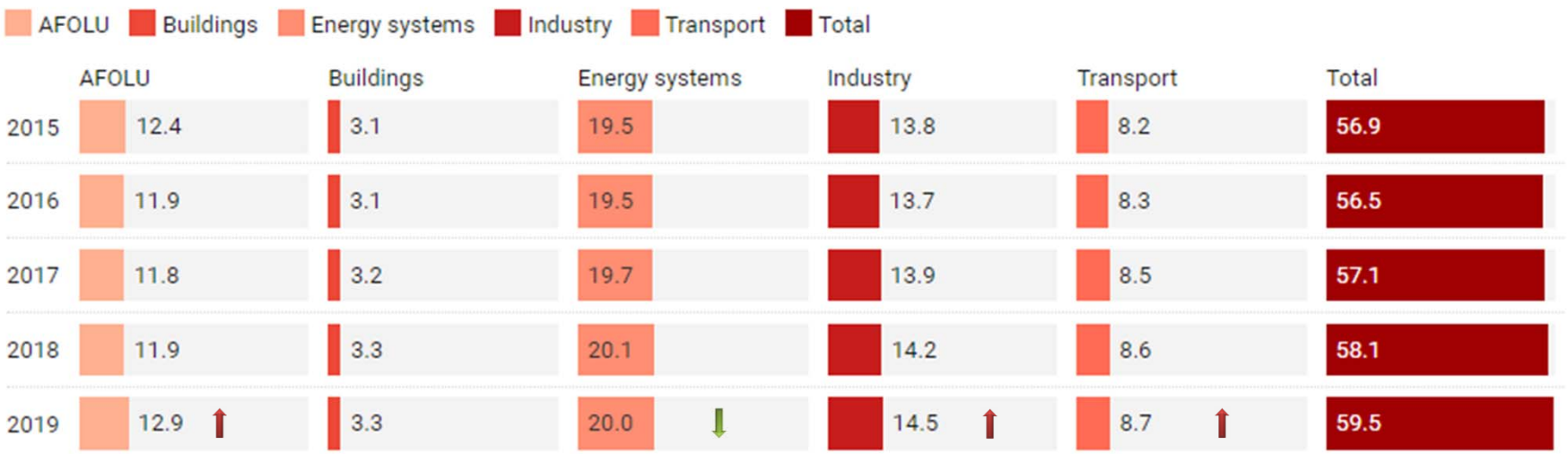
Enabling Pathways towards Sustainable Urban System Scenarios for Effective Climate Mitigation

Şiir KILKIŞ
The Scientific and Technological Research Council of Turkey
IPCC WGIII Lead Author and SDEWES ISC Member

Reducing GHG Emissions Decisively and Quickly

We still need to reverse course in reducing total greenhouse gas (GHG) emissions, and do so decisively and quickly



	AFOLU	Buildings	Energy systems	Industry	Transport	Total
2015	12.4	3.1	19.5	13.8	8.2	56.9
2016	11.9	3.1	19.5	13.7	8.3	56.5
2017	11.8	3.2	19.7	13.9	8.5	57.1
2018	11.9	3.3	20.1	14.2	8.6	58.1
2019	12.9 ↑	3.3	20.0 ↓	14.5 ↑	8.7 ↑	59.5

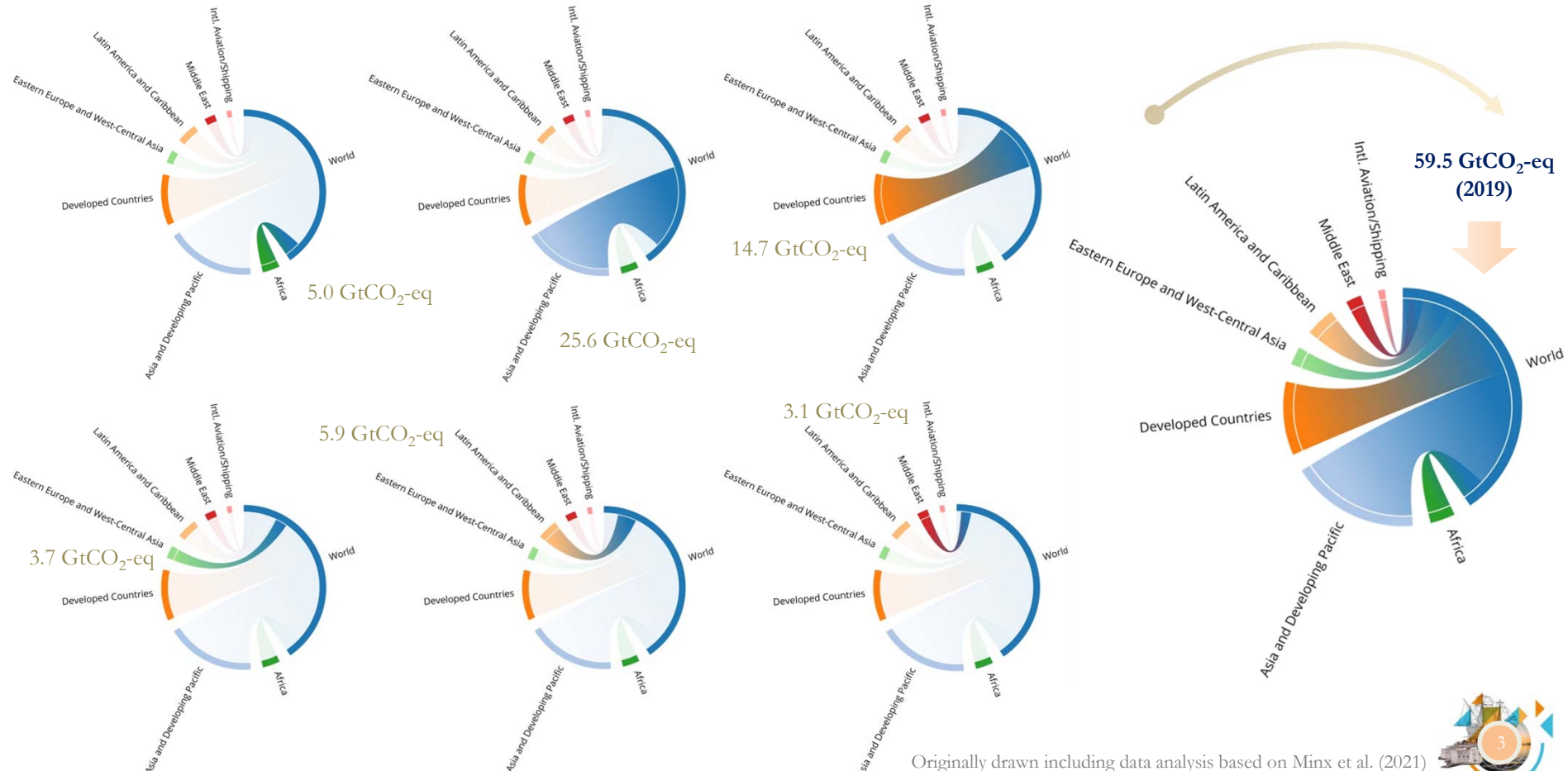
Unit: $GtCO_2eq$

Table originally drawn including data analysis based on Minx et al. (2021), Comprehensive dataset for global, regional and national greenhouse gas emissions by sector 1970-2019, *Earth System Science Data* <https://doi.org/10.5194/essd-2021-228>

Annual GHG emissions reductions need to be about 2.0 $GtCO_2$-eq per year on *average* and sustained across the world to approach net-zero emissions by mid-century

Regional Distribution of Territorial GHG Emissions

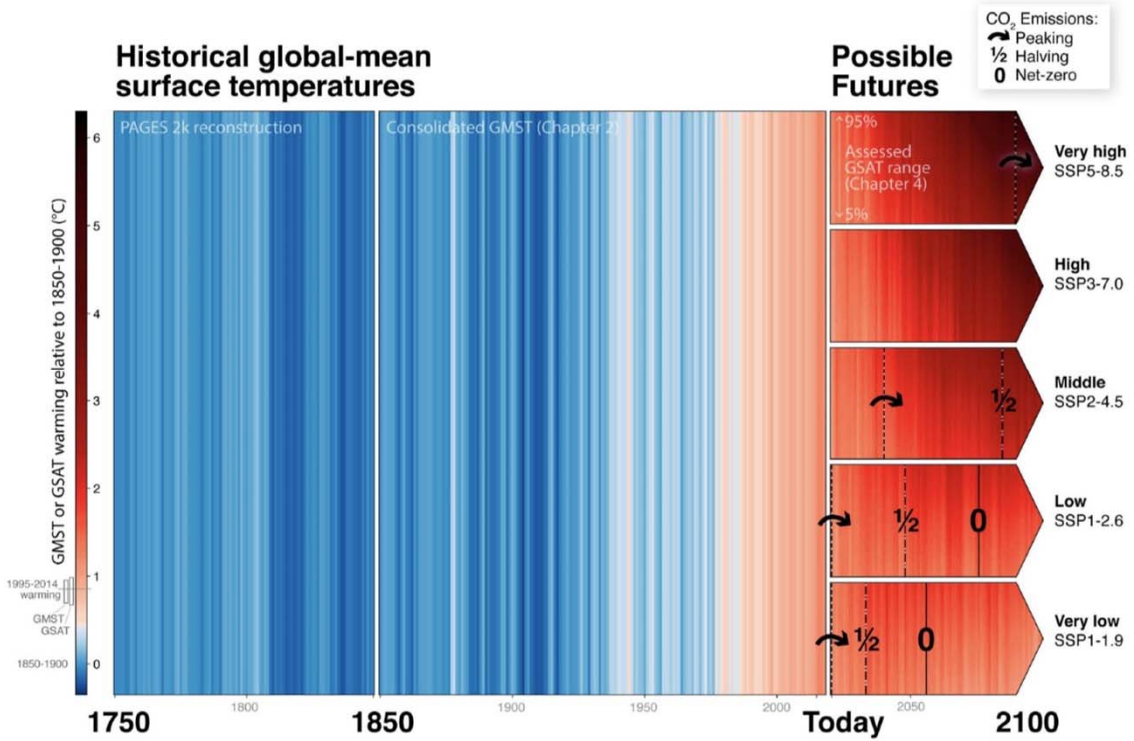
Distributions of territorial GHG emissions differs widely while decoupling opportunities exist for all regions

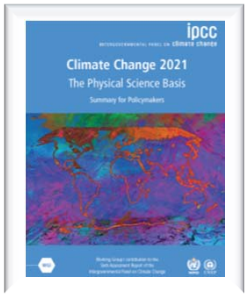


Originally drawn including data analysis based on Minx et al. (2021)

Acting Quickly and More Integratively Is Urgent

CO_2 emissions need to be halved globally from present levels by 2030 for any chance of remaining within 1.5°C





Scenario	Best Estimates	*Very Likely* Range (2021-2100)
SSP1-2.6 (Low)	1.5°C (2021-2040), 1.7°C (2041-2060), 1.8°C (2081-2100)	1.2 °C to 2.4°C
SSP1-1.9 (Very Low)	1.5°C (2021-2040), 1.6°C (2041-2060), 1.4°C (2081-2100)	1.2 °C to 1.8°C

Source: IPCC (2021), Climate Change 2021: The Physical Science Basis <https://www.ipcc.ch/report/ar6/wg1/>

Urban Emissions Scenarios in the SSP-RCP Framework

Beyond static urban footprints, there has been a need for urban emissions scenarios within the SSP-RCP framework

Data inputs – Urban emissions and trends
- Global Gridded Model of Carbon Footprints
- Recent urban emissions trends by region
- Urban share of the total population by SSP

The scenarios are prepared based on carbon footprints of 13,000 urban areas

Source: GGMCF; Moran et al. (2018), Carbon footprints of 13,000 cities, *Environmental Research Letters* 13(6): 064041

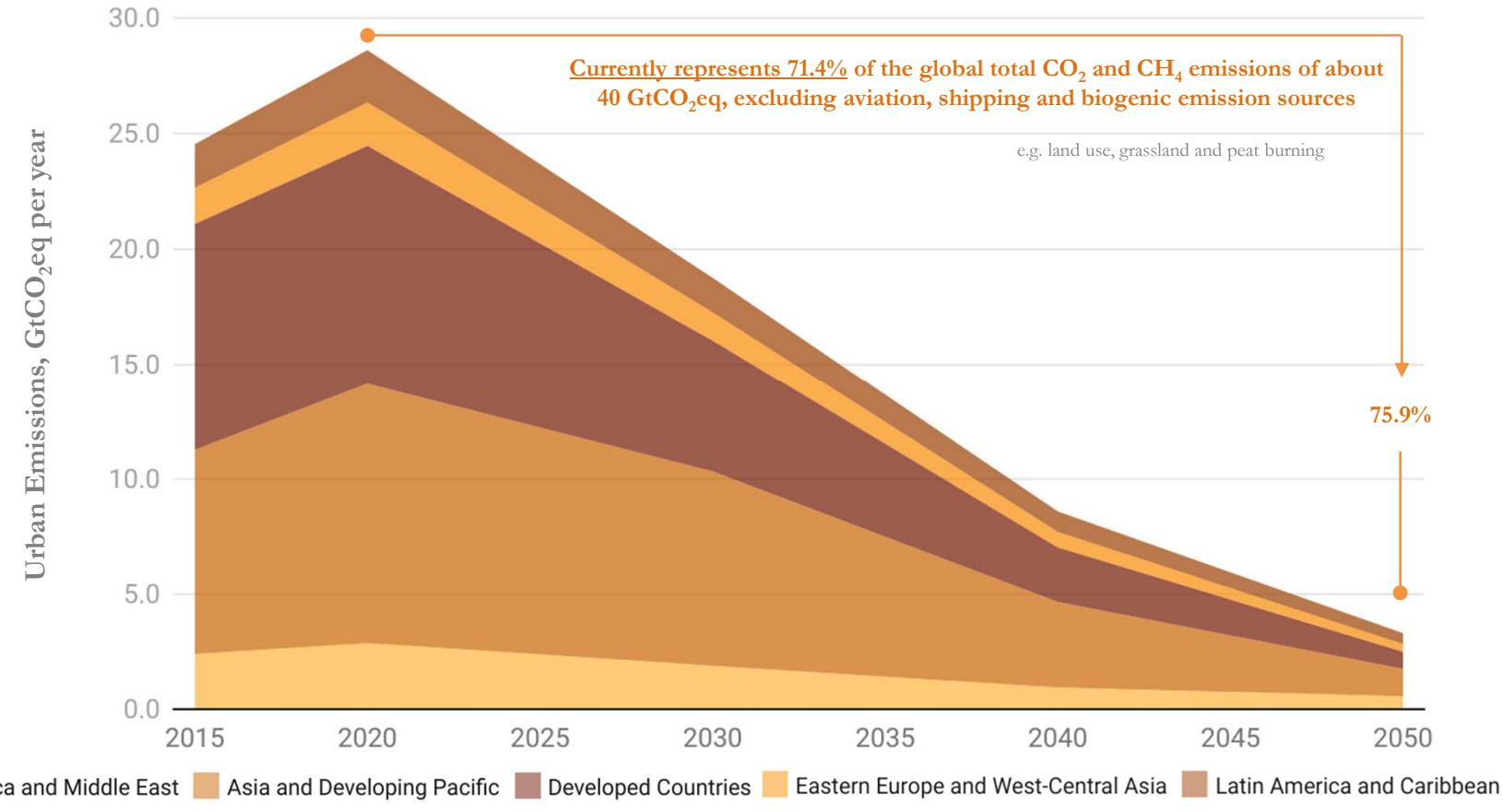
Climate scenario inputs
- Spatially-explicit SSP-RCP projections of the Coupled Model Intercomparison Project Phase 6 (CMIP6)

Scenario	Urbanization Qualities	Electrification	Renewable energy deployment	Energy and material efficiency	Technology development / innovation	Behavioral and lifestyle responses	Afforestation and re-forestation
SSP1-1.9	**Rapid / Compact**	**Higher**	**Higher**	**Higher**	**Higher**	**Higher**	**Higher**
SSP1-2.6	**Rapid / Compact**	**High**	**High**	**High**	**High**	**High**	**High**
SSP2-4.5	Moderate	Medium	Medium	Medium	Medium	Medium	Medium
SSP3-7.0	Slow / Poor Urban Planning	Medium	Low	Low	Medium	Low	Low
SSP4-3.4	Mixed / Inequalities	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
SSP4-6.0	Mixed / Inequalities	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
SSP5-8.5	Rapid	High	Low	High	Low	Low	-

Sources: Based on Jiang and O'Neill (2017); Rogelj et al.(2018); van Vuuren et al. (2017); Calvin et al.(2017); Fricko et al. (2017); Fujimori et al. (2017); Kriegler et al. (2017); Gidden et al. (2019); Feng et al. (2020)

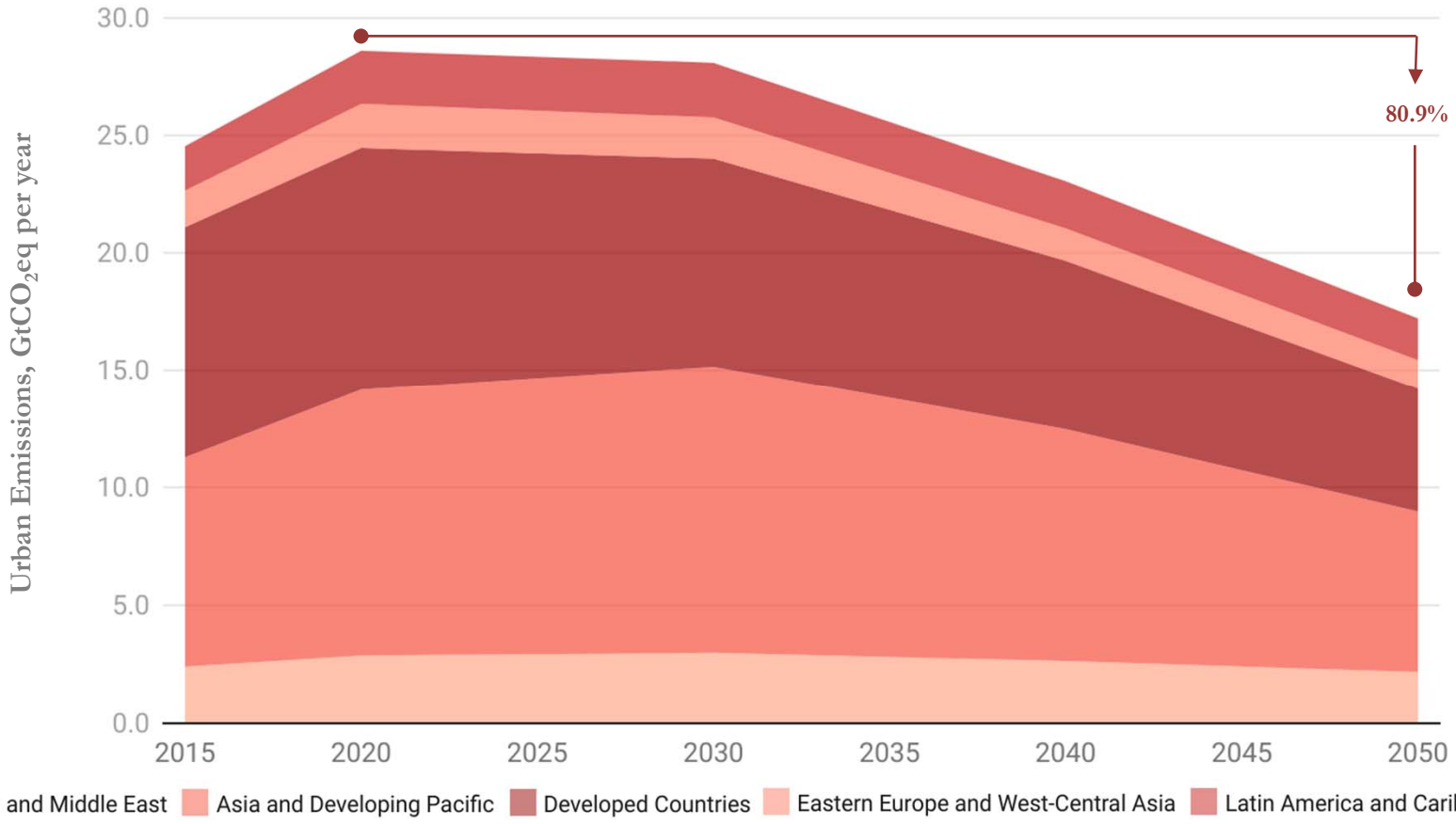
Urban Emissions Scenarios in the Context of SSP1-1.9

In the context of SSP1-1.9, urban emissions reduce from about 28.6 $GtCO_2eq$ in 2020 to ~3.3 $GtCO_2eq$ in 2050



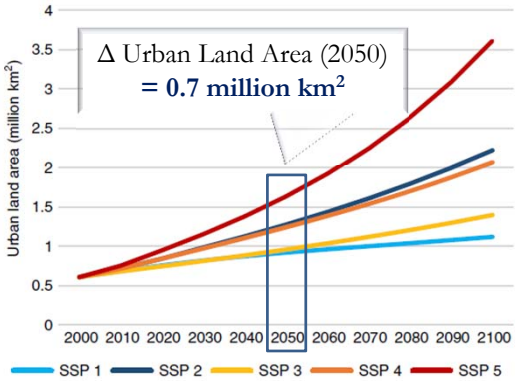
Urban Emissions Scenarios in the Context of SSP1-2.6

In the context of SSP1-2.6, urban emissions reduce more gradually, reaching about ~17.2 $GtCO_2eq$ in 2050



What Will It Take to Transform Urban Systems?

