# Synthesis of LCLUC Studies on Urbanization

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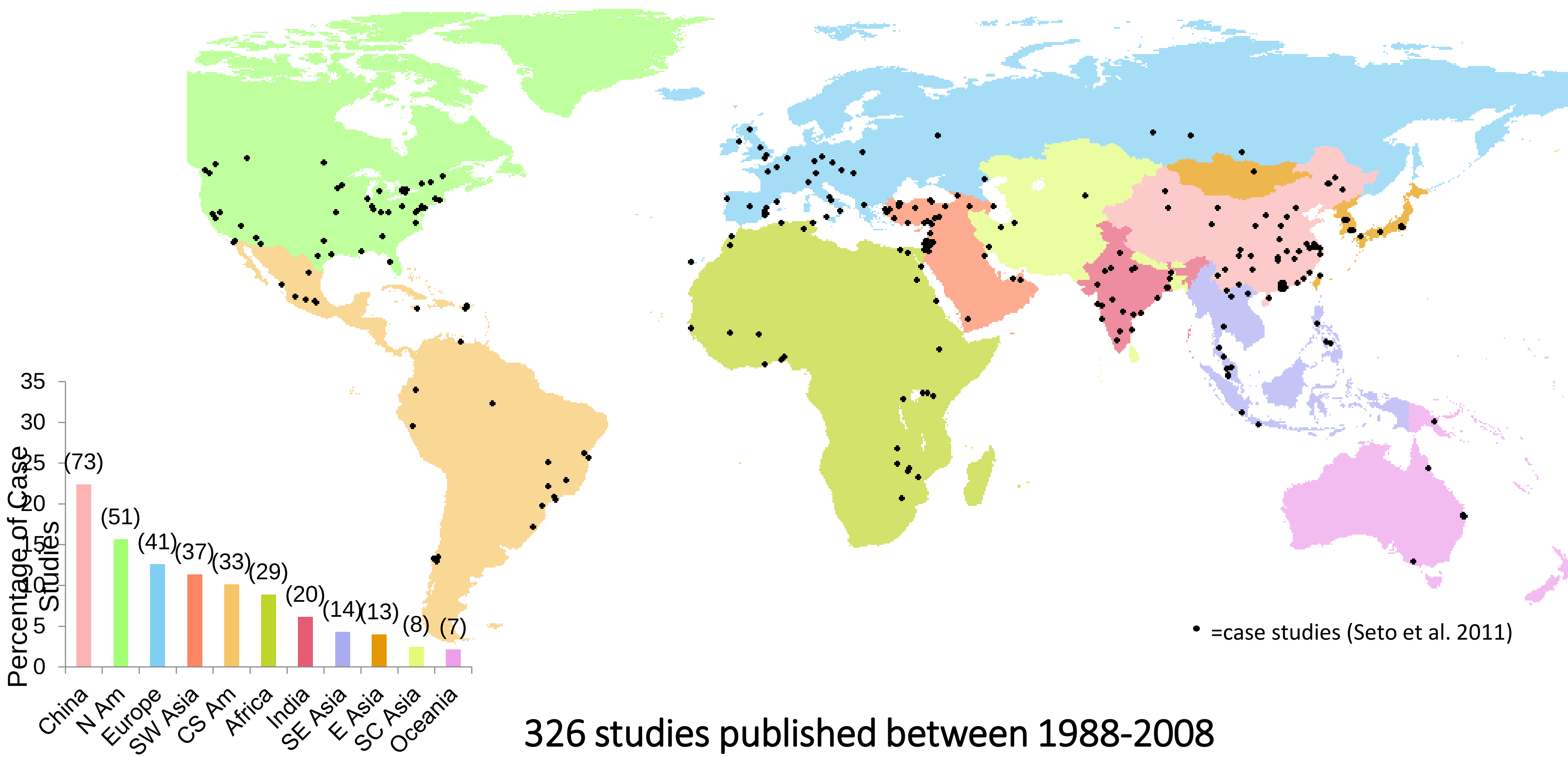
# Project Objective

- How do urban remote sensing studies contribute to advancing fundamental and theoretical knowledge of urban LCLUC, sustainability, and the functioning of the Earth system?

# Key Research Questions

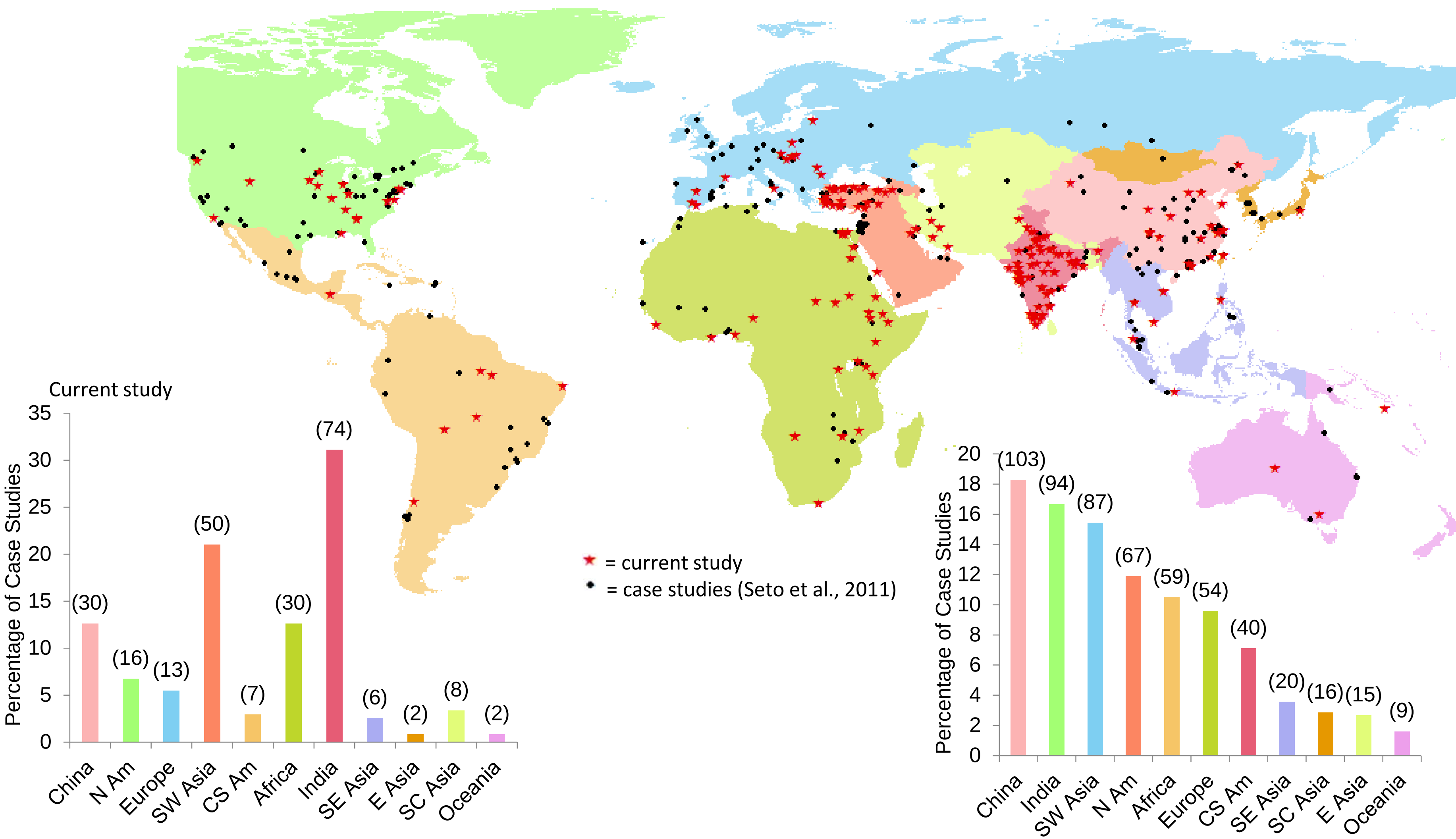
1. What are the patterns of urban LCLUC globally?
2. What are the drivers of urban LCLUC globally?
3. How do change detection algorithms characterize urban LCLUC?
4. What are best practices for applying urban change detection algorithms?
5. What are the effects of urban LCLUC on other LCLU?

