让我们共同打造气候中和的未来
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Sino-Swiss Zero Emission Building Project
Impact Simulation of the Chinese ZEB Standard

中瑞零碳建筑项目
中国零碳建筑标准影响模拟分析

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Aim of the Project

General Aim: To assess the impact of new zero-carbon building standards on energy and carbon reductions across four distinct climate regions in China.

Focus Regions and Cities:

- **Hot Summer / Warm Winter:** Shenzhen
- **Extremely Cold:** Harbin
- **Cold:** Beijing
- **Hot Summer / Cold Winter:** Shanghai

Specific Aims:

- Identify region-specific retrofit measures at the building level to reach zero-carbon standard
- Develop a methodology for upscaling building-level analysis to larger urban areas to estimate the impact of zero-carbon standard
- Test the upscaling methodology based on street blocks for a 1 km^2 area for the four selected cities / climate zones

项目目标

总体目标：评估零碳建筑标准在中国四个不同气候区对能源节约和碳减排的影响。

重点区域及城市：
- **夏热/冬暖**地区：深圳
- **严寒**地区：哈尔滨
- **寒冷**地区：北京
- **夏热/冬冷**地区：上海

具体目标：
1. 确定建筑层面的区域性改造措施，以实现零碳标准
2. 开发一种方法，将建筑层面的分析扩展至更大城市范围，以评估零碳标准的影响
3. 基于四个选定城市/气候区的1平方公里街区，测试该扩展方法的适用性

Main Findings of the Project

项目主要研究发现

1. Current Building Performance

- Current buildings do not meet emission thresholds according to the new zero-emission standard, and older low-rise buildings perform worse due to poor insulation and high shape-factor.

2. Improved Building Performance

- Almost all buildings can be transformed to meet the new ZEB standard with dedicated retrofit measures, including passive and HVAC measures combined with PV.
- In cold climates most important is envelope + HVAC, in hot climates shading + HVAC
- Electrification is the desired strategy for decarbonization, even though currently with high carbon intensity in China (3 times the one of natural gas)

3. Superblock vs. Building-Level Analysis

- Superblock scale improves fidelity by accounting for shading and urban layout
- Superblock as a building block for upscaling proved to be effective but needs further validation with areas of more complete datasets

2. Impact of Zero-Carbon Standard

Annual reduction potential (per upscaling zone):

- Beijing: 68’100 t CO_2eq/y
- Harbin: 73’606 t CO_2eq/y
- Shanghai: 73’296 t CO_2eq/y
- Shenzhen: 118’390 t CO_2eq/y

1. 当前建筑性能

- 当前建筑未能达到新的零碳建筑标准要求的排放阈值，尤其是老旧的低层建筑，由于隔热不到位以及较高的体型系数，导致性能较差。

2. 改善后的建筑性能

- 几乎所有建筑都可以通过专门的改造措施，结合被动式设计、暖通空调（HVAC）措施和光伏系统，转变为符合新的零碳建筑（ZEB）标准。
- 在寒冷气候条件下，最重要的是建筑维护结构和暖通空调系统；在热带气候下，则是遮阳和暖通空调系统。
- 尽管目前中国的电力碳排放强度是天然气的三倍，电气化仍然是脱碳的理想策略。

3. 超级街区与建筑层面分析

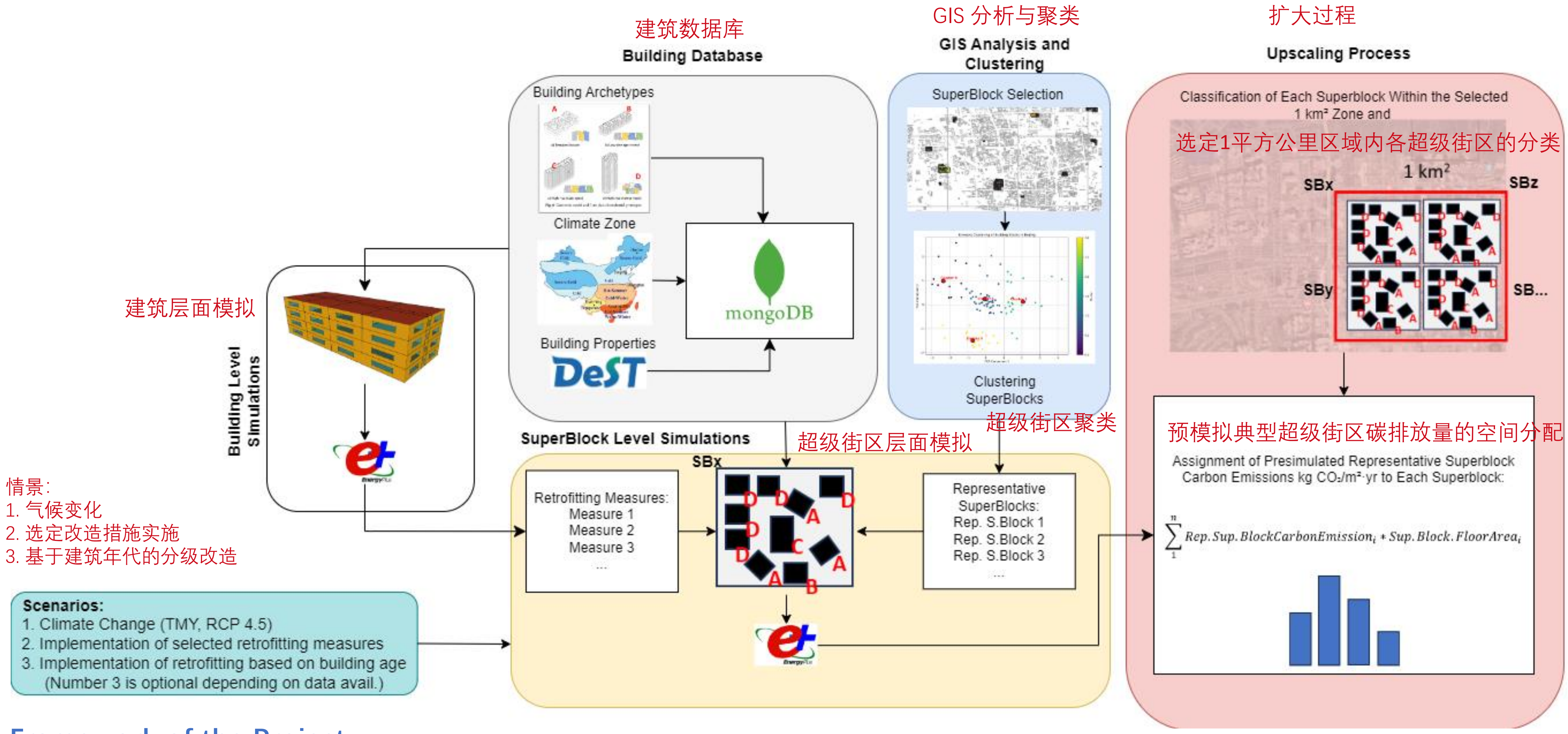
- 超级街区尺度通过考虑遮阳和城市布局，提高了准确性。
- 将超级街区作为放大尺度的建筑单元已证明有效，但需要进一步验证，尤其是在数据更完整的区域。

4. 零碳标准的影响

每个放大区域的年减排潜力：

- 北京：68,100 吨 CO_2eq/年
- 哈尔滨：73,606 吨 CO_2eq/年
- 上海：73,296 吨 CO_2eq/年
- 深圳：118,390 吨 CO_2eq/年

01 项目介绍
Introduction



Framework of the Project
项目框架

02 建筑层面分析

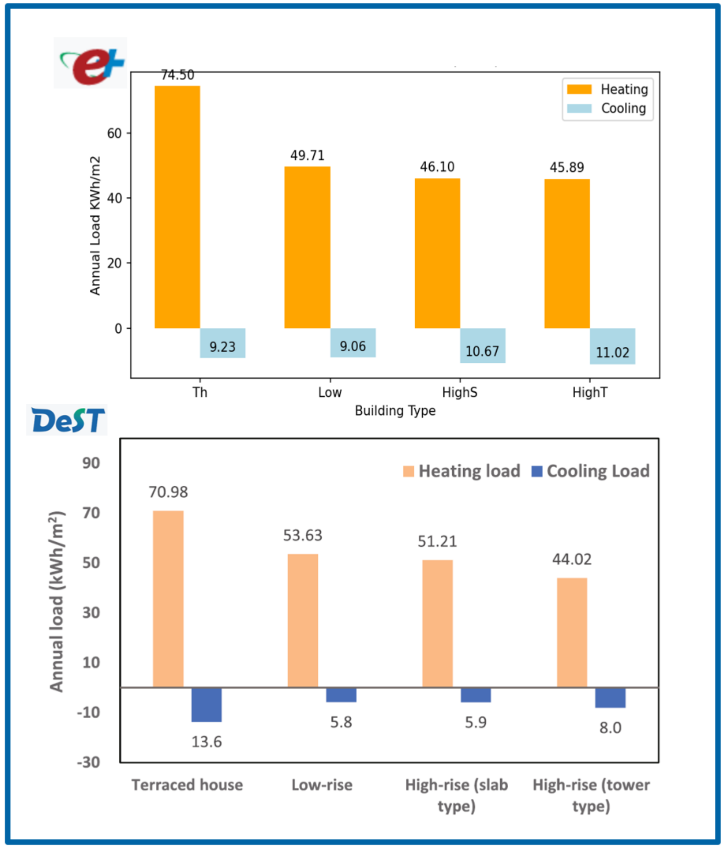
Building Level Analysis

典型建筑的基准模拟与验证：

Baseline Simulations and Validation for Archetype Buildings:

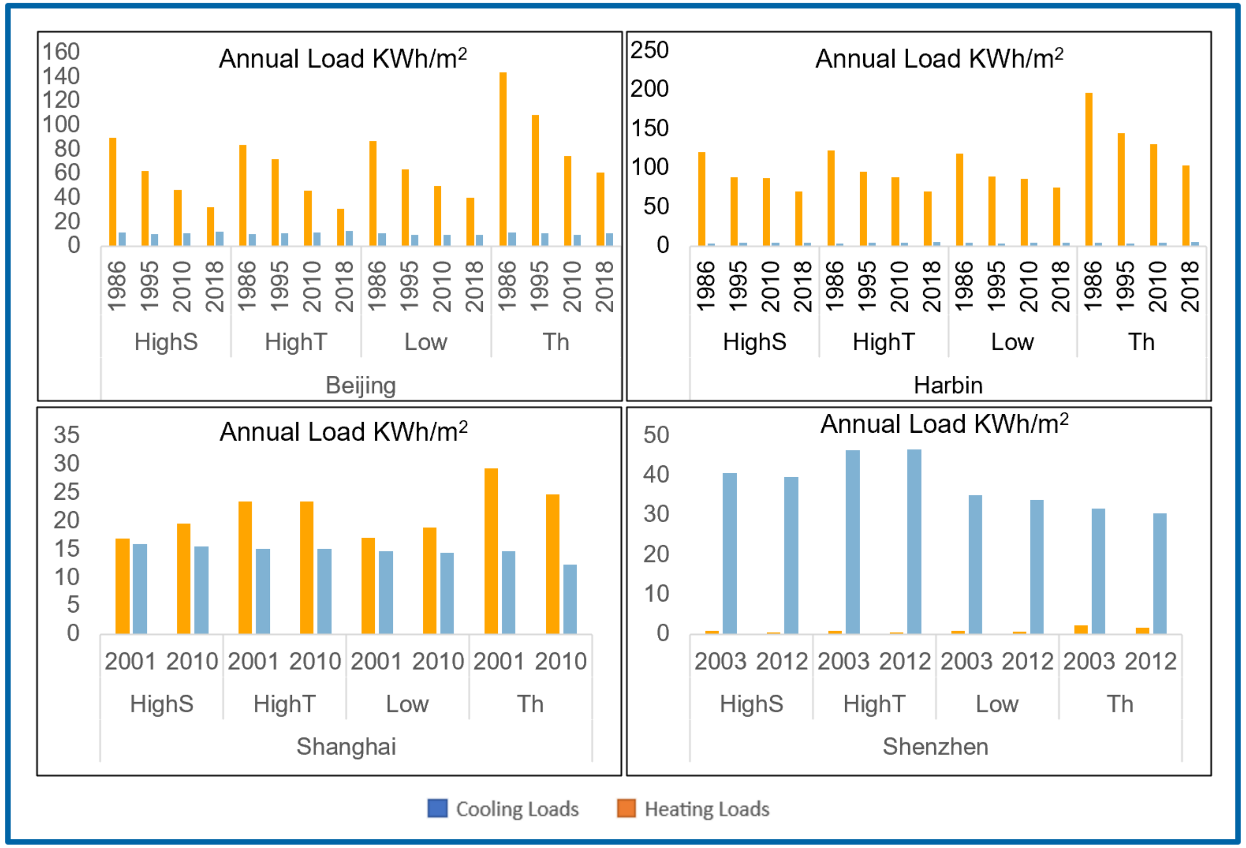
验证分析

Validation Analysis



基准建筑原型参照模拟

Baseline Simulations for Reference Archetype Buildings



The baseline simulation results using EnergyPlus for buildings constructed in Beijing between 2010-2018 (left-top) and results from An et al. 2023 (left-bottom) are displayed:

使用 EnergyPlus 对2010–2018年间在北京建造的建筑进行的基准模拟结果（左上）以及 An 等人于2023年发布的研究结果（左下）如下所示：

02 建筑层面分析

Building Level Analysis

识别实现零碳建筑标准的脱碳路径

脱碳措施依据文献综述以及中国近零能耗建筑标准（《近零能耗建筑技术标准》2019年版）确定。

Identification of Decarbonization Pathways to Meet the ZEB Standard

Decarbonization measures are determined based on a literature review and China's near-zero energy building standards (Technical Standard for Nearly Zero Energy Buildings 2019).

脱碳路径

Decarbonization Pathways

Measures No:	Ground Floor Insulation	Roof Insulation	Wall Insulation	Windows Upgrade	HVAC Improvement	PV-Panels	Shading Elements
1	+	+		+			
2	+	+	+	+			
3	+	+		+	+		
4	+	+	+	+	+		
5	+	+		+	+	+	
6	+	+	+	+	+	+	
7	+	+		+			+
8	+	+	+	+			+
9	+	+		+	+		+
10	+	+	+	+	+		+
11	+	+		+	+	+	+
12	+	+	+	+	+	+	+

	既有建筑 Existing Building	改造选项 Retrofit Option
	Heating Dominated Climate (Harbin, Beijing)	
Space Heating	Centralized gas heater	Centralized airsource hp
DHW	Centralized gas heater	Centralized airsource hp
Space Cooling	Decentralized split unit (air-air hp)	Decentralized split unit (air-air hp)
	Cooling Dominated Climate (Shanghai, Shenzen)	
Space Heating	Decentralized split unit (air-air hp)	Decentralized split unit (air-air hp)
DHW	Decentralized gas heater	HP water heater
Space Cooling	Decentralized split unit (air-air hp)	Decentralized split unit (air-air hp)

02 建筑层面分析

Building Level Analysis

结合脱碳路径的建筑层级模拟结果（北京）

Results from Building-Level Simulations with Decarbonization Pathways (Beijing)

Year	Archetype	Location	Baseline	Measure 1	Measure 2	Measure 3	Measure 4	Measure 5	Measure 6	Measure 7	Measure 8	Measure 9	Measure 10	Measure 11	Measure 12
1986	HighS	Beijing	35.2	16.3	9.2	16.4	10.8	-3.7	-9.2	15.4	7.7	15.4	9.4	-4.6	-10.6
1986	HighT	Beijing	32.3	13.6	9.1	14.3	10.6	6.8	3.1	12.5	7.7	13.2	9.3	5.7	1.8
1986	Low	Beijing	32.8	15.7	9.5	16.4	11.3	-28.7	-33.7	15.1	8.6	15.6	10.4	-29.5	-34.7
1986	Th	Beijing	55.8	22.7	12.7	22.1	14.1	-68.0	-76.0	21.4	11.9	20.9	13.1	-69.2	-77.0
1995	HighS	Beijing	22.9	10.7	9.1	12.0	10.8	-8.0	-9.3	9.5	7.7	10.8	9.3	-9.2	-10.7
1995	HighT	Beijing	26.8	13.6	9.1	14.3	10.6	6.8	3.1	12.5	7.7	13.2	9.3	5.7	1.8
1995	Low	Beijing	22.5	11.2	9.5	12.8	11.3	-32.3	-33.8	10.2	8.5	11.8	10.3	-33.3	-34.8
1995	Th	Beijing	38.0	15.6	12.5	16.3	13.9	-73.8	-76.1	14.6	11.6	15.2	12.9	-74.9	-77.3
2010	HighS	Beijing	17.8	11.6	9.1	12.8	10.7	-7.2	-9.3	10.4	7.7	11.7	9.3	-8.4	-10.7
2010	HighT	Beijing	17.8	11.8	9.1	12.9	10.6	5.4	3.1	10.7	7.7	11.8	9.2	4.3	1.7
2010	Low	Beijing	17.9	11.4	9.4	13.0	11.3	-32.1	-33.8	10.5	8.5	12.0	10.3	-33.1	-34.8
2010	Th	Beijing	25.0	14.7	12.4	15.7	13.9	-74.4	-76.2	13.7	11.6	14.6	12.8	-75.5	-77.3
2018	HighS	Beijing	13.2	9.6	9.1	11.2	10.7	-8.9	-9.3	8.3	7.6	9.8	9.3	-10.2	-10.7
2018	HighT	Beijing	12.9	9.6	9.1	11.1	10.6	3.6	3.1	8.4	7.7	9.8	9.2	2.3	1.7
2018	Low	Beijing	14.4	10.1	9.4	11.9	11.2	-33.2	-33.8	9.2	8.4	10.9	10.2	-34.2	-34.8
2018	Th	Beijing	20.2	13.7	12.4	14.8	13.8	-75.3	-76.2	12.9	11.6	13.8	12.8	-76.3	-77.4

kg CO_2eq/m^2.y

表格中，蓝色单元格代表符合近零能耗住宅建筑碳排放阈值的建筑；绿色单元格表示接近该阈值且碳排放较低的建筑；黄色单元格表示碳排放中等的建筑；红色单元格则突出显示碳排放较高的建筑。

In the table, blue cells represent buildings that meet the carbon emission threshold for nearly zero-energy residential buildings. Green cells indicate buildings that are close to the threshold and have low carbon emissions. Yellow cells represent buildings with moderate carbon emissions, while red cells highlight buildings with high carbon emissions.