The way cities continue to be planned, interact with the energy system and utilize resources will be essential

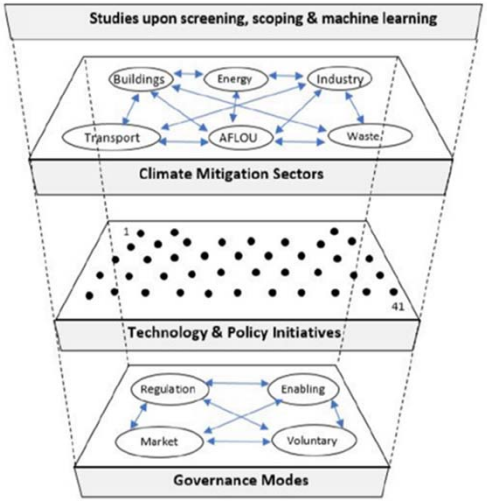


Source: Gao and O'Neill (2020), *Nature Communications* 11:2302

Modifying emerging urbanization

- 20–25% reduction of future urban energy use until 2050

Source: Creutzig et al. (2016); Creutzig et al. (2015)



Source: Sethi et al (2020), Climate change mitigation in cities: a systematic scoping of case studies, *Environ. Res. Lett.* 15 093008

Reducing urban resource use

- Continuing to build cities the same way may require nearly 90 billion tonnes of materials by 2050

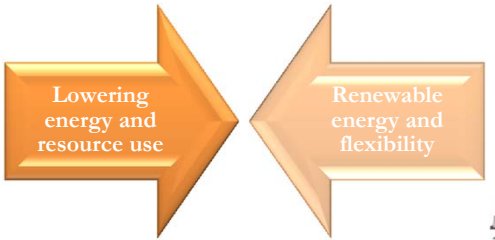
Source: Swilling et al. (2018), The Weight of Cities: Resource Requirements of Future Urbanization

Integrating measures across urban sectors realizes synergies in GHG emission reductions

Urban land use and spatial planning, urban energy planning and resource efficiency

Source: Kılkış (2021), *Energy* 236:121394

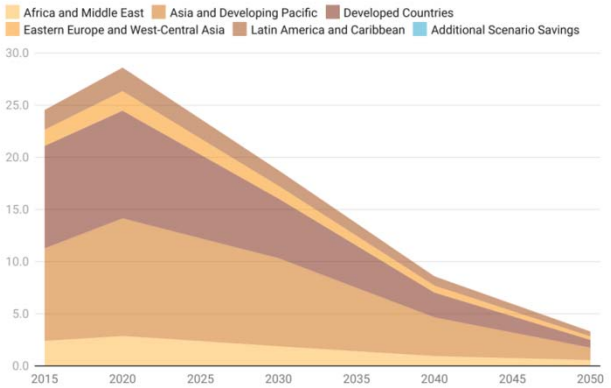
New opportunities

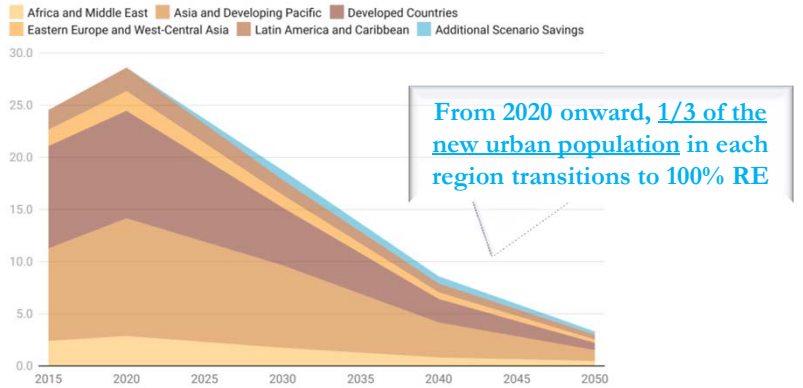


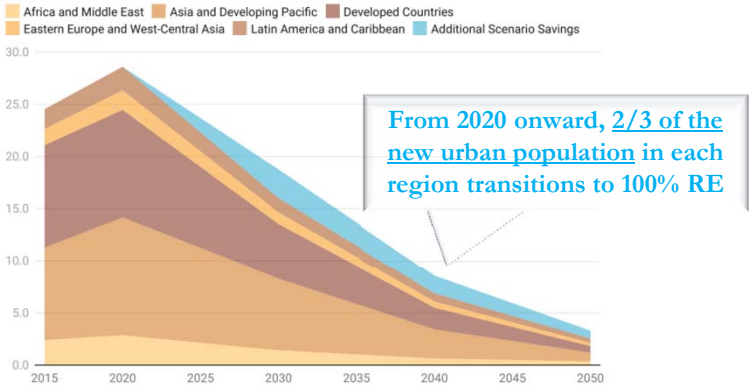
Urban Emissions Scenarios – Net-Zero Infrastructure

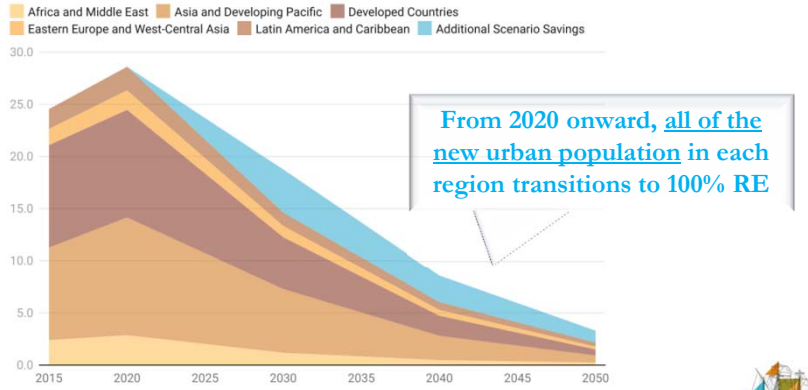
Considering 100% RE infrastructure and consumption patterns <u>only for the new urban population</u> is also insufficient

Urban Emissions, $GtCO_2eq$ per year









Analyses from this slide onward extend beyond a forthcoming publication in *Global Environmental Change* based on the original research work of the presenter

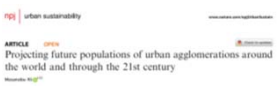
Urban Emissions Scenarios in the SSP-RCP Framework

Additional datasets are integrated for SSP1 population projections per urban area and 100% renewable energy trends

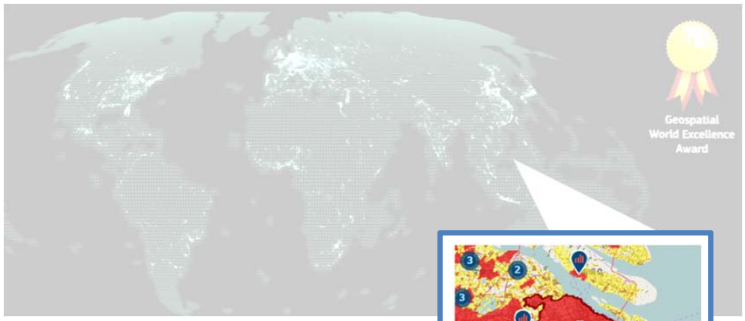
Data inputs – Urban emissions and trends

- Global Gridded Model of Carbon Footprints
- Global Human Settlement Layer GHSL-UCDB
- Urban population by SSP per urban cluster (*)

(*) **Source**: Kii (2021), npj *Urban Sustainability* 1:10



The focus is on the top 500 urban areas with the highest footprint, 420 being harmonized across urban datasets



Source: JRC (2019), Global Human Settlement Layer / Urban Center Database (UCDB)

Climate scenario inputs

- Additional SSP1 scenario involving 100% renewable energy based on regional GHG emission trends

Scenario	Urbanization Qualities	Electrification and flexibility	Renewable energy deployment	Energy and material efficiency	Technology development / innovation	Behavioral and lifestyle responses	Afforestation and re-forestation
SSP1-RE	**Rapid / Compact**	**Highest**	**Highest**	**Highest**	**Highest**	**Highest**	**Higher**
SSP1-1.9	Rapid / Compact	Higher	Higher	Higher	Higher	Higher	Higher
SSP1-2.6	Rapid / Compact	High	High	High	High	High	High

Additional Source: Bogdanov et al. (2021), Low-cost renewable electricity as the key driver of the global energy transition towards sustainability, *Energy* 227 <https://doi.org/10.1016/j.energy.2021.120467>

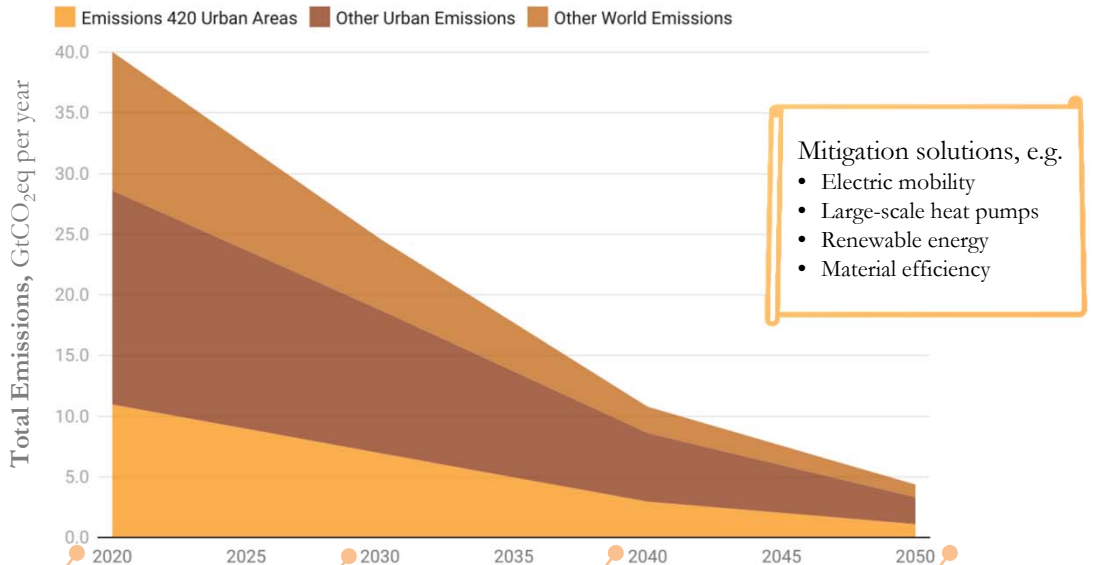
Emissions for the 420 Urban Areas Under SSP1-1.9

Among the 71.4% responsibility of urban areas in emissions, the 420 urban areas are responsible for a share of ~27%

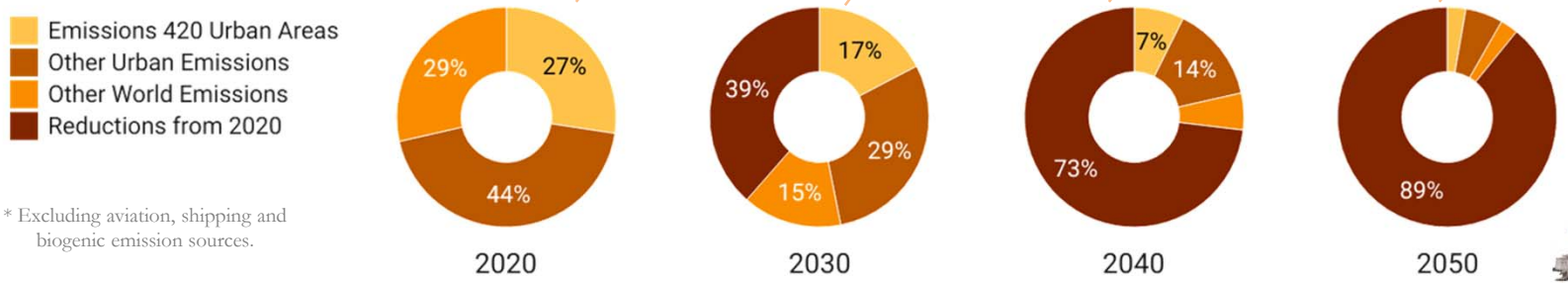
Urban implications: Compact urban form with **wide-spread electrification and efficiency**

Descriptions Relative to Other Scenarios

• Electrification of end uses	Higher
• Renewable energy deployment	Higher
• Energy and material efficiency	Higher
• Technology development / innovation	Higher
• Behavioral and lifestyle responses	Higher
• Afforestation and re-forestation	Higher



Mitigation solutions, e.g.
- Electric mobility
- Large-scale heat pumps
- Renewable energy
- Material efficiency



* Excluding aviation, shipping and biogenic emission sources.

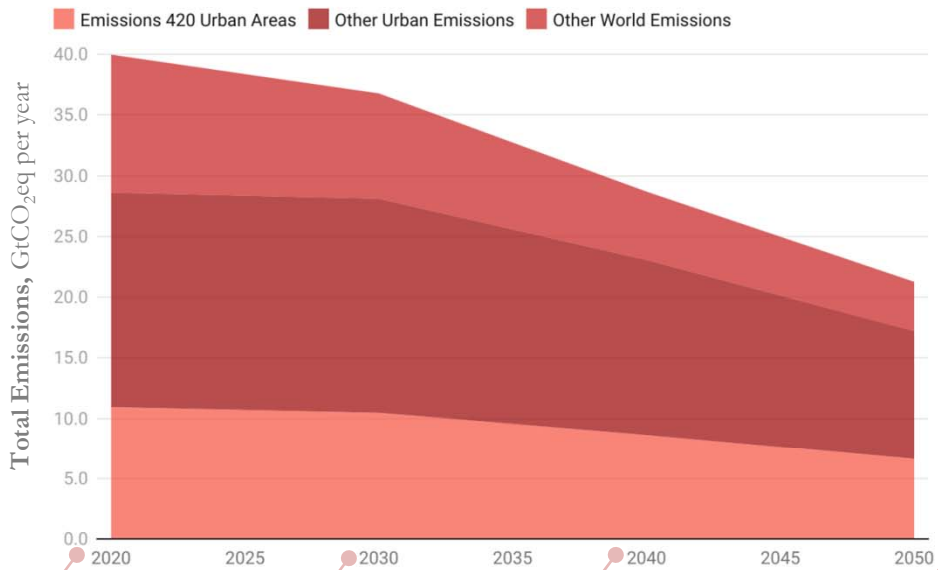
Emissions for the 420 Urban Areas Under SSP1-2.6

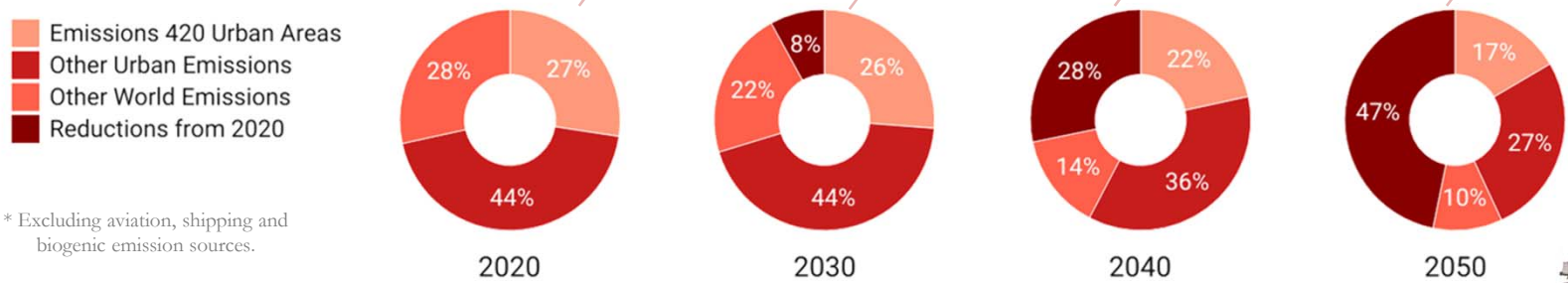
Including reductions from 2020, the share of the 420 urban areas changes only between 27-17% in this scenario

Urban implications: Same principles with relatively slower progress **in urban areas**

Descriptions Relative to Other Scenarios

• Electrification of end uses	High
• Renewable energy deployment	High
• Energy and material efficiency	High
• Technology development / innovation	High
• Behavioral and lifestyle responses	High
• Afforestation and re-forestation	High





* Excluding aviation, shipping and biogenic emission sources.