# Where has RS been used to study urban LCLUC?

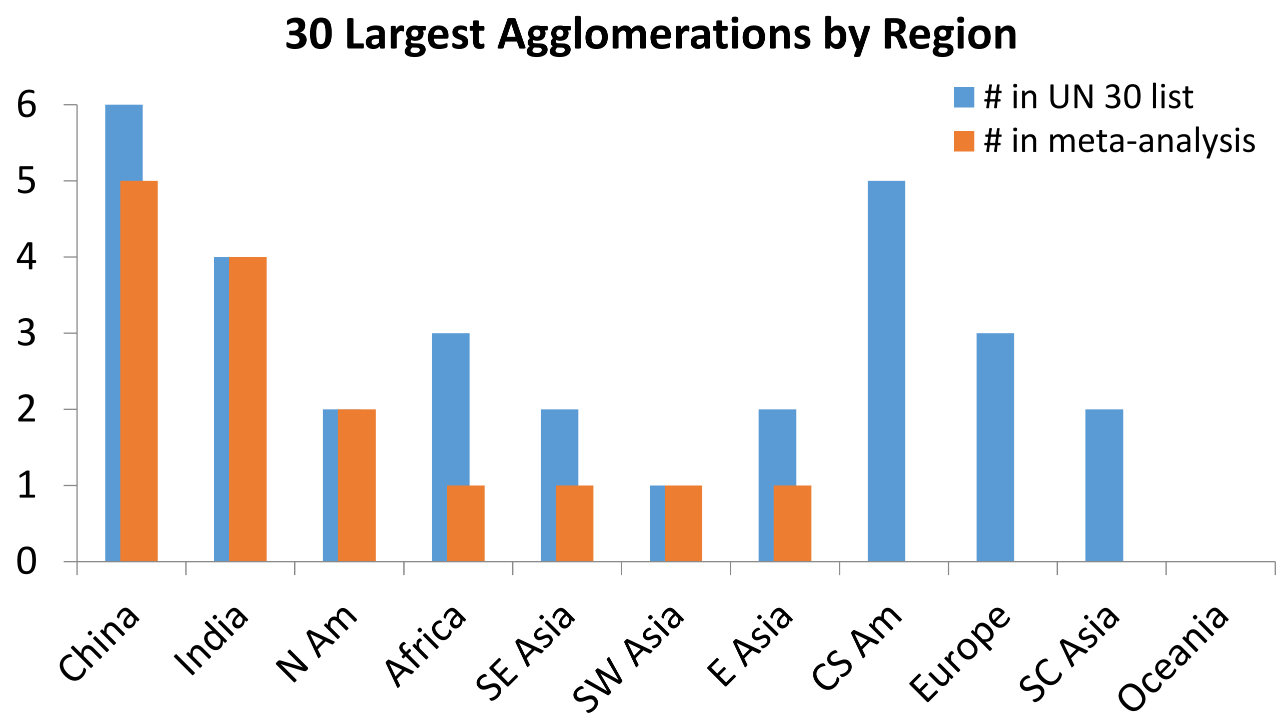



326 studies published between 1988-2008

# 256 RS studies of urban LCLUC since 2008



# Unexpected finding: We're not studying all the largest agglomerations



# Factors influencing global annual percent expansion, 1988-2008

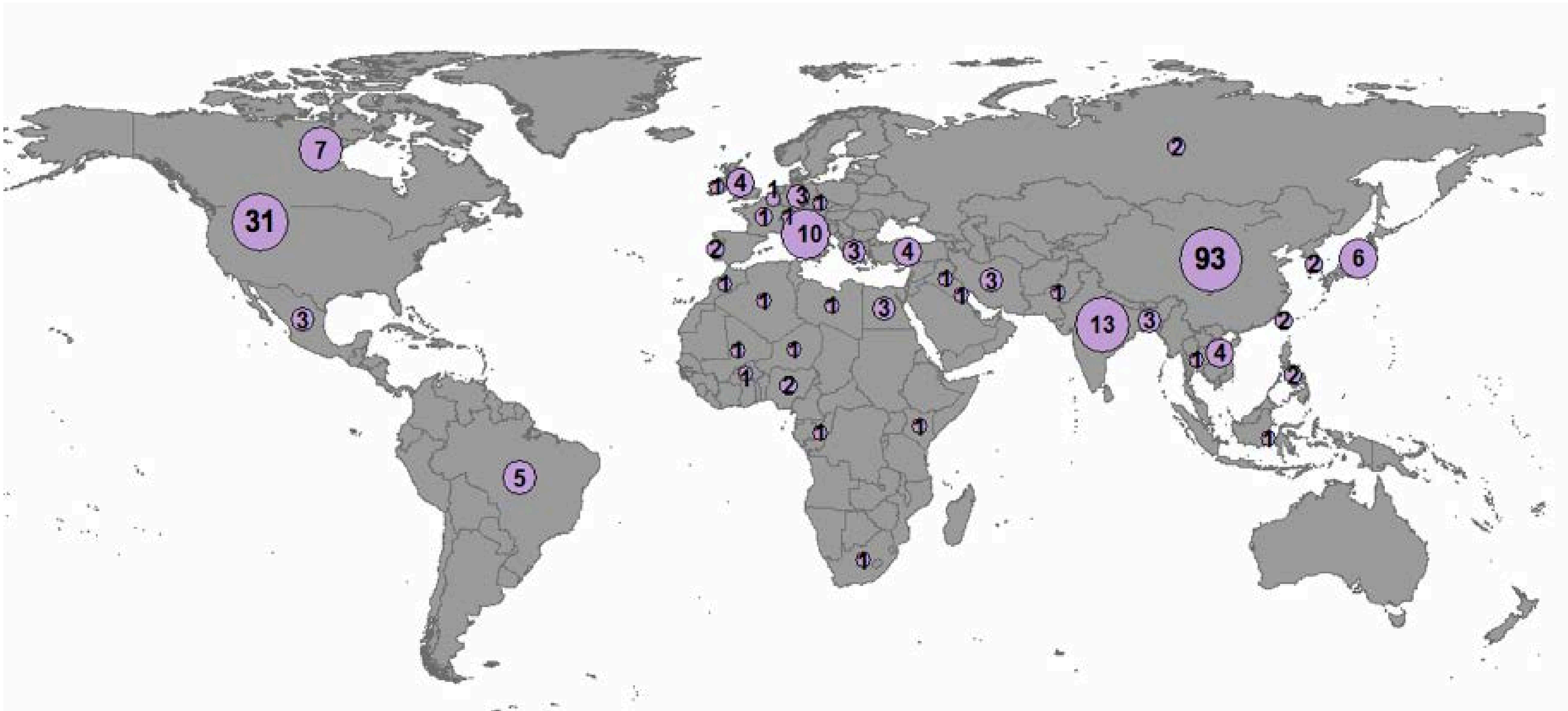
| *Variable* | *Coef.* | *Std. Err.* |
|---|---|---|
| Population growth rate (% annual) | 0.563*** | 0.129 |
| Middle income (China excluded) GDP growth rate squared (% annual) | 0.130*** | 0.0355 |
| China GDP growth rate squared (% annual) | 0.046*** | 0.00614 |
| Automobile-oriented high income GDP growth rate squared (% annual)† | 0.430*** | 0.140 |
| Other high income GDP growth rate (% annual) | 0.980** | 0.433 |
| Farm subsidy | -2.430*** | 0.884 |
| Coastal zone location | 0.829 | 0.514 |
| 1980s indicator | 1.347** | 0.559 |
| Study area size | -0.0000479** | 0.0000225 |
| Constant | 2.273 | 0.526 |

Notes:
†the group consists of the U.S., Canada, and Australia;
*indicates significant at $\alpha = 0.1$;