02

建筑层面分析

Building Level Analysis

结合脱碳路径的建筑层级模拟结果（深圳）

Results from Building-Level Simulations with Decarbonization Pathways (Shenzhen)

Year	Archetype	Location	Baseline	Measure 1	Measure 2	Measure 3	Measure 4	Measure 5	Measure 6	Measure 7	Measure 8	Measure 9	Measure 10	Measure 11	Measure 12
2003	HighS	Shenzhen	21.7	16.5	16.2	17.3	17.1	-0.9	-1.1	15.3	15.0	16.2	15.9	-2.0	-2.3
2003	HighT	Shenzhen	23.4	16.5	16.3	17.4	17.2	10.6	10.4	15.4	15.2	16.3	16.1	9.5	9.2
2003	Low	Shenzhen	20.6	16.4	16.3	17.2	17.0	-23.6	-23.8	15.4	15.1	16.2	15.9	-24.7	-24.9
2003	Th	Shenzhen	23.6	18.9	18.6	19.7	19.4	-62.0	-62.4	17.7	17.3	18.4	18.1	-63.2	-63.6
2012	HighS	Shenzhen	20.9	16.4	16.1	17.2	17.0	-1.0	-1.2	15.2	14.9	16.0	15.8	-2.1	-2.4
2012	HighT	Shenzhen	22.9	16.4	16.2	17.3	17.1	10.5	10.3	15.3	15.1	16.2	16.0	9.4	9.2
2012	Low	Shenzhen	19.8	16.3	16.2	17.1	17.0	-23.7	-23.9	15.3	15.1	16.1	15.9	-24.8	-25.0
2012	Th	Shenzhen	22.1	18.8	18.6	19.5	19.3	-62.2	-62.5	17.5	17.2	18.3	18.0	-63.4	-63.7

kg $CO_2eq/m^2.y$

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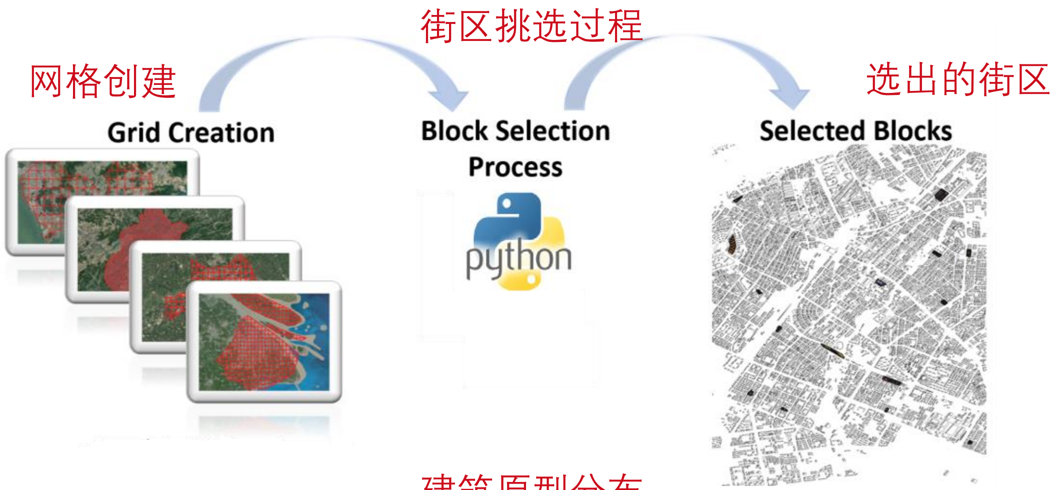
03 超级街区层面分析

Superblock-Level Analysis

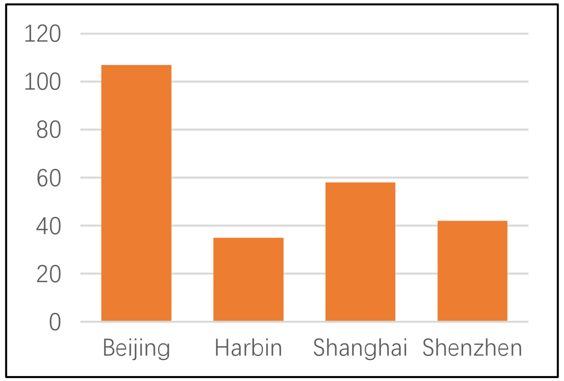
街区选取方法与统计结果

Block Selection Process and Statistics



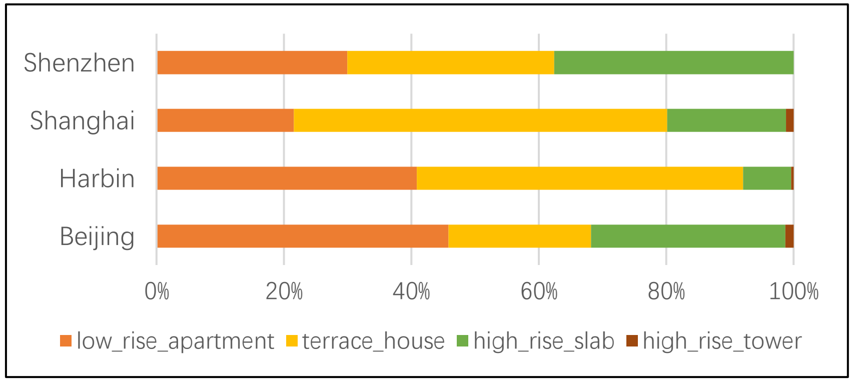
样本数量

Number of Samples



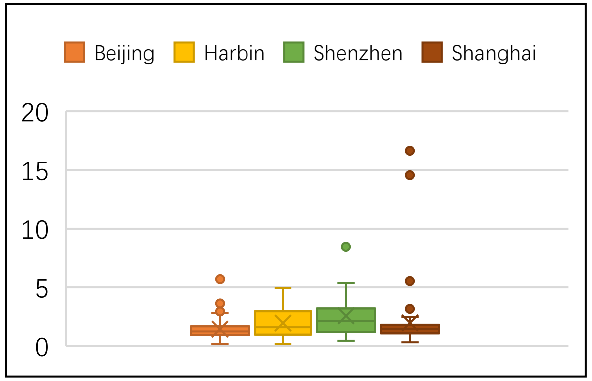
建筑原型分布

Building Archetype Distribution



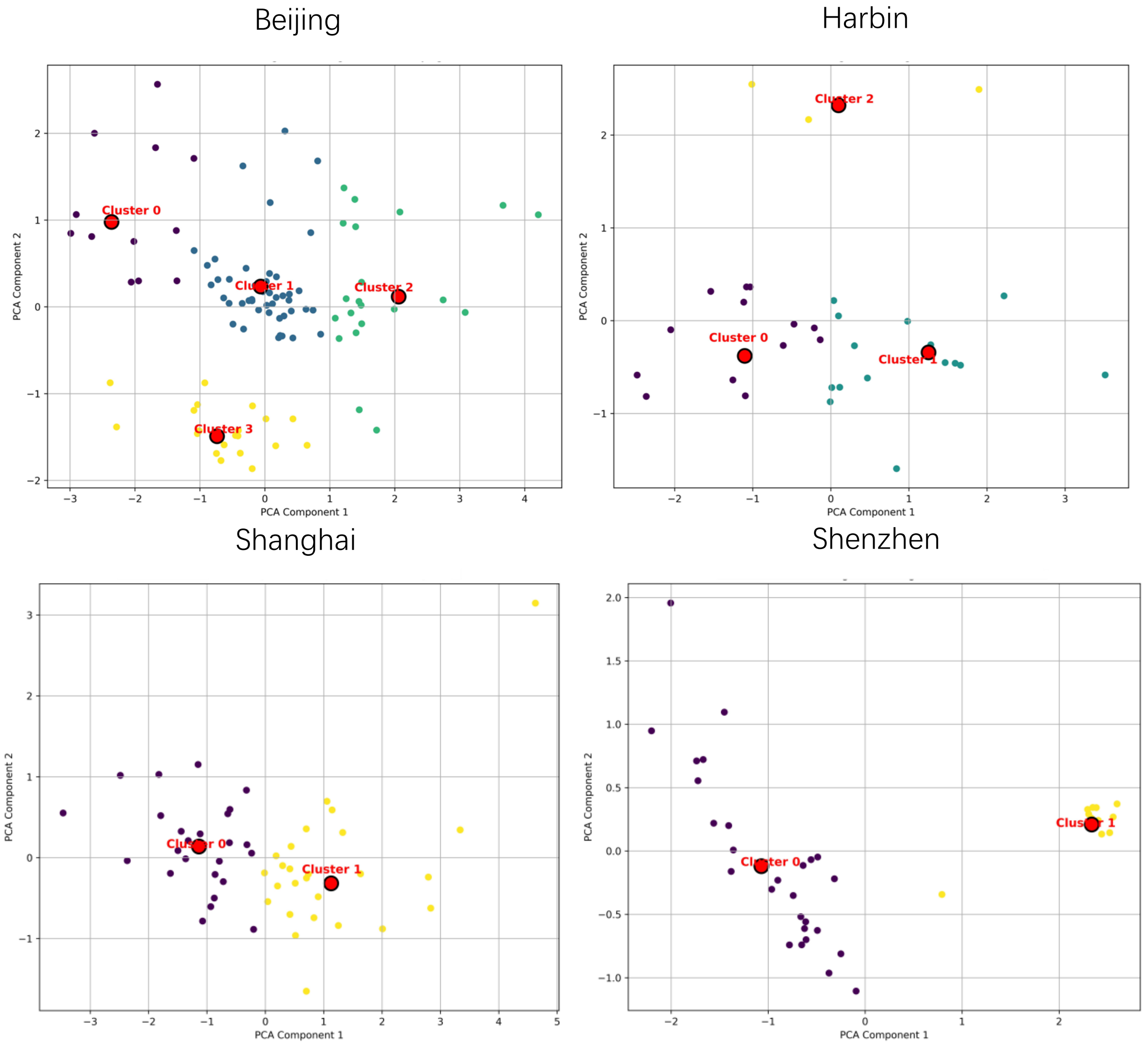
样本数量

Density of Samples



03 超级街区层面分析

Superblock-Level Analysis



聚类分析流程

采用K均值聚类算法进行分析:

- 街区密度指标：通过总建筑面积与超级街区面积的比值进行计算
- 建筑紧凑度评估（街区层面）：采用外表面积与体积比（形态系数）作为衡量标准
- 整体热工性能：基于建筑群的加权平均热传导系数（U值）

Clustering Process

K-Means Clustering for the clustering process:

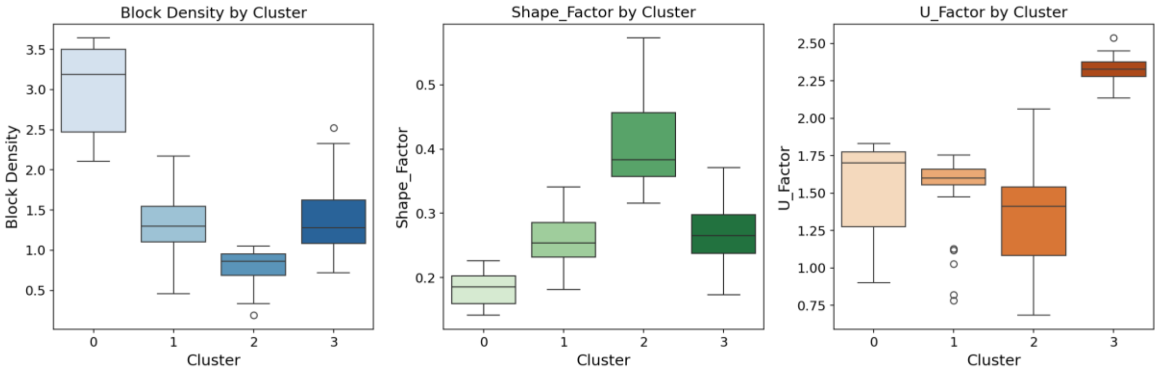
- The density of the block is measured as the ratio of the total floor area to the superblock area.
- Compactness of buildings in a street block: surface area to volume ratio (shape factor)
- Overall U-factor: weighted U-factor of the buildings

超级街区层面分析

Superblock-Level Analysis

位于北京的代表性超级街区

Representative Superblocks (Beijing)



Superblock-Level Scenario Analysis

#Scenario	Ground Floor Ins.	Roof Ins.	Wall Ins.	Windows Upgrade	HVAC Improvement	PV Panels	Shading Elements	Global Warming
Baseline	-	-	-	-	-	-	-	-
Scenario 1	+	+	+	+	-	-	+	-
Scenario 2	-	-	-	-	+	+	-	-
Scenario 3	+	+	+	+	+	+	+	-
Scenario 4	-	-	-	-	-	-	-	+
Scenario 5	+	+	+	+	-	-	+	+
Scenario 6	-	-	-	-	+	+	-	+
Scenario 7	+	+	+	+	+	+	+	+