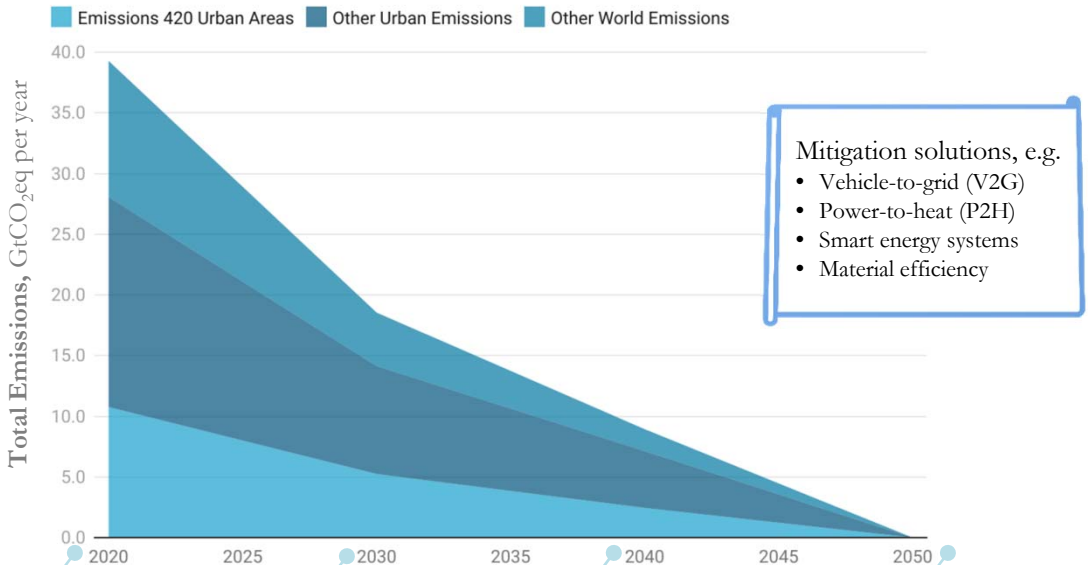
Emissions for the 420 Urban Areas Under SSP1-RE

Especially the 100% renewable energy scenario requires key support from urban areas to increase system flexibility

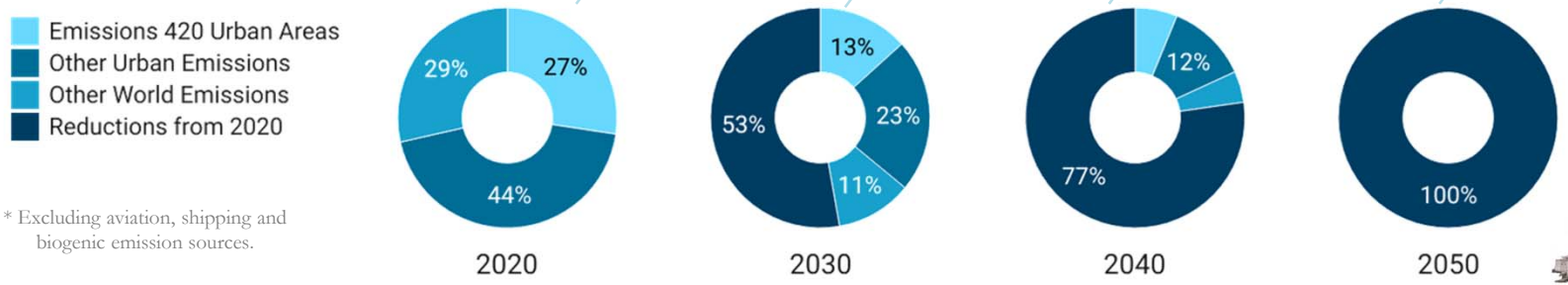
Urban implications: Support for system flexibility for **100% renewable energy penetration**

Descriptions Relative to Other Scenarios

• Electrification and flexibility	Highest
• Renewable energy deployment (100%)	Highest
• Energy and material efficiency	Highest
• Technology development / innovation	Highest
• Behavioral and lifestyle responses	Highest
• Afforestation and re-forestation	Higher



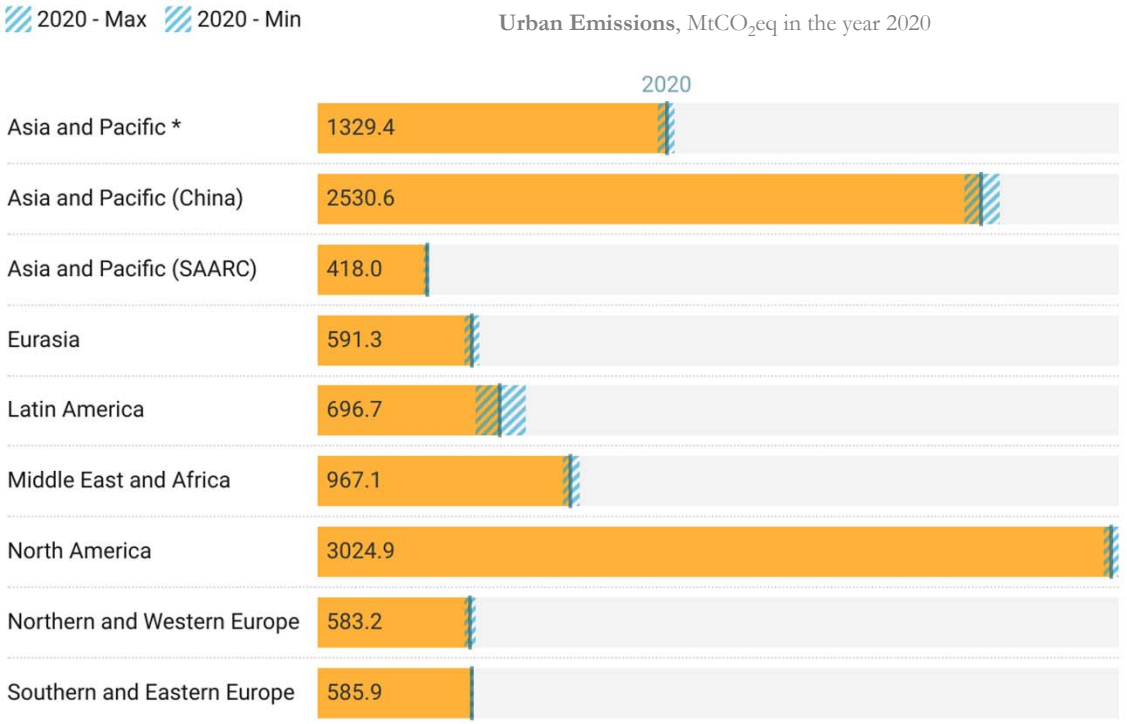
Mitigation solutions, e.g.
- Vehicle-to-grid (V2G)
- Power-to-heat (P2H)
- Smart energy systems
- Material efficiency

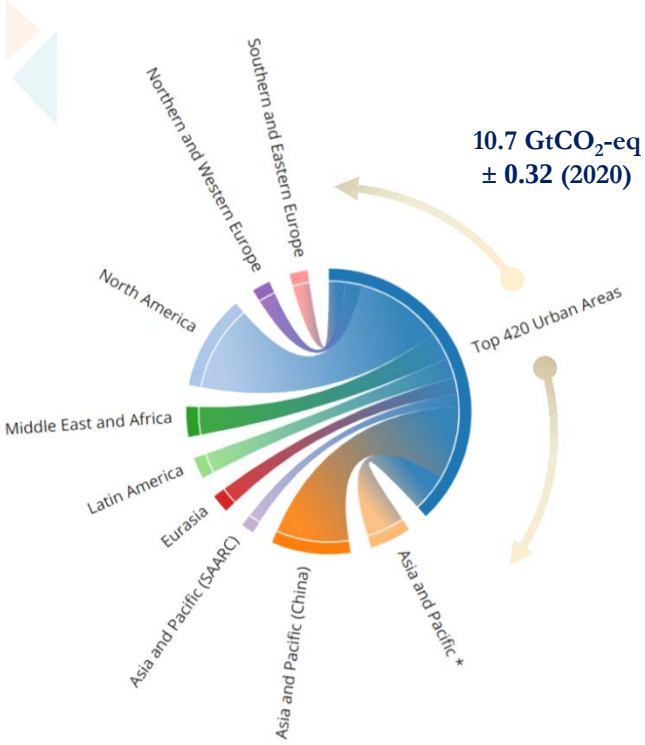


* Excluding aviation, shipping and biogenic emission sources.

Emissions of 420 Urban Areas Across World Regions

The top 420 urban areas with the highest consumption based urban emissions are located across all world regions



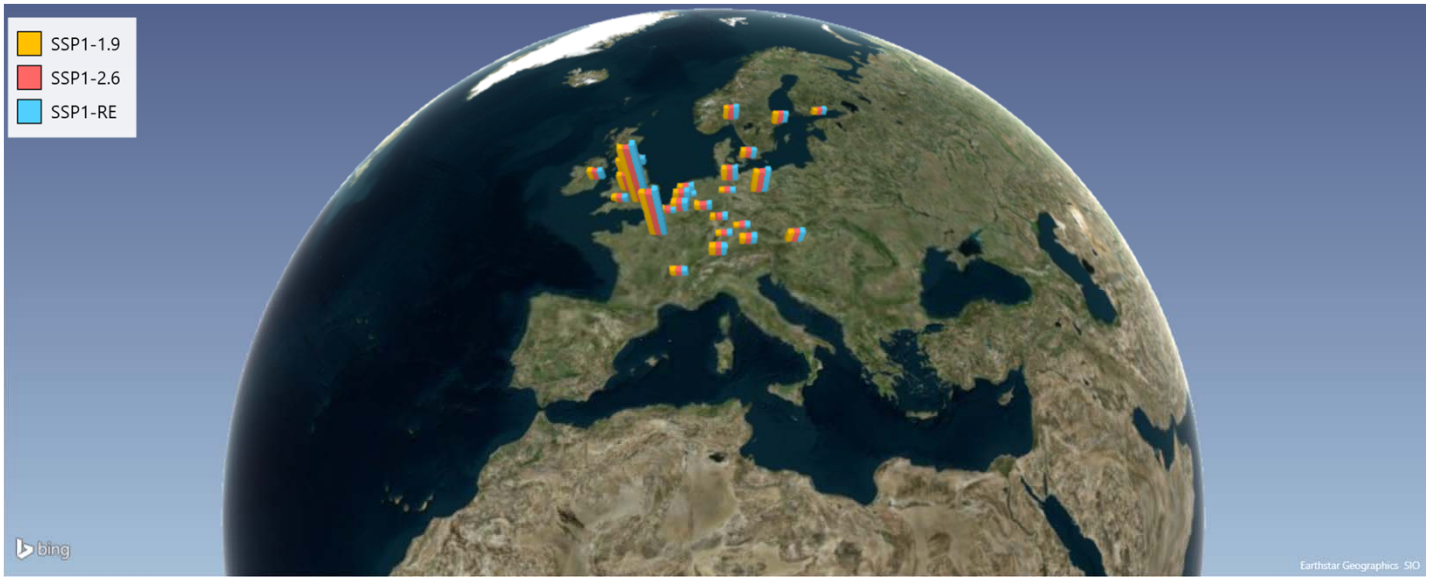


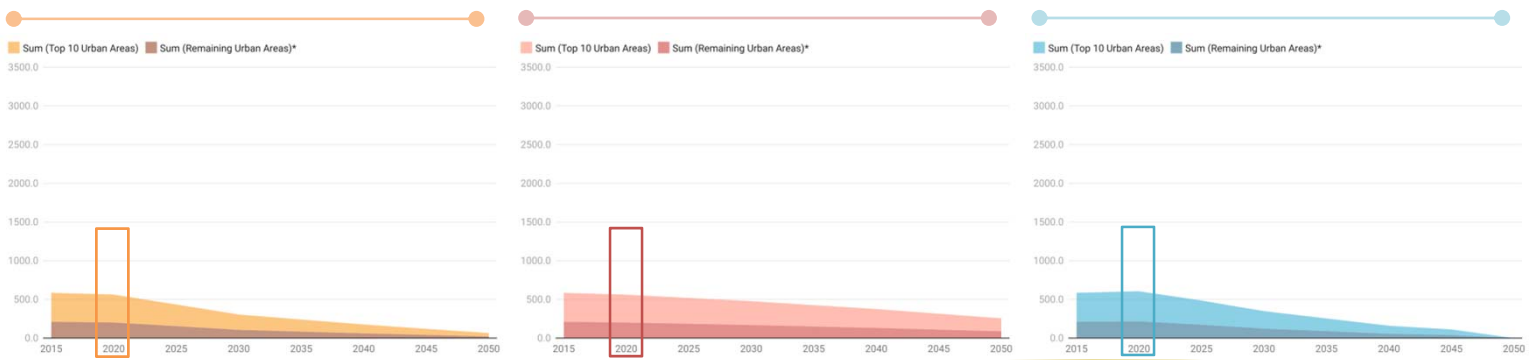
- Relevant urban emissions are given separately for China and the South Asian Association for Regional Cooperation (SAARC).
- The shaded areas of the bars indicate the range of estimated values for 2020 with the line being the average value across scenarios.

* Excluding urban areas in China and SAARC that are given separately.

Future Outlook of Emissions for 420 Urban Areas

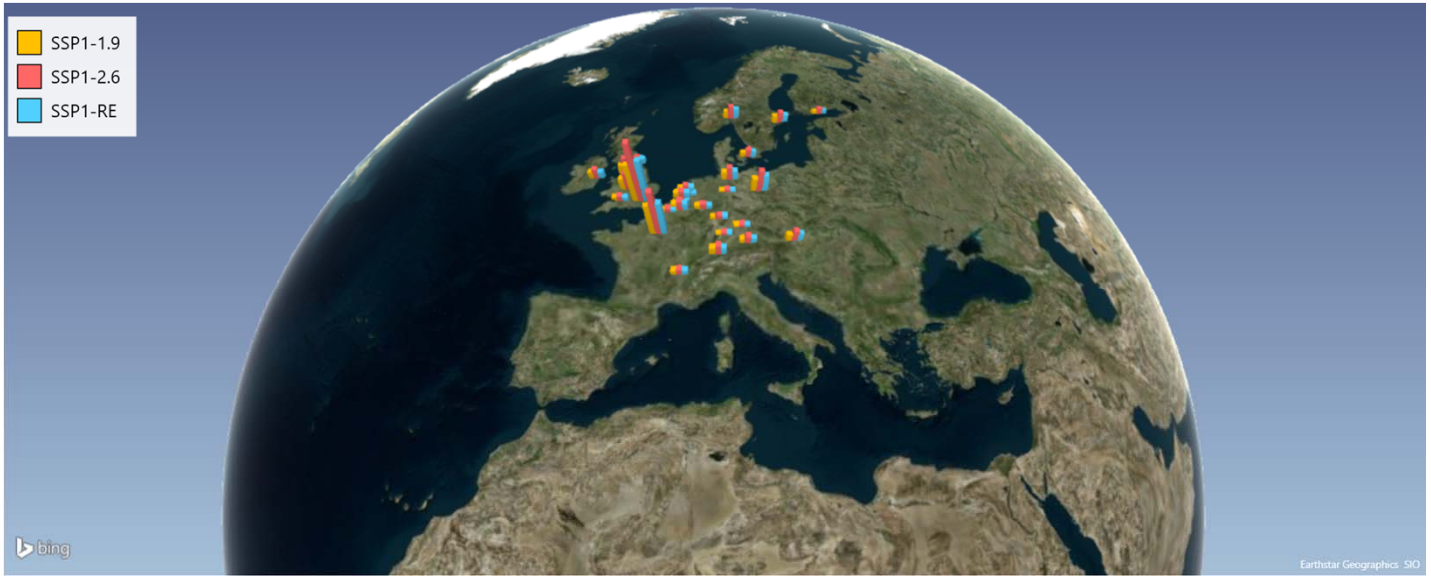
In Northern and Western Europe, urban emissions for 31 of the top 420 urban areas are 583.2 ± 21.8 $MtCO_2eq$ in 2020

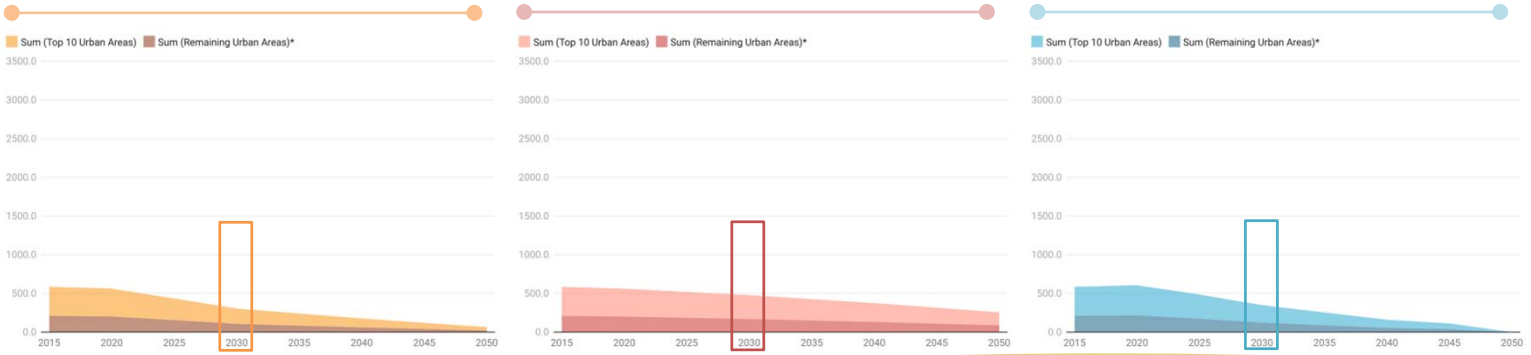




Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emissions pathways can lead to 304.7, 477.0 or 347.9 $MtCO_2eq$ in 2030

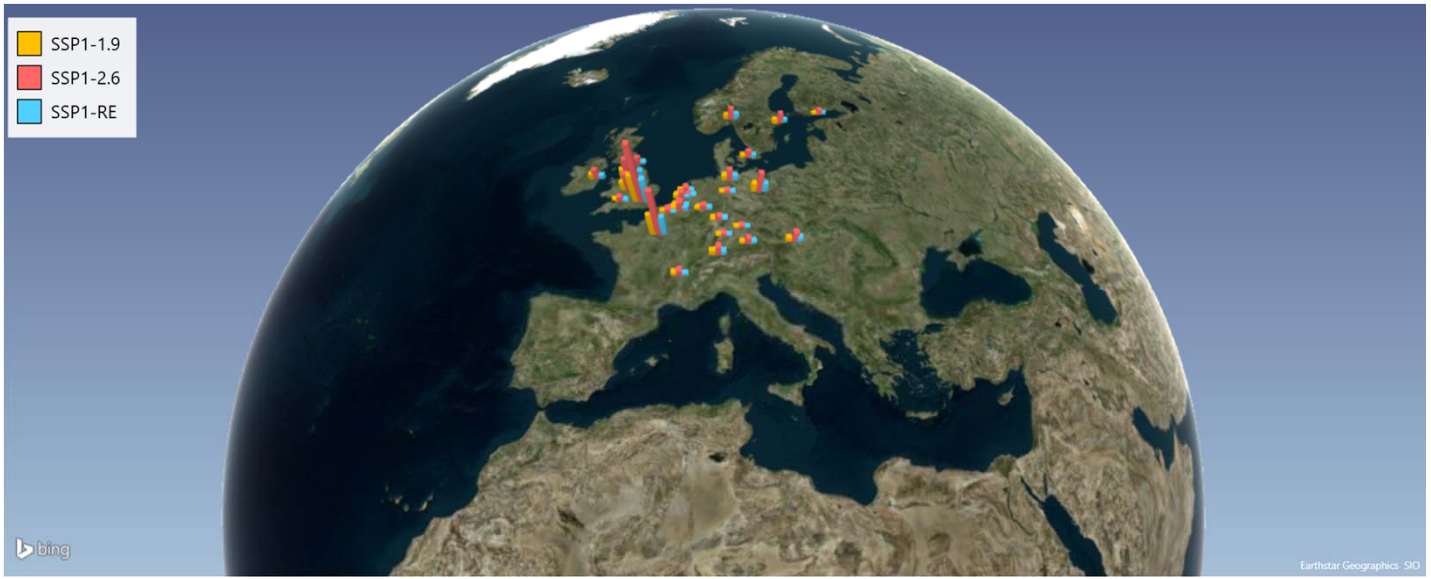




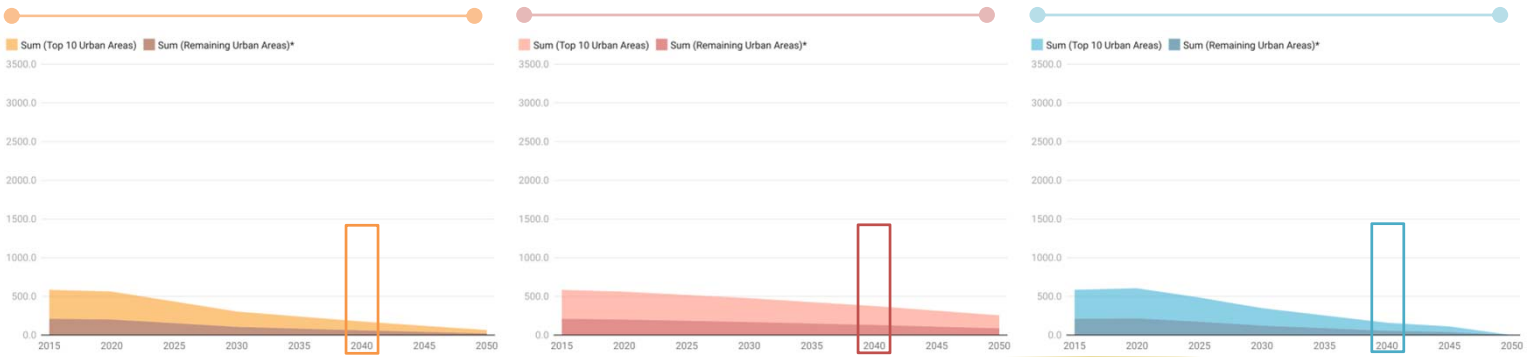
Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emissions pathways can lead to 174.9, 375.4 or 159.4 $MtCO_2eq$ in 2040