**indicates significant at $\alpha = 0.05$;
***indicates significant at $\alpha = 0.01$.

# Percentage of urban LCLUC explained by population or GDP growth by region, 1988-2008

| *Location* | *Average annual urban expansion growth rate* | *Approximate percent of urban land expansion attributed to* | |
|---|---|---|---|
| | | *Population growth rate* | *GDP per capita growth rate* |
| China | 7.48 | 18 | 53 |
| India | 4.84 | 30 | 23 |
| Africa | 4.32 | 43 | Not significant |
| North America | 3.31 | 28 | 72 |
| Europe | 2.50 | 4 | 86 |

# How do change detection algorithms characterize urban LCLUC?




**Urban change varies significantly around the world, but most RS change detection algorithms are developed for a few regions**

1. What types of urban changes are being measured with RS? Which are not?

2. What are the RS methods used for different types of urban change?

3. Are the RS methods useful to inform policy or science?

4. Which RS change detection methods work best and where?

# Key findings of RS meta-analysis

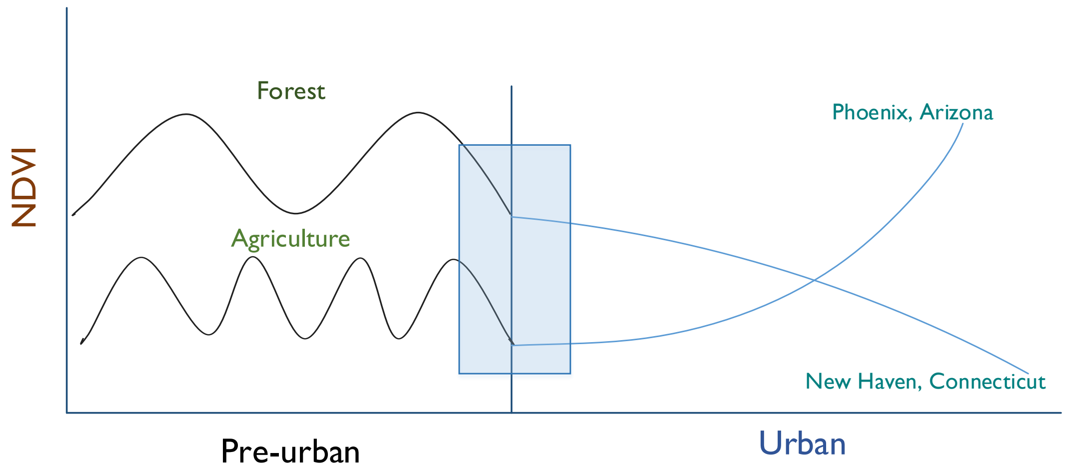
1. Wholesale transformation versus qualitative changes

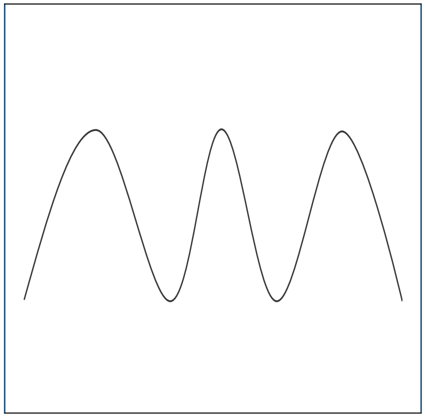
2. Transitions
   - Qualitative versus quantitative
   - Changes within urban class

