



# Data and Models to Inform Actions in Multi-Sector Sustainable Urban Systems (SUS)

**Anu Ramaswami**

*Director, Sustainable Healthy Cities Network*

*Professor, Public Affairs & Engineering, University of Minnesota*



UNIVERSITY OF MINNESOTA

**Driven to Discover<sup>SM</sup>**



**Sustainable  
Healthy Cities**

A National Science Foundation-supported  
Sustainability Research Network (SRN)



# Acknowledgement:

## Four Major NSF Grants + Sponsored Projects with Cities

**Integrative Graduate Education, Research and Traineeship (IGERT)- Sustainable Urban Infrastructure, Lead PI**

**Partnerships in International Research and Education (PIRE): Developing Low-Carbon Cities in the US, China, and India. Lead PI**

**Sustainability Research Network (SRN) - Sustainable Healthy Cities Network, Lead PI**

**Smart & Sustainable Communities: Smart Spatial Infrastructure Planning to Improve Access (Co-Lead w Shashi Shekhar)**



# My New Coordinates after Aug 1:



Ramaswami, researcher of urban sustainability, appointed inaugural director of M.S. Chadha Center for Global India

**Pooja Makhijani, Princeton Institute for International and Regional Studies**

June 20, 2019 10 a.m.

Anu Ramaswami, an interdisciplinary environmental engineer who is recognized as a pioneer and leader on the topic of sustainable urban systems, has been named professor of India studies, civil and environmental engineering, and the Princeton Environmental Institute, and the inaugural director of the M.S. Chadha Center for Global India. She will assume her new duties at **Princeton on Aug. 1.**

# Five Topics Today

**A. My interdisciplinary journey & overarching reflections**

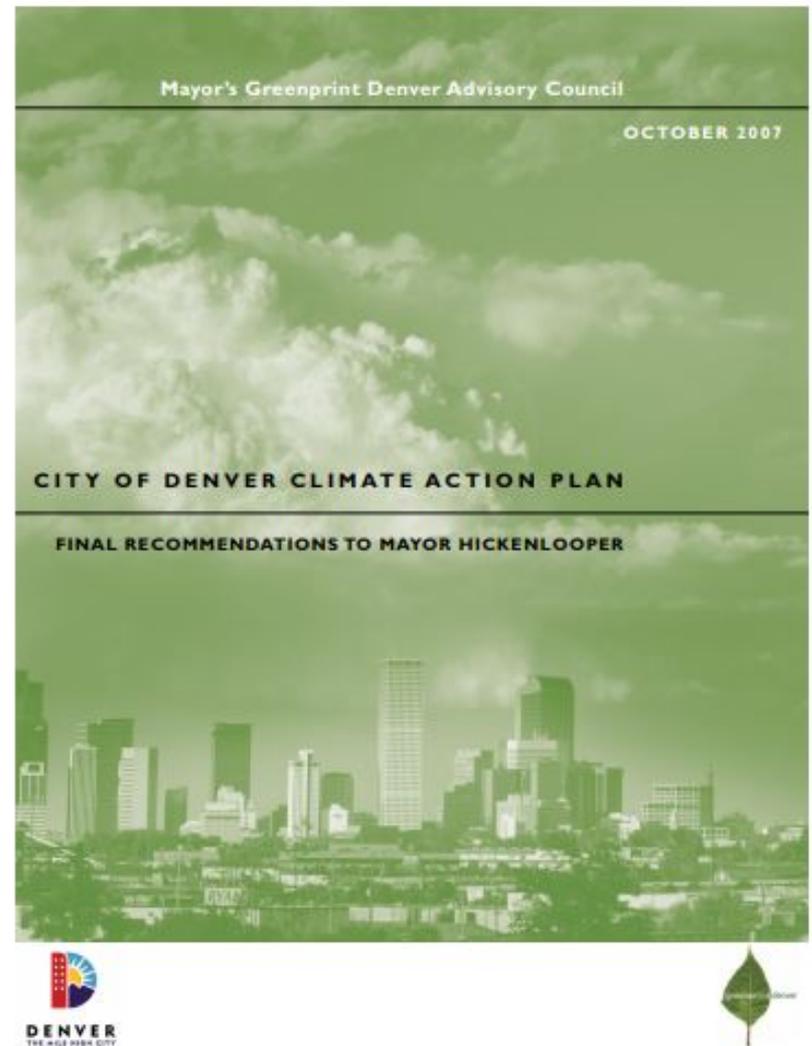
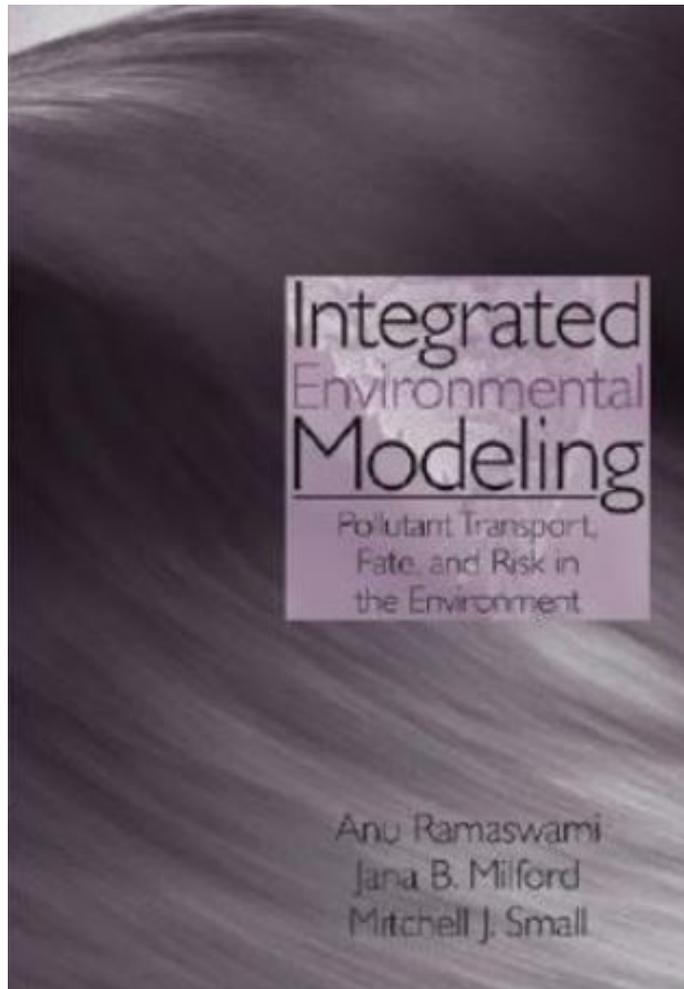
**B. An inter-disciplinary Social-Ecological-Infrastructural Urban Systems Framework for studying SUS**

**C. Multi-Sector Multi-Objective SUS Modeling in NSF's Sustainable Healthy Cities Network**

**D. Science to Action Linkages (Science of Co-Production)**

**E. The NSF "SUS" Report**

# An Interdisciplinary Journey: Environmental Science & Engineering → Sustainable Urban Systems w Policy Impact



# Key Reflections

- **Important to ask: Multi-sector dynamic modeling for whom and for what (societal) outcomes?**
- **The “whom” and “for what” profoundly and foundationally impacts the {basic + applied} science**
- **Sustainable Urban Systems (SUS) is a larger construct than in-boundary urban environment**
- ✓ **Data and models are needed both within urban boundary + transboundary; i.e., multi-scale;**
- ✓ **Must address nexus among multiple societal goals;**
- ✓ **Transition models must address people, policy & technology/infrastructure change;**
- ✓ **Co-Production is a science by itself.**

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# Rationale and Key Features of Sustainable Urban Systems