Beijing: 北京

Cluster	Location	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
0	Beijing	29.6	8.8	2.2	-8.7	28.2	10.4	3.2	-7.0
1	Beijing	28.0	8.4	-21.4	-31.8	26.8	9.8	-20.8	-30.3
2	Beijing	33.4	10.4	-69.2	-80.8	31.8	11.6	-69.2	-79.7
3	Beijing	23.9	9.3	-7.5	-15.3	23.5	10.6	-6.4	-13.9

kg $CO_2eq/m^2.y$

Shenzhen: 深圳

Cluster	Location	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
0	Shenzhen	18.4	15.0	-16.1	-19.5	24.0	19.6	-12.2	-16.7
1	Shenzhen	18.0	14.4	0.8	-2.8	23.3	18.3	5.2	0.2

kg $CO_2eq/m^2.y$

脱碳情景与分析结果

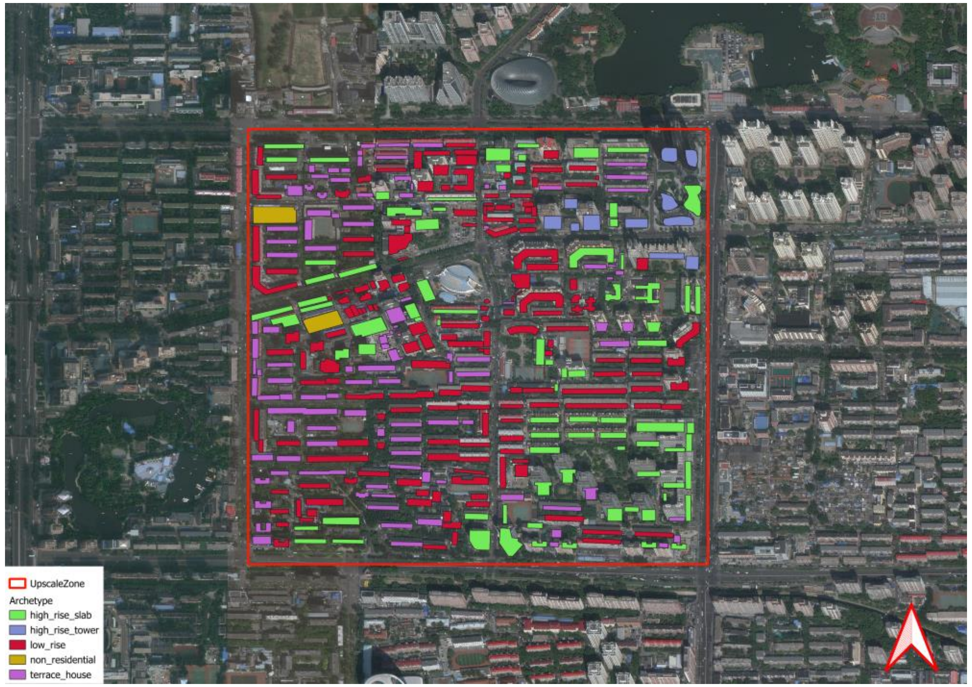
蓝色标识 - 实现净零排放
绿色标识 - 接近净零排放
红色标识 - 高碳排放

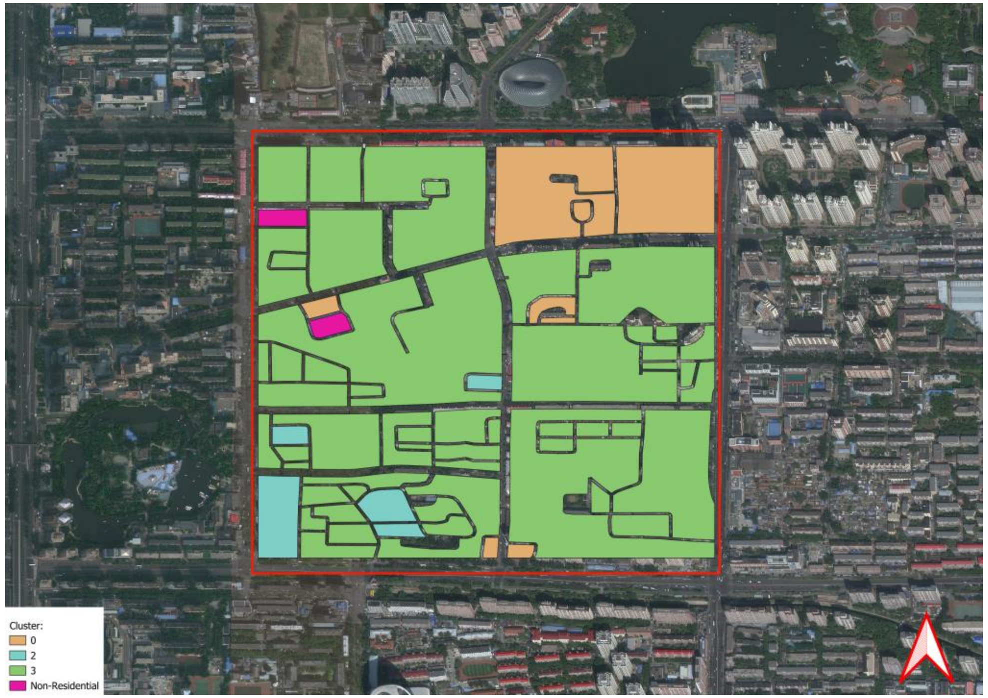
Decarbonization Scenarios and Results of the Analysis

Blue – Achieves Net-Zero
Green – Near Net-Zero
Red – High Carbon Emissions

扩大尺度和结果（北京）

Upscaling Process and Results (Beijing)





Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
25.69	9.14	-5.65	-14.46	24.98	10.58	-4.58	-12.93

kg $CO_2eq/m^2.y$

The baseline simulation results using EnergyPlus for buildings constructed in Beijing between 2010-2018 (left-top) and results from An et al. 2023 (left-bottom) are displayed:

使用 EnergyPlus 对2010–2018年间在北京建造的建筑进行的基线模拟结果（左上）以及 An 等人于2023年发布的研究结果（左下）如下所示：

Conclusions and Outlook

Building-level performance analysis: The building-level analysis proved useful for identifying the most features and promising retrofit measures for different buildings and regions and support the development of a dedicated decarbonization strategy
Simulation framework: The simulation framework allows for a quick scale-up of results on potential emission reduction, with a building-level resolution (bottom-up modelling), providing a forecast for potential carbon reduction for a selected urban area.
Data Limitations: Incomplete and low-resolution data constrained the framework's potential. High-quality data from Chinese authorities would enhance accuracy and predictive power.
Building Typology: The study focused on residential buildings. Including commercial buildings in future analyses is crucial due to their higher energy demands.
PV Integration: Currently limited to rooftops. Future research should explore facade integration, especially in high-rises, and retrofitting existing facades with e.g. lightweight thin film PV.
Electrification & Energy Sources: Electrification reduces emissions, but reliance on fossil fuels impacts results. Future studies should consider decarbonization pathways of national electricity grid by integration of renewable energy
Life-cycle Emissions: Both operational and embodied emissions must be considered for a holistic approach to decarbonizing the building sector.
Net Zero Perspective: Assumes renewable generation reducing emissions proportionally. Needs refinement with increased renewable capacity, especially during peak hours (excess generation).

结论与展望

建筑单体性能分析：建筑层面的分析能有效识别不同建筑类型和区域的关键特征及最具潜力的改造措施，为制定针对性脱碳策略提供支撑。

模拟框架体系：该仿真框架支持基于建筑单体分辨率（自下而上建模）的快速结果推演，可对指定城市区域的潜在碳减排量进行预测。

数据局限性：不完整及低分辨率数据制约了框架的预测能力，采用中国官方高质量数据可显著提升分析精度。

建筑类型学：本研究聚焦住宅建筑。鉴于商业建筑更高的能耗需求，未来分析须纳入此类建筑类型。

光伏集成应用：当前仅考虑屋顶光伏。后续研究应探索高层建筑立面集成方案，特别是现有幕墙改造中轻质薄膜光伏的应用潜力。

电气化与能源结构：电气化虽能降低排放，但化石能源依赖仍影响减排效果。未来研究需结合国家电网可再生能源整合的脱碳路径。

全生命周期排放：要实现建筑领域全面脱碳，必须同时考量运营碳排放和隐含碳排放。

净零排放视角：现有模型假设可再生能源按比例减排，需结合可再生能源装机容量提升（特别是峰时超额发电）进行优化。

让我们共同打造气候中和的未来
Building a climate-neutral future together

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住房和城乡建设部

IBE 环能科技

中国建筑节能协会

Schweizerische Eidgenossenschaft
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Your questions?

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Building a climate-neutral future together

中华人民共和国
住房和城乡建设部

中国建筑碳排放测算与预测

Measurement and Prediction of Building Carbon Emissions in China

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School of Management Science & Real Estate, CQU

2025-04-14

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中国建筑能耗（BEC）数据争议

Backgrounds: Controversy about building energy consumption (BEC) data of China

➢ BEC在全国能源消费总量中所占比例是多少?

What is the proportion of BEC in the country's total energy consumption?

- 清华大学（2014）：19%
  Tsinghua Univ.(2014)：19%
- 龙惟定（2005）：20%
  LONG WEIDING (2005)：20%
- 王庆一（2006）：21.7%
  WANG QINGYI (2006)：21.7%
- LBNL（2008）：26%
- **住建部（2005）：27.5%**
  MHOURD (2005)：27.5%

宏观层面的建筑碳排放数据更为薄弱。

building carbon emissions at the macro level is even weaker.

领导专业委员会 - Leading Professional Committee

- **中国建筑节能协会-建筑能耗与碳排放数据专委会**
  Professional Committee of Building Energy and Emissions, China Association of Building Energy Efficiency (CABEE)

2016年3月成立专委会，旨在整合行业力量，协同开展建筑能耗和建筑碳排放专项研究，通过数据共享夯实建筑节能数据基础。

In March 2016, the Building Energy Consumption Committee was established with the aim of integrating industry efforts to collaboratively conduct specialized research on building energy consumption and carbon emissions. The committee's focus was to strengthen the foundation of building energy efficiency data through data sharing.

公益性 Public welfare	研究型 Research-oriented	数据驱动 Data-driven

发布专业报告 - Publish professional reports

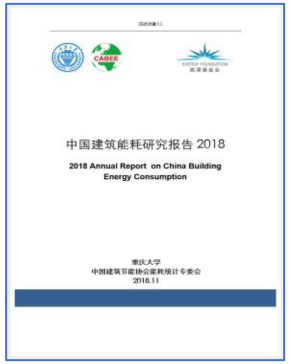
- 每年发布“中国建筑能耗与碳排放研究报告”

  Annually publish the “China Building Energy Consumption and Carbon Emission Annual Report”

  - 2016，全国建筑能耗 - National building energy consumption
  - 2017，分省建筑能耗 - Provincial Building Energy Consumption
  - 2018，建筑碳排放核算 - Building Carbon Emissions Accounting
  - 2019，建筑碳达峰预测 - Building Carbon Peak Forecast
  - 2020，建筑全过程碳排放与碳中和情景预测

    Measurement of Whole-Process Carbon Emissions from Buildings and Forecasting of Carbon Neutral Scenarios
  - 2021，省级建筑碳达峰评估 - Peak Carbon Assessment
  - 2022，城乡建设领域碳排放核算

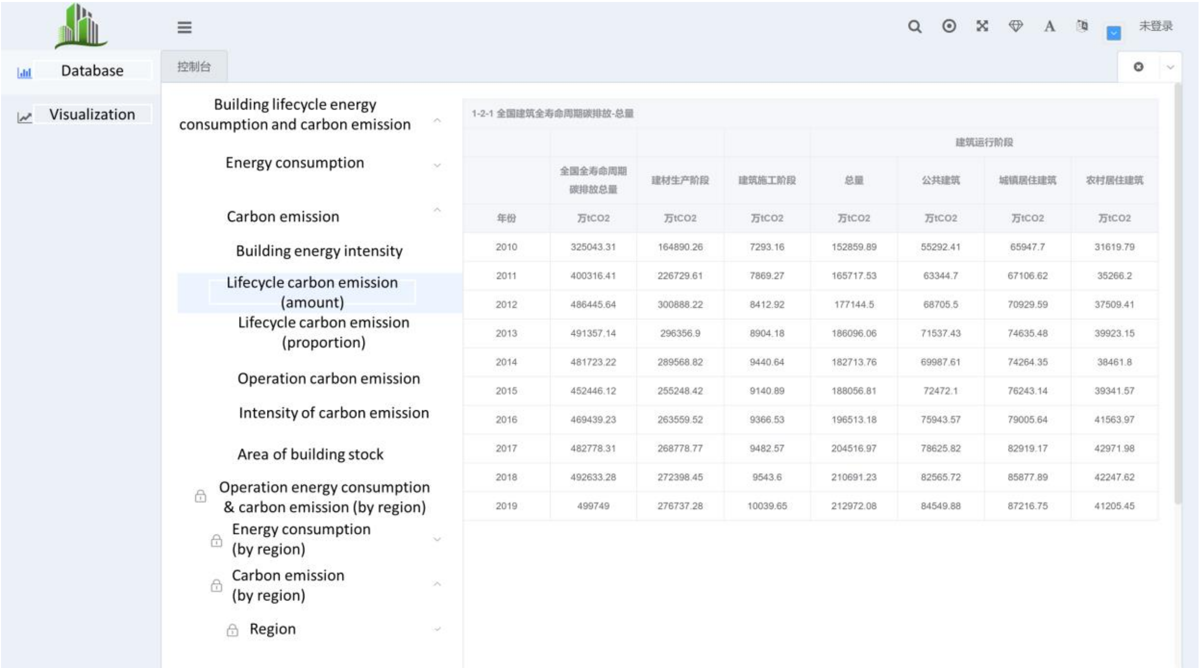
    Carbon Emission Accounting for Urban and Rural Construction Sectors
  - 2023，建筑隐含碳测算 - Embodied Carbon Emissions
  - 2024，建筑领域碳减排贡献 - Building Carbon Reduction



开发数据库 - Development Database

➢ 构建中国城乡建设领域碳排放数据库，开发数据分析AI智能体（ChatBEE）

Build a carbon emissions database for China's urban and rural construction sector and develop a data analysis AI agent (ChatBEE)



				建筑运行阶段			
	全国全寿命周期碳排放总量	建材生产阶段	建筑施工阶段	总量	公共建筑	城镇居住建筑	农村居住建筑
年份	万tCO2	万tCO2	万tCO2	万tCO2	万tCO2	万tCO2	万tCO2
2010	325043.31	164890.26	7293.16	152859.89	55292.41	65947.7	31619.79
2011	400316.41	226729.61	7869.27	165717.53	63344.7	67106.62	35266.2
2012	486445.64	300888.22	8412.92	177144.5	68705.5	70929.59	37509.41
2013	491357.14	296356.9	8904.18	186096.06	71537.43	74635.48	39923.15
2014	481723.22	289568.82	9440.64	182713.76	69987.61	74264.35	38461.8
2015	452446.12	255248.42	9140.89	188056.81	72472.1	76243.14	39341.57
2016	469439.23	263559.52	9366.53	196513.18	75943.57	79005.64	41563.97
2017	482778.31	268778.77	9482.57	204516.97	78625.82	82919.17	42971.98
2018	492633.28	272398.45	9543.6	210691.23	82565.72	85877.89	42247.62
2019	499749	276737.28	10039.65	212972.08	84549.88	87216.75	41205.45

数据库及AI工具网址：https://www.cbeed.cn

Database and AI tool website: https://www.cbeed.cn

- China's building stock estimation and energy intensity analysis. ***J. Clean. Prod.*** 2019.
- China's energy consumption in the building sector: A Statistical Yearbook-Energy Balance Sheet based splitting method. ***J. Clean. Prod.*** 2018.

02 建筑碳排放数据测算

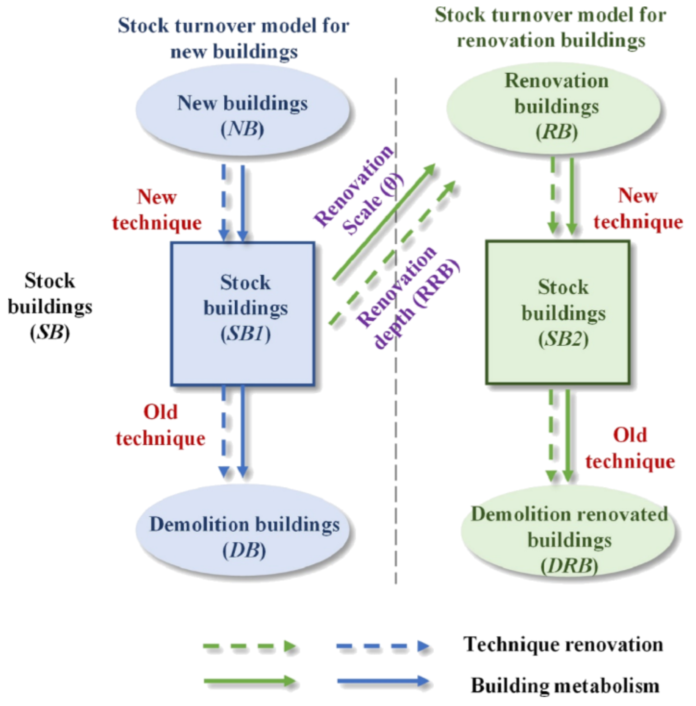
Calculation of building carbon emissions data

“自上而下”的核算方法学体系

“Top-down” methodological systems of accounting

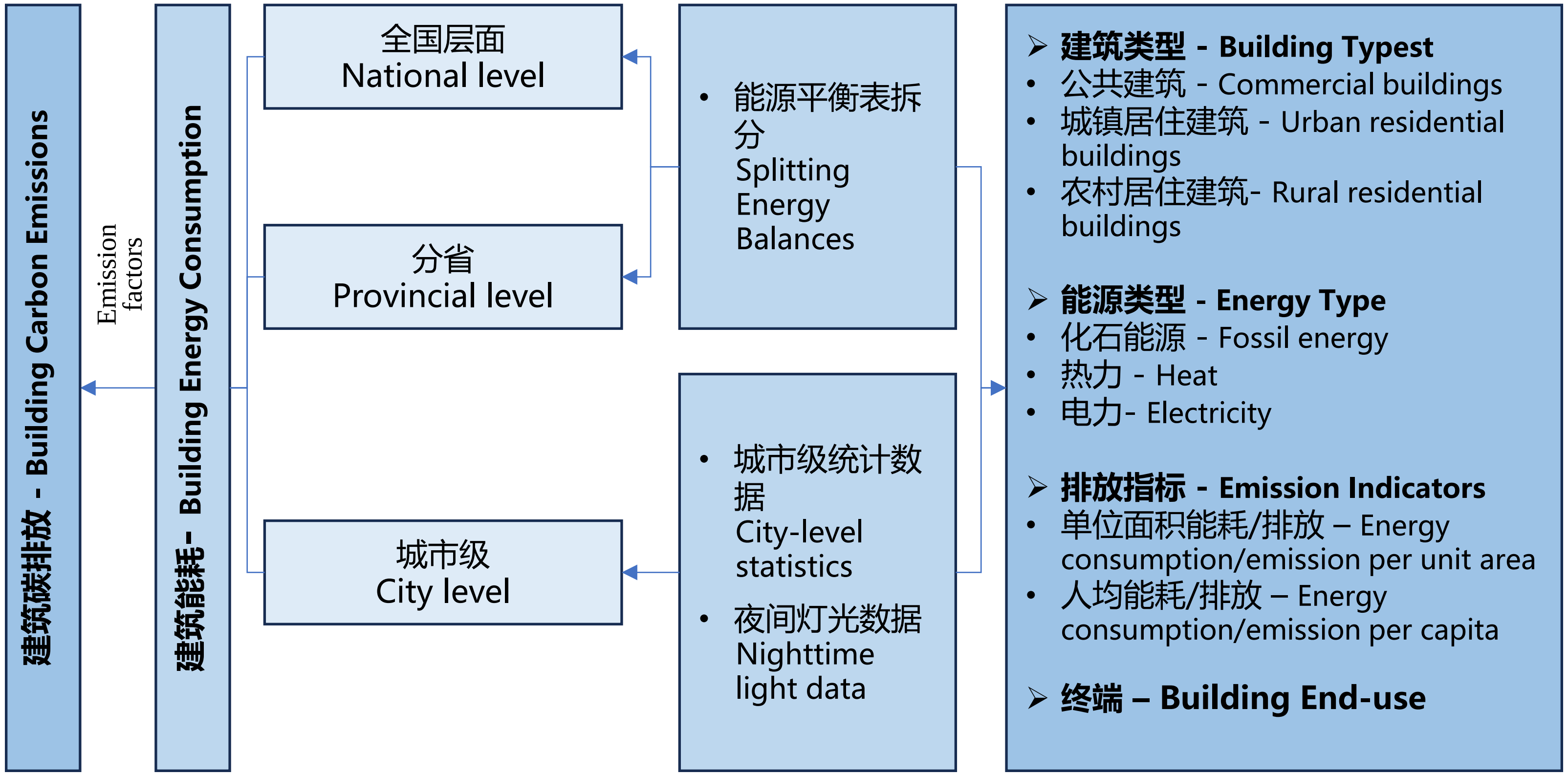
➢ 建筑面积：存量周转模型

Building Floor Area: Stock Turnover Model



➢ 建筑能耗与碳排放核算体系

Building energy consumption and carbon emission accounting system



- China's building stock estimation and energy intensity analysis. ***J. Clean. Prod.*** 2019.
- Estimating urban residential building-related energy consumption and energy intensity in China based on improved building stock turnover model. ***Sci. Total Environ.*** 2019.