3. Spatial patterns

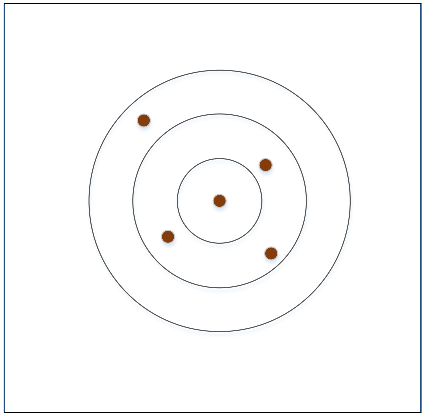
# Need to conceptualize signature of urban change

- "Best" change detection method depends on pre-urban phase, trajectory, and type of urban change



Temporal



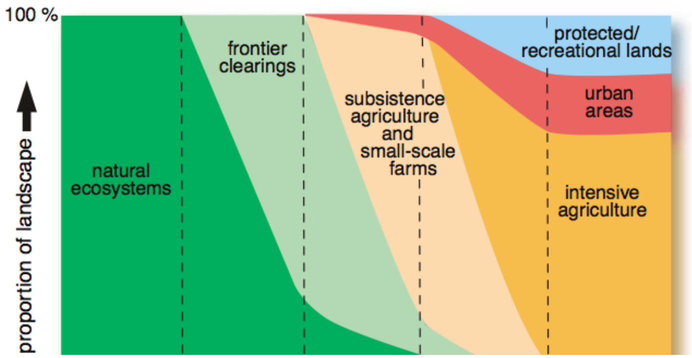
Spatial

| Type of Change | Average Interval between Images (years) | Average Number of Images Used in Study |
|---|---|---|
| Expansion | 16.4 | 8.4 |
| Change/No Change | 3.7 | 2.8 |

## Type of Change

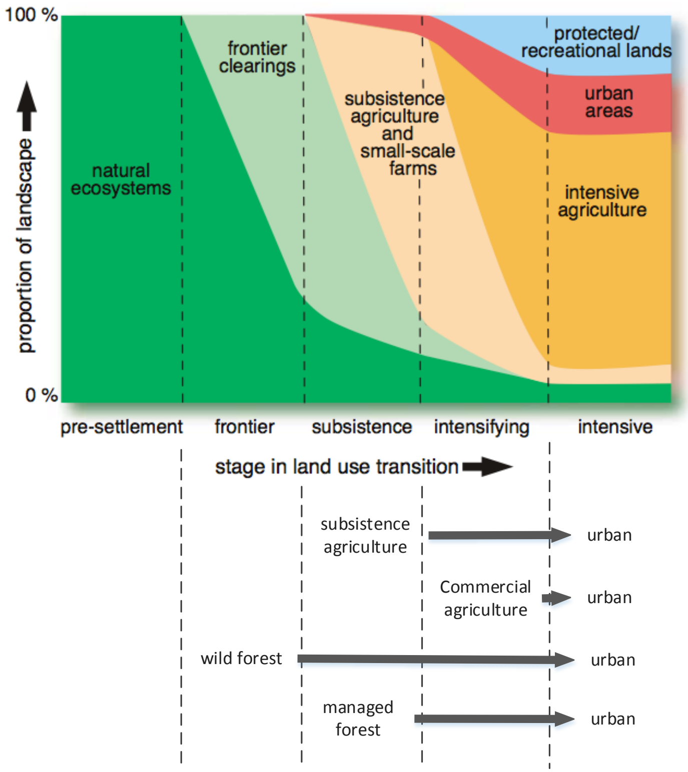
| General Technique | Expansion | Change/No Change | Pattern | Building | Within Class | Vegetation |
|---|---|---|---|---|---|---|
| Post Classification | 26 | 1 | 5 | | 1 | 1 |
| GIS/RS | 11 | | 8 | 1 | 1 | 1 |
| Thresholding | 5 | 5 | | 3 | 2 | 2 |
| Differencing | 3 | 4 | | 2 | | |
| PCA | 2 | | 1 | | | |
| Change Vector | 4 | | | | | |
| Neural Networks | 3 | 2 | | | 1 | |
| Image Ratio | 1 | 1 | | | 1 | |

# What are the effects of urban LCLUC on other LCLU?




(Foley et al., 2010 )

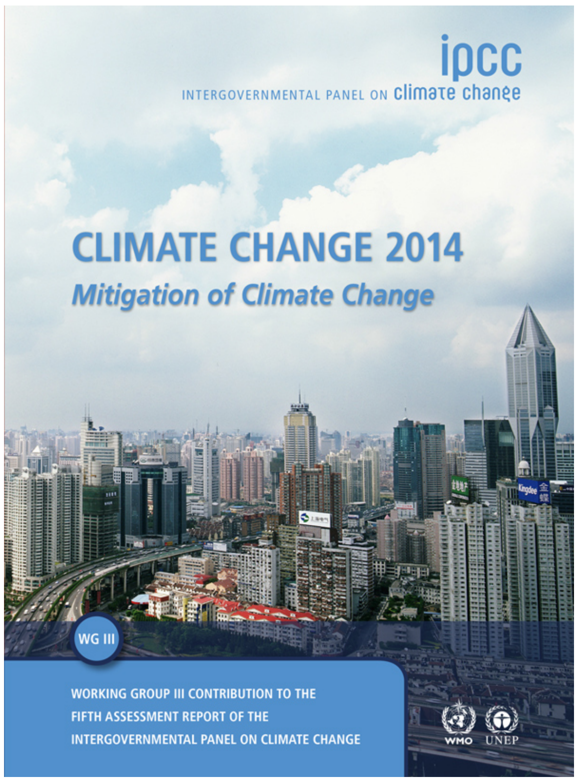
# What are the effects of urban LCLUC on other LCLU?




(Foley et al., 2010 )

| Mountains | Coastal | Desert | Tropical | Temperate |
|---|---|---|---|---|
| clouds | sea-level rise/flooding | vegetation↑ | clouds | vegetation↓ |
| topography | unique vegetation | albedo | dense biomass | seasonality |

# Are there urban changes that are important for policy and science that are not being monitored by remote sensing algorithms?