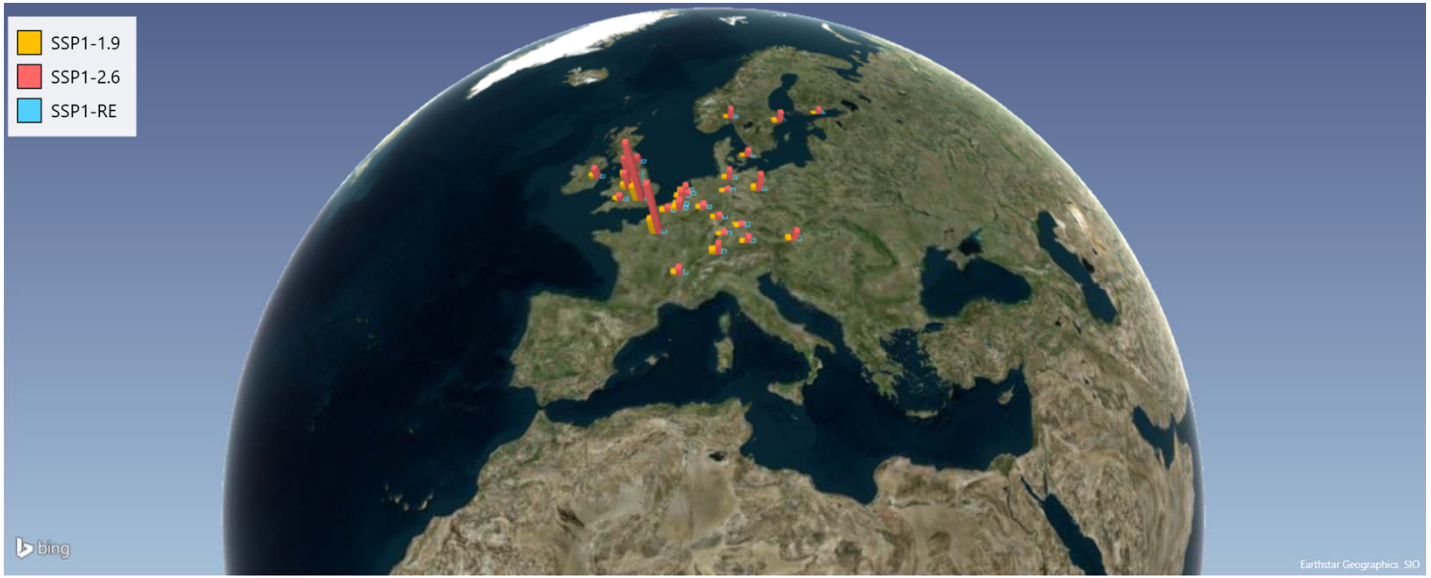


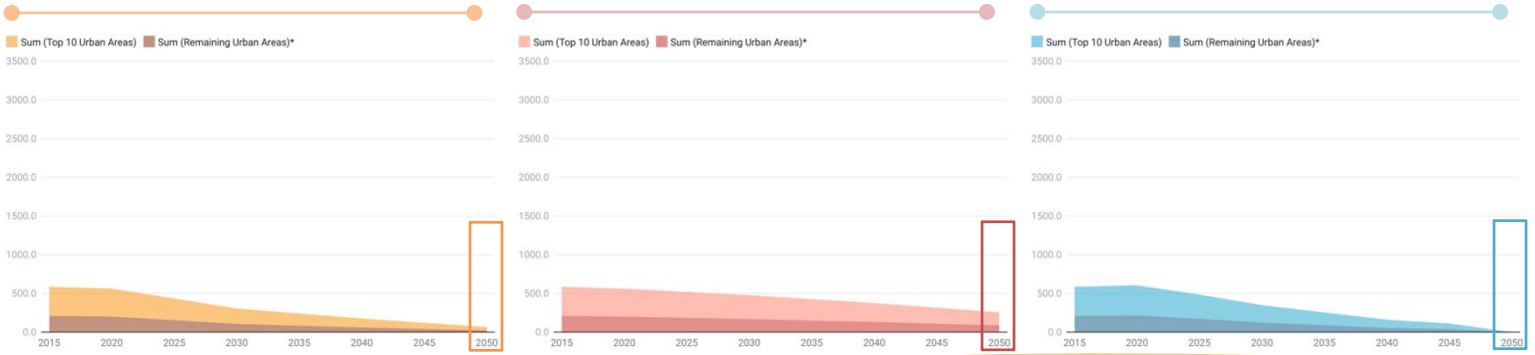
Urban Emissions
$MtCO_2eq$ per year



Future Outlook of Emissions for 420 Urban Areas

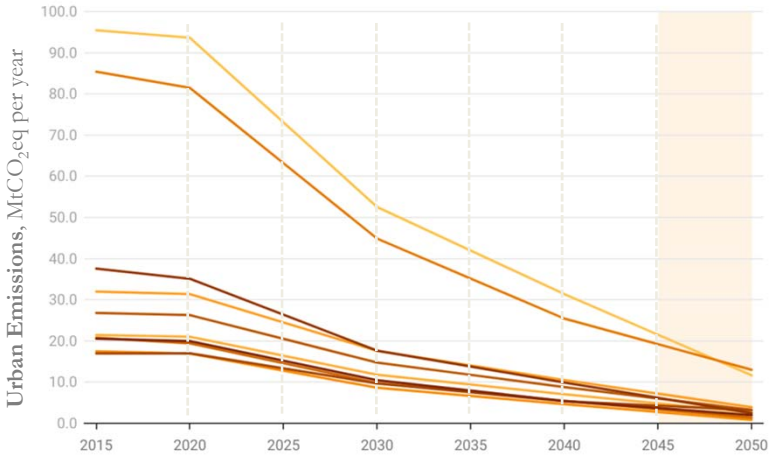
Across the SSP1 scenarios, urban emissions pathways can lead to 65.4, 255.4 or ~0.0 $MtCO_2eq$ in 2050





Top 10 Emitting Areas – Northern and Western Europe

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 317.9 $MtCO_2eq$ by 2050



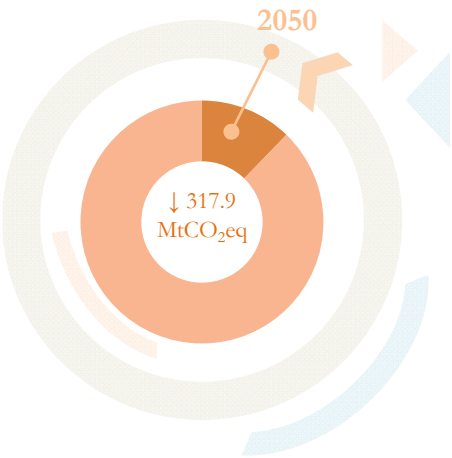
Search in table

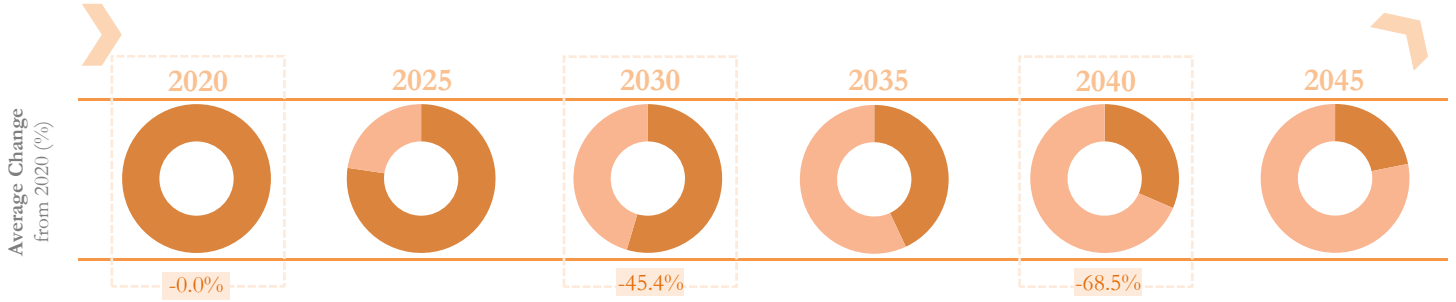
Region → Northern and Western Europe

0.3 95.4

Uj	2015	2020	2025	2030	2035	2040	2045	2050
London	95.4	93.6	73.1	52.5	42.0	31.4	21.5	11.7
Paris	85.4	81.5	63.2	44.9	35.2	25.4	19.2	13.0
Berlin	37.6	35.1	26.4	17.7	13.8	9.9	6.2	2.5
Manchester	32.0	31.4	24.5	17.6	14.1	10.5	7.2	3.9
Birmingham	26.8	26.3	20.5	14.7	11.8	8.8	6.0	3.3
West Yorkshire	21.4	21.0	16.4	11.8	9.4	7.1	4.8	2.6
Hamburg	20.8	19.4	14.6	9.8	7.6	5.5	3.4	1.4
Vienna	20.6	20.0	15.2	10.5	7.9	5.4	3.7	2.0
Oslo	17.5	16.9	12.8	8.6	6.6	4.7	2.8	0.9
Zurich	17.0	17.0	13.3	9.7	7.5	5.4	4.3	3.2

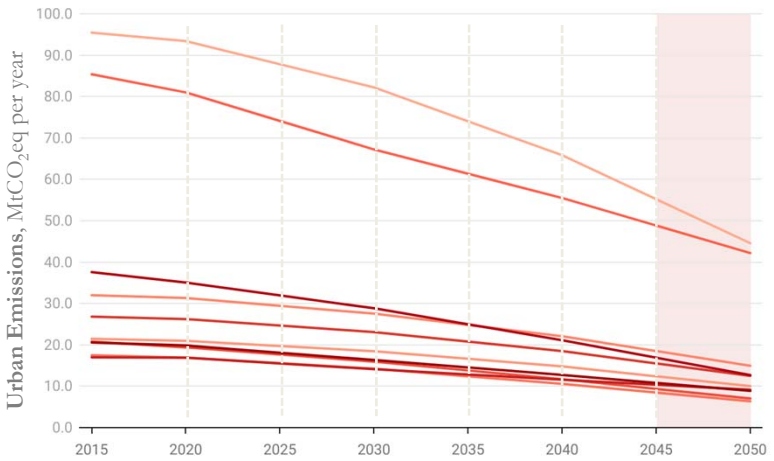
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Northern and Western Europe

Reductions in SSP1-2.6 remain just over half in 2050 at 192.8 $MtCO_2eq$, largely forgoing a missed 1.5°C target



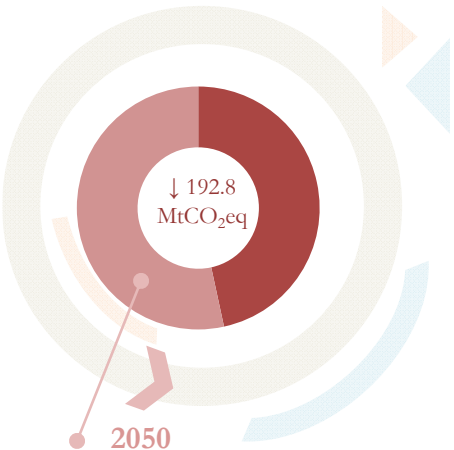
Search in table

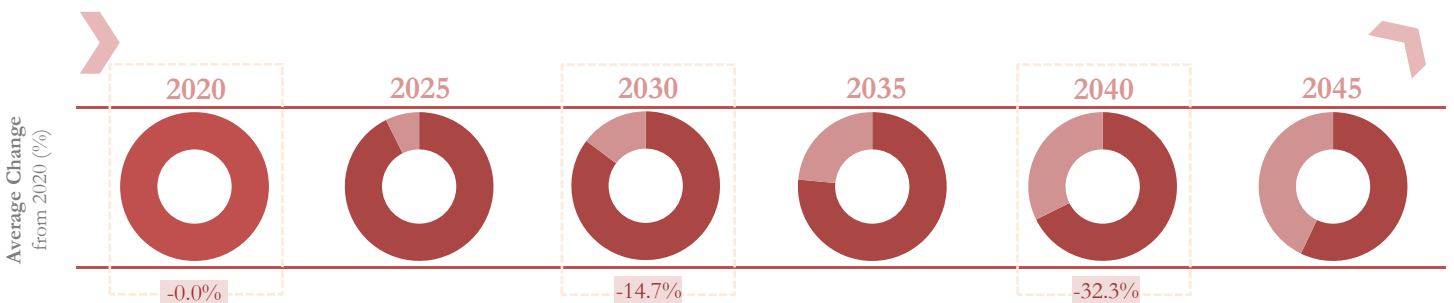
Region → Northern and Western Europe

1.7 — 95.4

Uj	2015	2020	2025	2030	2035	2040	2045	2050
London	95.4	93.4	87.8	82.2	74.0	65.8	55.2	44.6
Paris	85.4	81.0	74.1	67.2	61.4	55.5	48.8	42.2
Berlin	37.6	35.1	31.9	28.8	25.0	21.1	16.9	12.7
Manchester	32.0	31.3	29.4	27.6	24.8	22.1	18.5	14.9
Birmingham	26.8	26.2	24.7	23.1	20.8	18.5	15.5	12.5
West Yorkshire	21.4	21.0	19.7	18.5	16.6	14.8	12.4	10.0
Hamburg	20.8	19.4	17.7	16.0	13.8	11.7	9.3	7.0
Vienna	20.6	19.9	18.1	16.3	14.5	12.7	10.8	8.9
Oslo	17.5	16.9	15.6	14.2	12.4	10.6	8.5	6.3
Zurich	17.0	16.9	15.5	14.1	12.8	11.6	10.4	9.1

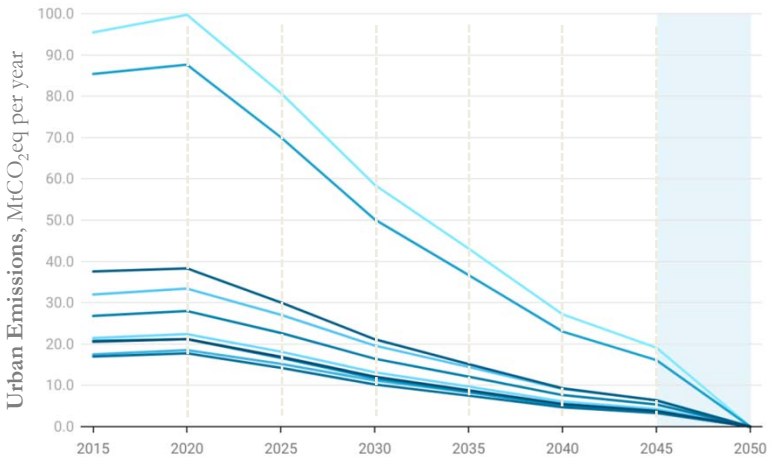
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Northern and Western Europe

For these areas, 100% RE scenarios provide opportunities to eliminate 388.2 $MtCO_2eq$ of urban emissions in 2050



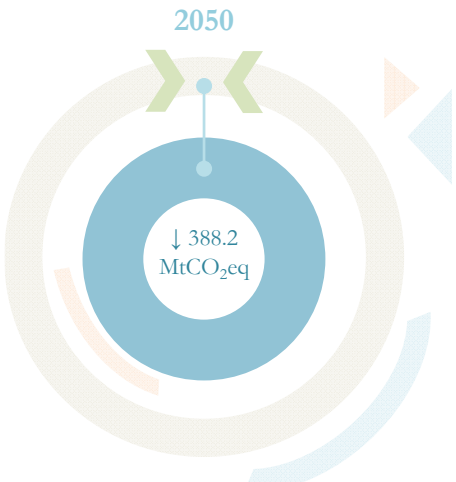
Search in table

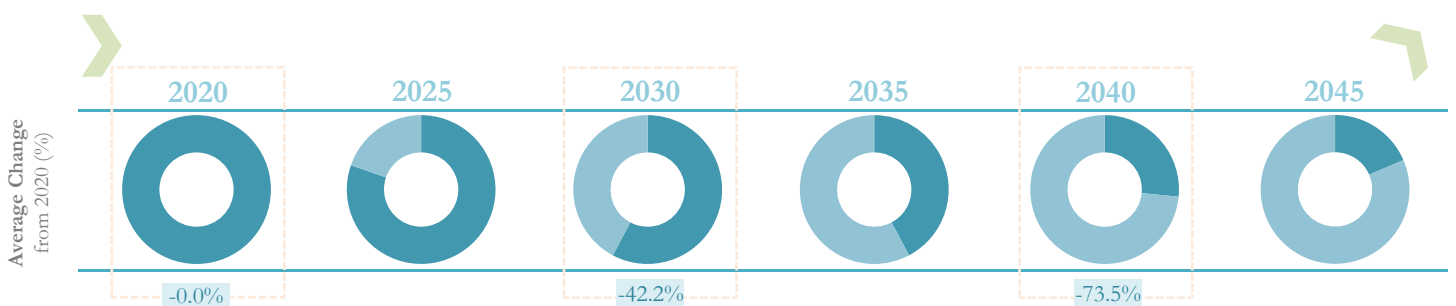
Region → Northern and Western Europe

0.0 — 99.7

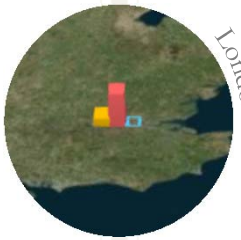
Uj	2015	2020	2025	2030	2035	2040	2045	2050
London	95.4	99.7	80.8	58.5	43.1	27.2	19.1	0.0
Paris	85.4	87.6	70.0	50.1	36.7	23.0	16.1	0.0
Berlin	37.6	38.3	30.1	21.1	15.1	9.3	6.3	0.0
Manchester	32.0	33.4	27.1	19.6	14.4	9.1	6.4	0.0
Birmingham	26.8	28.0	22.7	16.4	12.1	7.6	5.4	0.0
West Yorkshire	21.4	22.4	18.1	13.1	9.7	6.1	4.3	0.0
Hamburg	20.8	21.2	16.6	11.7	8.4	5.1	3.5	0.0
Vienna	20.6	21.2	16.9	12.1	8.8	5.5	3.8	0.0
Oslo	17.5	18.5	15.2	11.2	8.3	5.3	3.8	0.0
Zurich	17.0	17.8	14.2	10.2	7.5	4.7	3.3	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

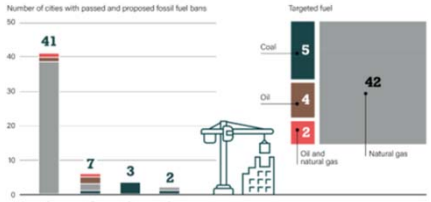




Actions Urban Areas Are Taking and Opportunities

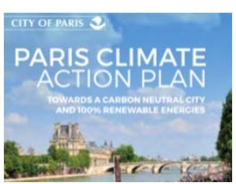


- One of the first 12 cities declaring **divesting from fossil fuels** for a green and just recovery
- One of the cities with a **fossil fuel ban** and restrictions for natural gas use in buildings

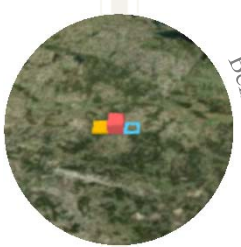


Source: REN21 (2021)

- Reducing local GHG emissions and outer Paris footprint >40% in 2030 with **100% RE in 2050**
- Phasing out petrol-powered mobility by 2030

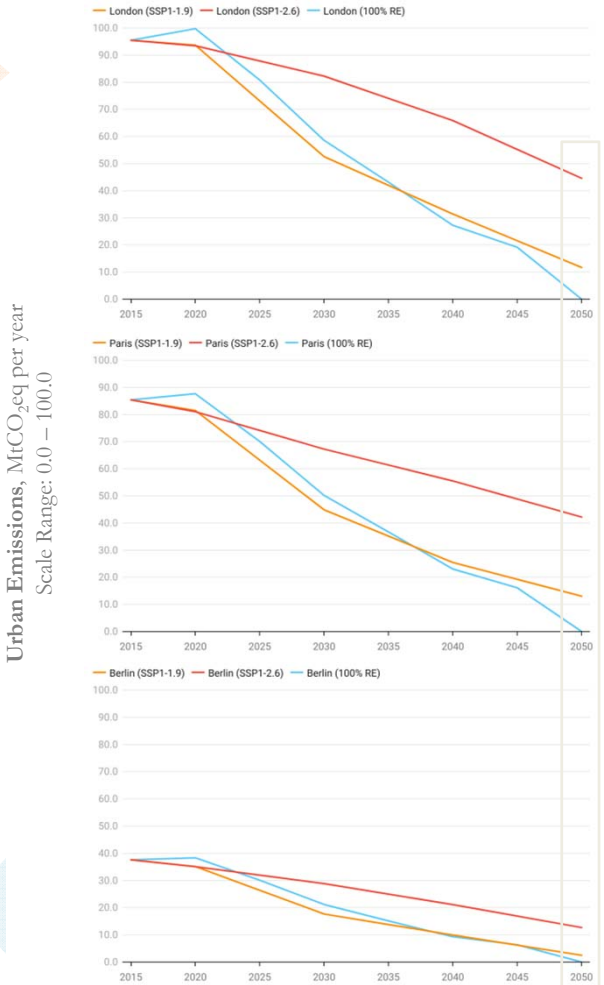


Source: City of Paris



- **Obligatory target** to reduce CO_2 emissions by 70% by 2030 with climate neutrality by 2045
- **Berlin Climate Protection** and Energy Turnaround Act (adopted August 19, 2021)