02.a 建筑碳排放数据测算

Calculation of building carbon emissions data

建筑面积：存量周转模型

"Building Floor Area: Stock Turnover Model

➢ 物质流思想

Material Flow Analysis

建筑存量
Building stock

=

既有建筑存量
Existing building stock

+

新建建筑面积
Newly built building area

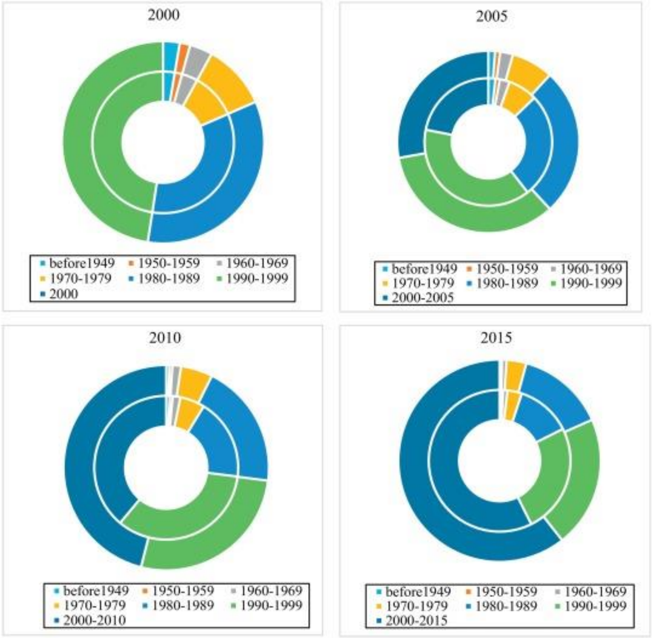
−

拆除建筑面积
Demolished building area

➢ 数据验证

Data Validation

人口普查数据 - Population Census Data



计算结果与中国人口普查数据的比较：各年份建筑存量占比构成

Comparison between the CBFSEM results with data from the ***China Population Census***. Share composition of the building stock in each vintage (Note: The outside circle represents the results of this study and the inside circle denotes the data scale in the ***China Population Census.)***

02.a 建筑碳排放数据测算

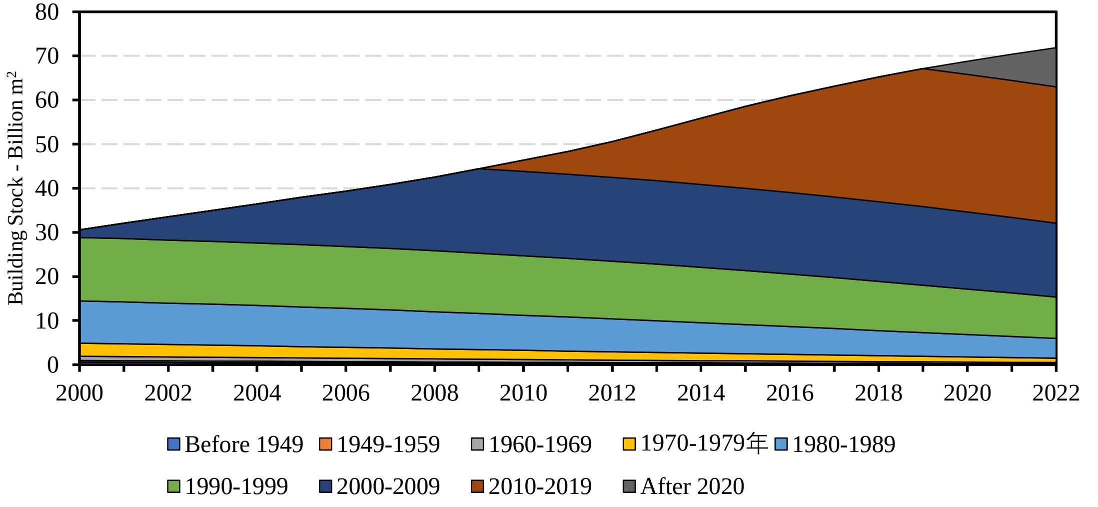
Calculation of building carbon emissions data

建筑面积：存量周转模型

"Building Floor Area: Stock Turnover Model

➢ 建筑年代谱

Building Stock Age Spectrum



中国建筑存量年代谱

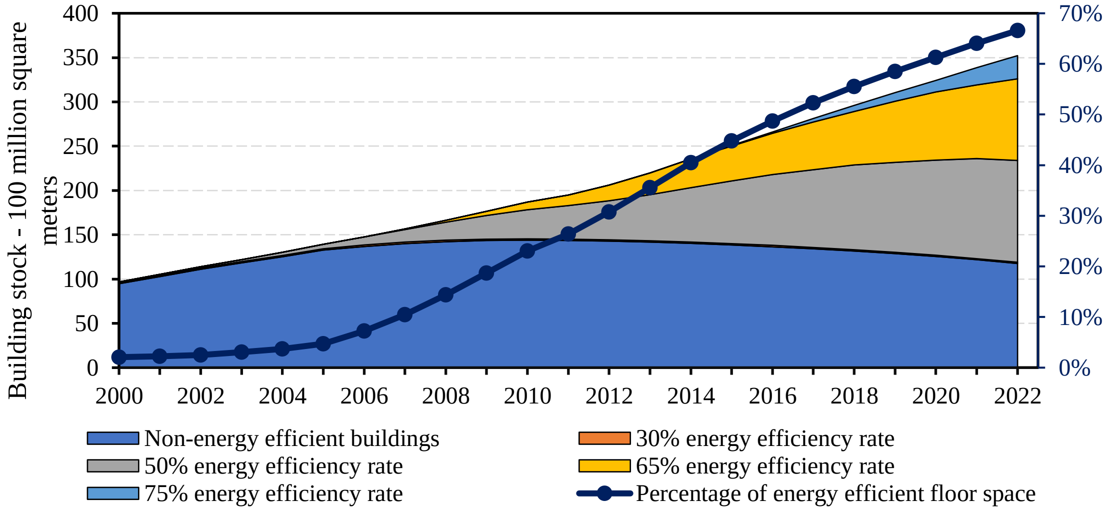
A chronological spectrum of China's building stock

- 2022年底，全国建筑存量达到719亿m_2，其中78.7%为2000年以后建成。

At the end of 2022, the nation's building stock reached 71.9 billion m2, of which 78.7% was built after 2000.

➢ 建筑能效谱

Building Stock Energy Efficiency Spectrum



中国城镇居住建筑能效谱

Energy Efficiency Spectrum of Urban Residential Buildings in China

- 2022年底，城镇住宅节能建筑总量已达235亿m_2，占全国城镇住宅总量的67%。

In the provinces of Beijing and Yunnan, carbon emissions from building operations declined significantly five years after peaking, by 10% and 22%, respectively.

02.b 建筑碳排放数据测算

Calculation of building carbon emissions data

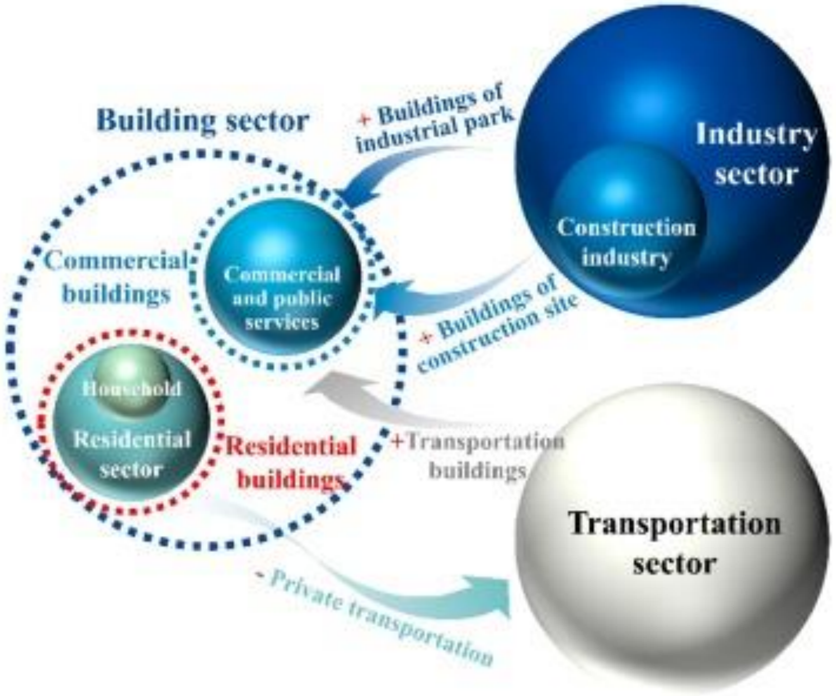
- China's energy consumption in the building sector: A Statistical Yearbook-Energy Balance Sheet based splitting method. ***J. Clean. Prod.*** 2018.

宏观总量数据：国家、省份

Aggregate data at the macro level for countries and provinces

➢ 能耗测算方法：“自上而下”- 能源平衡表拆分

Energy Consumption Measurement Methodology: “top-down” - splitting energy balances



能源平衡表拆分 - Splitting Energy Balances

Carbon-dioxide mitigation in the residential building sector: A household scale-based assessment. ***Energy Convers. Manage.*** 2019.

➢ 化石能源碳排放因子

Fossil Energy Carbon Emission Factor

➢ 电力碳排放因子

Electricity Carbon Emission Factor

$$EF_{Ele} = \frac{\text{Carbon emissions from power generation}}{\text{Clean Energy Generation} + \text{Fossil Energy Generation}}$$

➢ 集中采暖碳排放因子

Centralized Heating Carbon Emission Factor

$$EF_{heating} = \frac{\sum \text{Boiler Energy Consumption} \times \text{Energy Carbon Emission Factor}}{\text{Quantity of Heat Supplied}}$$

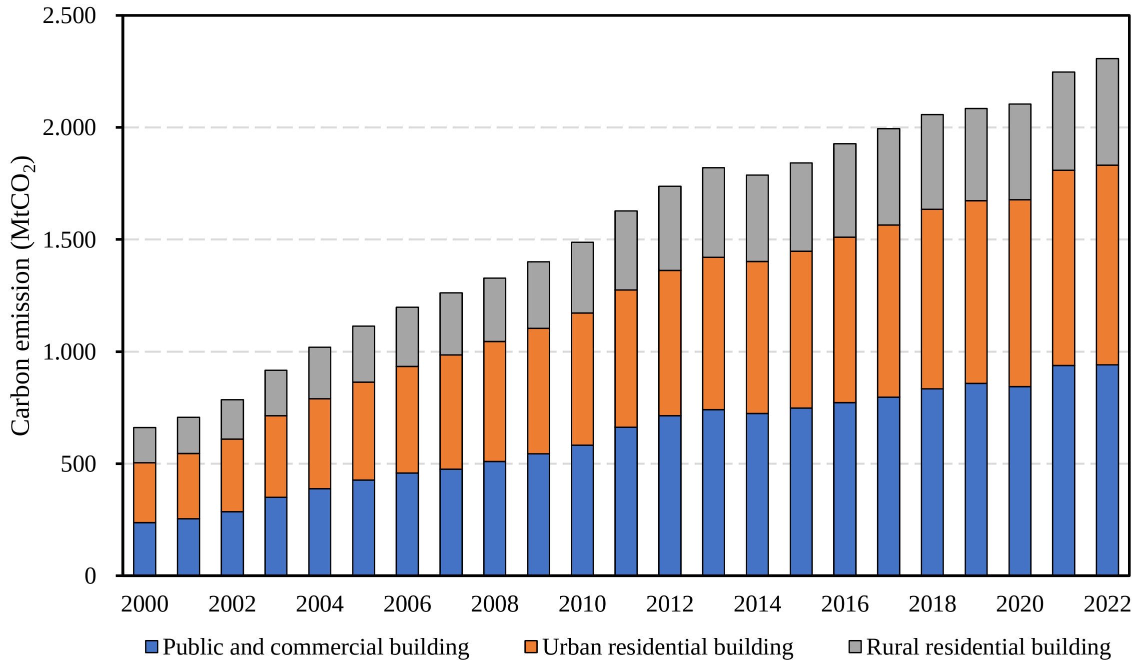
- 燃煤锅炉 - Coal-fired boilers
- 燃气锅炉 - Gas-fired boilers
- 热电联产 - Cogeneration, combined heat and power

宏观总量数据：国家、省份

Aggregate data at the macro level for countries and provinces

测算结果 - Calculation Results

➢ 全国建筑碳排放数据
National building carbon emissions data



中国建筑运行碳排放 - CO2 emissions of the Chinese building sector

- 2022年，全国建筑运行能耗为11.9亿tce，同比增长5.29%；碳排放23.1亿tCO_2，同比增长2.66%，其增长幅度小于能耗增幅；

  In 2022, the national energy consumption of building operation was 1.19 billion tce, a year-on-year increase of 5.29%; carbon emissions were 2.31 billion tCO_2, a year-on-year increase of 2.66%, and its growth was smaller than the increase in energy consumption;

- 2000 - 2022年间，全国建筑运行碳排放总量增长了16.5亿tCO_2，其中公共建筑碳排放增长7.0 亿tCO_2，城镇居住建筑增长6.3 亿tCO_2，农村居住建筑增长了3.2 亿tCO_2；

  Between 2000 and 2022, total carbon emissions from building operations increased by 1.65 billion tCO_2, of which public buildings increased by 700 million tCO_2, urban residential buildings by 630 million tCO_2, and rural residential buildings by 320 million tCO_2.;

- 不同类型的建筑的碳排放总量的增速不尽相同，但其占比情况相对固定。总的来看，公共建筑、城镇居住建筑和农村居住建筑的碳排放比重为“4 : 4 : 2”；

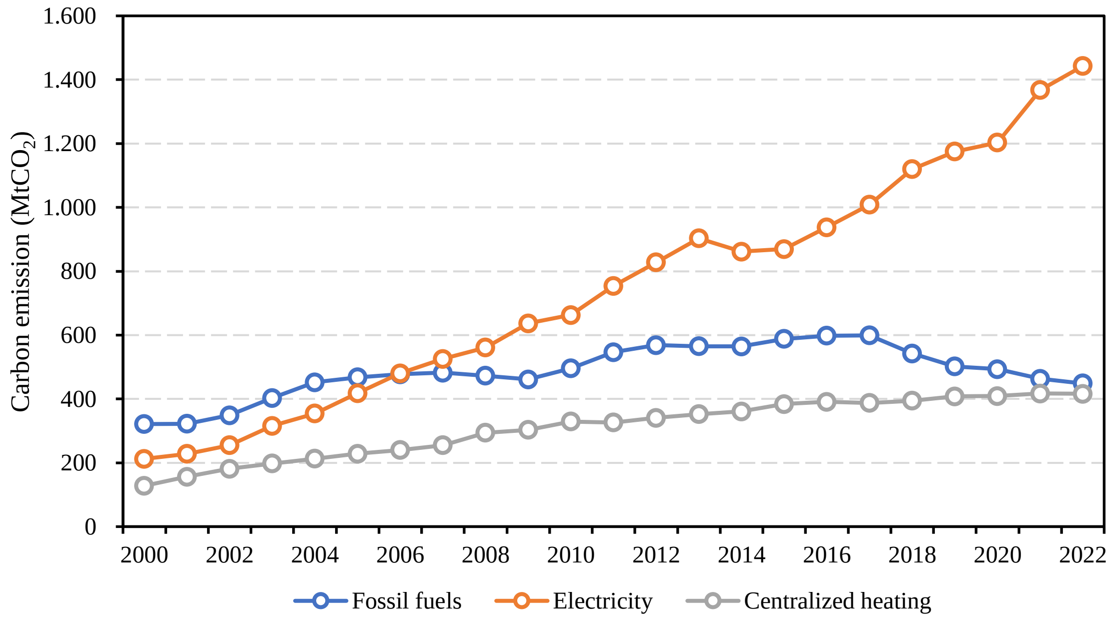
  The growth rate of total carbon emissions varies among different types of buildings, but their share is relatively constant. In general, the proportion of carbon emissions from public buildings, urban residential buildings and rural residential buildings is “4 : 4 : 2”;

宏观总量数据：国家、省份

Aggregate data at the macro level for countries and provinces

测算结果 - Calculation Results

- 全国建筑碳排放数据
  National building carbon emissions data



中国建筑运行碳排放 - CO2 emissions of the Chinese building sector

- 建筑能源结构持续优化，电力碳排放占比则从2000年的31%上升至2022年的63%；

  The building energy mix continues to be optimized, while the share of carbon emissions from electricity rises from 31% in 2000 to 63% in 2022;

- 热力碳排放比例近年来保持在20%的水平；

  The share of carbon emissions from heat has remained at 20% in recent years;

- 建筑直接碳排放占比在2016年前高于30%，之后持续下降，到2022年降至19%。

  The share of direct carbon emissions from fossil energy in buildings is above 30% until 2016, and then continues to decline, falling to 19% by 2022.