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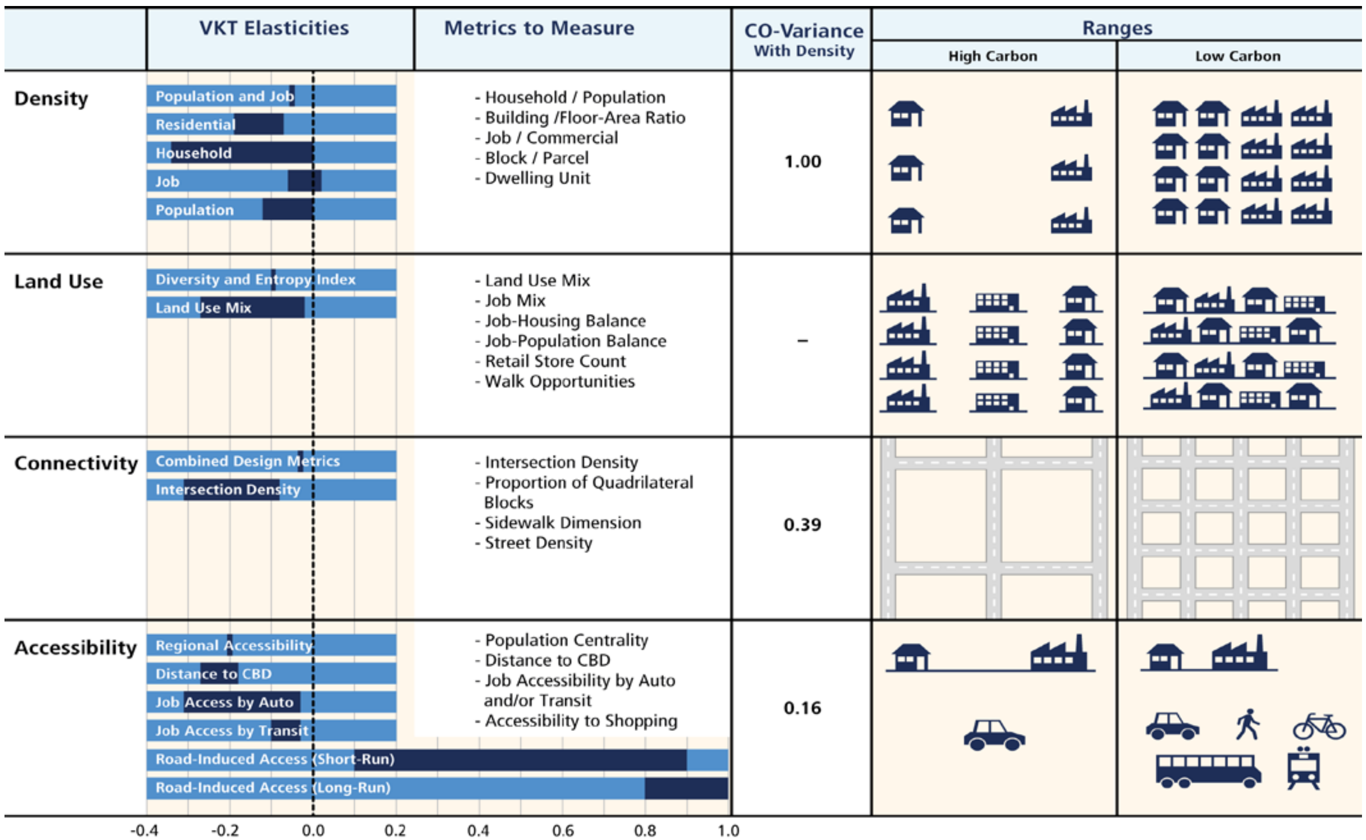
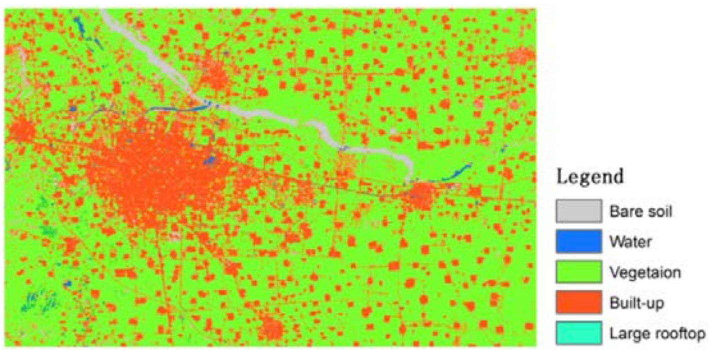
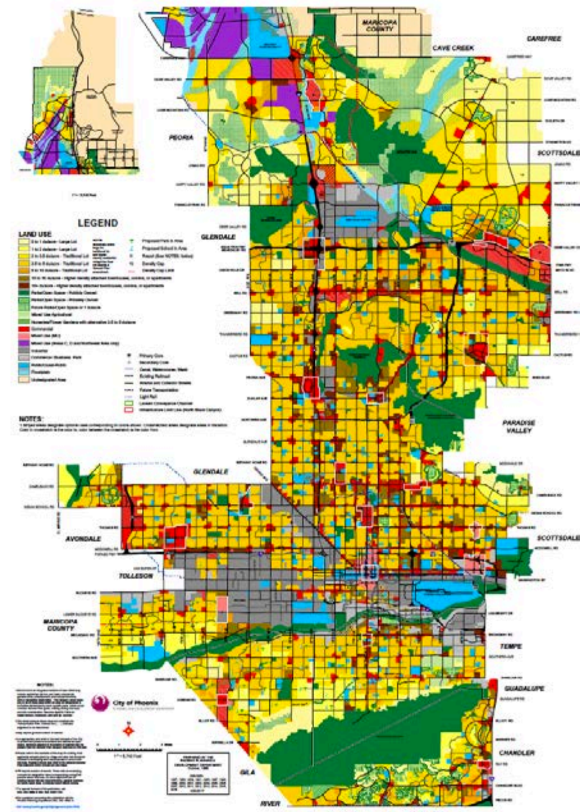
# If the top 50 emitting cities were a single country, it would rank 3rd in emissions behind China and the U.S.