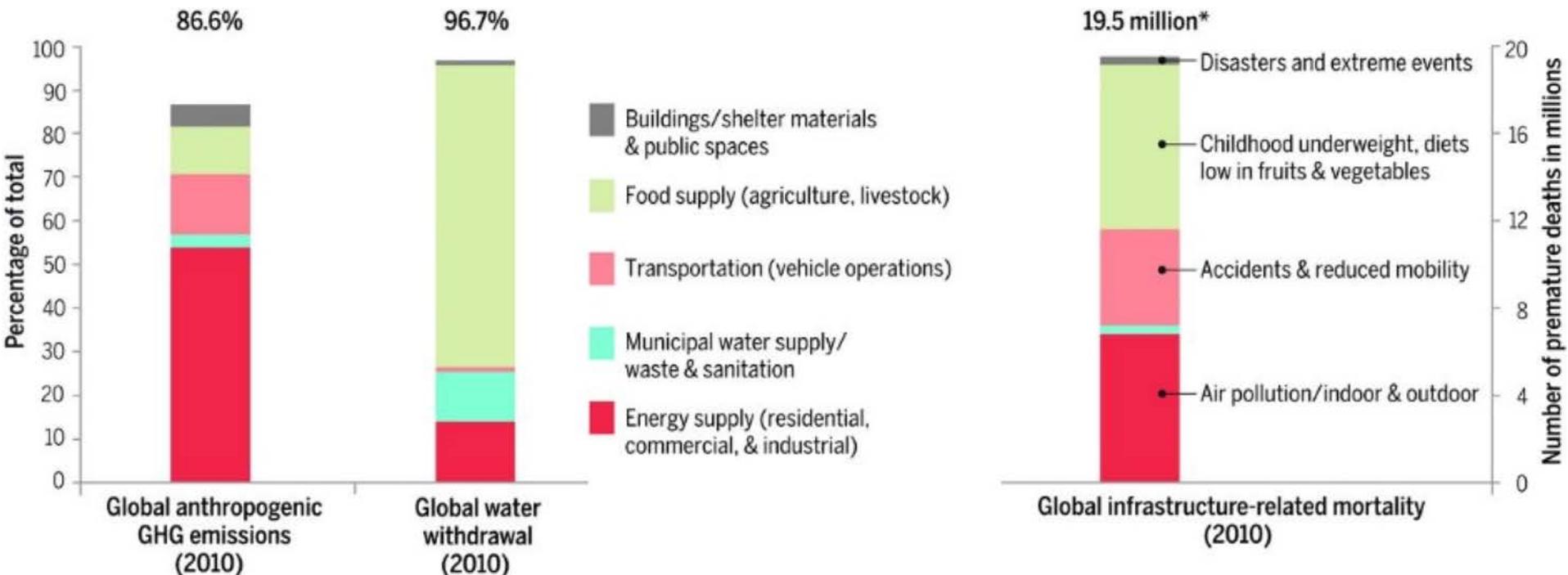
- **We now live on an urban planet:** urban areas directly occupy only ~3% land area but are impacting the planet through large transboundary resource draws, economic interactions & trade → **multi-scale urban-to-global impacts**
- **Cities/Urban areas seek multiple sustainability outcomes:** Some within their boundary (e.g., equity, health, resilience) and some transboundary (GHG mitigation; regional water)
- **Seven key physical provisioning sectors** - infrastructures and food systems - lie at the core of many outcomes
- There is an **urgency and a historic opportunity** to act, leveraging social & technological innovation
- **Needs partnerships for actions** – public, private, community, NGOs, multi-level.



**Multiple Sustainability Outcomes:**  
New Urban Agenda; UN SDGs and SDG 11; World Bank Urban Sustainability Framework; One NYC Plan.

# Focus on Seven Key Sectors: Global Resource Use & Environment-Related Human Risks

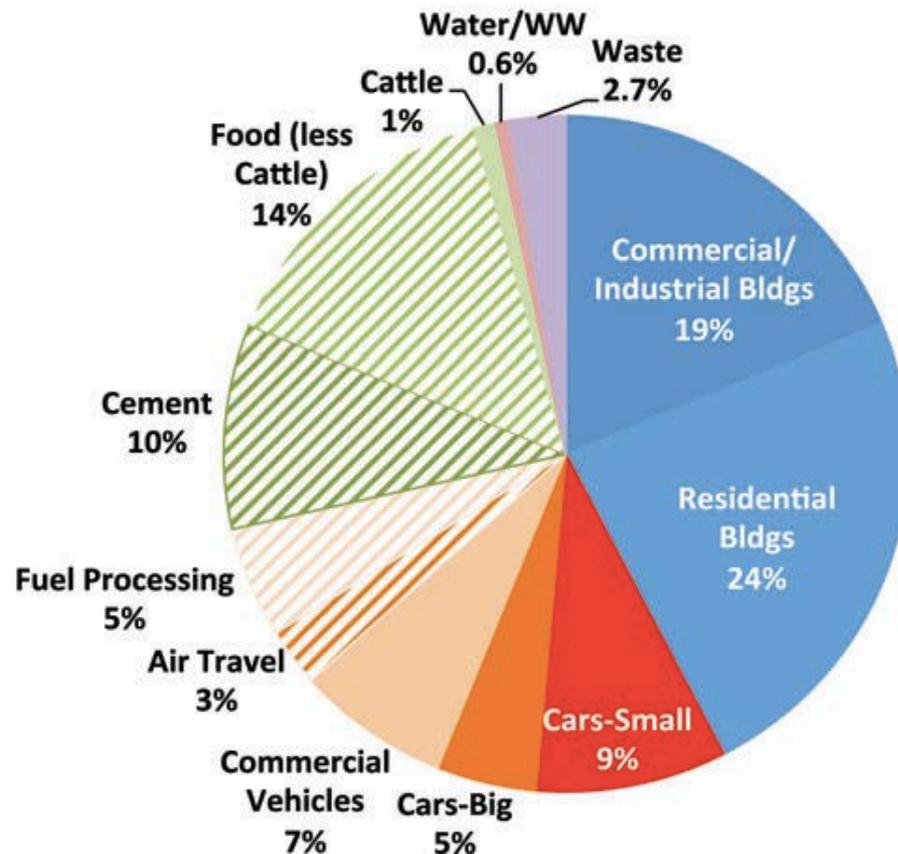
Urban Infrastructure contributions are beginning to dominate. For example, ~70% global greenhouse gas emissions are associated with cities, when accounting for fuel and electricity imports to cities



