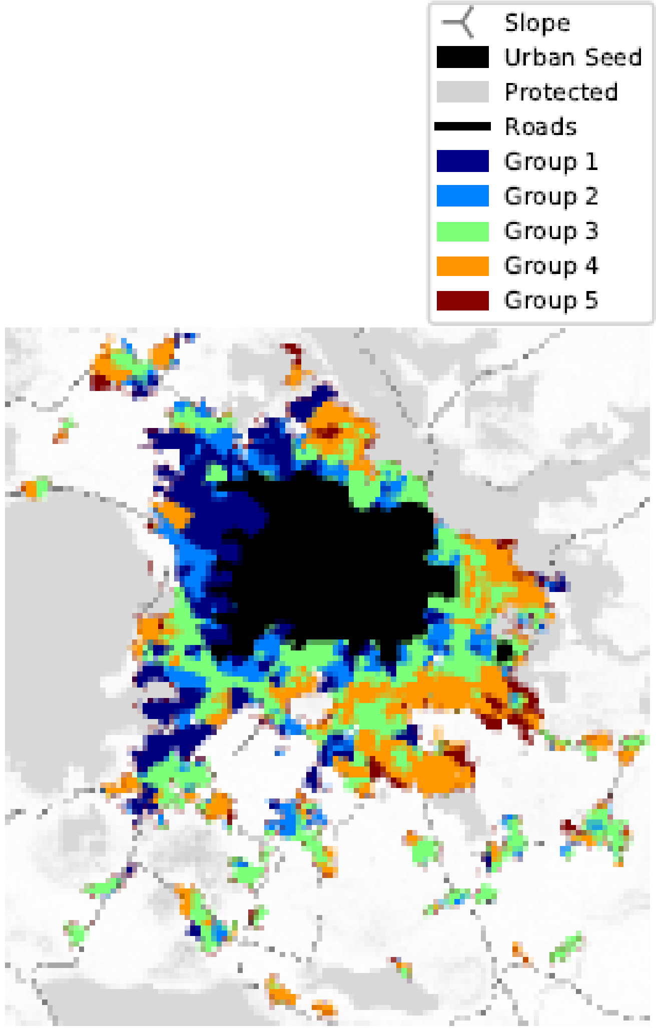
Statistical model to calculate energy consumption for every cel

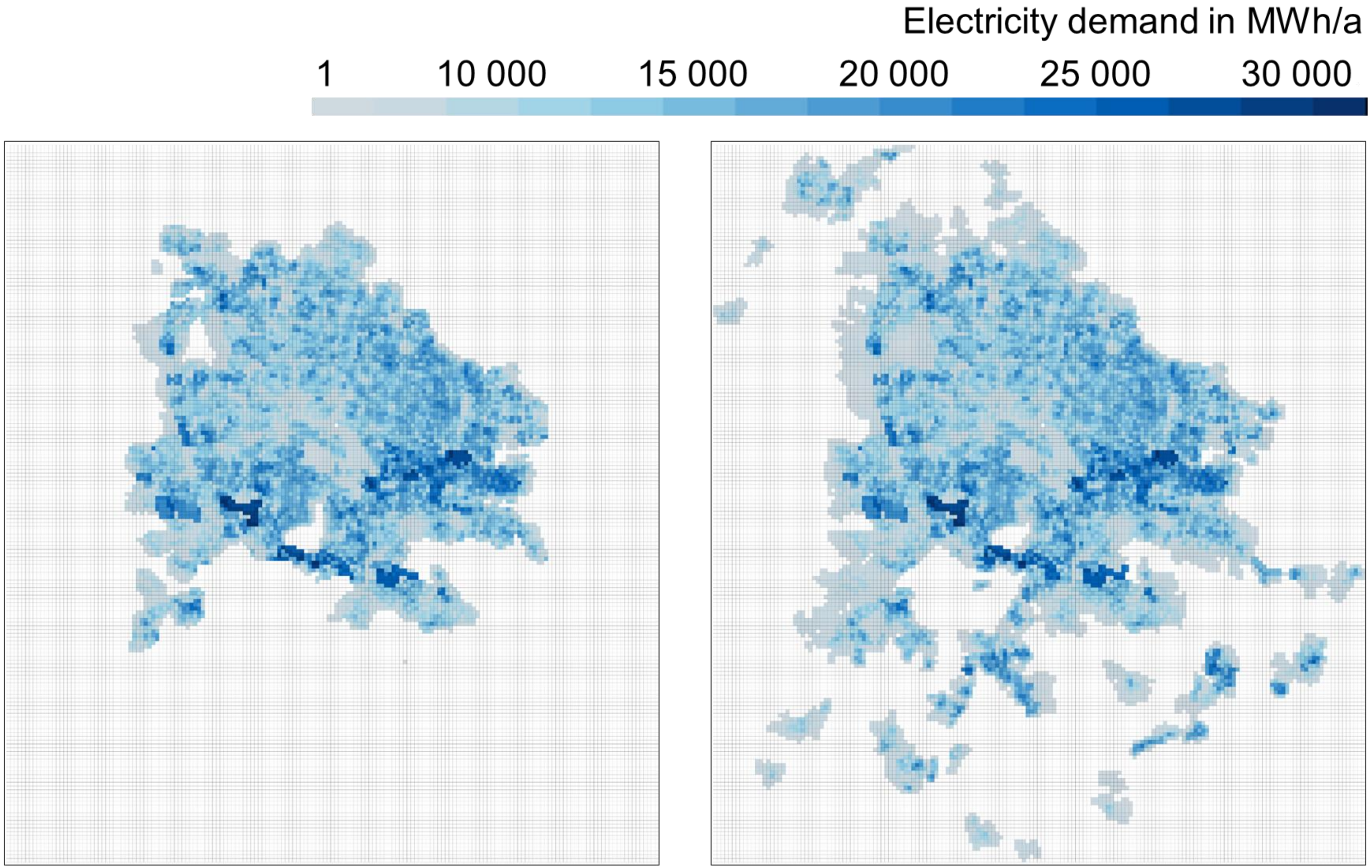
Expenses on energy services in Mexican households (Rodríguez-Oreggia & Yepez-García 2014)