# Both science and policy require more information about urban structure and change



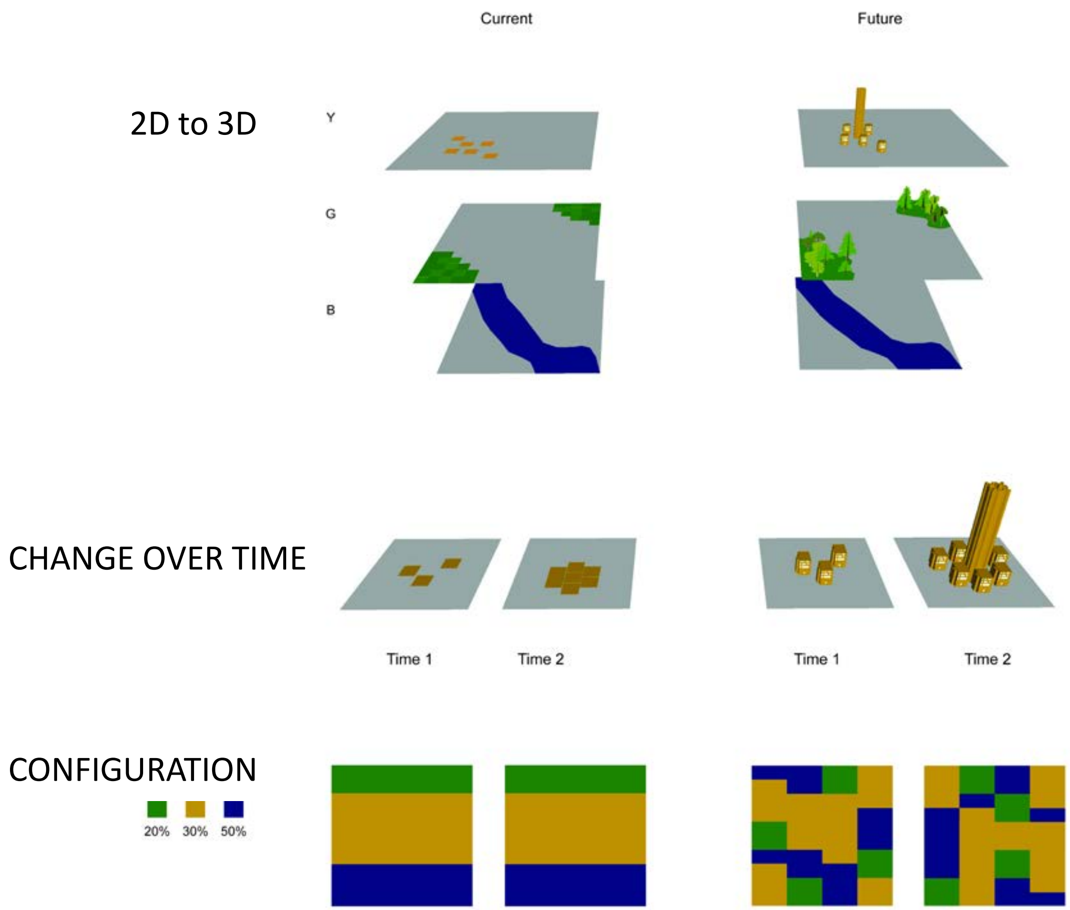

Liu et al. 2015



Basic 2D structure of urban form

Complex 2D structure of urban form

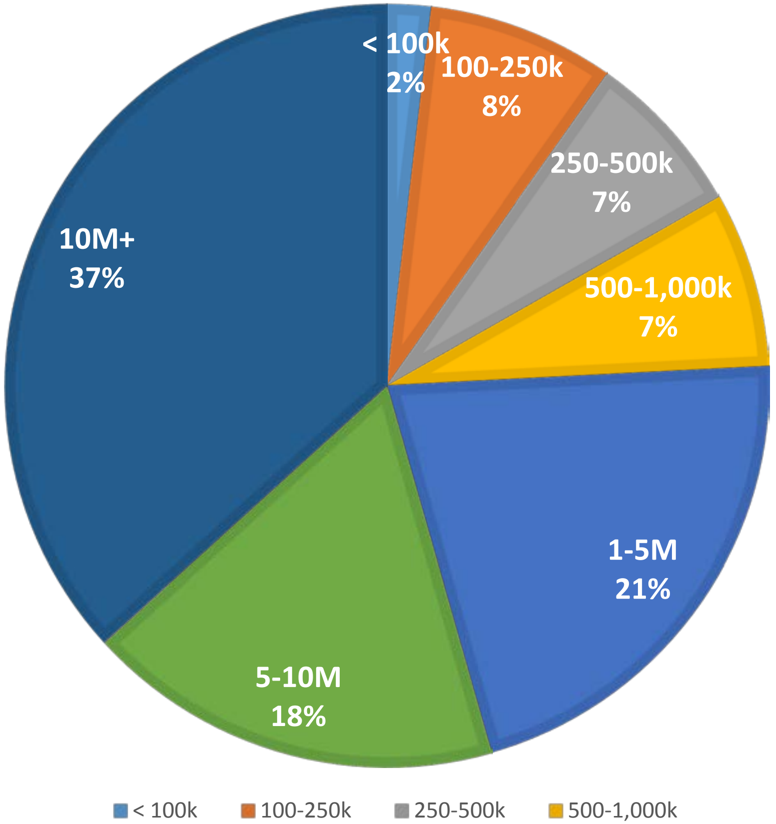
Liu et al., 2015




York, A.M., Alberti, M., Conrow, L., Fischer, H., Inostroza, L., Jantz, C., Pickett, S.T.A., Seto, K.C., Taubenböck, H., Wentz, E.A. Seven Aspects for Conceptualizing Multidimensional Urban Form, in prep.

# Nearly half of the world's 4+ billion urban dwellers are in settlements < 500,000

# Fastest growth in 21st century will be cities <500K, but less than 20% of RS methods are for developed for these




Distribution of urban change detection algorithms by city size

# What types of croplands are most vulnerable to urban conversion?

PNAS

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SPECIAL FEATURE

SUSTAINABILITY SCIENCE

## Future urban land expansion and implications for global croplands

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Edited by Jay S. Golden, Duke University, Durham, NC, and accepted by Editorial Board Member B. L. Turner November 29, 2016 (received for review June 19, 2016)

**Urban expansion often occurs on croplands. However, there is little scientific understanding of how global patterns of future urban expansion will affect the world's cultivated areas. Here, we combine spatially explicit projections of urban expansion with datasets on global croplands and crop yields. Our results show that urban expansion will result in a 1.8–2.4% loss of global croplands by 2030, with substantial regional disparities. About 80% of global cropland loss from urban expansion will take place in Asia and Africa. In both Asia and Africa, much of the cropland that will be lost is more than twice as productive as national averages. Asia will experience the highest absolute loss in cropland, whereas African countries will experience the highest percentage loss of cropland. Globally, the croplands that are likely to be lost were responsible for 3–4% of worldwide crop production in 2000. Urban expansion is expected to take place on cropland that is 1.77 times more productive than the global average. The loss of cropland is likely to be accompanied by other sustainability risks and threatens livelihoods, with diverging characteristics for different megaurban regions. Governance of urban area expansion thus emerges as a key area for securing livelihoods in the agrarian economies of the Global South.**

urbanization | global land use change | livelihoods | agricultural productivity | megaurban regions

Urban land expansion—the process of creating the built environment to house urban populations and their activities—is one of the fundamental aspects of urbanization. Urban land expansion modifies habitats, biogeochemistry, hydrology, land cover, and surface energy balance (1). In most parts of the world, urban land is expanding faster than urban populations (2). Whereas urban populations are expected to almost double from 2.6 billion in 2000 to 5 billion in 2030 (3), urban areas are forecast to triple between 2000 and 2030 (4). A defining characteristic of contemporary urbanization is the rise of megaurban regions (MURs): the merging of multiple urban areas into a contiguous and continuous urban fabric. These MURs differ from megacities with populations of 10 million or more in two important and fundamental ways: administratively, they consist of multiple contiguous entities with discrete governance structures; biophysically, they are a single continuous urban area whose absolute spatial size creates challenges for urban, land, and transport governance. The rate and magnitude of urban land expansion are influenced by many macro factors, including income, economic development, and population growth, as well as a number of local and regional factors such as land use policies, the informal economy, capital flows, and transportation costs (5).