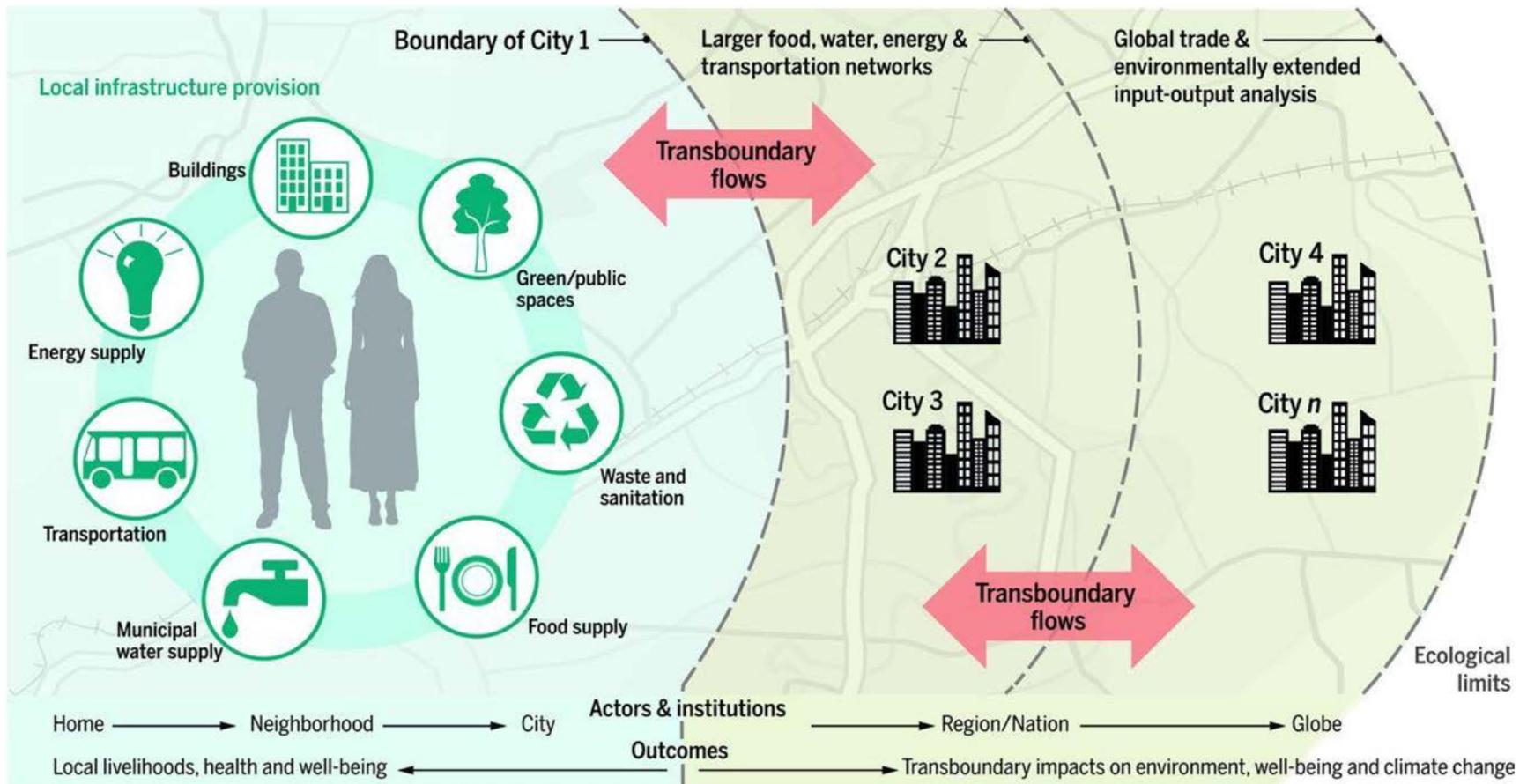
# New Transboundary Multi-Sector Urban-Scale GHG Accounting: Illustrating Multi-Scale Linkages

Delhi 2009 Community-Wide GHG Emissions = 40.3 million t CO<sub>2</sub>-eq  
948 t CO<sub>2</sub>-eq/mill \$ GDP (2.3 t CO<sub>2</sub>-eq/cap)

Community-wide Infrastructure Footprints combine material- and energy-flows associated with service-demand of the whole city with trans-boundary LCA of producing these flows.



# Interdisciplinary Research Framework: *Multi-Scale, Multi-Sector, Multi-Objective, Multi-Actor*



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# Sustainable Healthy Cities Network:

A National Science Foundation supported Sustainability Research Network

## University Partners



UNIVERSITY OF MINNESOTA



THE OHIO STATE UNIVERSITY



TEXAS  
The University of Texas at Austin



## City Partners

Minneapolis

Saint Paul

Atlanta

New York City

Tallahassee

Austin

Detroit

Denver

Fort Collins

Municipal Corporations  
in India

## Multi-city and International Policy Organizations



## Industry Partners



# Sustainable Healthy Cities (SHCN) Research Logic: Seven Key Infrastructure & Food Provisioning Sectors & Their Interactions



Buildings & Energy



Food Systems



Green Infrastructure



Transportation



Water & Waste



Cross-sector Interactions

# SHC Research Logic: Key Outcomes



Wellbeing



Health



Environment



Equity



Livability



Co-Benefits & Tradeoffs

# SHC Logic: Key Pathways of Change



Technology & Design  
Innovation



Spatial Reconfiguration



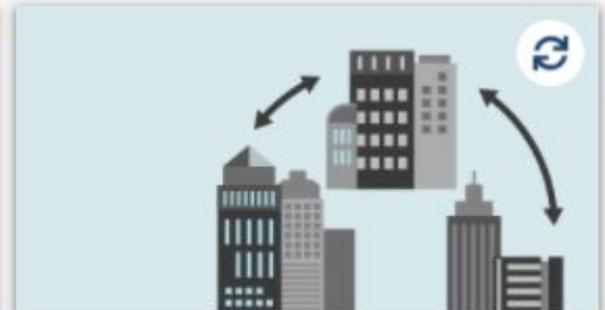
Business & Finance



Policy & Governance



Behavior Change



Integrative Scenarios

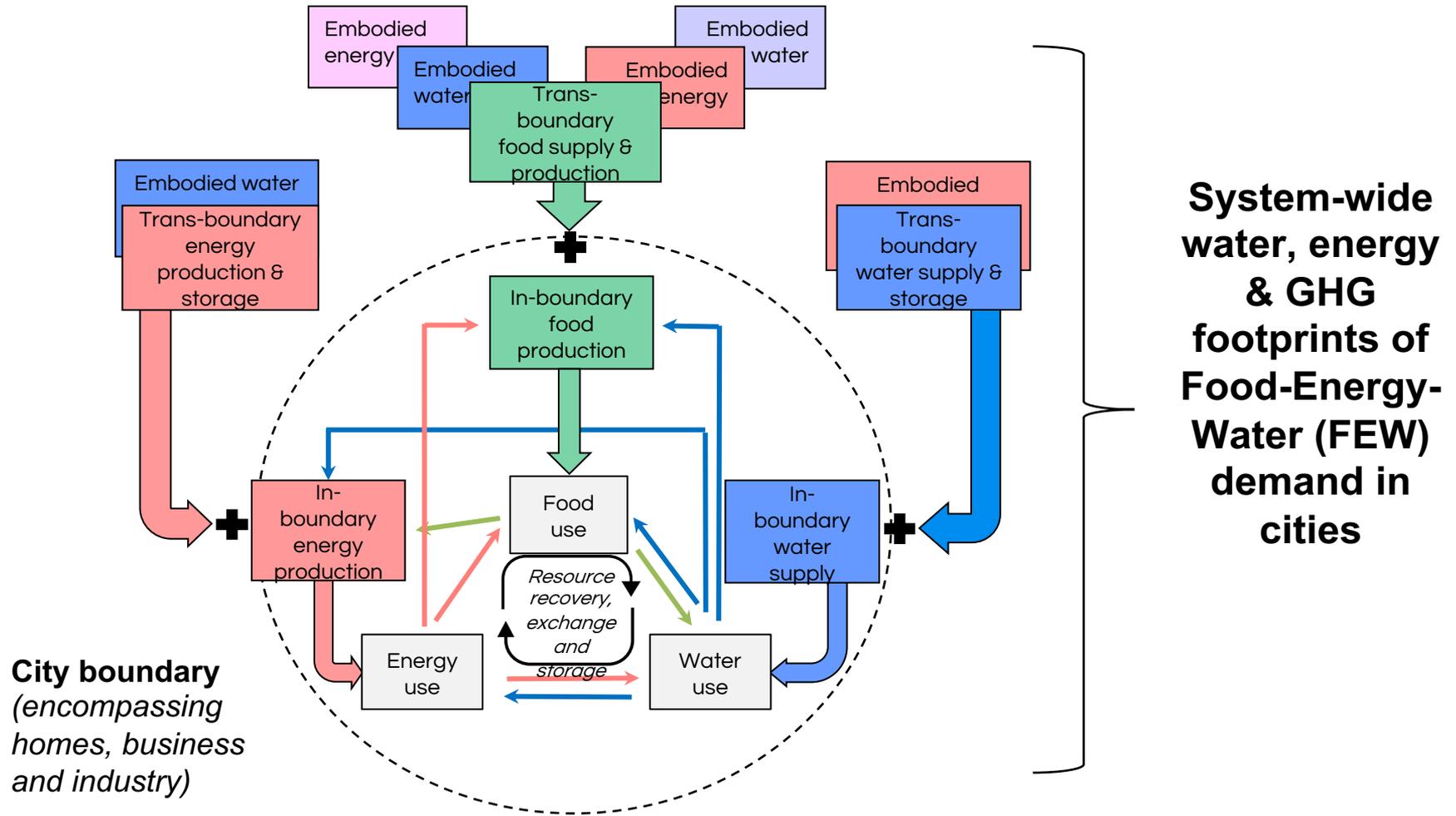
# Example: Exploring the Food-Energy-Water Nexus from an Urban Systems Perspective