Urban growth: 1940-2014







1999 | 22.8 TWh

2014 | 27.1 TWh

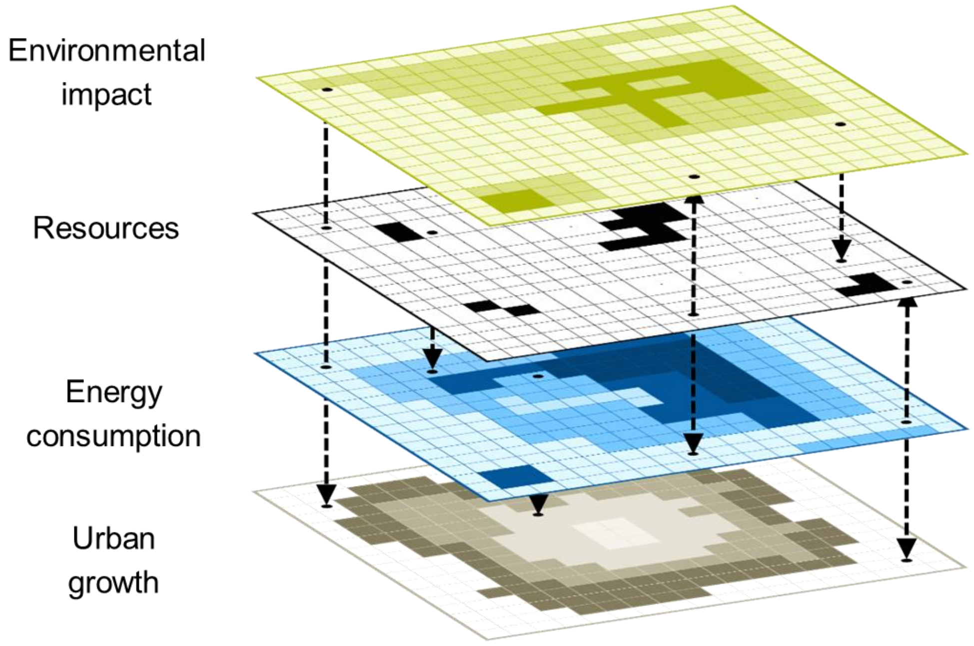
Key messages

1. **CA + ABM + machine learning** were used to simulate the urban energy demand. **Coupling** urban growth and energy demand models allows a better understanding of the **energy use patterns** in cities.

2. **Integrated modeling** is necessary to capture the complexity of cities.

3. The inclusion of the **spatially explicit urban transformations** expands the possibilities for incorporating other **dynamic urban processes: transport, technology adoption**

4. The development of integrated urban planning **tools** is crucial for the **successful management of emerging cities** and the shaping of a **sustainable future**.



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