More than 60% of the world's irrigated croplands are located near urban areas (6), highlighting the potential competition for land between agricultural and urban uses. Individual case studies show that high rates of urban expansion over the last three decades have resulted in the loss of cropland all around the world, with examples from China, the United States, Egypt, Turkey, India, and other countries (7–9). Although cropland loss has become a significant concern in terms of food production and livelihoods (10) for many countries, there is very little scientific understanding of how future urban expansion and especially growth of MURs will affect croplands. However, this knowledge is key given the potential large-scale land conflicts between agriculture and urban uses in an era of rapid megaurbanization.

Most of the future urban population and urban area expansion are forecast to take place in Asia and Africa (4), often in places with high poverty rates and potentially prone to systemic disruptions in the food system (11, 12). For many of these countries, agriculture is a crucial economic sector in terms of income generation, percentage of total national gross domestic product (GDP), and employment source. Thus, there is a need to assess the implications of urban expansion on croplands on global, national, and subnational scales to identify potential areas of conflict as well as strategies for shaping more sustainable forms of urban expansion.

This paper fills these knowledge gaps by addressing the following questions: (*i*) Where are croplands most vulnerable to conversion due to future urban expansion? (*ii*) What is the magnitude of cropland loss, especially of prime cropland, due to future urban expansion? (*iii*) How will the loss of croplands affect total cropland area and relative economic importance of agriculture for different countries? Sustainability in the era of megaurbanization will require understanding the "hidden linkages" between urbanization and food systems (13), including where and how to maintain croplands to grow food, the most basic of all human necessities. Here, we define food systems as "the chain of activities connecting food production, processing, distribution, consumption, and waste management, as well as all the associated regulatory institutions and activities" (14).

**Significance**

**Urbanization's contribution to land use change emerges as an important sustainability concern. Here, we demonstrate that projected urban area expansion will take place on some of the world's most productive croplands, in particular in megaurban regions in Asia and Africa. This dynamic adds pressure to potentially strained future food systems and threatens livelihoods in vulnerable regions.**

Author contributions: C.B.d., F.R., F.C., and K.C.S. designed research; C.B.d., F.R., S.B., B.G., F.C., and K.C.S. performed research; C.B.d., F.R., and G.B. contributed analytic tools; C.B.d., F.R., G.B., S.B., B.G., K.-H.E., F.C., and K.C.S. analyzed data; and C.B.d., F.R., G.B., S.B., B.G., K.-H.E., H.H., F.C., and K.C.S. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. J.S.G. is a Guest Editor invited by the Editorial Board.

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1606036114/-/DCSupplemental.

# Global agricultural land loss to urban expansion is relatively small

| Region or country | Expected cropland loss, Mha | Relative cropland loss, % of cropland | Production loss, $Pcal \cdot y^{-1}$ | Production loss, % of total crop production | Productivity compared to domestic/regional average |
|---|---|---|---|---|---|
| World | 30 (27–35) | 2.0 (1.8–2.4) | 333 (308–378) | 3.7 (3.4–4.2) | 1.77 |
| Asia | 18 (16–21) | 3.2 (2.9–3.7) | 231 (214–264) | 5.6 (5.1–6.3) | 1.59 |
| Africa | 6 (5–6) | 2.6 (2.4–3) | 49 (45–52) | 8.9 (8.3–9.4) | 3.32 |
| Europe | 2 (2–3) | 0.5 (0.5–0.9) | 17 (16–23) | 1.2 (1.1–1.5) | 2.18 |
| Americas | 5 (4–5) | 1.2 (1.1–1.4) | 35 (32–40) | 1.3 (1.2–1.5) | 1.09 |
| Australasia | 0.1 (0–0.1) | 0.2 (0.1–0.3) | 0.3 (0.1–0.3) | 0.2 (0.1–0.3) | 0.94 |
| China | 7.6 (7.1–8.6) | 5.4 (5–6.1) | 137 (128–153) | 8.7 (8.2–9.8) | 1.53 |
| India | 3.4 (3.3–3.7) | 2.0 (1.9–2.2) | 34 (32–38) | 3.9 (3.7–4.3) | 1.61 |
| Nigeria | 2.1 (1.8–2.5) | 5.7 (5–6.9) | 16 (15–17) | 11.7 (10.7–12.6) | 1.82 |
| Pakistan | 1.8 (1.7–2) | 7.6 (7.2–8.6) | 9 (9–10) | 8.8 (8.4–9.9) | 1.22 |
| United States | 1.5 (1.4–1.6) | 0.8 (0.8–0.9) | 11 (11–12) | 0.7 (0.7–0.8) | 0.90 |
| Brazil | 1.0 (0.9–1.2) | 2.0 (1.7–2.4) | 10 (9–12) | 2.4 (2.1–2.8) | 1.22 |
| Egypt | 0.8 (0.7–0.8) | 34.1 (31.6–35.8) | 25 (23–26) | 36.5 (34–38) | 1.07 |
| Vietnam | 0.8 (0.7–0.8) | 10.3 (9.3–11.2) | 15 (15–17) | 15.9 (15.2–17.2) | 1.41 |
| Mexico | 0.7 (0.6–0.8) | 1.9 (1.7–2.3) | 4 (4–5) | 3.7 (3.2–4.4) | 1.91 |
| Indonesia | 0.6 (0.5–0.7) | 1.1 (0.9–1.3) | 10 (8–11) | 2.3 (2–2.7) | 2.03 |

(Bren d'Amour et al., 2016)

# Regional losses will be acute

| Region or country | Expected cropland loss, Mha | Relative cropland loss, % of cropland | Production loss, Pcal·y$^{-1}$ | Production loss, % of total crop production | Productivity compared to domestic/regional average |
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(Bren d'Amour et al., 2016)

# Regional losses will be acute

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(Bren d'Amour et al., 2016)