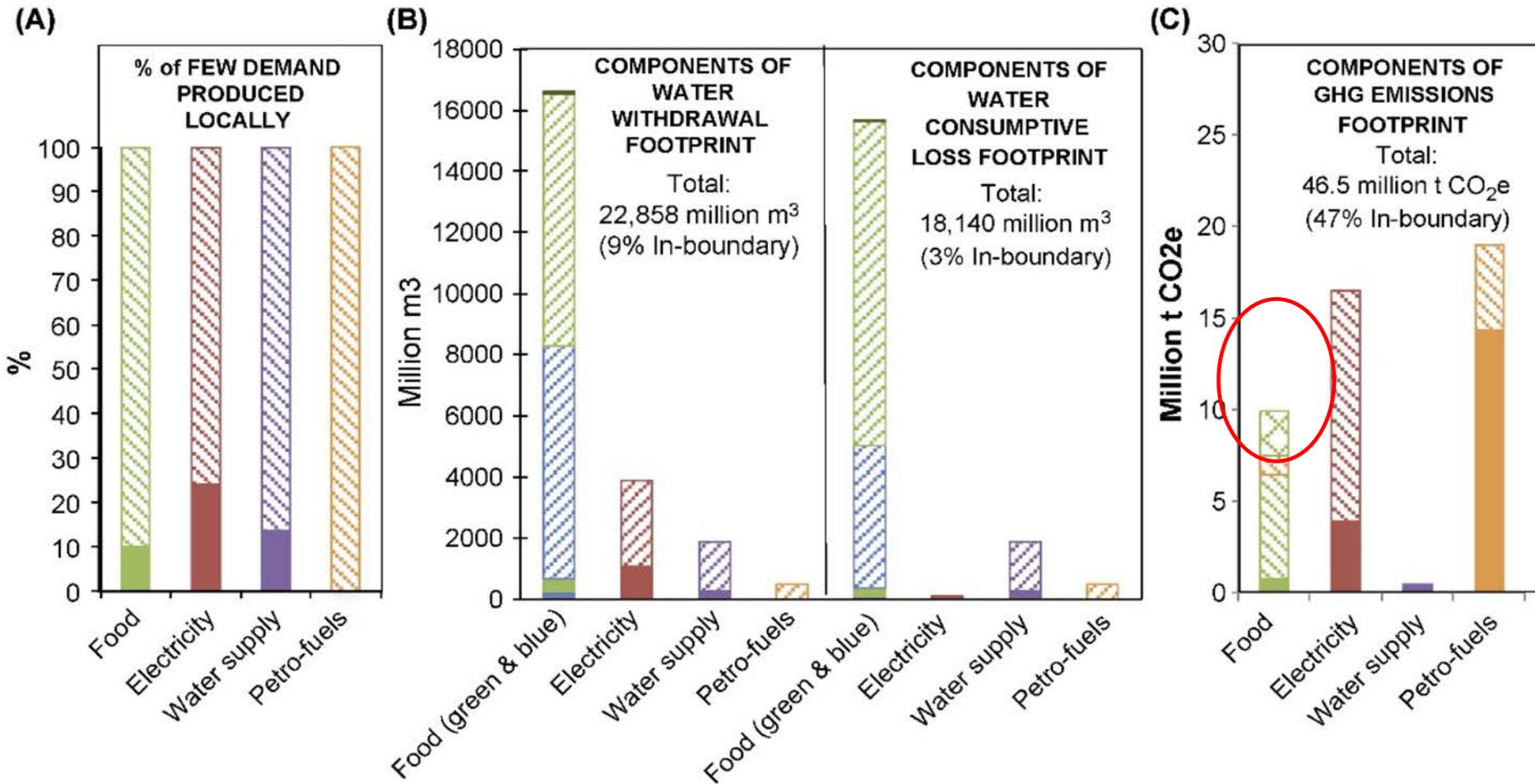
**Population: 16 million**

- **20% lacking sufficient calories**
- **25% lacking water from treated source**
- **10% lacking clean cooking fuel (LPG)**

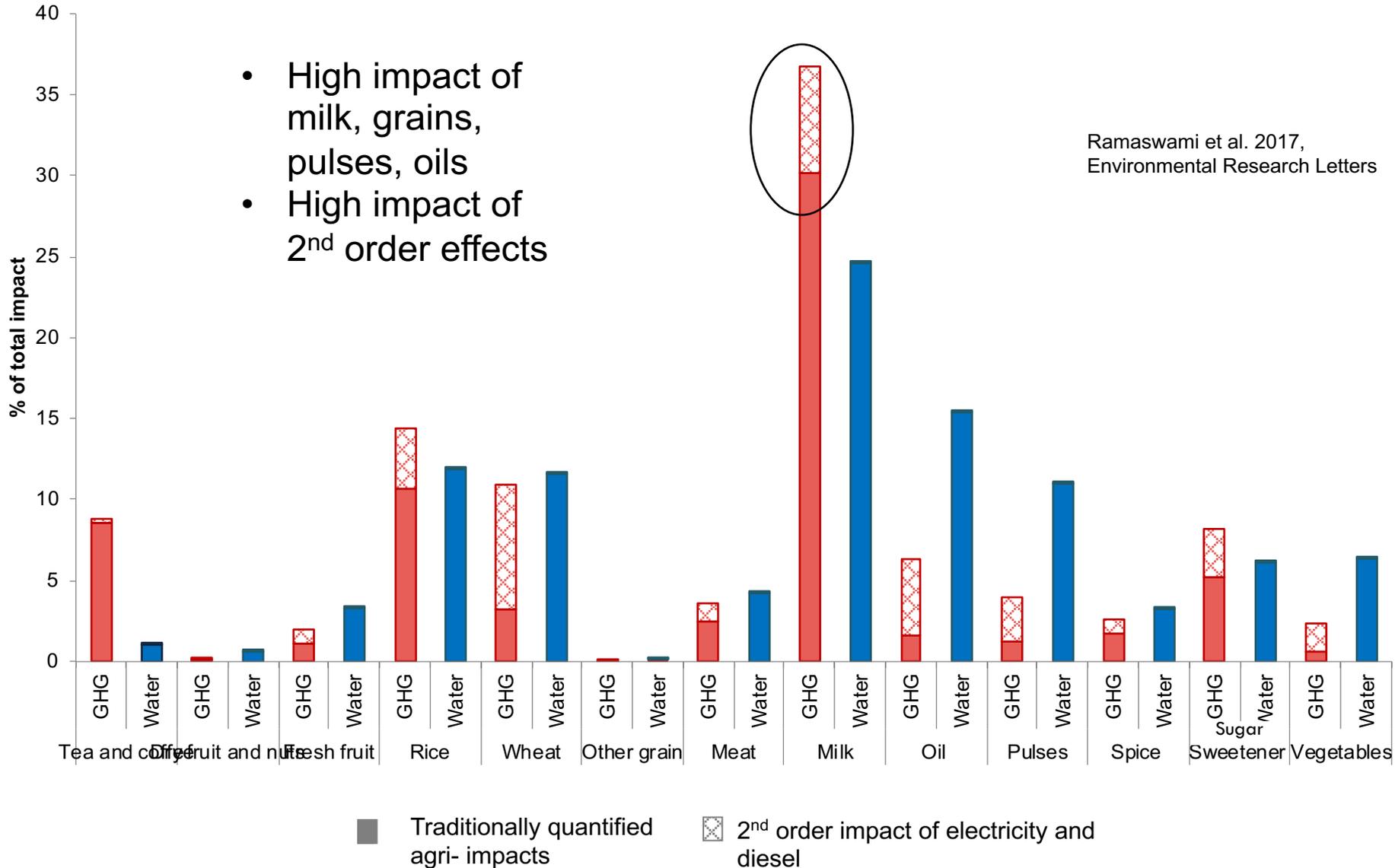
# Coupled Water, Energy & GHG Footprints of FEW-Supply to Delhi