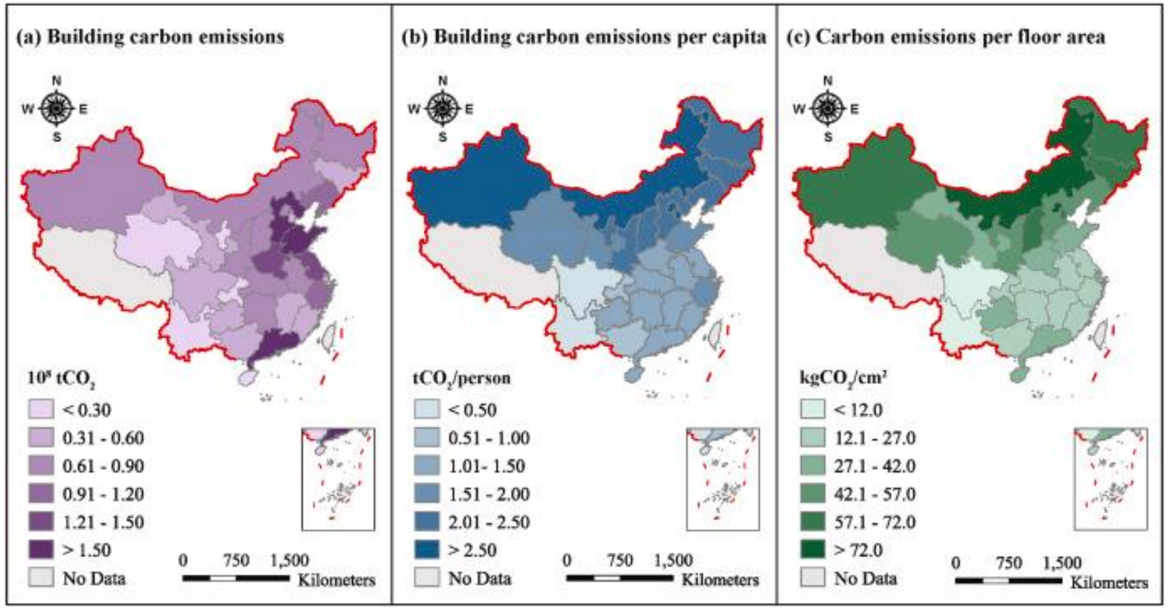
Interprovincial differences in the historical peak situation of building carbon emissions in China: Causes and enlightenments. ***J. Environ. Manage.*** (2023)

宏观总量数据：国家、省份、城市

Aggregate data at the macro level for countries, provinces, and cities

◘ 测算结果 - Calculation Results

➢ 省级建筑碳排放数据
Provincial building carbon emissions data



2020 年中国各省的建筑运行碳排放及强度
Carbon Emissions and Intensity of Building Operations by Province in China in 2020

- 7个省份的建筑运行碳排放超过1 亿tCO_2，其排放总量占全国建筑运行碳排放总量的44%；3个省份的排放总量低于2000 万tCO_2；
  Seven provinces emit more than 100 million tCO2 from building operations, accounting for 44% of the national total carbon emissions from building operations; three provinces emit less than 20 million tCO2 ;
- 一般来看，人口数量越多、地区生产总值越高、清洁发电占比越低的地区，其建筑碳排放总量就越高；受冬季采暖的影响，相同人口规模或相同建筑体量下，北方省份因冬季采暖需求较大，其建筑运行碳排放更高；
  Generally speaking, the larger the population, the higher the GDP, and the lower the proportion of clean power generation, the higher the total carbon emissions from buildings; due to the influence of winter heating, with the same population size or the same building volume, the northern provinces have higher carbon emissions from building operation due to the higher demand for winter heating;
- 内蒙古、东北等集中采暖地区的单位面积碳排放和人均碳排放显著高于其他省份。
  Carbon emissions per unit area and per capita in centralized heating areas such as Inner Mongolia and Northeast China are significantly higher than in other provinces.

Interprovincial differences in the historical peak situation of building carbon emissions in China: Causes and enlightenments. ***J. Environ. Manage.*** (2023)

02.b 建筑碳排放数据测算

Calculation of building carbon emissions data

宏观总量数据：国家、省份、城市

Aggregate data at the macro level for countries, provinces, and cities

◘ 测算结果 - Calculation Results

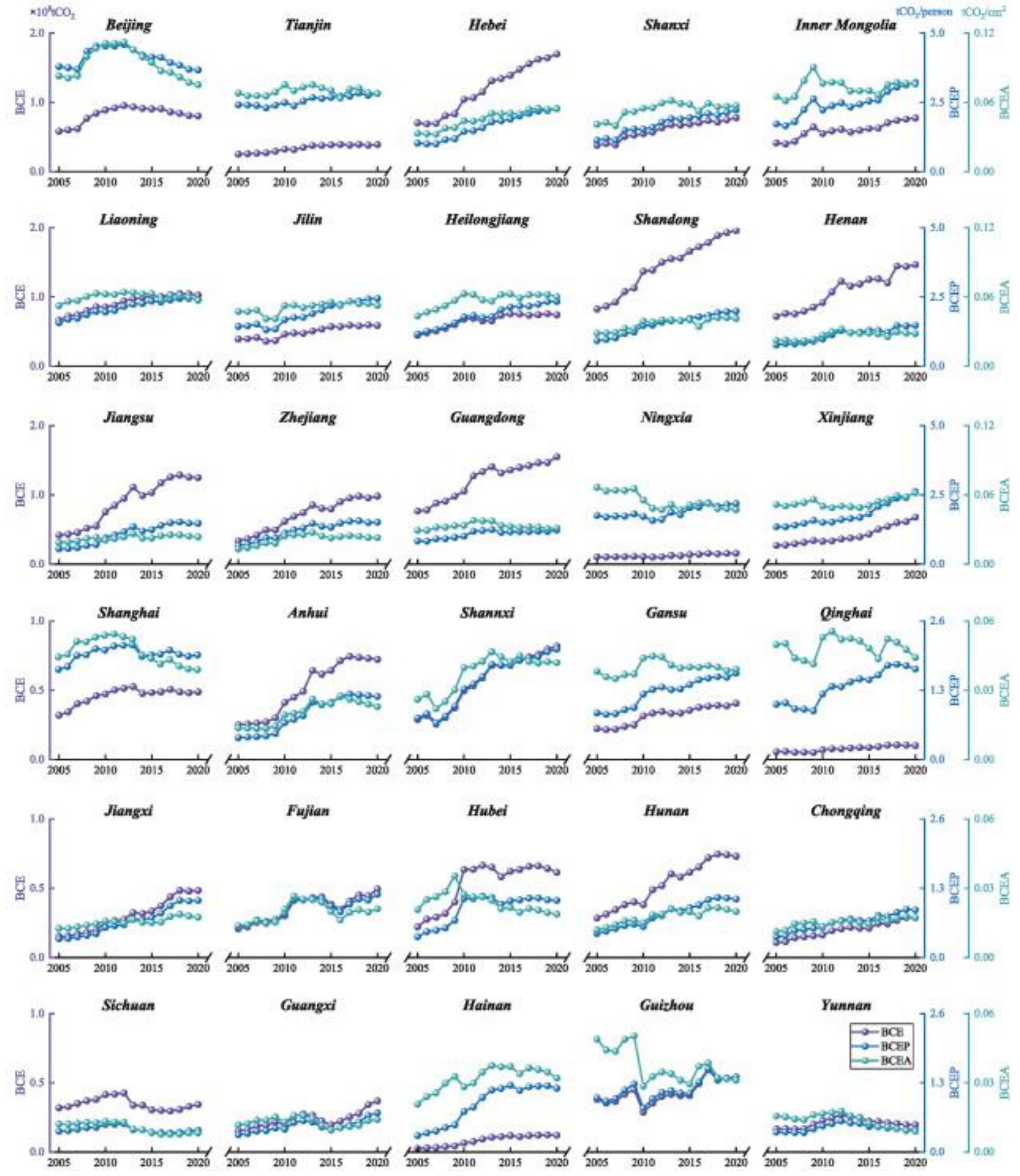
➢ 省级建筑碳排放数据
Provincial building carbon emissions data

- 北京和云南两个省份的 BCE 在达到峰值后的 5 年内出现明显下降，分别下降了 10%和 22%；

  In the provinces of Beijing and Yunnan, carbon emissions from building operations declined significantly five years after peaking, by 10% and 22%, respectively;

- 在人口增长地区，建筑碳排放的达峰顺序遵循顺序：单位面积碳排放先达峰，人均建筑碳排放再达峰，碳排放总量最后达峰。

  In areas of population growth, the order of peak building carbon emissions follows the sequence: carbon emissions per unit area peak first, per capita building carbon emissions peak second, and total carbon emissions peak last.



中国省级建筑运行碳排放变化趋势

Trends in carbon emissions from provincial-level building operations in China

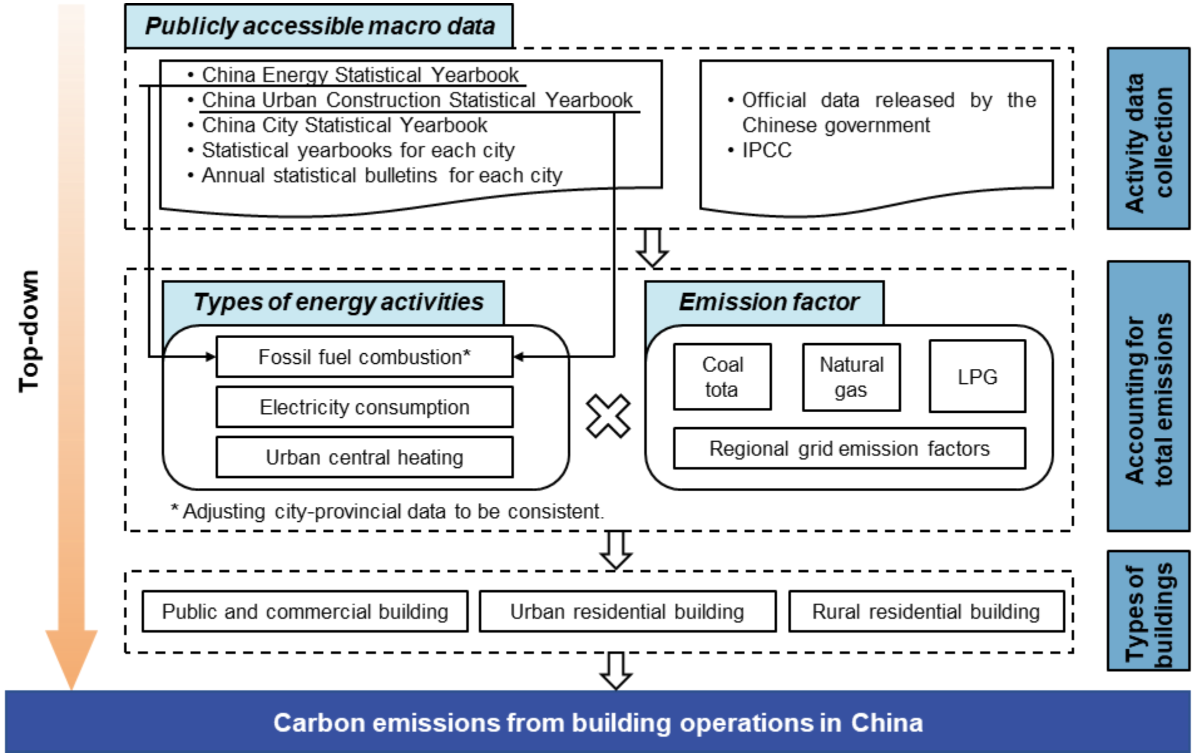
02.c 建筑碳排放数据测算

Calculation of building carbon emissions data

城市碳排放总量与终端拆分

City-level carbon aggregates and end-use unbundling

◻ 测算方法：自上而下降尺度 - Methodology: Top-down downscaling

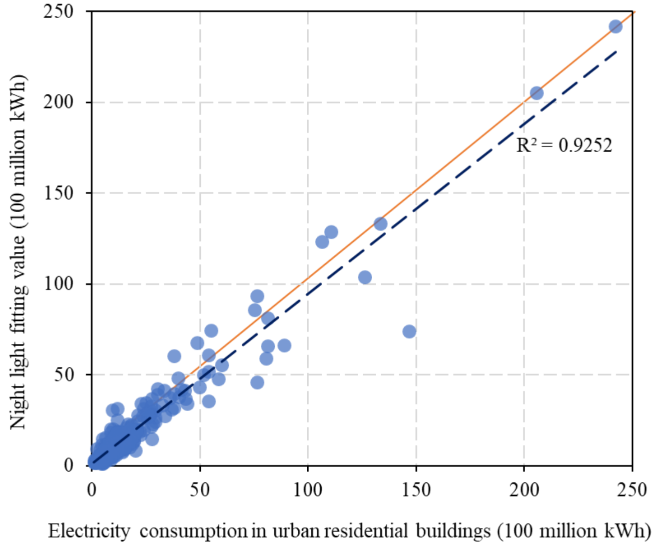


城市级建筑碳排放数据测算流程

City-level building carbon emissions data measurement process

➤ 缺失数据补全 - Completion of missing data

- 化石能源和采暖的基础数据使用《城市建设统计年鉴》，结合省级能源平衡表进行调整；
  The underlying data for fossil energy and centralized heating are taken from the Statistical Yearbook of Urban Construction, adjusted in conjunction with provincial Energy Balance Sheets boilers;
- 建筑用电缺失数据使用夜间灯光数据进行拟合；
  Missing building electricity data were fitted using nighttime lighting data.