Source: Senate Department for the Environment, Transport and Climate Protection (2021)



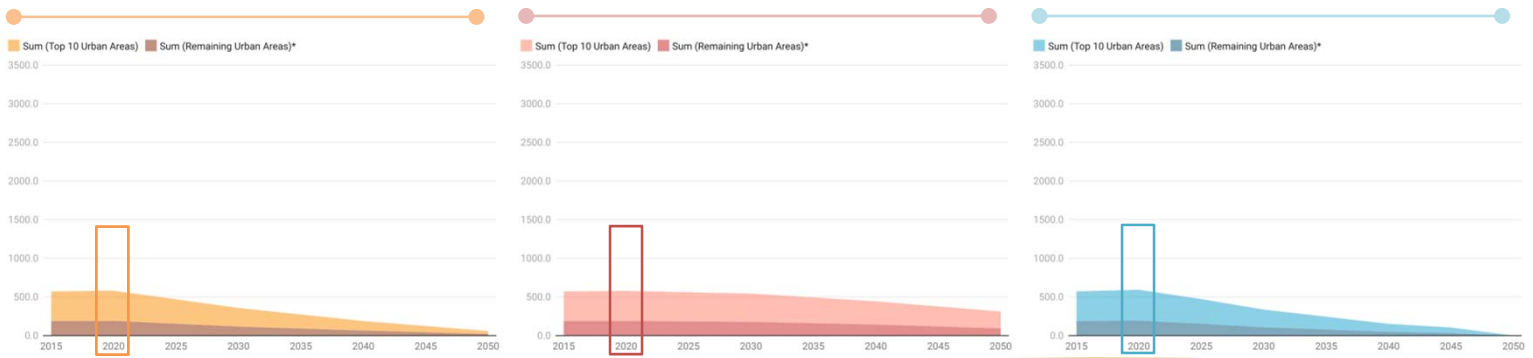
Making the complete shift for the urban energy system and beyond

Co-benefits of 100% RE in these 3 urban areas:
~ 236 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

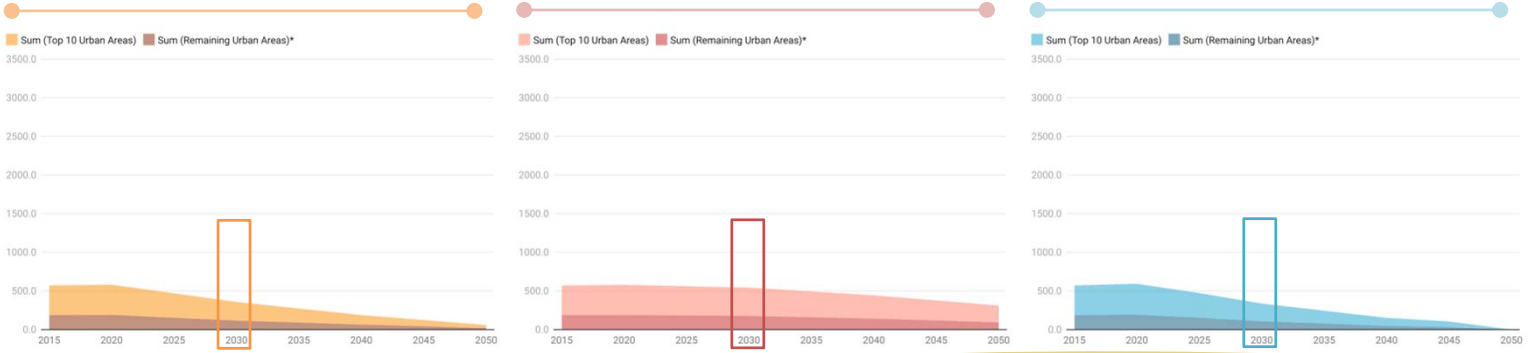
In Southern and Eastern Europe, urban emissions for 32 of the top 420 urban areas are 585.9 ± 7.0 $MtCO_2eq$ in 2020



Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emissions pathways can lead to 357.6, 543.5 or 336.6 $MtCO_2eq$ in 2030

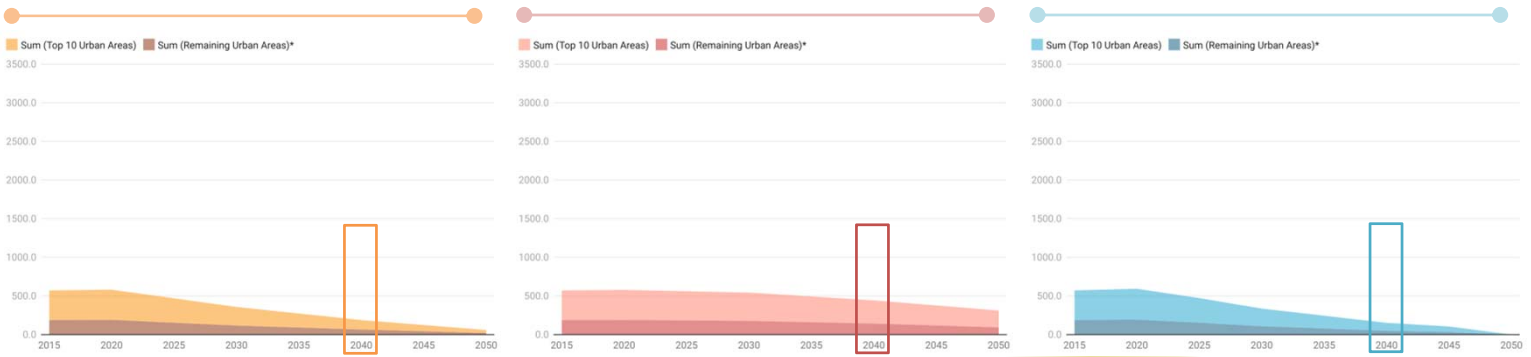
Urban Emissions
$MtCO_2eq$ per year



Future Outlook of Emissions for 420 Urban Areas

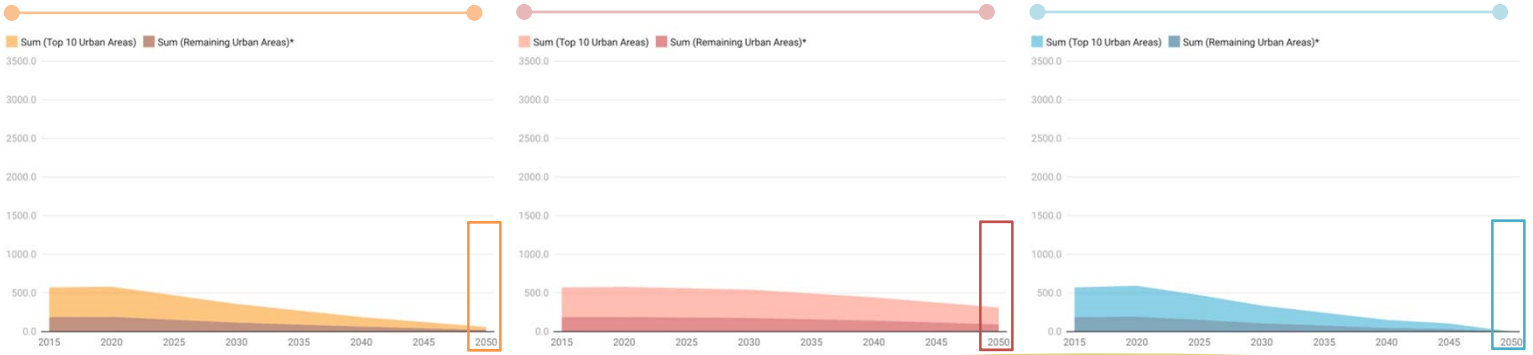
Across the SSP1 scenarios, urban emissions pathways can lead to 187.9, 442.8 or 151.8 $MtCO_2eq$ in 2040

Urban Emissions
$MtCO_2eq$ per year



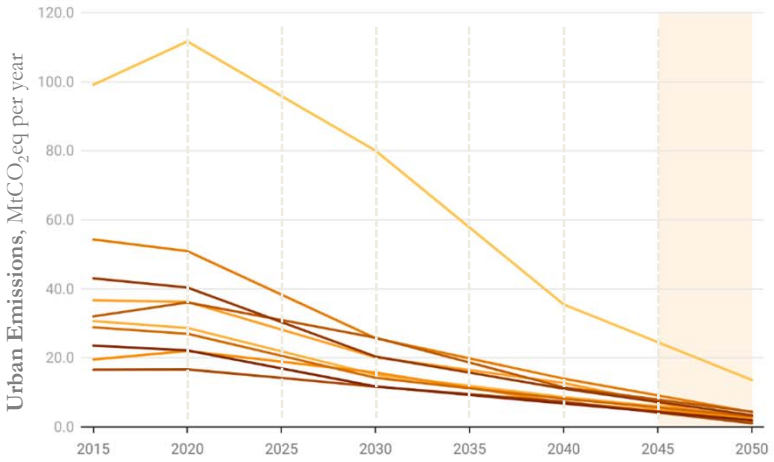
Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emissions pathways can lead to 58.7, 311.3 or ~0.0 $MtCO_2eq$ in 2050



Top 10 Emitting Areas – Southern and Eastern Europe

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 352.7 $MtCO_2eq$ by 2050



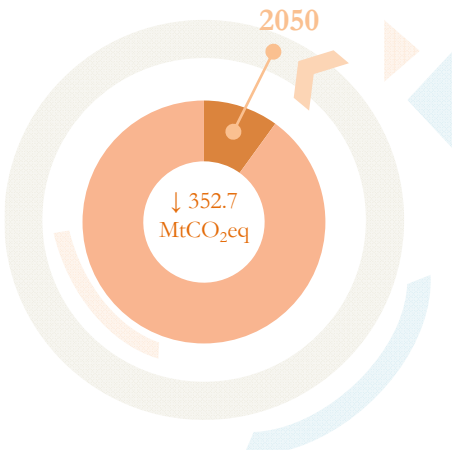
Search in table

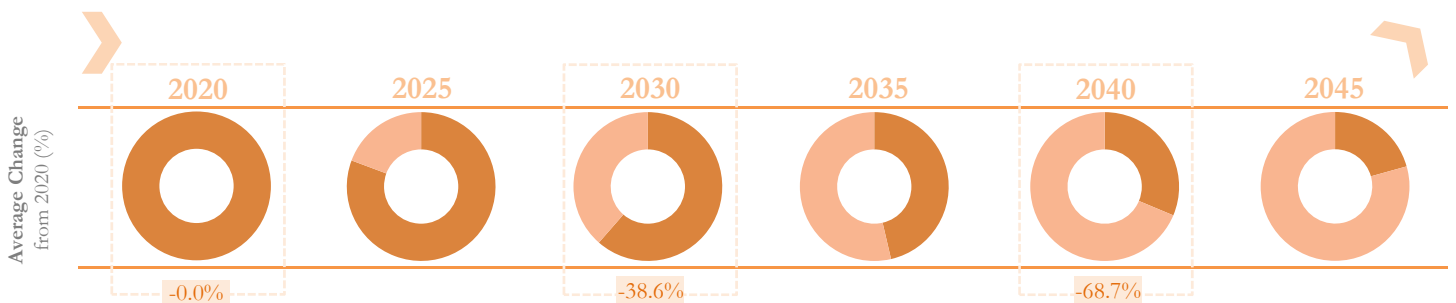
Region → Southern and Eastern Europe

0.3 — 111.7

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Istanbul	99.1	111.7	95.9	80.0	57.8	35.5	24.5	13.6
Madrid	54.3	50.9	38.3	25.7	19.8	14.0	9.1	4.3
Barcelona	43.1	40.4	30.4	20.4	15.7	11.1	7.2	3.4
Athens	36.7	36.2	28.2	20.2	16.5	12.7	7.1	1.4
Ankara	32.0	36.1	31.0	25.9	18.7	11.5	7.9	4.4
Milan	30.7	28.7	21.9	15.1	11.9	8.7	6.0	3.3
Rome	28.9	27.0	20.6	14.2	11.2	8.2	5.6	3.1
Lisbon	23.6	22.2	17.0	11.7	9.3	6.8	4.4	1.9
Izmir	19.5	22.0	18.9	15.8	11.4	7.0	4.8	2.7
Kiev	16.6	16.7	14.2	11.7	9.5	7.3	4.2	1.1

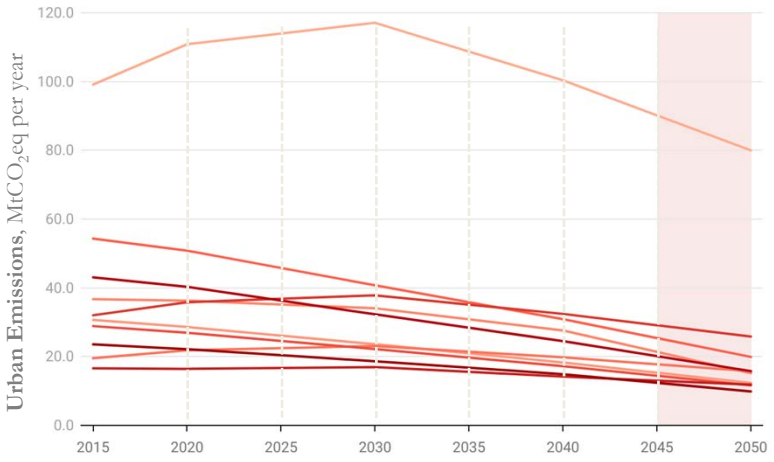
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Southern and Eastern Europe

Reductions in SSP1-2.6 remain less than half in 2050 at 171.9 $MtCO_2eq$, again forgoing a missed 1.5°C target



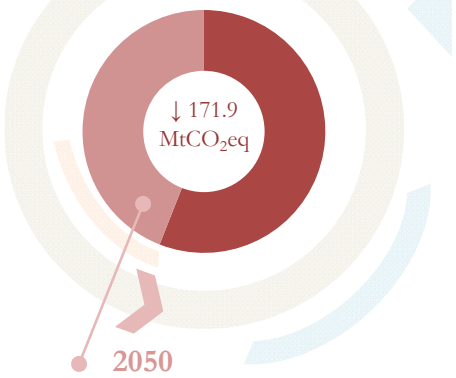
Search in table

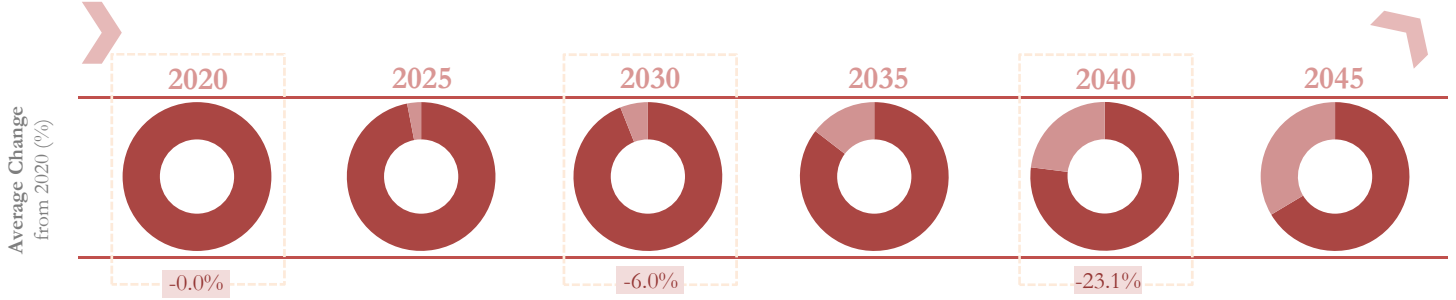
Region → Southern and Eastern Europe

1.1 — 117.1

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Istanbul	99.1	110.8	114.0	117.1	108.7	100.3	90.2	80.0
Madrid	54.3	50.8	45.8	40.7	35.8	30.9	25.4	19.9
Barcelona	43.1	40.3	36.3	32.3	28.4	24.5	20.1	15.8
Athens	36.7	36.3	35.2	34.1	30.8	27.6	21.4	15.2
Ankara	32.0	35.8	36.8	37.8	35.1	32.4	29.1	25.8
Milan	30.7	28.6	26.1	23.6	20.9	18.3	15.3	12.4
Rome	28.9	26.9	24.6	22.2	19.7	17.2	14.4	11.6
Lisbon	23.6	22.2	20.4	18.6	16.8	14.9	12.4	9.9
Izmir	19.5	21.8	22.5	23.1	21.4	19.8	17.8	15.8
Kiev	16.6	16.4	16.7	16.9	15.6	14.2	13.0	11.9

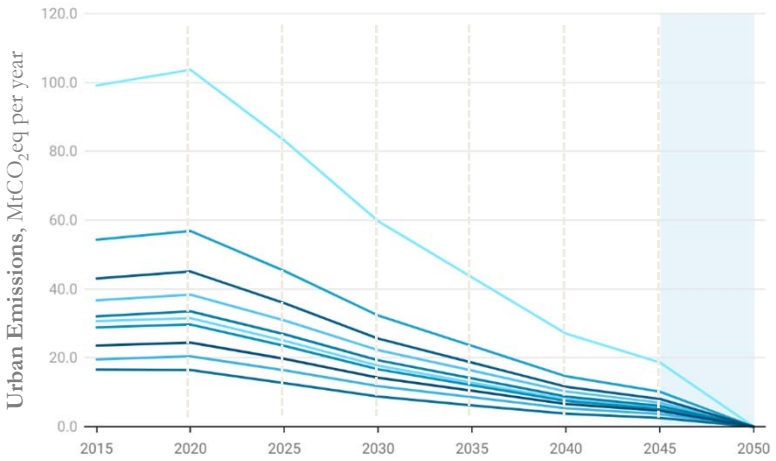
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Southern and Eastern Europe

For these areas, 100% RE scenarios provide opportunities to eliminate 400.0 $MtCO_2eq$ of urban emissions in 2050



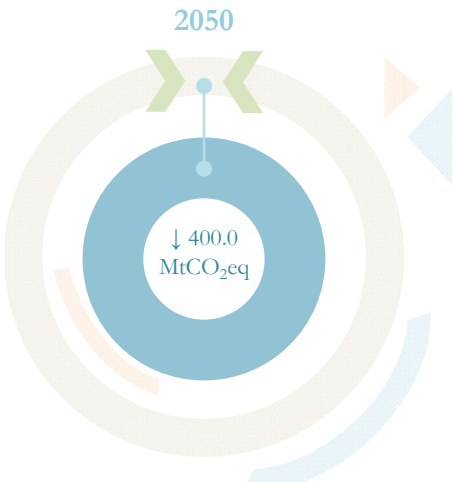
Search in table

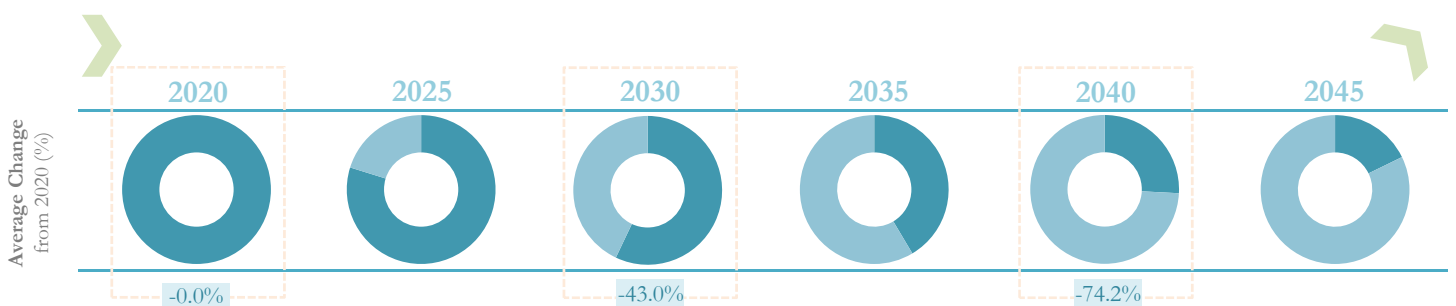
Region → Southern and Eastern Europe

0.0 — 103.7

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Istanbul	99.1	103.7	83.1	59.7	43.4	27.0	18.7	0.0
Madrid	54.3	56.8	45.3	32.3	23.5	14.6	10.2	0.0
Barcelona	43.1	45.1	35.9	25.6	18.6	11.6	8.0	0.0
Athens	36.7	38.4	30.9	22.2	16.3	10.2	6.9	0.0
Ankara	32.0	33.5	26.9	19.3	14.0	8.7	6.0	0.0
Milan	30.7	31.5	25.0	17.7	12.8	7.9	5.5	0.0
Rome	28.9	29.7	23.5	16.7	12.0	7.5	5.1	0.0
Lisbon	23.6	24.4	19.7	14.2	10.4	6.6	4.6	0.0
Izmir	19.5	20.4	16.4	11.8	8.5	5.3	3.7	0.0
Kiev	16.6	16.5	12.7	8.7	6.2	3.8	2.5	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