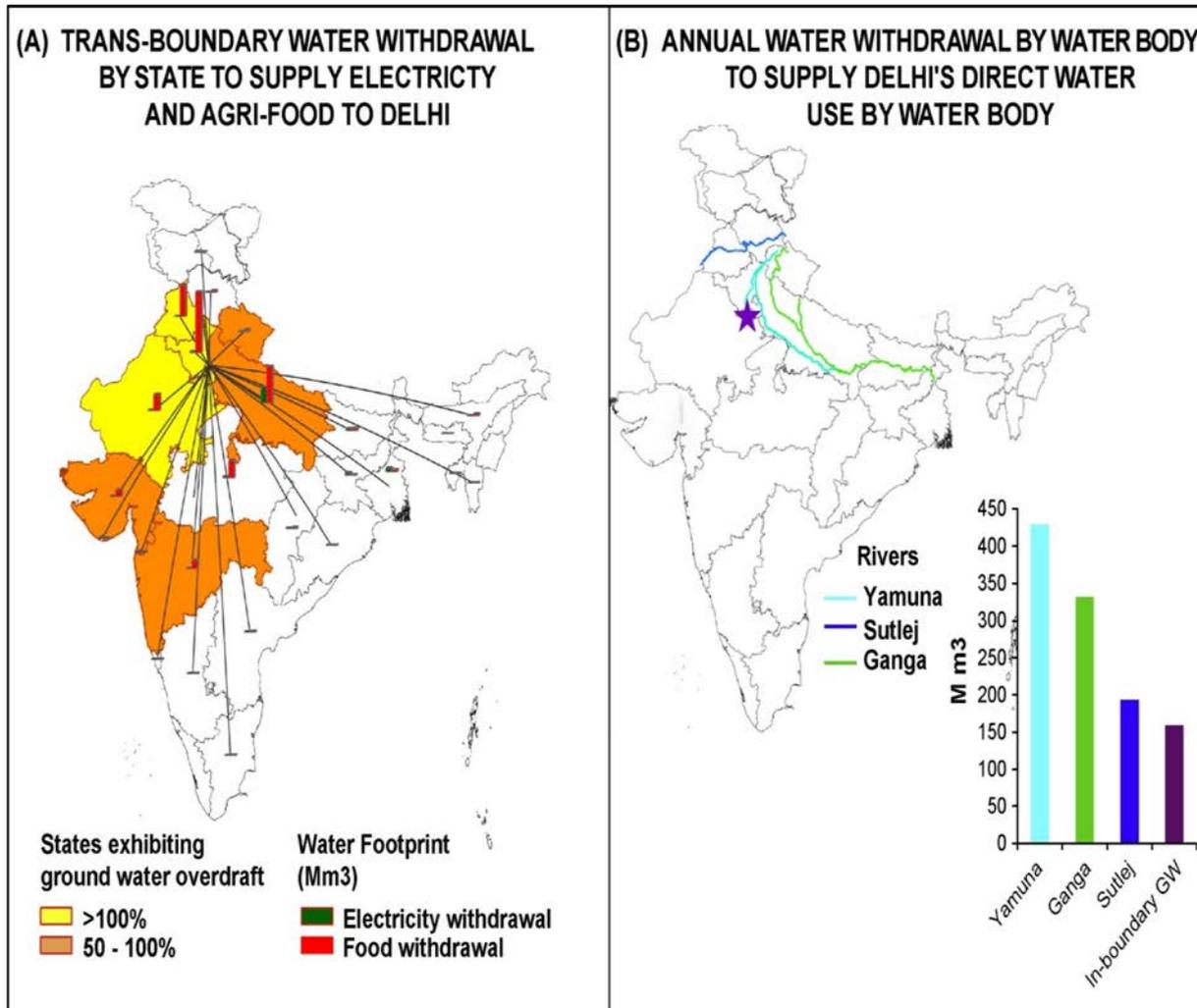
# Coupled Water-Energy-GHG Footprints of Food-Energy-Water Provisioning for Delhi



# GHG and Consumptive Water Loss Footprint of Specific Food Items Supplied to Delhi



# Supply Chain Informed Spatially Detailed Footprints of FEW Provisioning



Water and Electricity Intensity Factors of Food & Electricity production were detailed for the supply chains serving Delhi (and 8 other cities)

Supply chain data also informed water-vulnerability of these supplies

# Application to inform urban food policies

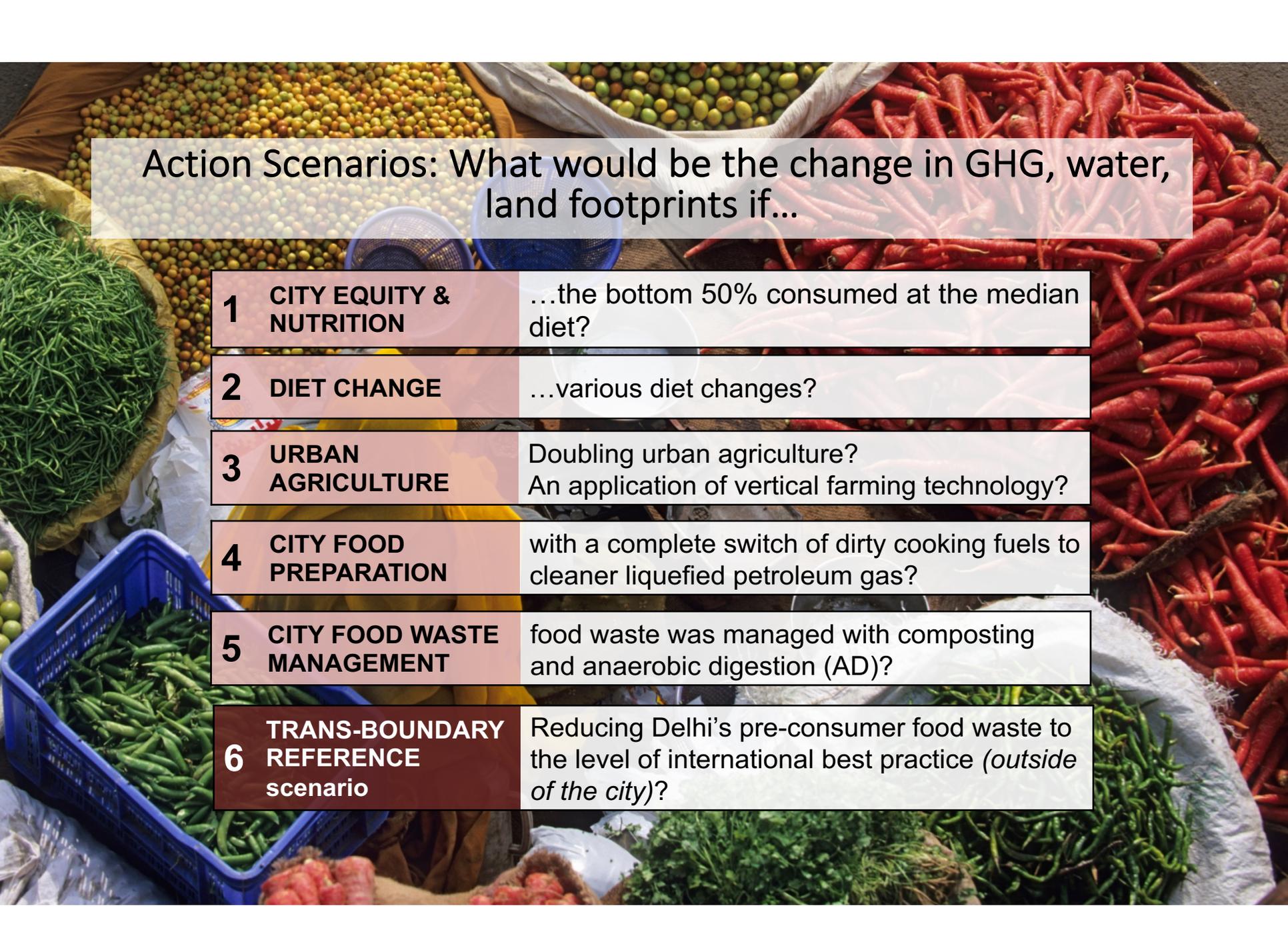
**ENVIRONMENTAL**  
Science & Technology