夜间灯光拟合城市建筑用电数据与真实用电量对比

Comparison of electricity consumption data of city buildings fitted with nighttime lights with real electricity consumption

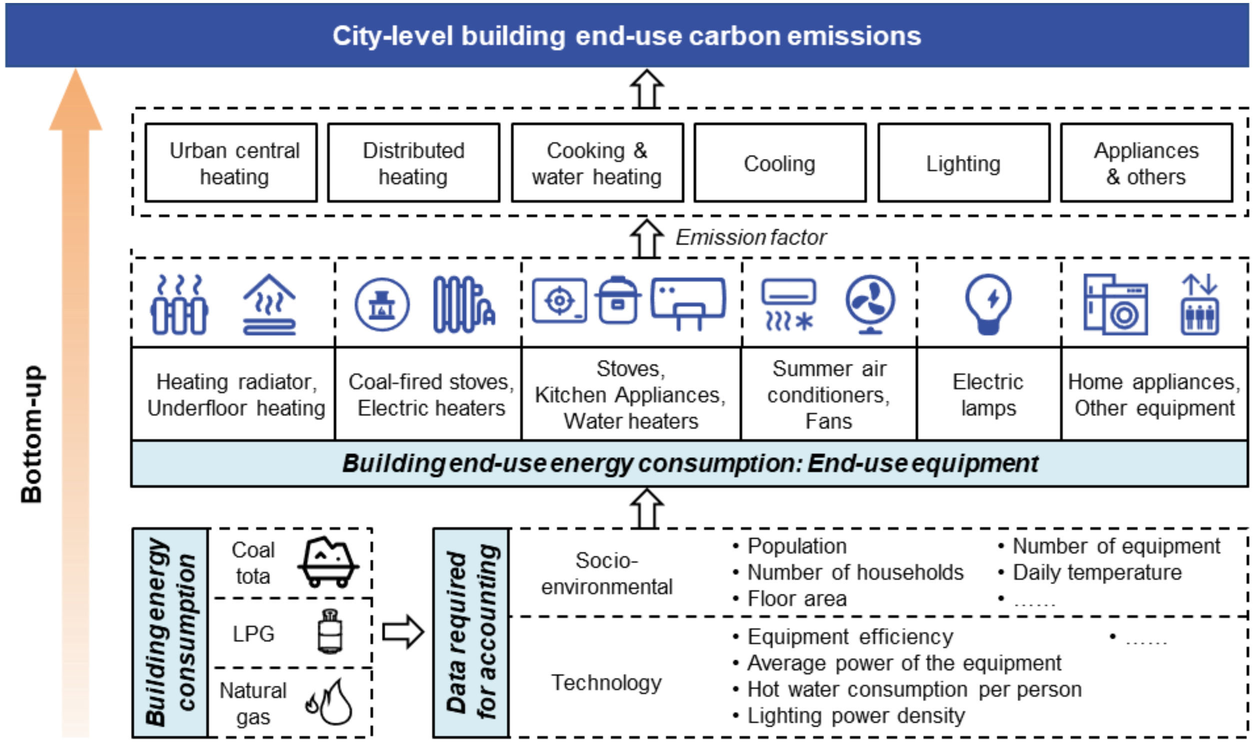
02.c 建筑碳排放数据测算

Calculation of building carbon emissions data

城市碳排放总量与终端拆分

City-level carbon aggregates and end-use unbundling

终端用能拆分 - Building end-use energy splitting

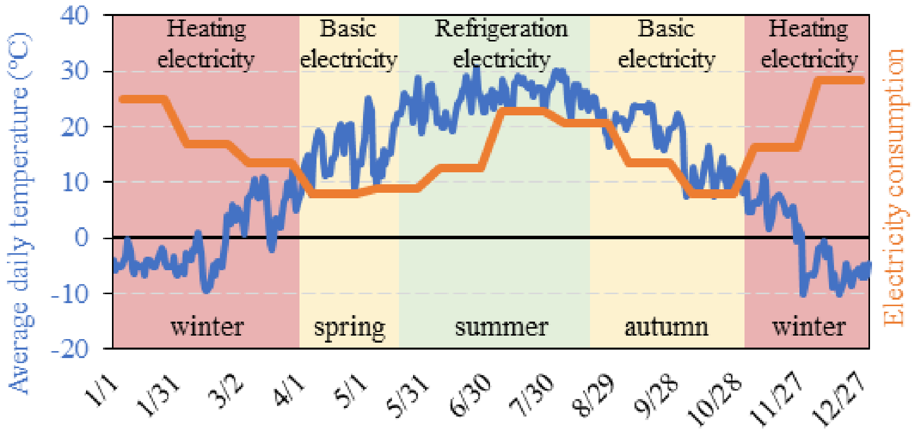


建筑终端用能与碳排放测算流程

Building End-Use Energy and Carbon Emission Measurement Process

➢ 空调采暖、制冷用电

Electricity for air conditioning, heating and cooling



➢ 建筑照明用电

Electricity for air conditioning, heating and cooling

- 照明能耗 = 照明功率密度 * 照明时长 * 照明面积

  Lighting energy consumption = Lighting power density * Lighting hours * Lighting area

➢ 炊事热水

Cooking & Hot Water

➢ 家电和其他设备

Appliances & Others

......

02.c 建筑碳排放数据测算

Calculation of building carbon emissions data

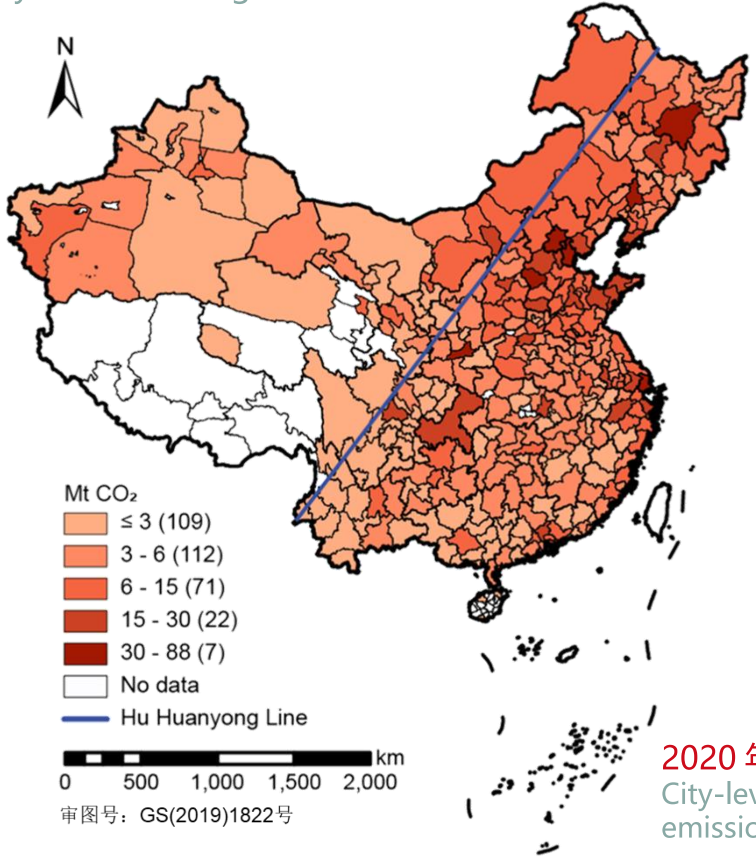
城市碳排放总量与终端拆分

City-level carbon aggregates and end-use unbundling

测算结果 - Calculation Results

➢ 城市级建筑碳排放数据

City-level building carbon emissions data

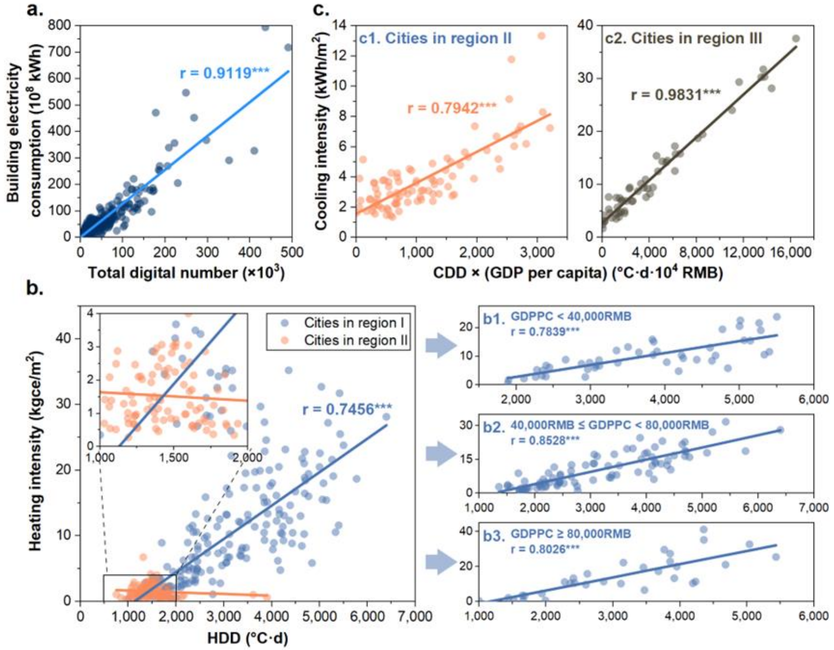


2020 年中国城市级建筑运行碳排放

City-level building operational carbon emissions in China in 2020

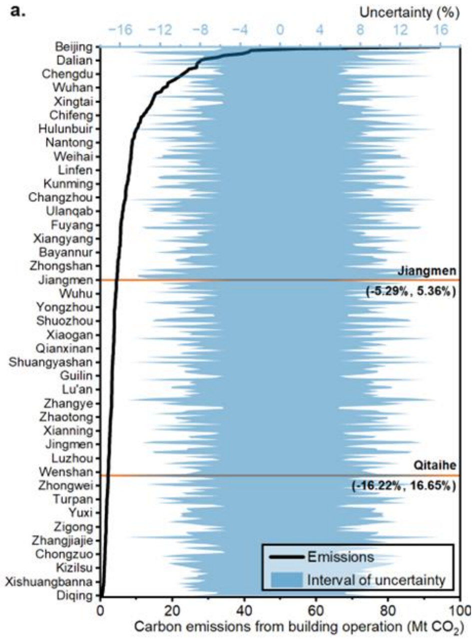
➢ 数据验证

Data Verification



城市级建筑碳排放数据相关性验证

Validation of the relevance of city-level building carbon emissions data



碳排放数据不确定性蒙特卡洛分析

Monte Carlo analysis of carbon emissions data uncertainty

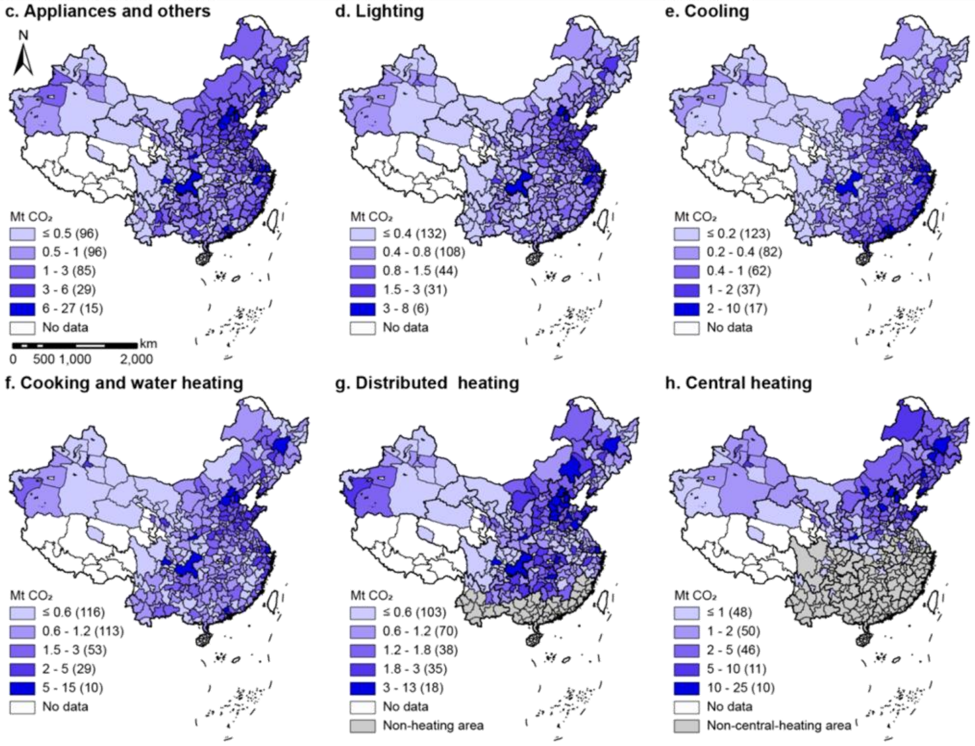
02.c 建筑碳排放数据测算

Calculation of building carbon emissions data

城市碳排放总量与终端拆分

City-level carbon aggregates and end-use unbundling

◘ 测算结果 - Calculation Results



2020年建筑终端碳排放

Building End-Use Energy and Carbon Emission Measurement Process

- 近年来中国建筑终端中的设备及其他的用电量迅速增长，致使其碳排放占比由2015年的18%上升至2020年的24%；

  In recent years, the electricity consumption of equipment and others in China's building terminals has been growing rapidly, resulting in its share of carbon emissions rising from 18% in 2015 to 24% in 2020;

- 制冷碳排放虽然增长量较小但有着较高的增长速率，年均增长率接近9%；

  Refrigeration carbon emissions, although growing in smaller quantities, have a high growth rate, with an average annual growth rate of nearly 9%;

- 得益于北方农村清洁取暖工作的开展，分散取暖碳排放的总量和占比均逐年下降，由2015年的22%降至2020年的15%；

  Benefiting from the cleaner heating efforts in northern rural areas, the total volume and share of carbon emissions from decentralized heating have been declining year by year, from 22 % in 2015 to 15 % in 2020;

- 高排放城市多集中在东部沿海地区，中西部地区中只有重庆、成都等少部分城市的碳排放较高。地处东南沿海地区的城市虽然也消费了较多的电力，但得益于该地区较高的清洁发电比例，其电力排放量并不突出。

  High-emission cities are mostly concentrated in the eastern coastal region, with only a few cities in the central and western regions, such as Chongqing and Chengdu, having higher carbon emissions. Cities located in the southeastern coastal region also consume more electricity, but thanks to the region's higher proportion of cleaner power generation, their electricity emissions do not stand out.

未来情景分析方法学体系

Methodological system for future scenario analysis

研究尺度 Research Scale

- 全国预测 National Forecast
- 分省预测 Provincial Forecast
- 城市预测 City Forecast

研究方法 Research Method

静态预测 Static Forecast

- Kaya identity
- System dynamics

动态预测 Dynamic Forecast

- Monte Carlo simulation

研究对象 Research Object

排放总量 Total Emissions

- Kaya identity
- System dynamics

分终端预测 Forecast by Terminal

- Monte Carlo simulation

Dynamic scenario simulations of carbon emission peak in China's city-scale urban residential building sector through 2050. ***Energy Policy*** (2021)

Modeling carbon emission trend in China's building sector to year 2060. *Resour. Conserv. Recycl.* (2023)

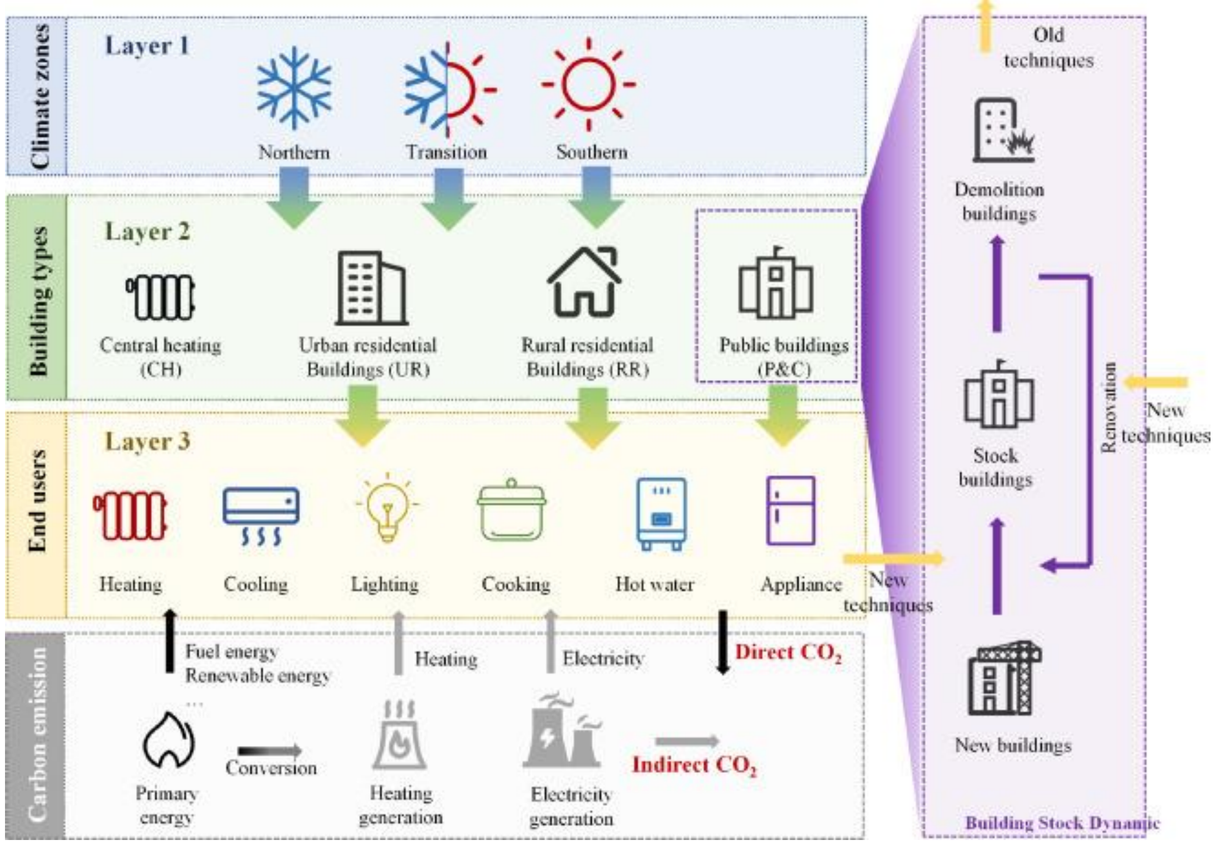
03 建筑碳排放未来预测

Future prediction of building carbon emissions

国家级建筑碳排放预测

National Building Carbon Emissions Forecast

- **全国 | 总量 | 静态 - National | Total | Static Forecast**



中国建筑碳排放预测模型的框架

A Framework for Carbon Emission Prediction Modeling of Buildings in China

- **政策视角情景设置**

  Scenario Setting in Policy Perspective

No	Single strategy scenario (Strategy)	Combined scenario Base	CS1	CS2	CS3	Input parameter	Sources
M1	Improving the building efficiency standard of new building		√	√	√	Energy saving-rate of new buildings	(MOHURD, 2021, 2022b)
M2	Building energy renovation on existing buildings		√	√	√	Building energy renovation rate of existing buildings	(GOC, 2021; MOHURD, 2022b)
M3	Improving the energy efficiency of end-use service equipment		√	√	√	Adjustment factor of equipment energy efficiency	(MOHURD, 2020, 2022b)
M4	Direct renewable energy application in building		√	√	√	Renewable energy utilization rate	(MOHURD, 2021, 2022b)
M5	Building electrification		√	√	√	Electricity utilization rate	(GOC, 2021)
M6	Decarbonization of electricity generation			√	√	Percentage of renewable energy in electricity generation	(GOC, 2021; Grid, 2021)
M7	Eliminating the boiler with weak efficiency			√	√	Energy conversion efficiency of heating	(CMEE, 2017; NEA, 2017)
M8	Clean energy application in central heating generation			√	√	Percentage of renewable energy in heating generation	(CMEE, 2017; NEA, 2017)
M9	Building stock regulation				√	Per capita floor area	(GOC, 2021)
M10	Green behaviors guidance				√	Adjustment factor of end-user service demand	(GOC, 2021; MOHURD, 2022b)