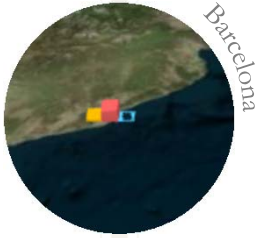




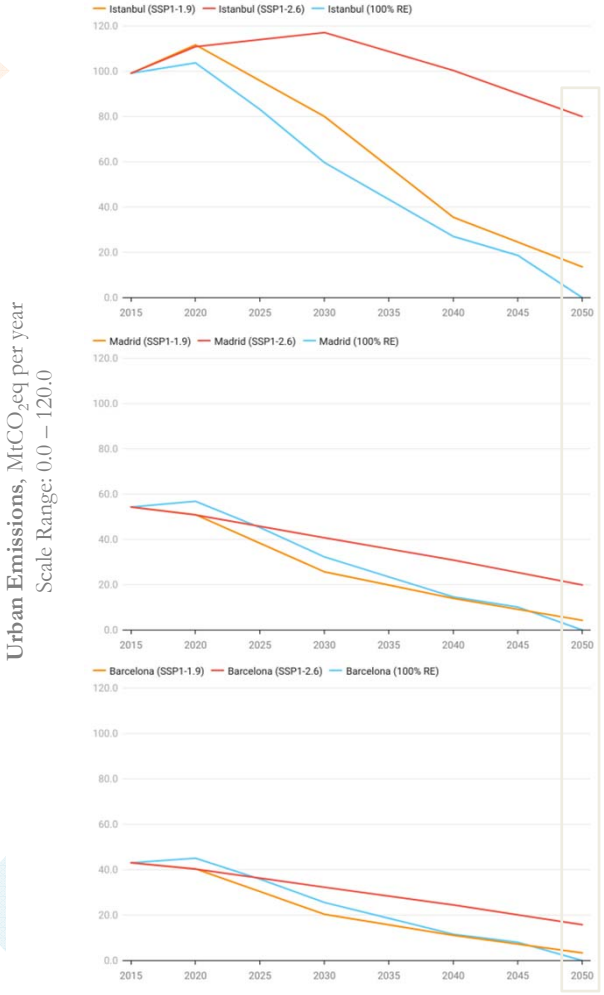
Actions Urban Areas Are Taking and Opportunities

- Can learn from other urban areas and **plan for realizing higher reduction targets**
- National strategy for smart and sustainable cities that are adding value to welfare
- → SDEWES Index: Challenged City

- Both Madrid and Barcelona supports the national 100% RE target of Spain by 2050
- Overall, Europe is where cities are mostly **adopting net-zero and RE targets together**



- Barcelona Climate Plan has aimed to reduce emissions by 45% by 2030 while this target is prior to the European Climate Law (55%) and Mission on Climate-Neutral and Smart Cities



Making the complete shift for the urban energy system and beyond

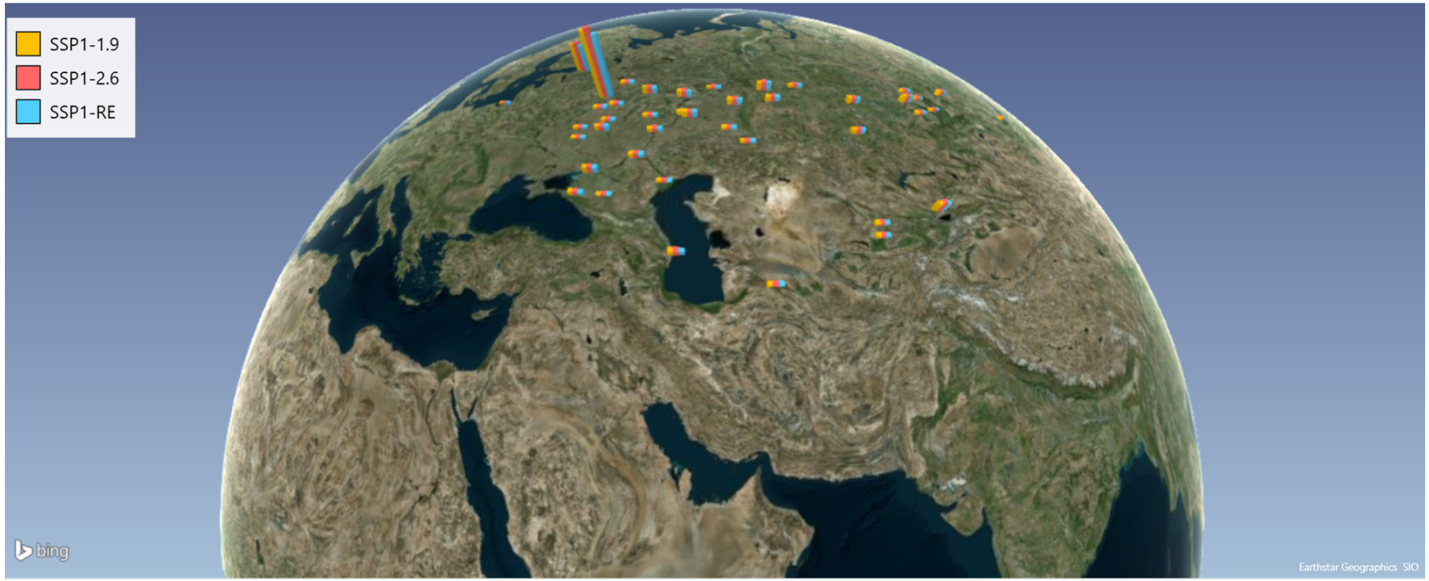
Co-benefits of 100% RE in these 3 urban areas:
~ 201 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

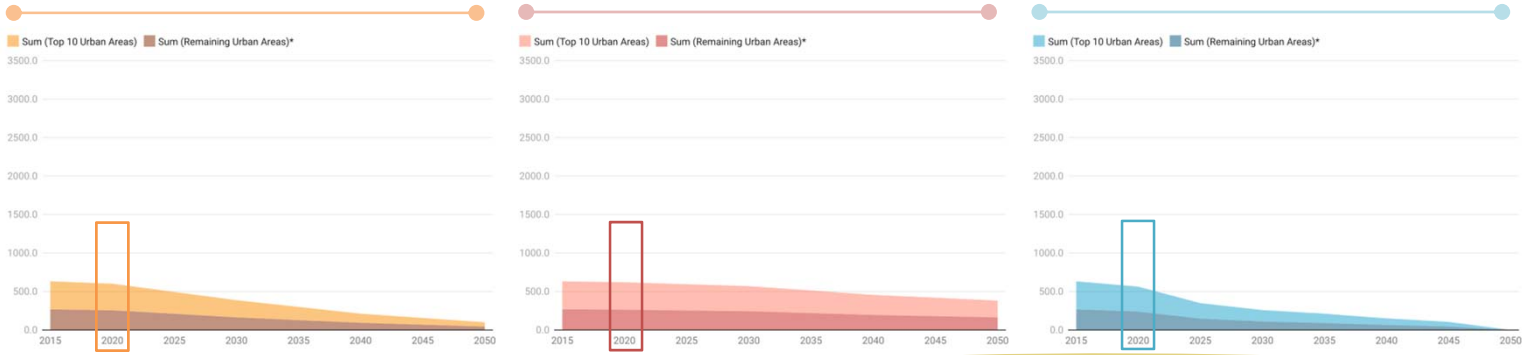
Sources: Ministry of Environment and Urbanization; Barcelona's Climate Plan 2018 – 2030

Future Outlook of Emissions for 420 Urban Areas

In Eurasia, urban emissions for 44 of the top 420 urban areas are 591.3 ± 28.4 $MtCO_2eq$ in 2020

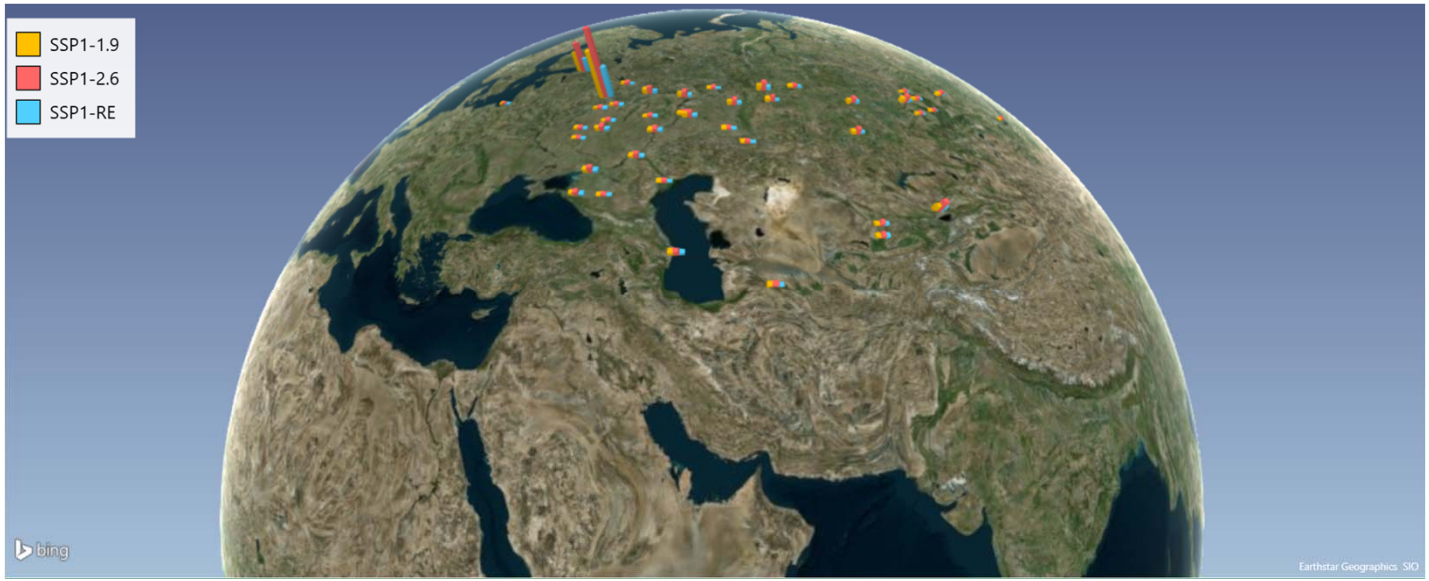


Urban Emissions
$MtCO_2eq$ per year

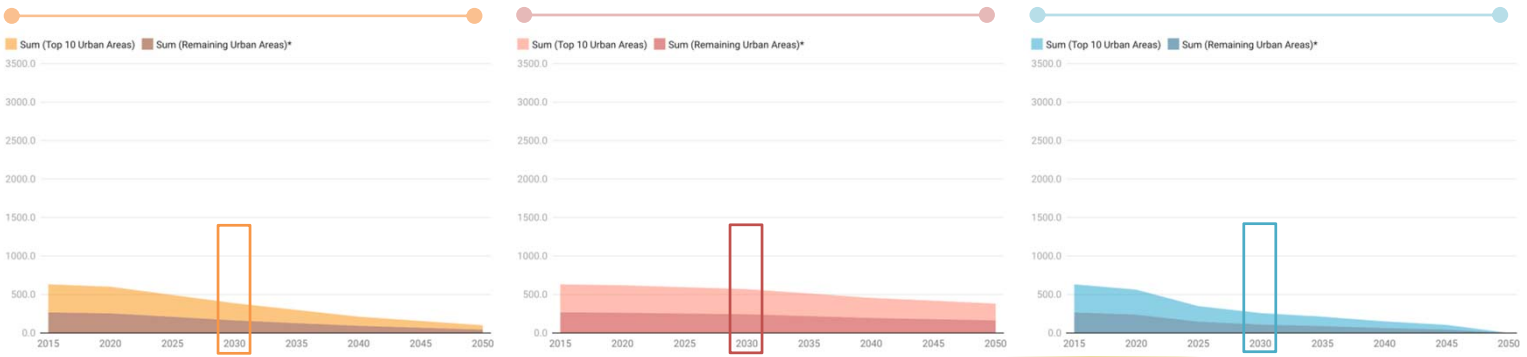


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 386.4, 569.6 or 258.3 $MtCO_2eq$ in 2030

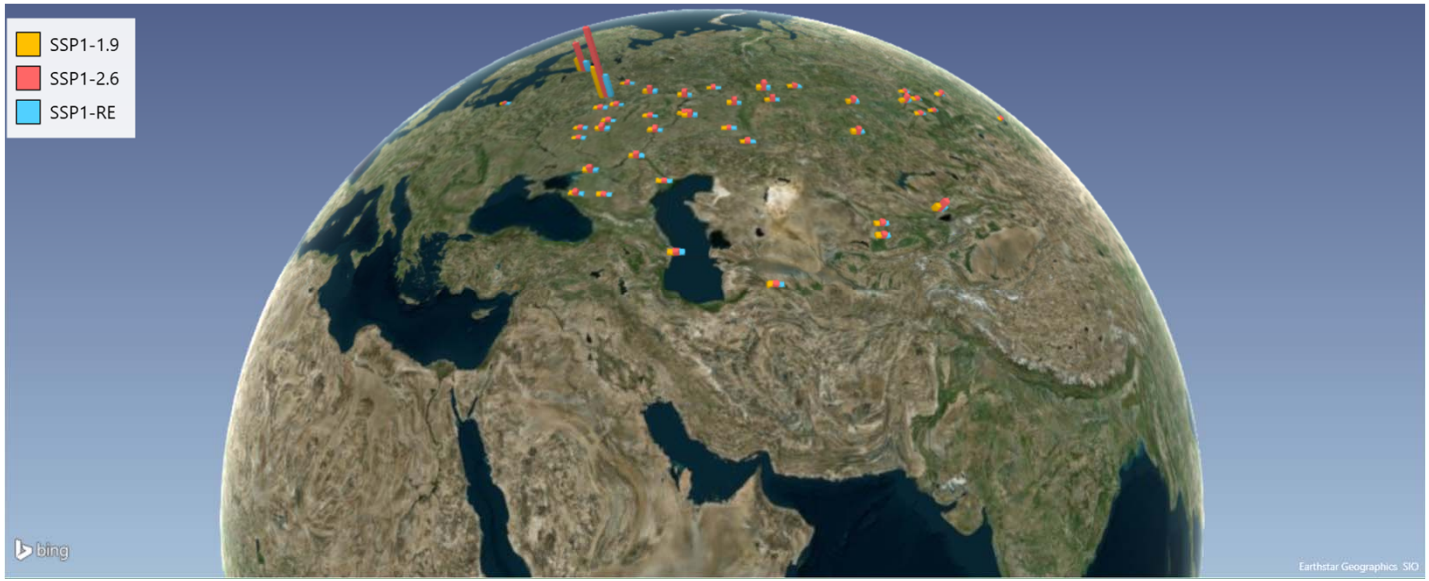


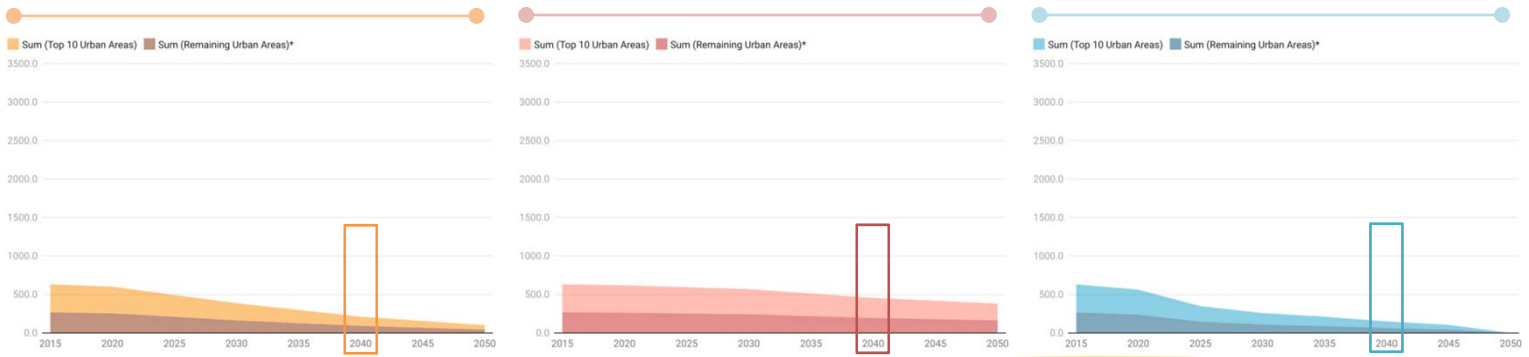
Urban Emissions
$MtCO_2eq$ per year



Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 211.7, 456.5 or 150.8 $MtCO_2eq$ in 2040

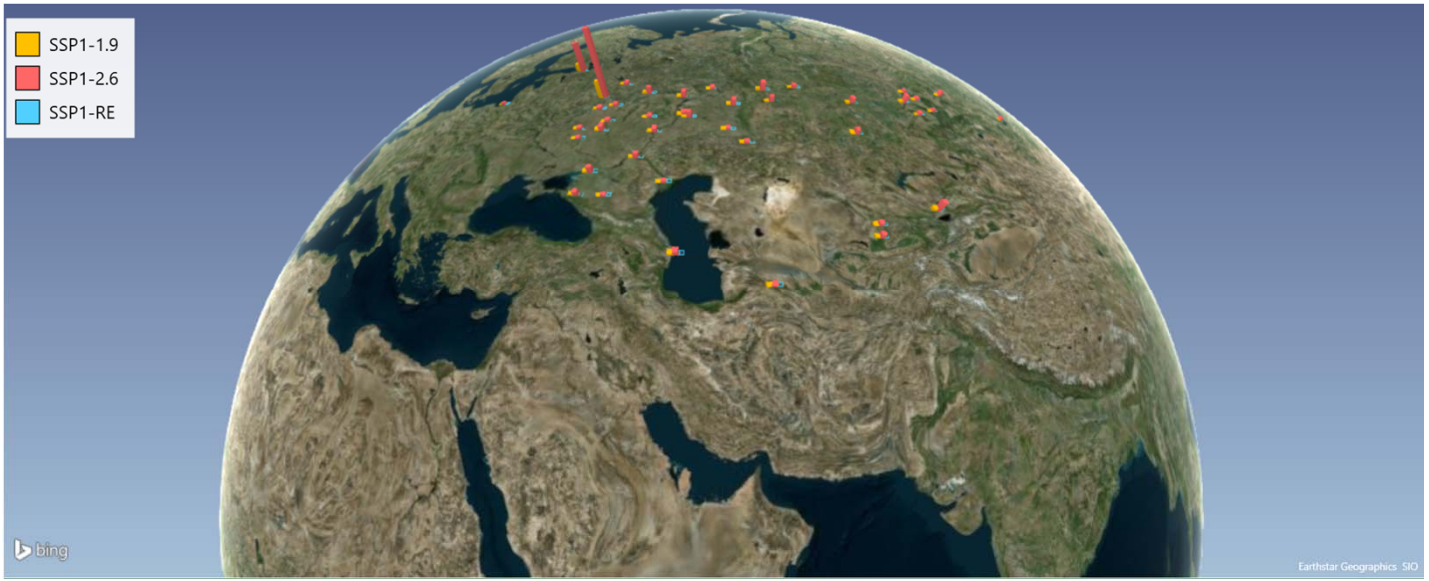




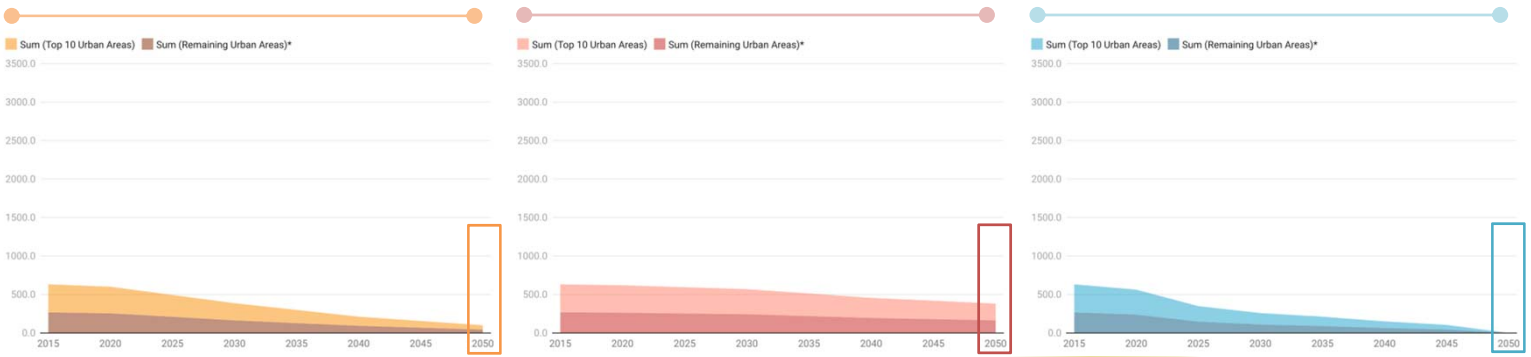
Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 99.5, 381.3 or ~0.0 $MtCO_2eq$ in 2050