Article

[pubs.acs.org/est](https://pubs.acs.org/est)

**What Is the Contribution of City-Scale Actions to the Overall Food System's Environmental Impacts?: Assessing Water, Greenhouse Gas, and Land Impacts of Future Urban Food Scenarios**

Dana Boyer<sup>\*,†</sup> and Anu Ramaswami<sup>†</sup>



## Action Scenarios: What would be the change in GHG, water, land footprints if...

### 1 CITY EQUITY & NUTRITION

...the bottom 50% consumed at the median diet?

### 2 DIET CHANGE

...various diet changes?

### 3 URBAN AGRICULTURE

Doubling urban agriculture?  
An application of vertical farming technology?

### 4 CITY FOOD PREPARATION

with a complete switch of dirty cooking fuels to cleaner liquefied petroleum gas?

### 5 CITY FOOD WASTE MANAGEMENT

food waste was managed with composting and anaerobic digestion (AD)?

### 6 TRANS-BOUNDARY REFERENCE scenario

Reducing Delhi's pre-consumer food waste to the level of international best practice (*outside of the city*)?

# City Food Actions Trade-offs & Co-Benefits

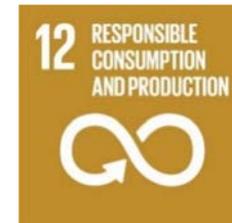
## Example Results Delhi, India

Increasing Food Consumption to Median Diets



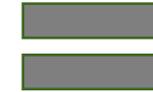
GHG

Changing Diets (Meats to Pulses)



Land

Cooking fuel interventions



Water

Food Waste Management (HH Organics to Compost)



Health

## **Example 2: Connecting Infrastructure, Carbon (GHG), Air Pollution & Health Risk in 637 Chinese Cities**

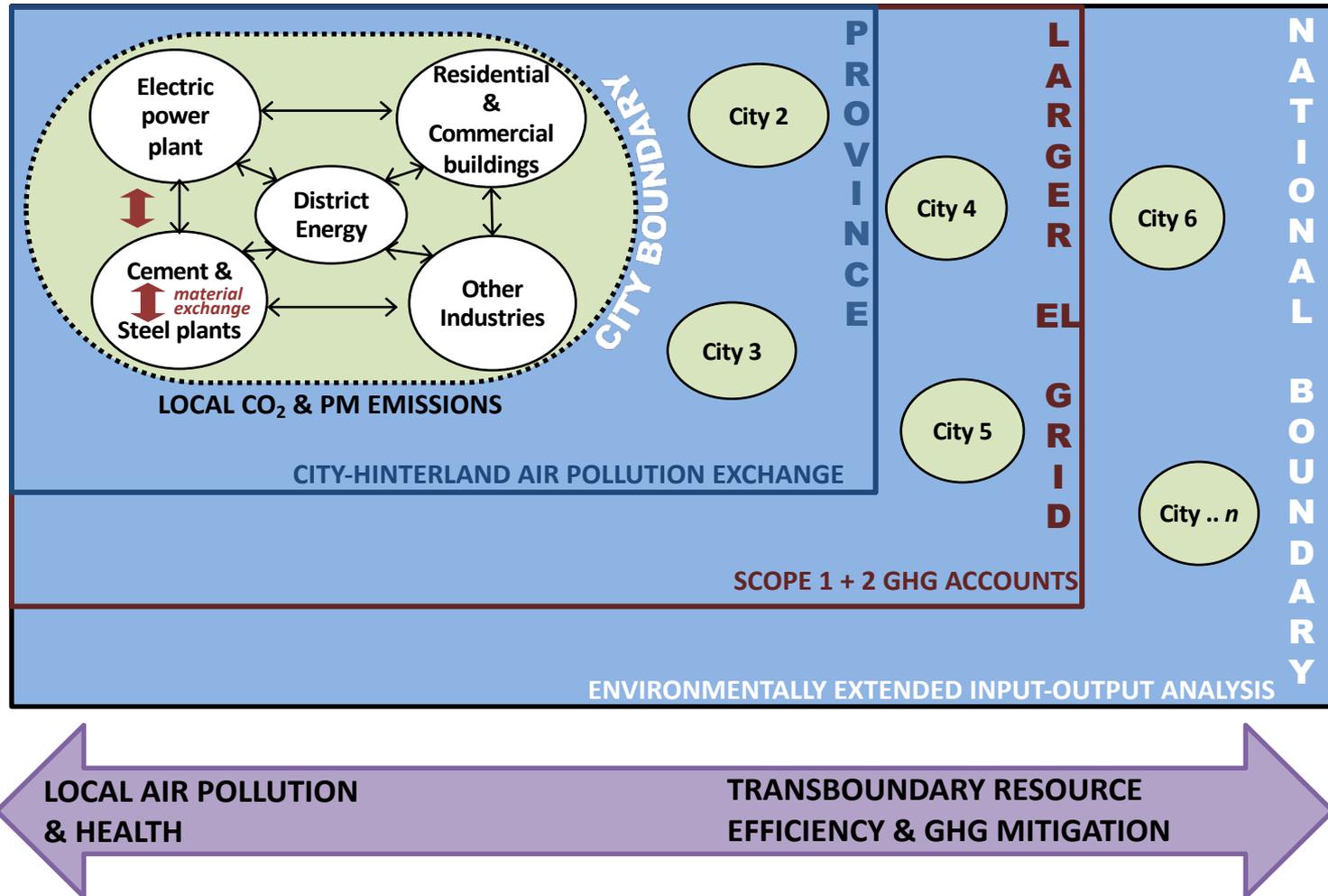
### *Urban Cross-Sector Actions for Carbon Mitigation with Local Health Co-Benefits in China*

Anu Ramaswami<sup>#,1</sup>, Kang Kang Tong<sup>1</sup>, Andrew Fang<sup>1</sup>, Raj Lal<sup>2</sup>, Ajay Nagpure<sup>1</sup>, Yang Li<sup>3</sup>, Yuajun Yu<sup>3</sup>, Daqian Jiang<sup>4</sup>, Armistead G. Russell<sup>2</sup>, Lei Shi<sup>3</sup>, Marian Chertow<sup>4</sup>, Yangjun Wang<sup>5</sup>, Shuxiao Wang<sup>3</sup>

1. University of Minnesota, Twin Cities Campus, Minneapolis, Minnesota, USA
2. Georgia Institute of Technology, Atlanta, Georgia, USA
3. Tsinghua University, Beijing, China
4. Yale University, New Haven, Connecticut, USA
5. Shanghai University, Shanghai, China

(Ramaswami et al., *Nature Climate Change*, 2017)