Modeling carbon emission trend in China's building sector to year 2060.
Resour. Conserv. Recycl. (2023)

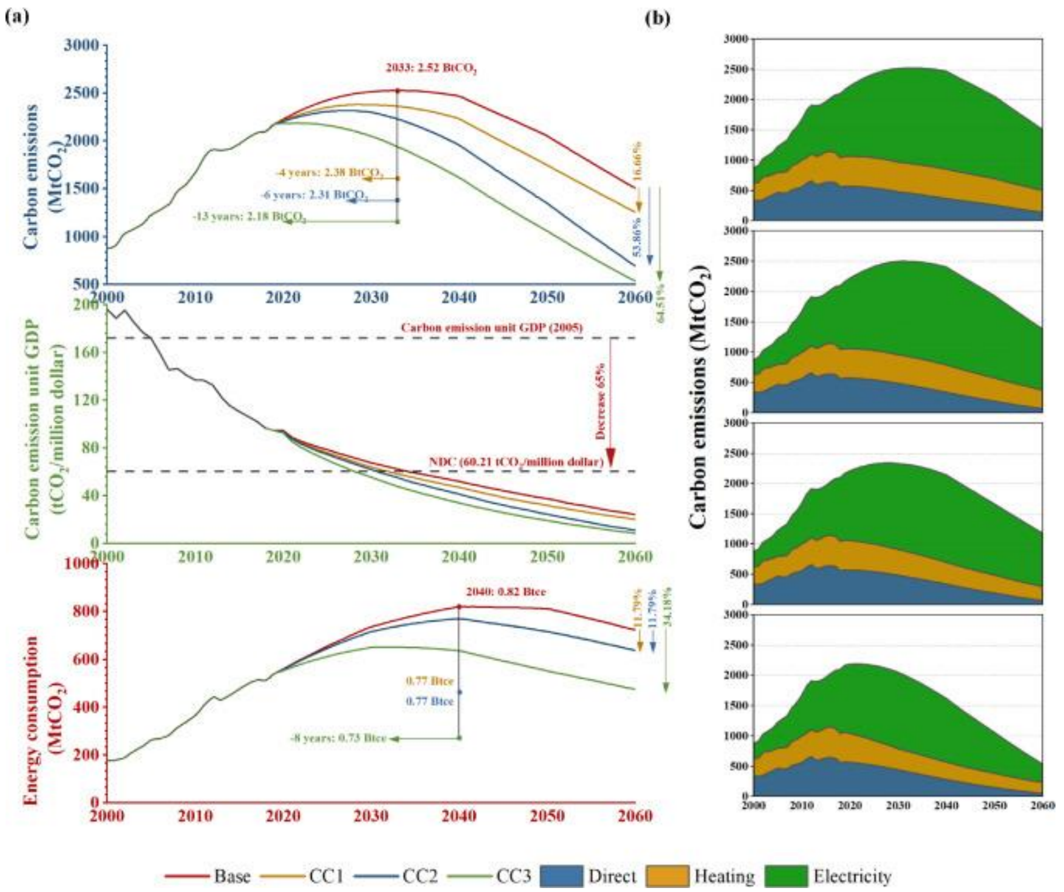
03 建筑碳排放未来预测

Future prediction of building carbon emissions

国家级建筑碳排放预测

National Building Carbon Emissions Forecast

➢ **全国 | 总量 | 静态 - National | Total | Static Forecast**



中国从2000年到2060年的国家级建筑运行碳排放

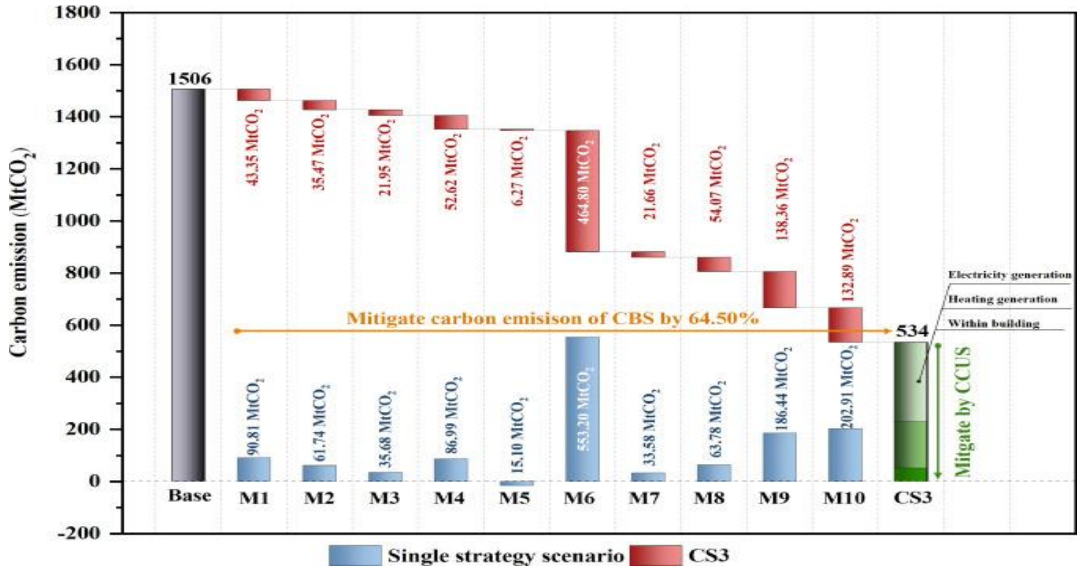
China's national-level carbon emissions from 2000 to 2060

- 基准情景下，中国建筑部门将于 2033 年达到碳排放峰值，峰值年和 2060 年的排放量分别为 2.52 $BtCO_2$ 和 1.51 $BtCO_2$；

  Under base scenario, China's building sector will reach carbon emission peak in 2033, with emissions of 2.52 BtCO2 and 1.51 BtCO2 in the peak year and 2060, respectively;

- 单一建筑部门（CS1）、多部门合作（CS2）和社会（CS3）将分别在 2029 年、2027 年和 2022 年加快碳排放峰值时间，在 2060 年的基础情景下分别大幅减少 16.66%、53.86% 和 64.51%的碳排放量。

  Single building sector (CS1), multi sector cooperation, (CS2), and society (CS3) will accelerate carbon peak time in 2029, 2027, and 2022, respectively, significantly mitigating the carbon emissions of the base scenario in 2060 by 16.66%, 53.86%, and 64.51%, respectively.



2060年基准情景与脱碳情景比较

Comparison of baseline and decarbonization scenarios for 2060

国家级建筑碳排放预测

National Building Carbon Emissions Forecast

➢ **全国 | 总量 | 静态 | 分指标 - National | Total | Static Forecast | Distinguished Indicators**

建筑碳达峰时间表与路线图
Timetable and roadmap for achieving carbon peak of China's building se

- 不同建筑类型，农村居住建筑率先达峰，随后城镇居住建筑达峰，最后商业建筑达峰；

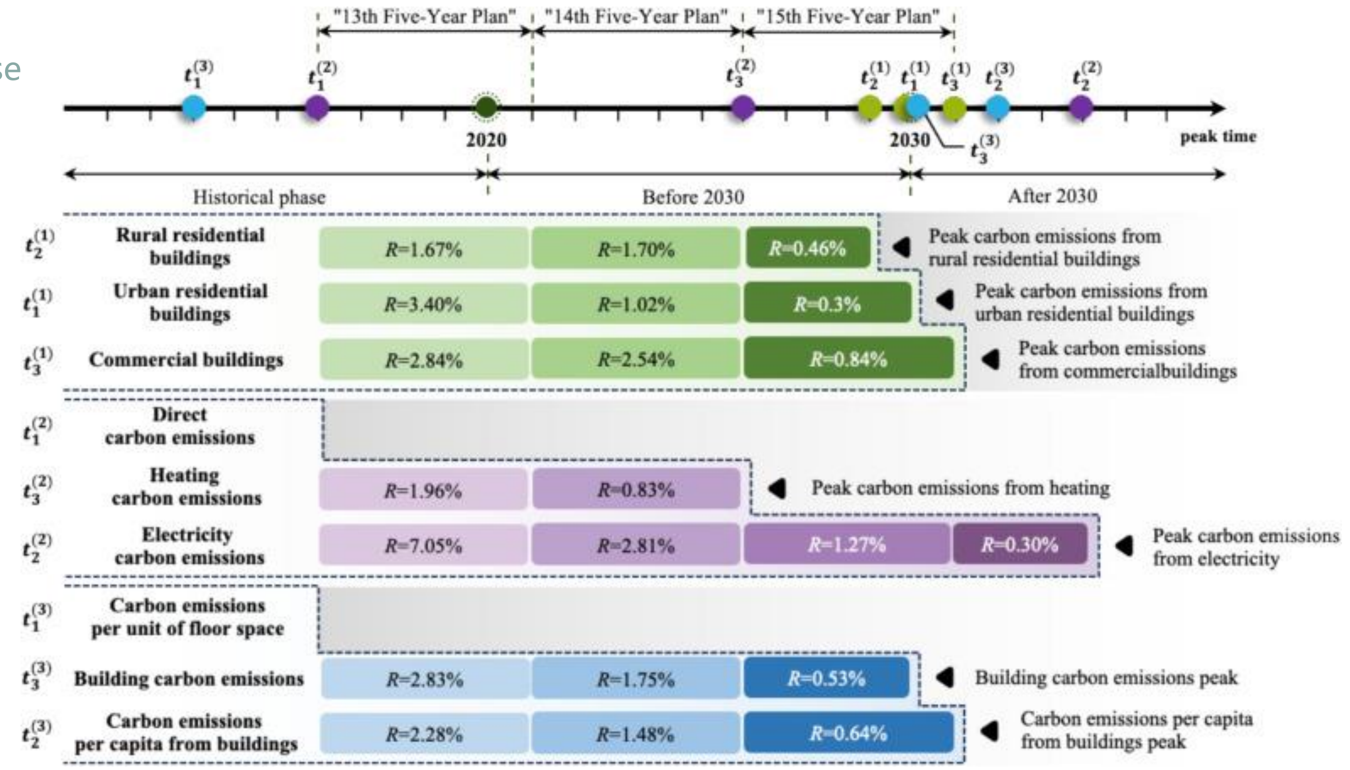
  Different building types, rural residential buildings are the first to peak, followed by urban residential buildings, and finally commercial buildings;

- 不同碳排放源，化石能源直接排放已达到峰值，热力碳排放将比电力碳排放提前达到峰值；

  Different carbon emission sources, direct fossil energy emissions have peaked, and thermal carbon emissions will peak earlier than electricity carbon emissions;

- 不同碳排放指标，单位面积碳排放率先达峰，随后建筑碳排放总量达峰，最后人均建筑碳排放达峰。

  Different carbon emission indicators, carbon emissions per unit area are the first to peak, followed by total building carbon emissions, and finally per capita building carbon emissions.



建筑领域碳排放梯次达峰路线图
The carbon emission echelon peak roadmap for the building sector

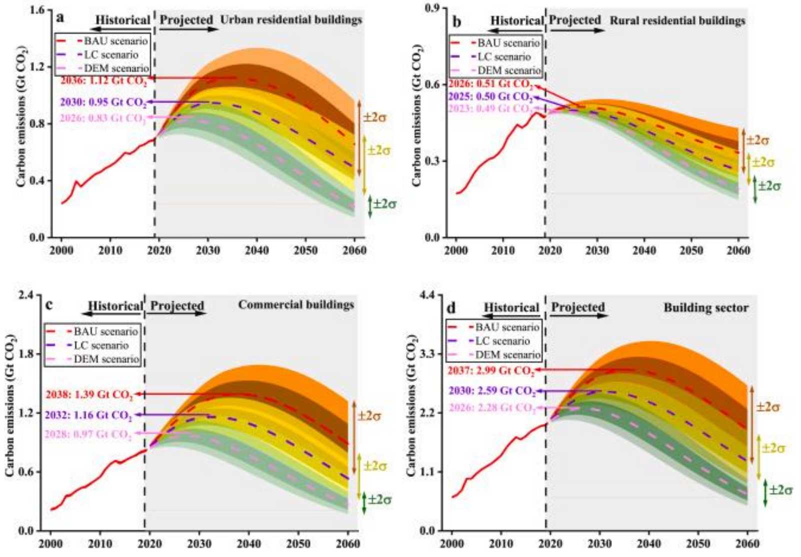
03 建筑碳排放未来预测

Future prediction of building carbon emissions

国家级建筑碳排放预测

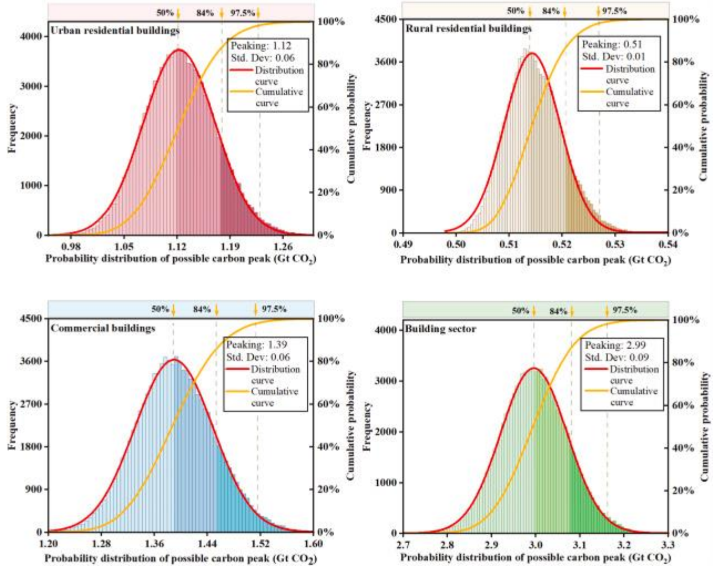
National Building Carbon Emissions Forecast

➢ **全国 | 总量 | 动态 - National | Total | Dynamic Forecast**



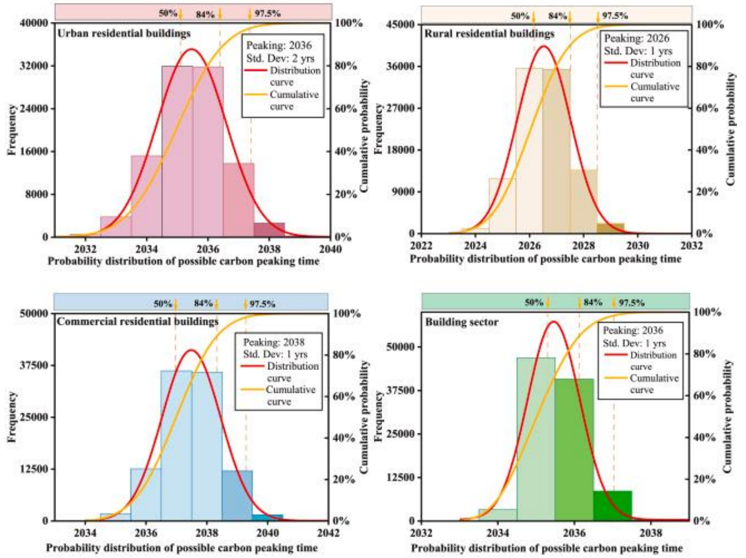
建筑部门碳排放的演变轨迹

Evolutionary trajectories of the carbon emissions across building sectors



建筑部门可能出现的排放峰值的概率分布

Probability distribution of the possible emission peaks across building sectors



建筑部门可能可能达到峰值的时间概率分布

Probability distribution of the possible peaking times across building sub-sectors

- 建筑行业可能在 2036 年达到峰值，为 2.99（±0.09） Gt CO_2（± 1）；

  Building sector will probably peak at 2.99 (±0.09) Gt CO2 in 2036 (±1);

- 要实现碳中和，建筑行业的碳排放量必须在 2026 年达到峰值，即 2.16-2.40 Gt CO_2 。；

  Achieving carbon neutrality requires the building sector to peak its carbon emissions in 2026 with 2.16–2.40 Gt CO_2.