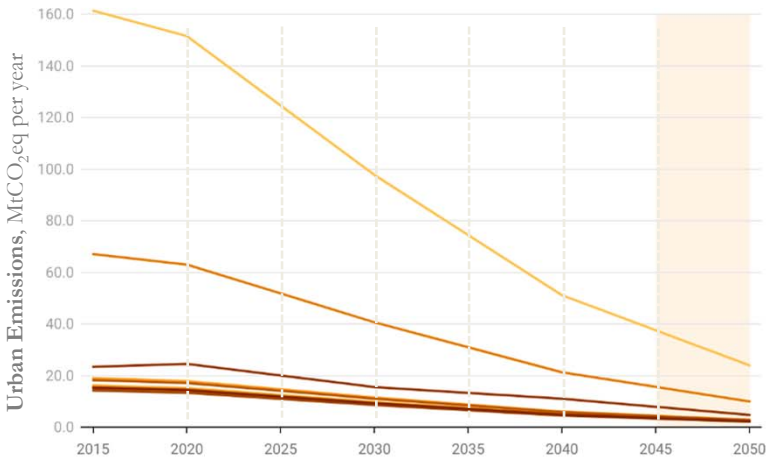


Urban Emissions
$MtCO_2eq$ per year



Top 10 Emitting Urban Areas – Eurasia

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 289.7 $MtCO_2eq$ by 2050



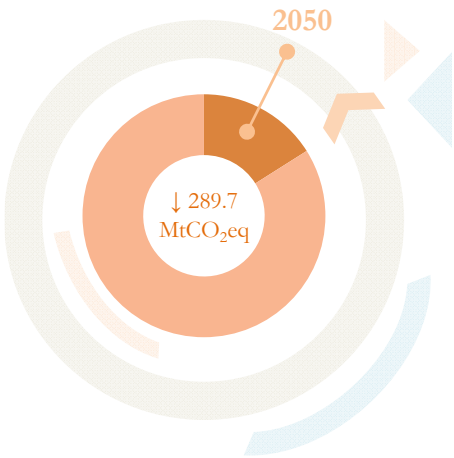
Search in table

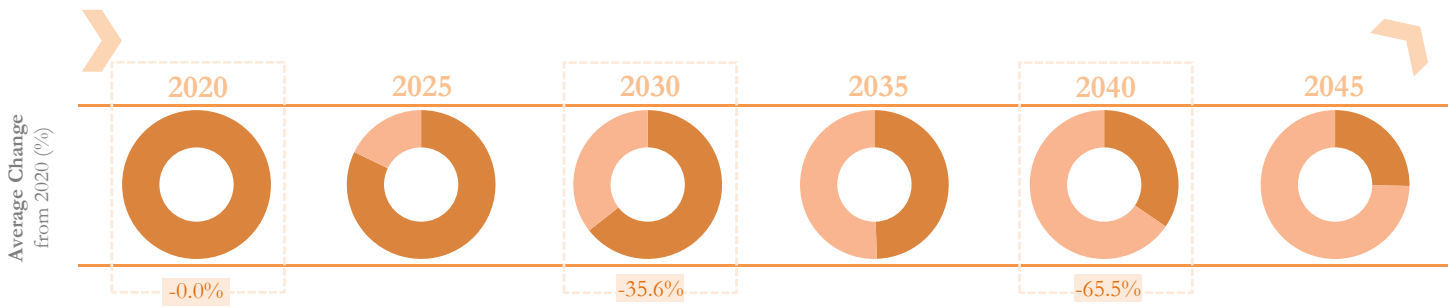
0.7 — 161.3

Region → Eurasia

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Moscow	161.3	151.5	124.6	97.7	74.4	51.1	37.5	23.9
Saint Petersburg	67.1	63.0	51.8	40.6	30.9	21.3	15.6	9.9
Almaty	23.4	24.5	20.0	15.5	13.3	11.0	7.9	4.8
Yekaterinburg	19.0	17.8	14.7	11.5	8.8	6.0	4.4	2.8
Novosibirsk	18.2	17.1	14.1	11.0	8.4	5.8	4.2	2.7
Nizhniy Novgorod	16.2	15.2	12.5	9.8	7.5	5.1	3.8	2.4
Kazan	15.6	14.6	12.0	9.4	7.2	4.9	3.6	2.3
Samara	15.2	14.3	11.8	9.2	7.0	4.8	3.5	2.3
Ufa	14.6	13.7	11.3	8.9	6.7	4.6	3.4	2.2
Rostov-on-Don	14.2	13.3	11.0	8.6	6.5	4.5	3.3	2.1

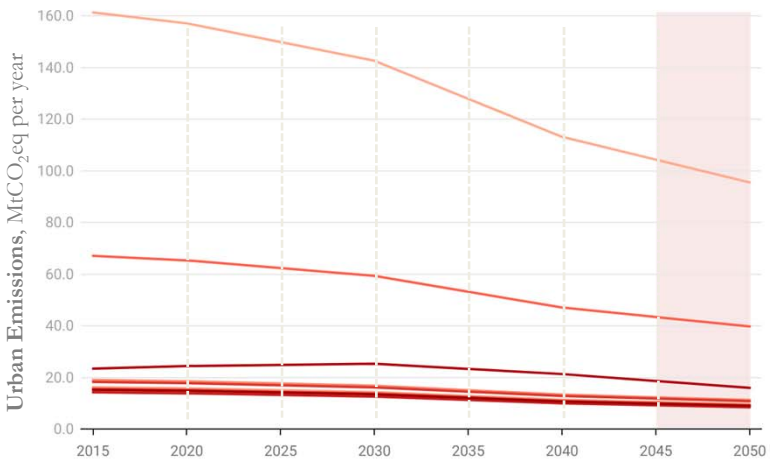
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – Eurasia

While reductions in SSP1-2.6 remain limited at 138.8 $MtCO_2eq$ by 2050, largely forgoing a missed 1.5°C target



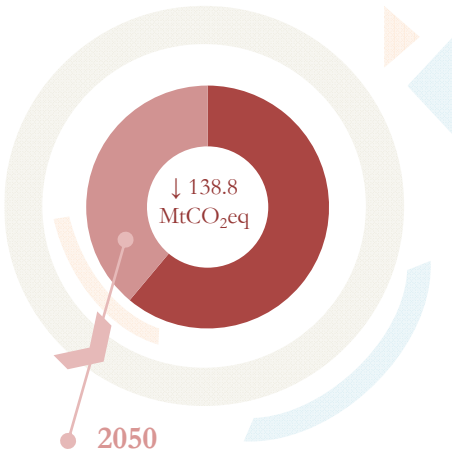
Search in table

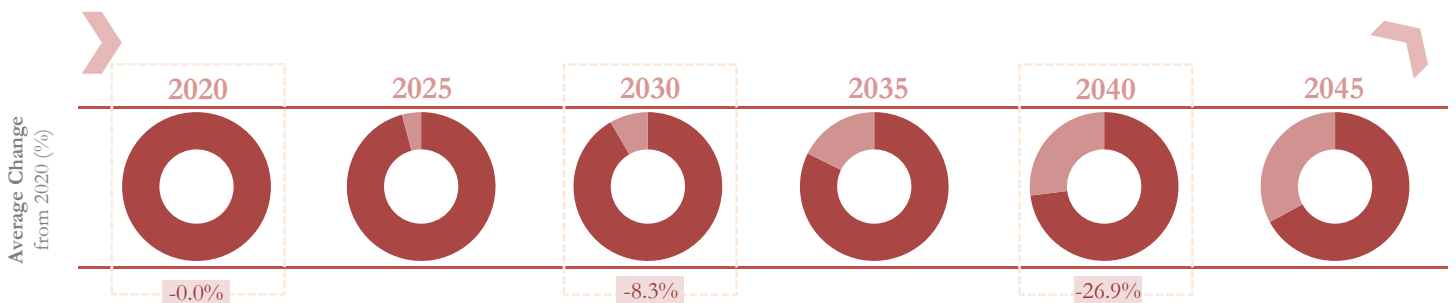
2.7 — 161.3

Region → Eurasia

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Moscow	161.3	157.1	149.8	142.6	127.9	113.1	104.3	95.5
Saint Petersburg	67.1	65.3	62.3	59.3	53.1	47.0	43.4	39.7
Almaty	23.4	24.4	24.8	25.3	23.3	21.3	18.6	15.9
Yekaterinburg	19.0	18.5	17.6	16.8	15.0	13.3	12.3	11.2
Novosibirsk	18.2	17.7	16.9	16.1	14.4	12.8	11.8	10.8
Nizhniy Novgorod	16.2	15.7	15.0	14.3	12.8	11.3	10.4	9.6
Kazan	15.6	15.2	14.5	13.8	12.3	10.9	10.1	9.2
Samara	15.2	14.8	14.1	13.5	12.1	10.7	9.8	9.0
Ufa	14.6	14.2	13.6	12.9	11.6	10.3	9.5	8.7
Rostov-on-Don	14.2	13.8	13.2	12.5	11.2	9.9	9.2	8.4

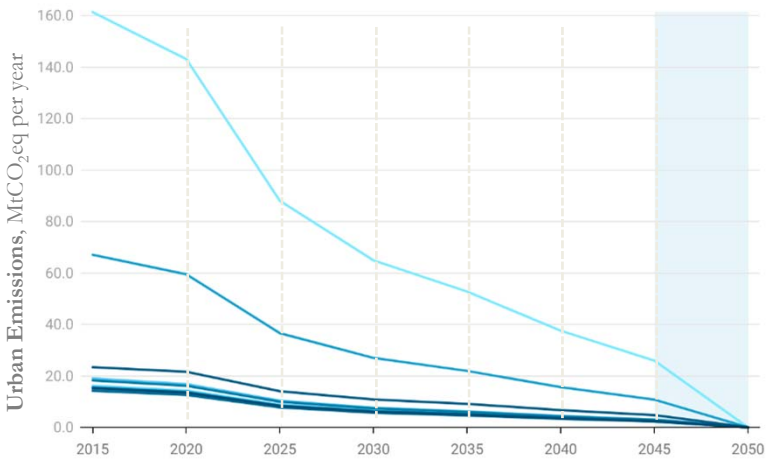
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – Eurasia

For these areas, 100% RE scenarios provide opportunities to eliminate 324.3 $MtCO_2eq$ of urban emissions in 2050



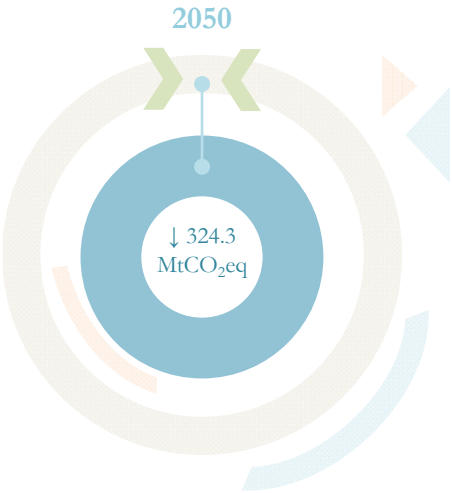
Search in table

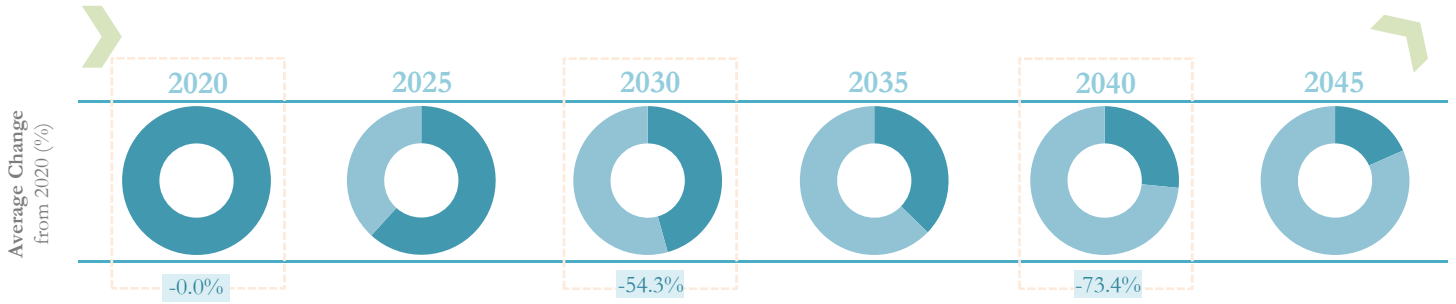
0.0 — 161.3

Region → Eurasia

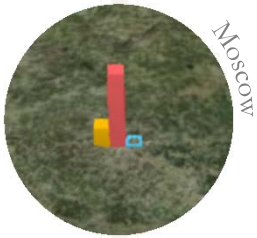
Uj	2015	2020	2025	2030	2035	2040	2045	2050
Moscow	161.3	143.1	88.0	64.9	52.7	37.6	25.9	0.0
Saint Petersburg	67.1	59.5	36.6	27.0	21.9	15.6	10.8	0.0
Almaty	23.4	21.6	14.0	10.9	9.1	6.7	4.8	0.0
Yekaterinburg	19.0	16.8	10.3	7.6	6.2	4.4	3.0	0.0
Novosibirsk	18.2	16.2	9.9	7.3	6.0	4.2	2.9	0.0
Nizhniy Novgorod	16.2	14.3	8.8	6.5	5.3	3.8	2.6	0.0
Kazan	15.6	13.8	8.5	6.3	5.1	3.6	2.5	0.0
Samara	15.2	13.5	8.3	6.1	5.0	3.5	2.4	0.0
Ufa	14.6	13.0	8.0	5.9	4.8	3.4	2.3	0.0
Rostov-on-Don	14.2	12.6	7.7	5.7	4.6	3.3	2.3	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.



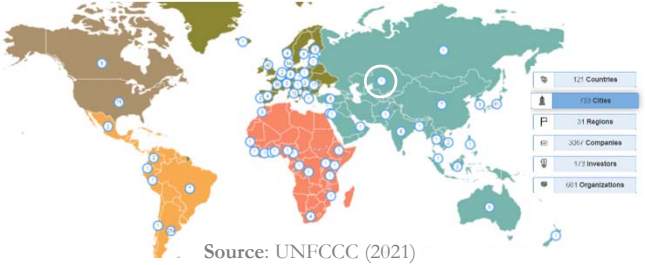


Actions Urban Areas Are Taking and Opportunities



- Intends a major urban area to be zero emissions by 2030 **with more opportunities**
- As other regions, impacted by wildfires, including unprecedented ones in 2021

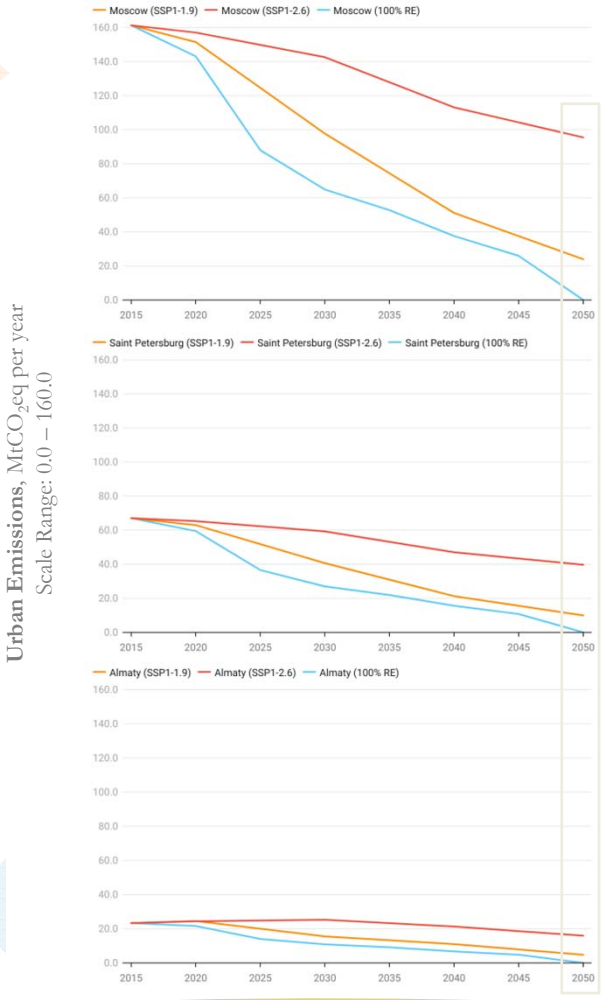
- Climate strategy of St. Petersburg to 2030
- **Focuses on climate adaptation** for urban infrastructure without mitigation targets



Source: UNFCCC (2021)

- Currently, only Nur-Sultan from Kazakhstan is taking part as a city in Net Zero by 2050

Sources: Moscow Times (2021); UNFCCC (2021); Administration of St. Petersburg



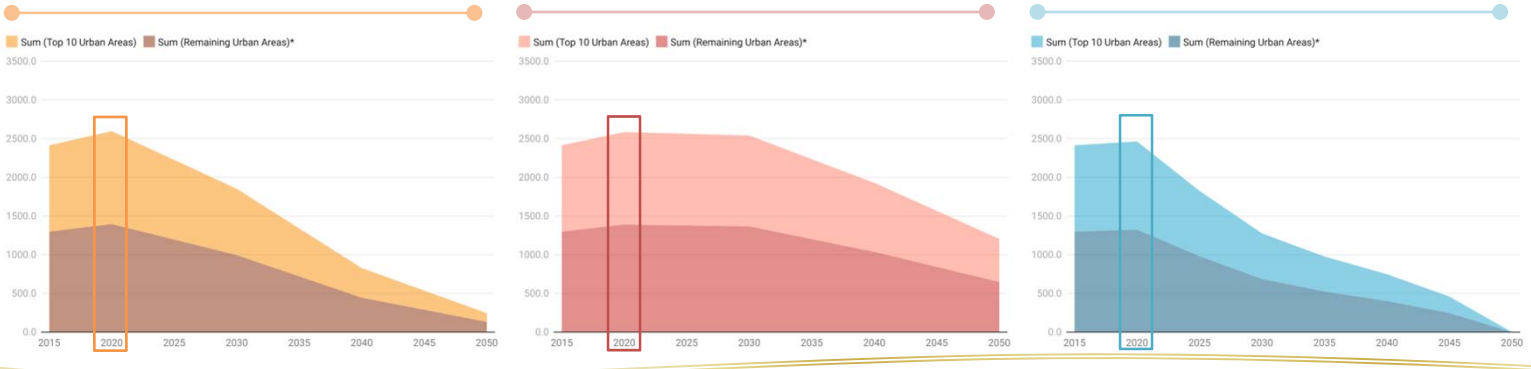
Making the complete shift for the urban energy system and beyond