# Nexus between Infrastructure, GHG & Air Pollution: Communitywide, Transboundary and Bidirectional Linkages

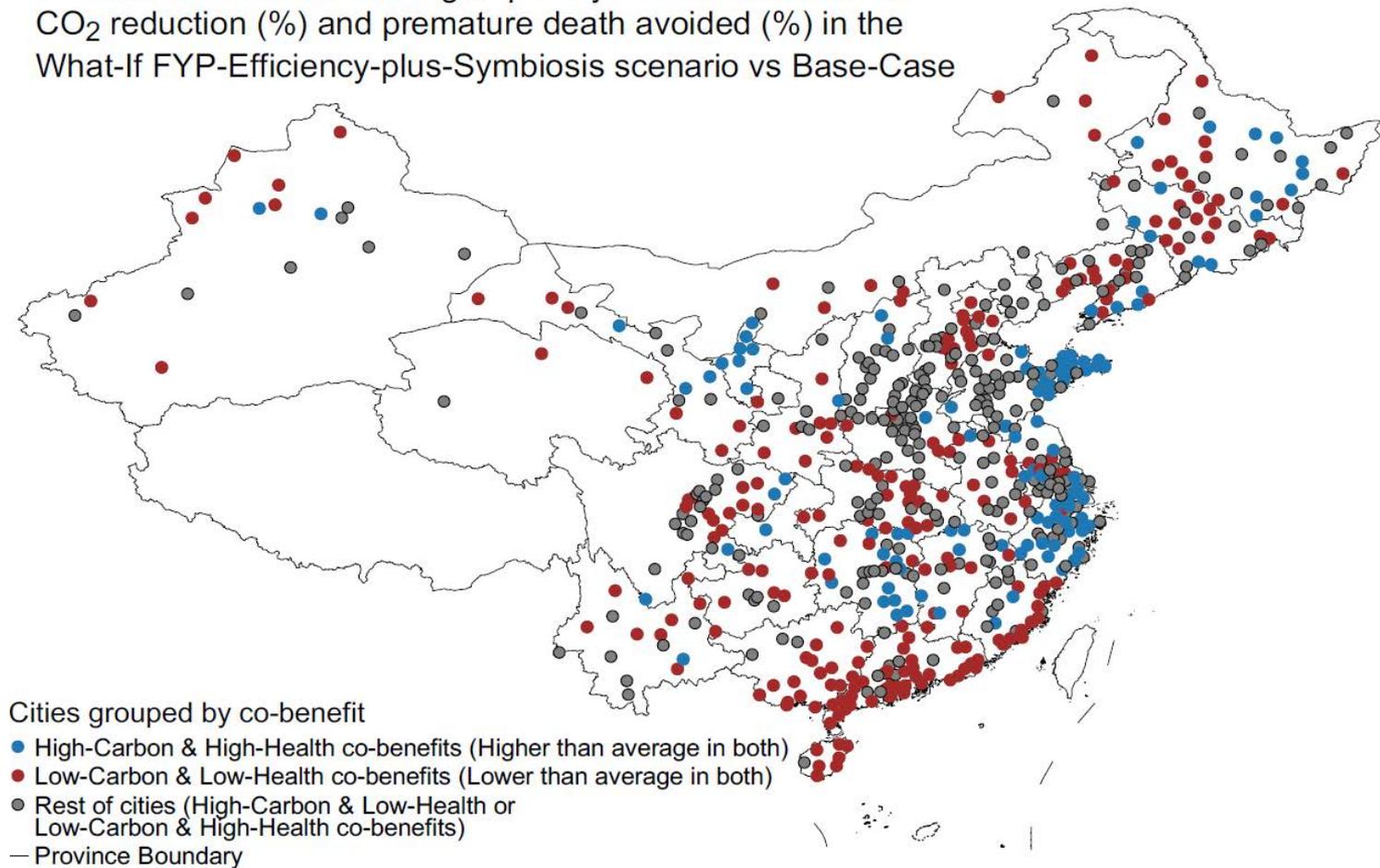


# Modeling Carbon, Air Pollution & Health Co-Benefits Requires Transboundary Carbon and Air Pollution Modeling

Overall: 45,000 premature deaths are avoided in cities from efficiency and urban-industrial symbiosis.

Interesting that the health co-benefits is not directly proportional to CO<sub>2</sub> reduction

b. Cities in mainland China grouped by co-benefits in direct CO<sub>2</sub> reduction (%) and premature death avoided (%) in the What-If FYP-Efficiency-plus-Symbiosis scenario vs Base-Case



# Infrastructure Transitions Studies in SHCN: Advancing Basic & Applied Science & Engr

- **Urban Green Infrastructure & Food Systems** (Ramaswami, Twine (UMN), Newell (UMI) et al. w City of Minneapolis)
- **Mobility (Shared Autonomous Electric Vehicles) & Power Sector Transitions toward Zero Carbon Cities** (Kockelman (UT), Modi (CU), Zimmerle (CSU); Russell (GT), Ramaswami (UMN) et al. w/ Austin & MSP)
- **Multi-Scale Flooding, Urban Heat & Green-Grey Infrastructure Transitions** (Merwade (Purdue), Culligan (CU), Twine (UMN), et al.; Comparing NYC, MSP, DET)
- **Overarching Social Actor Theories:** Feiock (FSU), Orlove (CU), Chan, Zhao & Ramaswami (UMN), et al.

High interest in collaborating and growing our network

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# Science to Action Experiences: *Co-Producing Science with Denver & ICLEI USA*

## Developing and Standardizing New Transboundary Greenhouse Gas Accounting Methods that Recognize Cities as Open Systems



### A Demand-Centered, Hybrid Life-Cycle Methodology for City-Scale Greenhouse Gas Inventories

Anu Ramaswami<sup>\*†</sup>, Tim Hillman<sup>†</sup>, Bruce Janson<sup>†</sup>, Mark Reiner<sup>†</sup> and Gregg Thomas<sup>‡</sup>

Department of Civil Engineering, University of Colorado Denver, Denver, Colorado, and Department of Environmental Health, City and County of Denver, Denver, Colorado

### Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight U.S. Cities

Tim Hillman<sup>†</sup> and Anu Ramaswami<sup>\*</sup>

Sustainable Urban Infrastructure Program, Department of Civil Engineering, University of Colorado Denver

### Two Approaches to Greenhouse Gas Emissions Foot-Printing at the City Scale

Anu Ramaswami<sup>\*†</sup>, Abel Chavez<sup>†</sup>, Jennifer Ewing-Thiel<sup>†</sup>, and Kara E. Reeve<sup>‡</sup>

<sup>†</sup> University of Colorado Denver, Colorado, United States

<sup>‡</sup> ICLEI-Local Governments for Sustainability USA, Boston, Massachusetts, United States