03 建筑碳排放未来预测

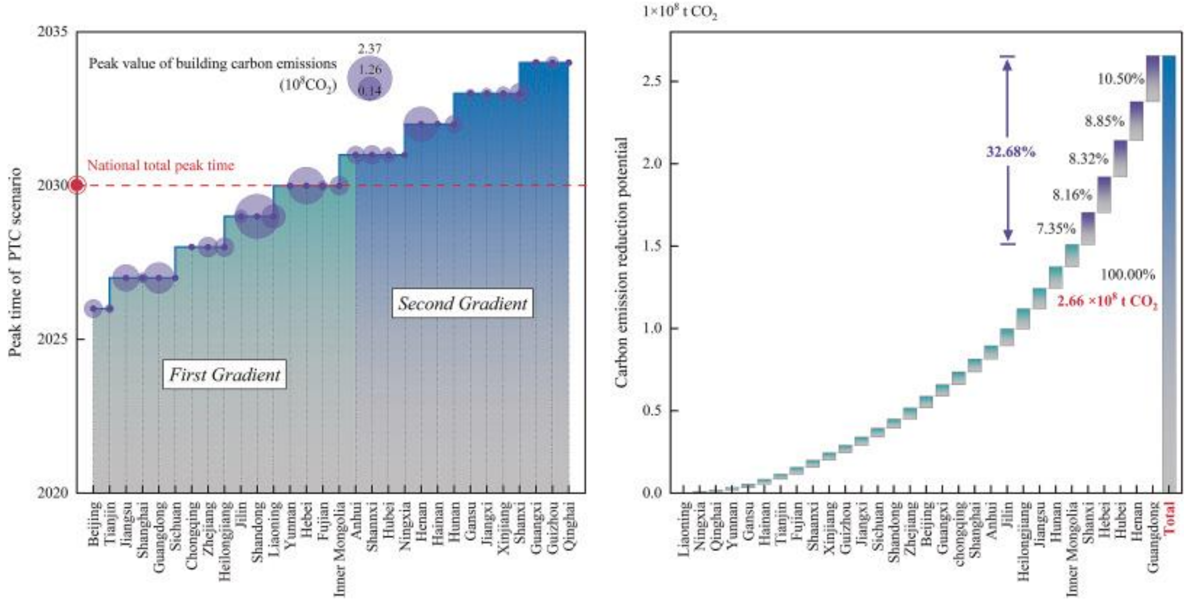
Future prediction of building carbon emissions

省级建筑碳排放预测

Provincial Building Carbon Emissions Forecast

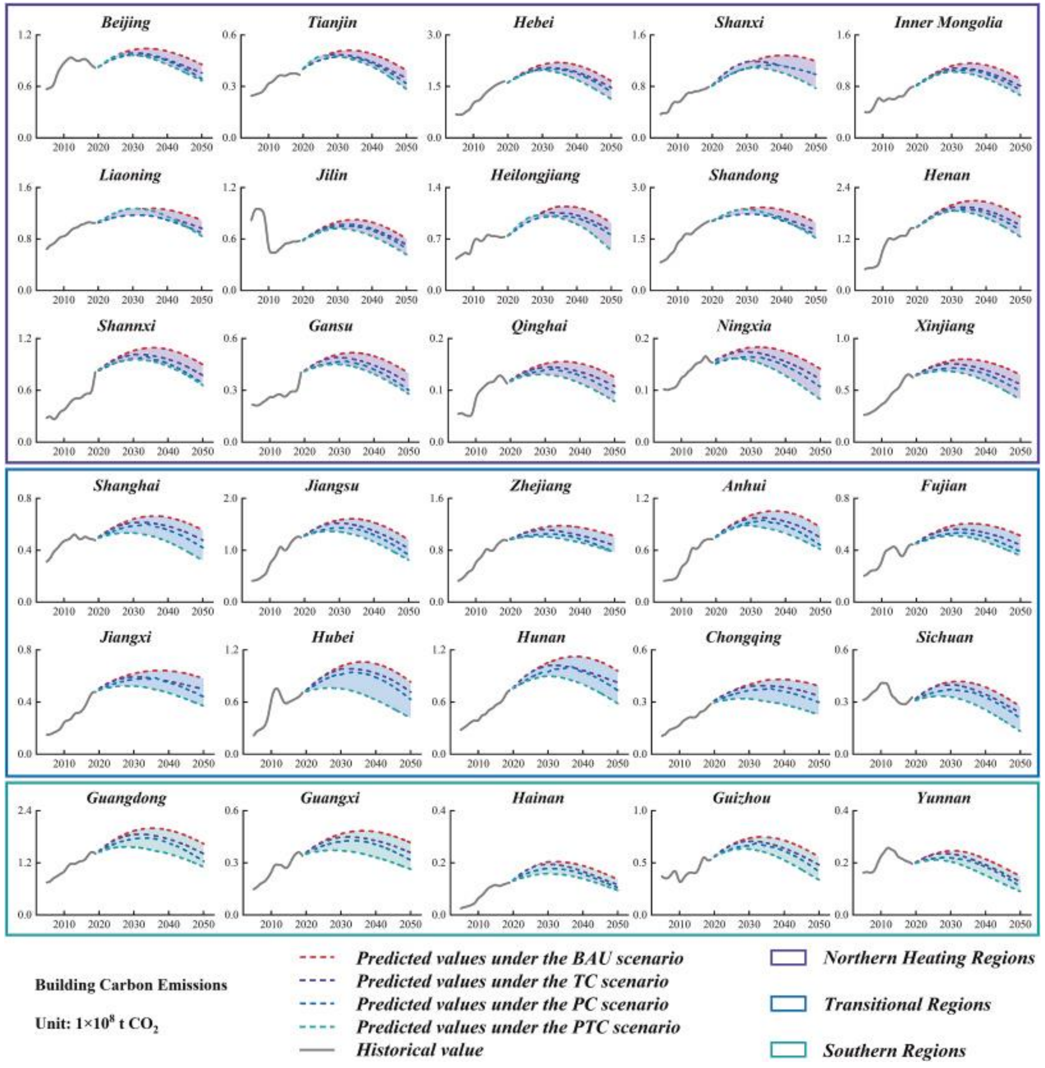
➢ **分省预测 | 总量 | 静态 - Forecast by Province | Total | Static Forecast**

- 各省根据自身条件，分批次实现碳达峰，同时确保全国总量在2030年前实现碳达峰。
- Each province will achieve peak carbon in batches according to its own conditions, while ensuring that the national total achieves peak carbon by 2030.



各省梯次达峰时间、峰值及减排潜力

Echelon peak time, peak value, and emission reduction potential of each province



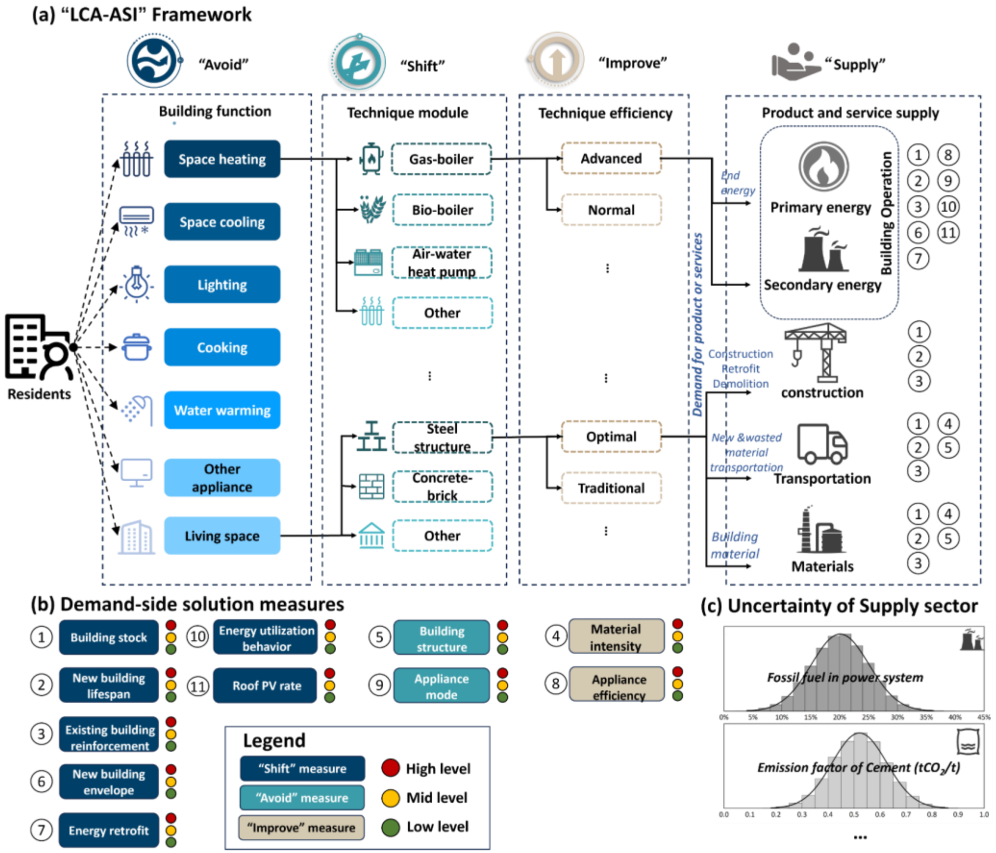
各省建筑碳排放情景模拟结果

Scenario simulation results of provincial building carbon emissions

全产业链建筑碳排放预测

Building Industry Chain Carbon Emission Forecast

➢ 全国 | 总量 | 终端技术
National | Total | Terminal Facilities and Technology Forecast



建筑LCA-ASI分析框架 - LCA-ASI framework of buildings

➢ 中国住宅建筑需求侧碳减排解决方案情景分析
Scenario Analysis of Demand-Side Carbon Reduction Solutions for Residential Buildings in China

需求侧提升措施 - Demand-side enhancement measures

Demand-side solutions	Building Materials Production	Building Construction	Transportation	Building Operation
Optimization of building stock (M1)	A-	A-	A-	A-
Enhancement of new building lifespan (M2)	A-	A-	A-	A+
Extension of existing building lifespan (M3)	A-	A-	A-	A+
Implementation of lightweight building structure (M4)	A-	A-	I-	--
Implementation of steel building (M5)	I-	--	S+	--
Enhancement of energy-saving standards for new buildings (M6)	S+	--	--	A-
Breadth of energy-saving renovation of existing buildings (M7)	--	--	--	A-
Purchase of energy-efficient household equipment (M8)	--	--	--	I-
Purchase of low-carbon equipment (M9)	--	--	--	S-
Cultivation of awareness of green energy use (M10)	--	--	--	A-
Implementing energy management systems (M11)	--	--	--	A-
Implementing metered charging for heating (M12)	--	--	--	A-
Increasing the proportion of photovoltaic in buildings (M13)	--	--	--	A-

Note: A, S and I correspond to avoidance, shifting and upgrading strategies, respectively; -- indicates no impact on carbon emission generation; + indicates an increase in carbon emissions and - indicates a decrease in carbon emissions.

全产业链建筑碳排放预测

Building Industry Chain Carbon Emission Forecast

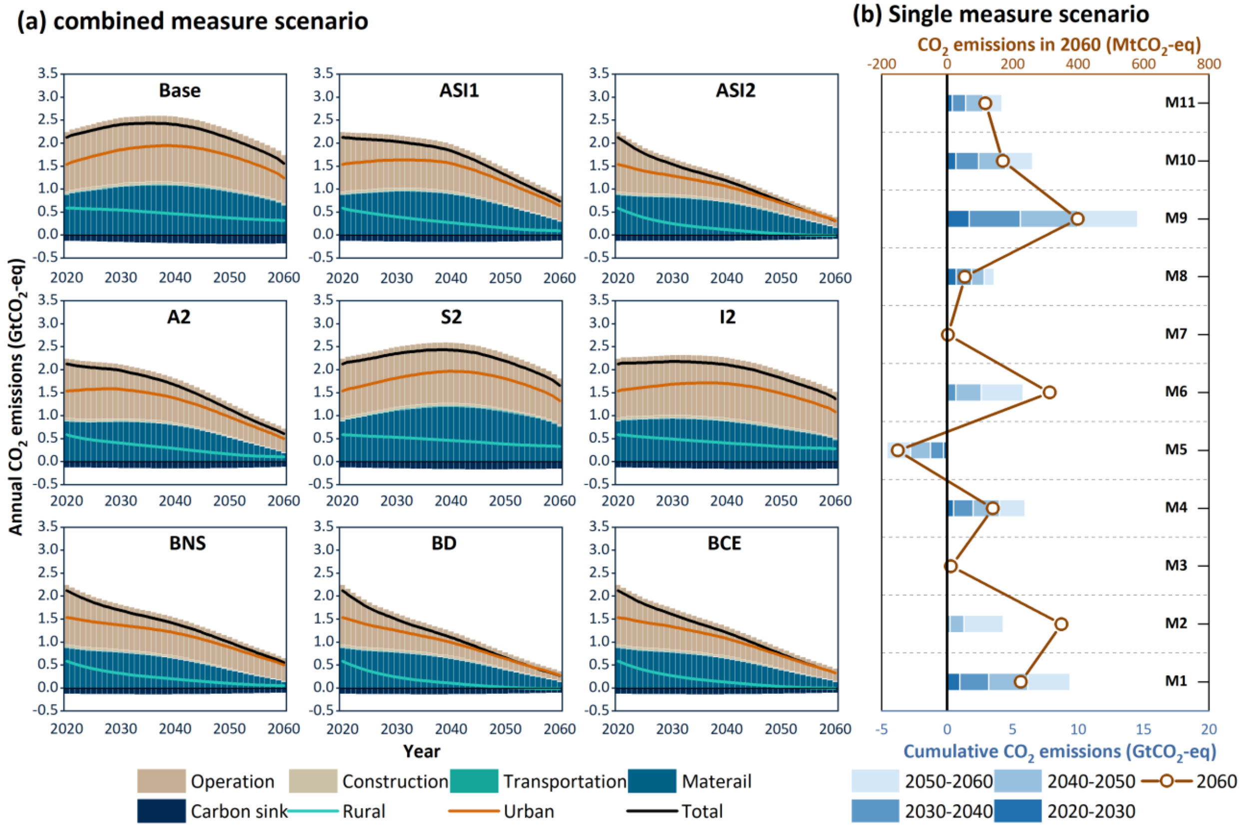
- **全国 | 总量 | 终端技术**
  National | Total | Terminal Facilities and Technology Forecast

- 成本效益最优的需求侧解决方案可在2020-2060年间减少46%的累计二氧化碳排放量（41.62 Gt CO2-eq），同时节省15.19%的成本净现值（17.38万亿元人民币）；

  The demand-side solution with best cost-effectiveness can cut 46% of accumulative CO2 emissions (41.62 Gt CO2 -eq), while saving 15.19% of the net present value of cost (17.38 trillion RMB) during the period of 2020-2060;

- 需求侧解决方案能够在不考虑二氧化碳移除方案的情况下使中国农村居民建筑的二氧化碳排放达到碳中和，同时降低实现碳中和的不确定性。

  Demand-side solution can make the CO2 emissions of Chinese rural residential buildings arrive neutrality without Carbon Dioxide Remove Options, and simultaneously reduce the uncertainty of reaching carbon neutrality.



不同需求侧情景的住宅建筑CO_2排放量

CO_2 emissions of different demand-side scenarios

感谢您的关注！

THANK YOU!

您的问题？

YOUR QUESTIONS?