# Significant loss of staple crops in Asia and Africa

| Region or country | Maize production in competing cells | | Rice production in competing cells | | Soybean production in competing cells | | Wheat production in competing cells | |
|---|---|---|---|---|---|---|---|---|
| | $Mton \cdot y^{-1}$ | Share of total production, % | $Mton \cdot y^{-1}$ | Share of total production, % | $Mton \cdot y^{-1}$ | Share of total production, % | $Mton \cdot y^{-1}$ | Share of total production, % |
| World | 25.8 | 4.3 | 51.8 | 9.1 | 3.3 | 2.1 | 39.6 | 7.1 |
| Asia | 15.1 | 9.6 | 48.2 | 9.2 | 1.7 | 7.0 | 31.9 | 12.9 |
| Africa | 5.1 | 14.1 | 2.9 | 18.8 | 0.1 | 11.2 | 4.0 | 26.0 |
| Europe | 1.0 | 1.5 | 0.1 | 2.2 | 0.1 | 2.8 | 2.7 | 1.6 |
| Americas | 4.6 | 1.4 | 0.6 | 2.2 | 1.5 | 1.1 | 0.9 | 0.9 |
| Australasia | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.1 |
| Top 10 | | | | | | | | |
| China | 12.7 | 10.9 | 18.7 | 10.2 | 1.4 | 9.0 | 20.6 | 20.5 |
| India | 0.7 | 6.5 | 10.5 | 8.3 | 0.1 | 2.2 | 5.7 | 8.2 |
| Nigeria | 0.5 | 11.7 | 0.5 | 17.5 | 0.0 | 11.6 | 0.0 | 10.4 |
| Pakistan | 0.2 | 13.0 | 0.8 | 12.2 | 0.0 | 13.2 | 3.1 | 16.7 |
| United States | 2.1 | 0.9 | 0.1 | 0.9 | 0.6 | 0.8 | 0.4 | 0.6 |
| Brazil | 0.7 | 1.9 | 0.2 | 1.8 | 0.4 | 1.3 | 0.1 | 2.2 |
| Egypt | 3.8 | 63.3 | 2.3 | 41.2 | 0.0 | 53.3 | 3.7 | 59.5 |
| Vietnam | 0.3 | 14.7 | 7.5 | 27.1 | 0.0 | 24.3 | — | — |
| Mexico | 0.9 | 4.9 | 0.0 | 4.3 | 0.0 | 0.9 | 0.2 | 5.4 |
| Indonesia | 0.7 | 7.3 | 4.5 | 9.2 | 0.1 | 9.2 | — | — |

(Bren d'Amour et al., 2016)

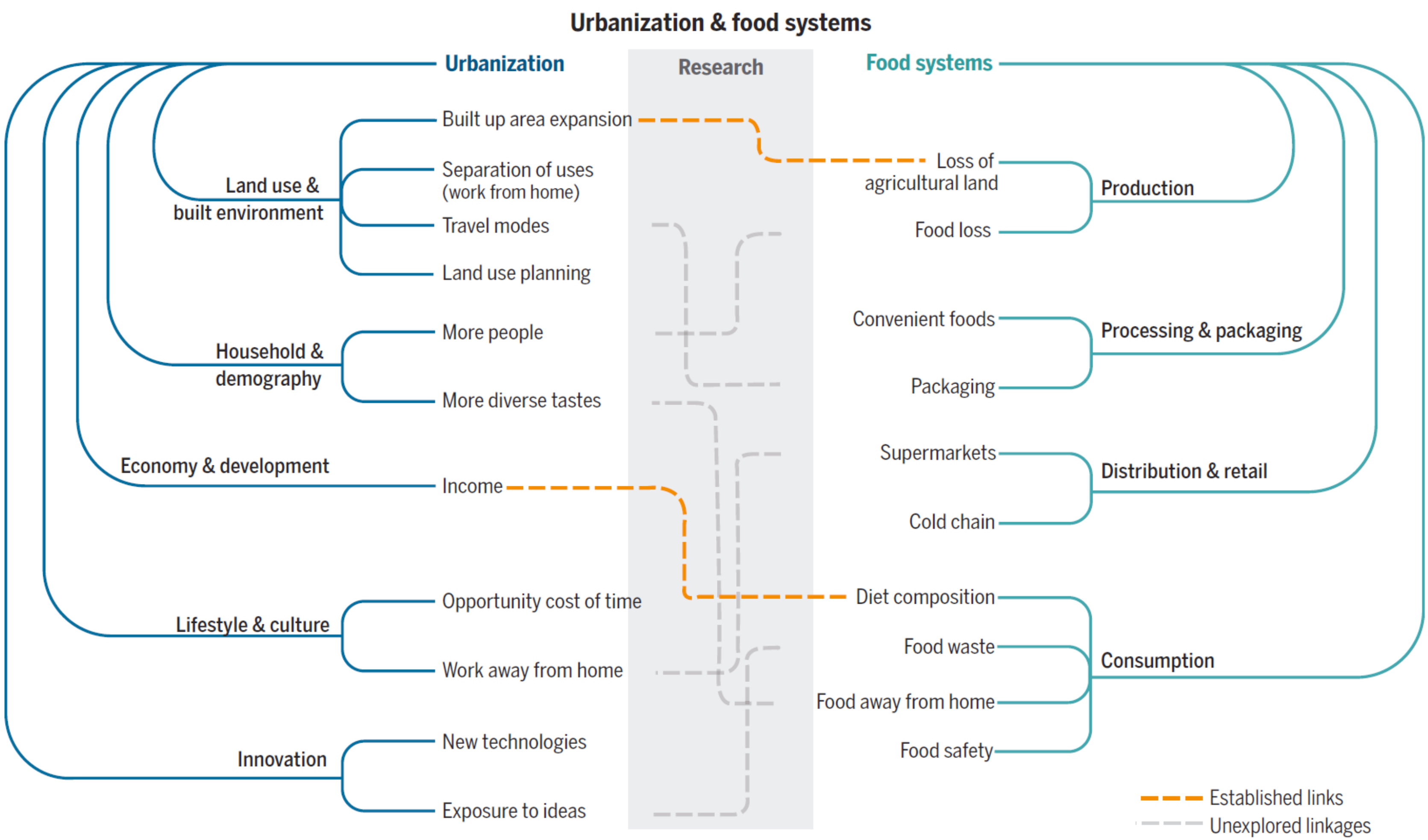


**Fig. 1. Established and underexplored linkages between urbanization and food systems.** The underexplored linkages are illustrative and not exhaustive.



Seto and Ramankutty, 2016

(Reba et al., 2016)