## U.S. Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions



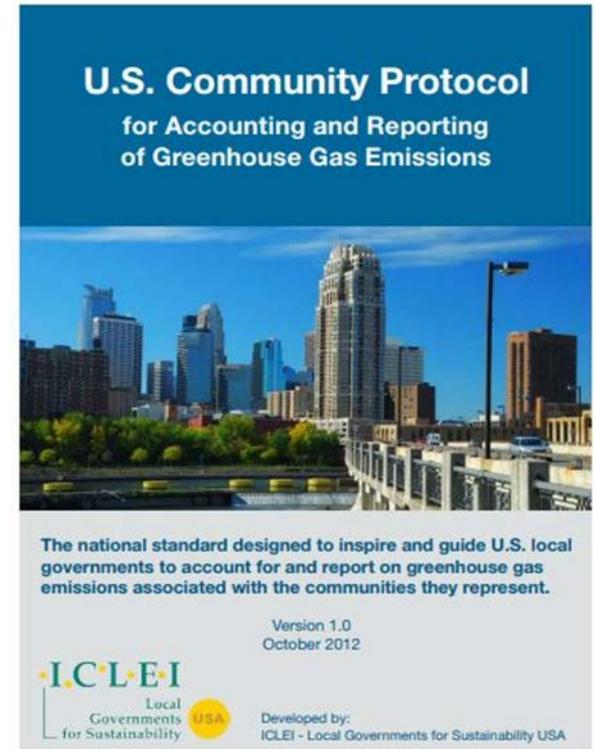
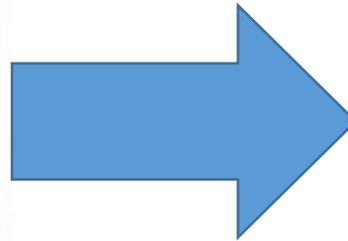
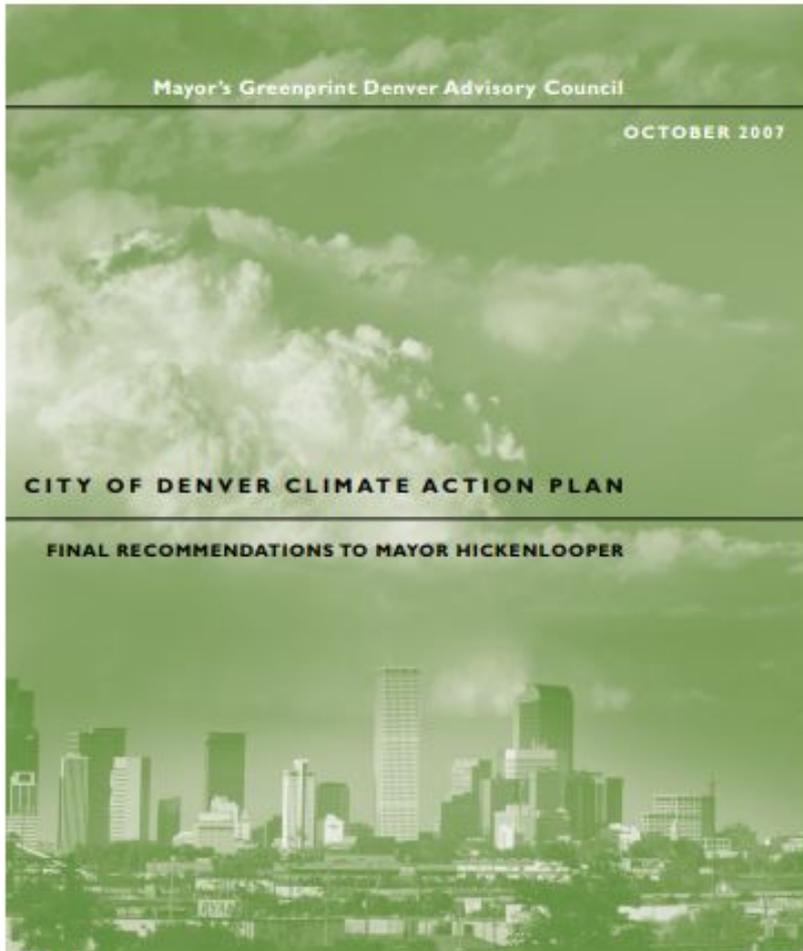
The national standard designed to inspire and guide U.S. local governments to account for and report on greenhouse gas emissions associated with the communities they represent.

Version 1.0  
October 2012



Developed by:  
ICLEI - Local Governments for Sustainability USA

# Science to Action: From Impacting Individual Cities to Impacting More than 500 US Cities



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# An Advisory Report to NSF from ACERE: SUS Sub Committee of ACERE

**Anu Ramaswami** (Chair), Humphrey School of Public Affairs,  
University of Minnesota

**Luis Bettencourt**, Mansueto Institute for Urban Innovation,  
University of Chicago

**Andres Clarens**, Department of Civil and Environmental  
Engineering, University of Virginia

**Sajal Das**, Department of Computer Science, Missouri University  
of Science and Technology

**Garrett Fitzgerald**, Urban Sustainability Directors Network USA

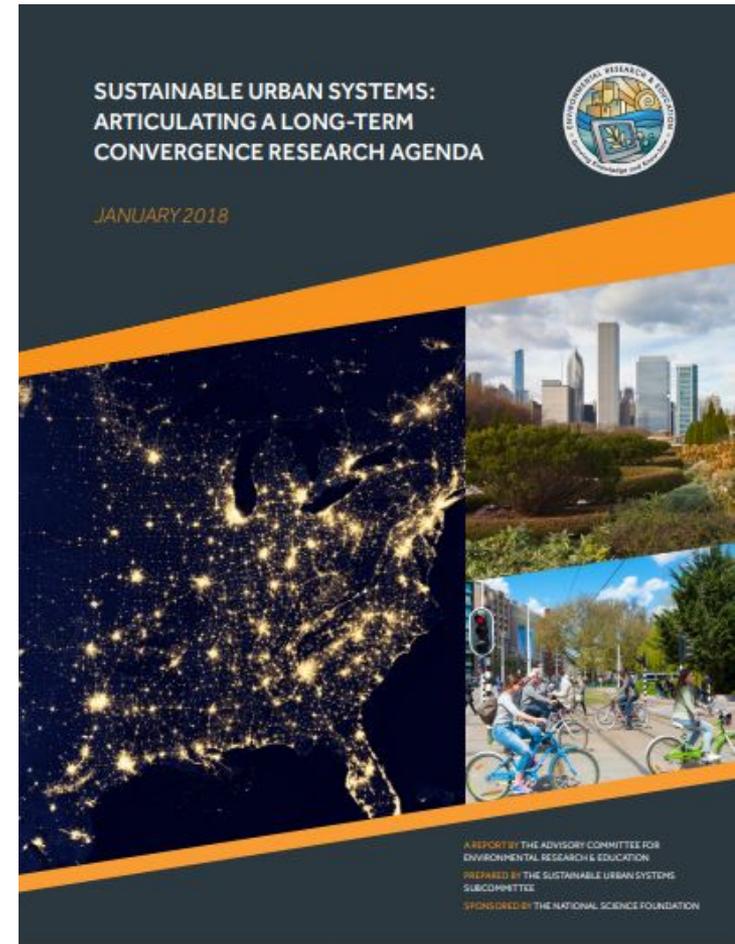
**Elena Irwin**, Department of Agriculture, Environmental, and  
Developmental Economics, The Ohio State University

**Diane Pataki**, Department of Biology, University of Utah

**Stephanie Pincetl**, Institute of the Environment and Sustainability,  
University of California, Los Angeles

**Karen Seto**, Yale School of Forestry and Environmental Studies,  
Yale University

**Paul Waddell**, Department of City and Regional Planning,  
University of California, Berkeley



# Key Features of Next Gen SUS Science: A Convergence Science

- Convergence Science
  - Deep interdisciplinary integration aimed at informing societal transitions
  - Knowledge co-production is more than “broader impacts”
  - It is an integral part of the research and intellectual merit itself



Credit: Knight Foundation



Credit: Sustainable Healthy Cities Network

# Key Features of Next Gen SUS Science: Three perspectives (i-iii)

Intentional integration across three perspectives

- i. Perspective 1- The study of **single urban areas/metropolitan regions** where multiple sustainability outcomes are addressed from a multiscale systems perspective that connects homes, businesses, and communities to regional and global scales.
- ii. Perspective 2- The study of **multiple cities and communities**, exploring inter-relationships among networks of cities and communities, and identifying city typologies for the study of cohort groups and comparison groups.
- iii. Perspective 3- The study of **supra-aggregations of cities and urban areas**, e.g., of all urban areas in an electrical grid region, a nation, a world region, or the world, to assess the collective impact of urban transformation on people and the planet.



Credit: Alanscottwalker



Credit: chensiyuan



Credit: NASA

# Key Features of Next Gen SUS Science: Integrate Elements (A:F) in Each Perspective

- A. New data & methods to understand interactions among natural-human and engineered systems within and across urban areas
- B. Science of the sustainability outcomes nexus across scale
- C. Theories of change, combining:
  - 1. Technology, design & socio-technical transitions
  - 2. Multi-level social actors & governance
- D. Comparative studies/Cohort studies/Scalability studies
- E. Modeling SUS futures
- F. Science of Knowledge Co-Production

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# Thank you



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