Co-benefits of 100% RE in these 3 urban areas:
~ 389 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

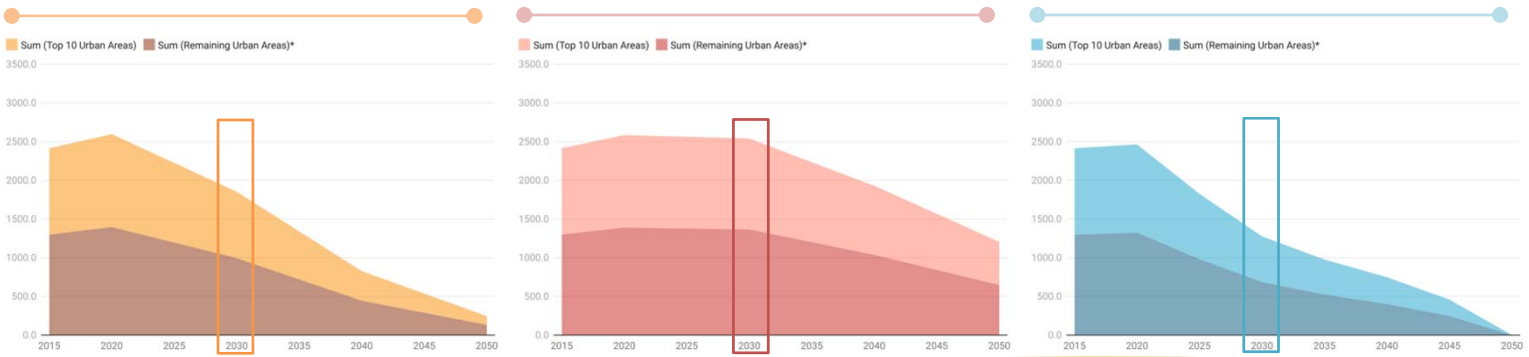
In Asia and Pacific (China), urban emissions for 87 of the top 420 urban areas are 2530.6 ± 66.8 $MtCO_2eq$ in 2020



Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

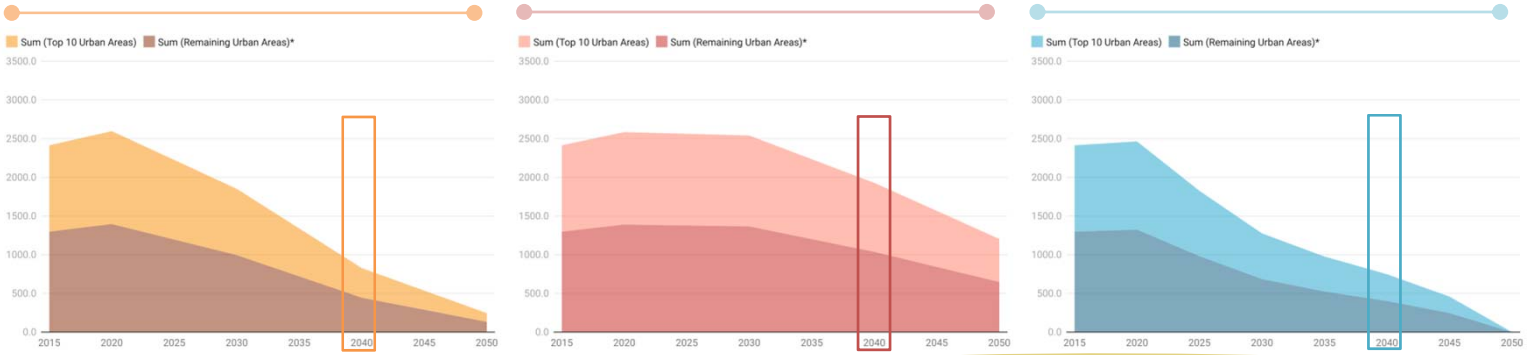
Across the SSP1 scenarios, urban emission pathways can lead to 1851.0, 2540.0 or 1274.8 $MtCO_2eq$ in 2030



Urban Emissions
$MtCO_2eq$ per year

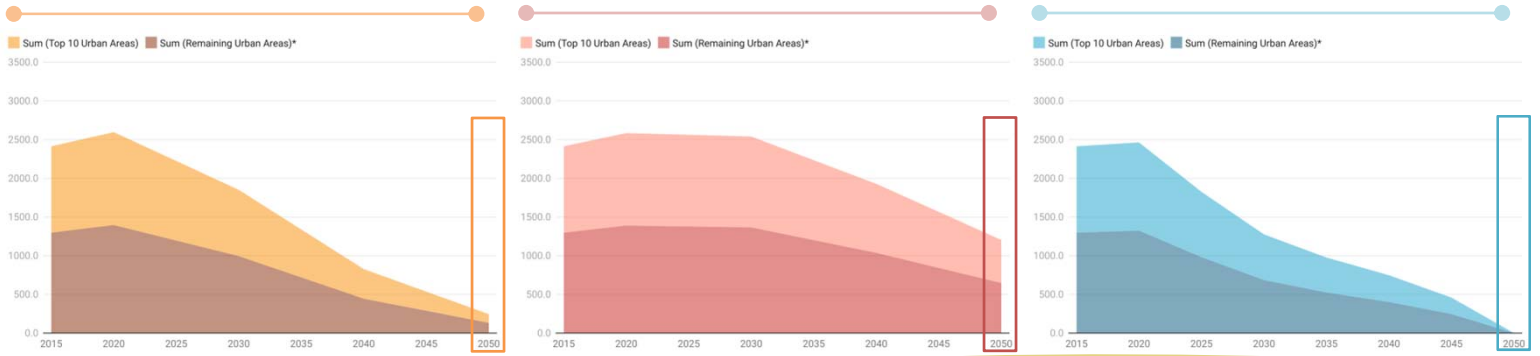
Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 827.0, 1928.3 or 747.8 $MtCO_2eq$ in 2040



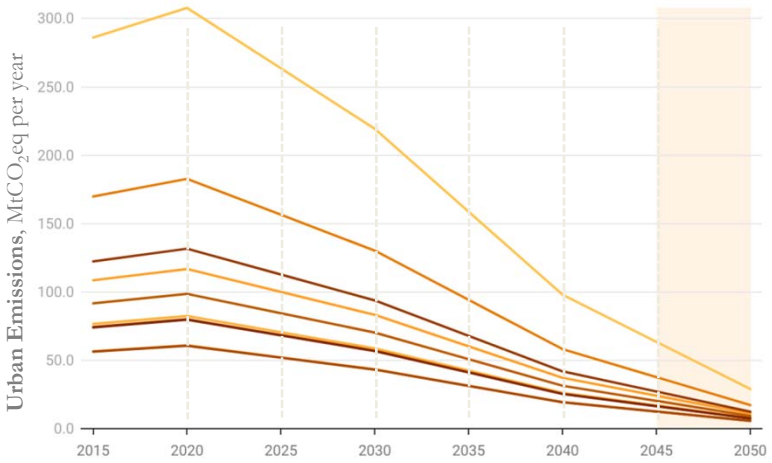
Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 244.5, 1203.8 or ~0.0 $MtCO_2eq$ in 2050



Top 10 Emitting Areas – Asia and Pacific (China)

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 1088.1 $MtCO_2eq$ by 2050



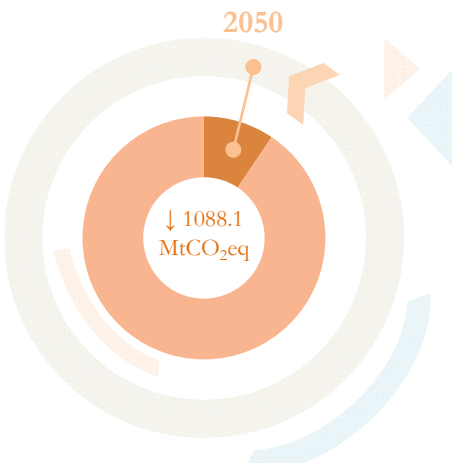
Search in table

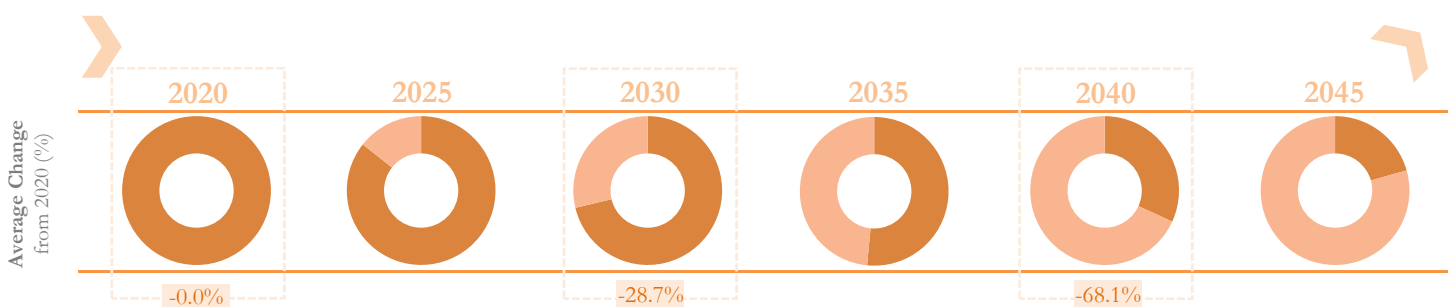
0.1 307.8

Region → Asia and Pacific (China)

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Hong Kong	286.1	307.8	263.6	219.3	158.7	98.0	63.5	29.0
Shanghai	169.8	182.7	156.5	130.2	94.2	58.2	37.7	17.2
Guangzhou	122.4	131.6	112.7	93.8	67.9	41.9	27.2	12.4
Tianjin	108.6	116.8	100.0	83.2	60.2	37.2	24.1	11.0
Chongqing	91.6	98.6	84.4	70.3	50.8	31.4	20.3	9.3
Beijing	76.6	82.4	70.5	58.7	42.5	26.2	17.0	7.8
Wuhan	74.4	80.0	68.5	57.0	41.3	25.5	16.5	7.5
Shenyang	74.1	79.7	68.2	56.8	41.1	25.4	16.4	7.5
Nanjing	56.6	60.9	52.1	43.4	31.4	19.4	12.6	5.7
Baotou	56.3	60.6	51.9	43.2	31.2	19.3	12.5	5.7

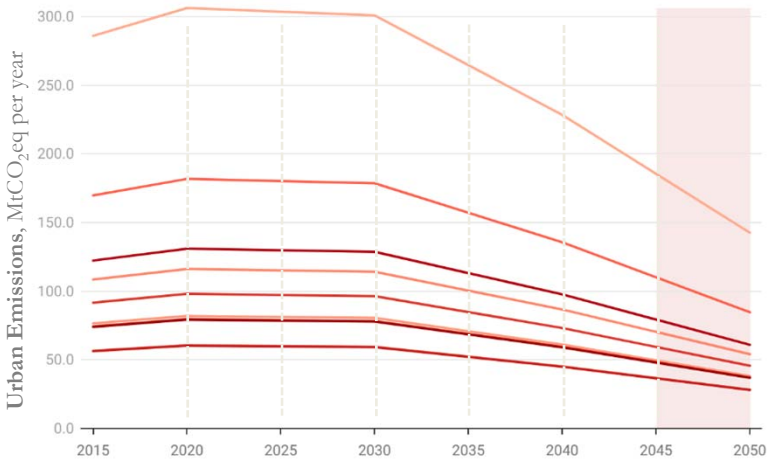
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Asia and Pacific (China)

While reductions in SSP1-2.6 remain limited at 638.7 $MtCO_2eq$ by 2050, largely forgoing a missed 1.5°C target



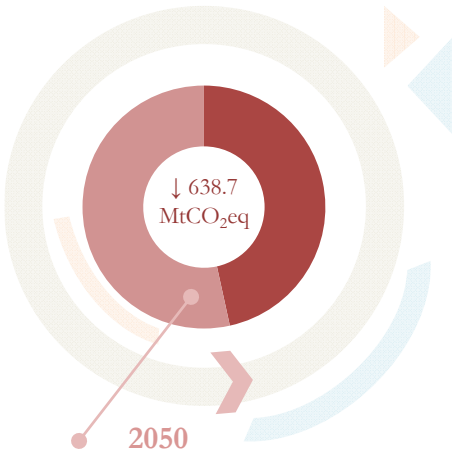
Search in table

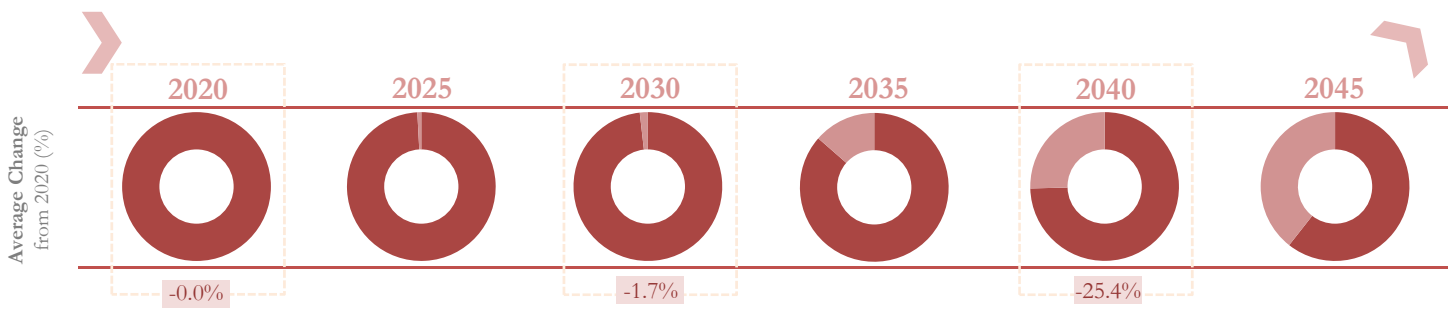
0.5 306.3

Region → Asia and Pacific (China)

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Hong Kong	286.1	306.3	303.6	301.0	264.7	228.5	185.6	142.6
Shanghai	169.8	181.8	180.3	178.7	157.2	135.6	110.2	84.7
Guangzhou	122.4	131.0	129.9	128.7	113.2	97.7	79.4	61.0
Tianjin	108.6	116.2	115.2	114.2	100.5	86.7	70.4	54.1
Chongqing	91.6	98.1	97.3	96.4	84.8	73.2	59.4	45.7
Beijing	76.6	82.0	81.3	80.6	70.9	61.2	49.7	38.2
Wuhan	74.4	79.6	79.0	78.3	68.8	59.4	48.3	37.1
Shenyang	74.1	79.3	78.6	77.9	68.5	59.2	48.0	36.9
Nanjing	56.6	60.6	60.1	59.5	52.4	45.2	36.7	28.2
Baotou	56.3	60.3	59.8	59.3	52.1	45.0	36.5	28.1

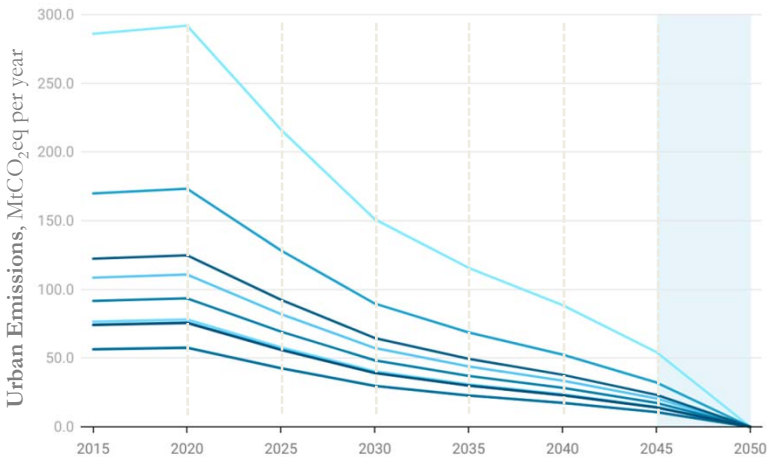
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Asia and Pacific (China)

For these areas, 100% RE scenarios provide opportunities to eliminate 1139.4 $MtCO_2eq$ of urban emissions in 2050



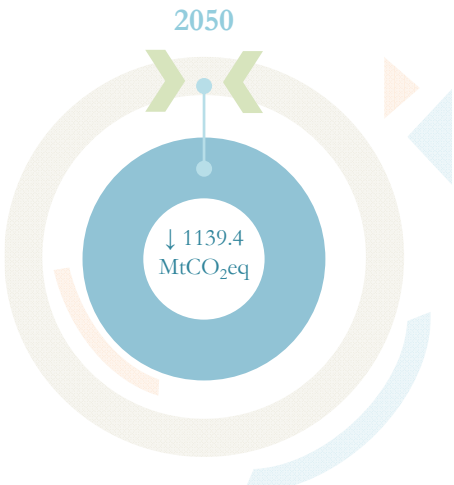
Search in table

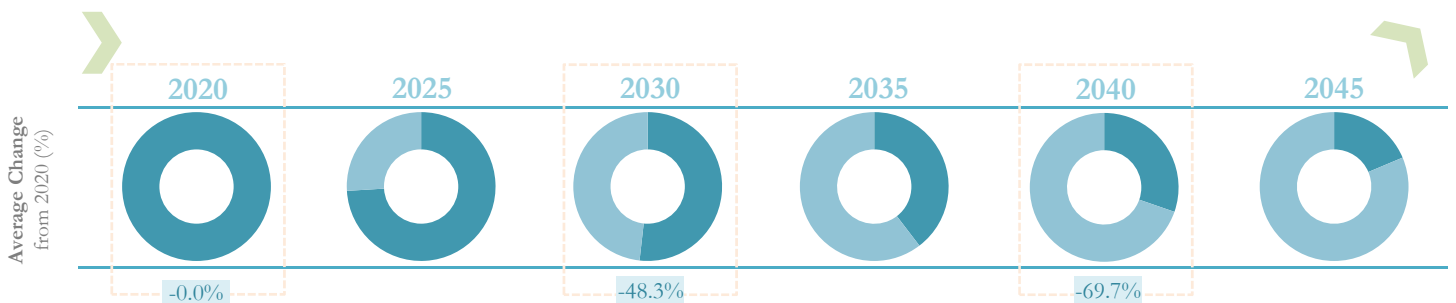
0.0 292.0

Region → Asia and Pacific (China)

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Hong Kong	286.1	292.0	216.3	151.1	115.7	88.6	54.4	0.0
Shanghai	169.8	173.3	128.4	89.7	68.7	52.6	32.3	0.0
Guangzhou	122.4	124.9	92.5	64.6	49.5	37.9	23.3	0.0
Tianjin	108.6	110.8	82.1	57.3	43.9	33.6	20.6	0.0
Chongqing	91.6	93.5	69.3	48.4	37.1	28.4	17.4	0.0
Beijing	76.6	78.1	57.9	40.4	31.0	23.7	14.6	0.0
Wuhan	74.4	75.9	56.2	39.3	30.1	23.0	14.1	0.0
Shenyang	74.1	75.6	56.0	39.1	30.0	22.9	14.1	0.0
Nanjing	56.6	57.8	42.8	29.9	22.9	17.5	10.8	0.0
Baotou	56.3	57.5	42.6	29.8	22.8	17.5	10.7	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

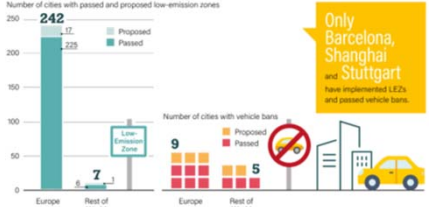




Actions Urban Areas Are Taking and Opportunities

- Has declared a committment to a net-zero target while focusing on zero emission buses, **requiring integrated mitigation solutions**

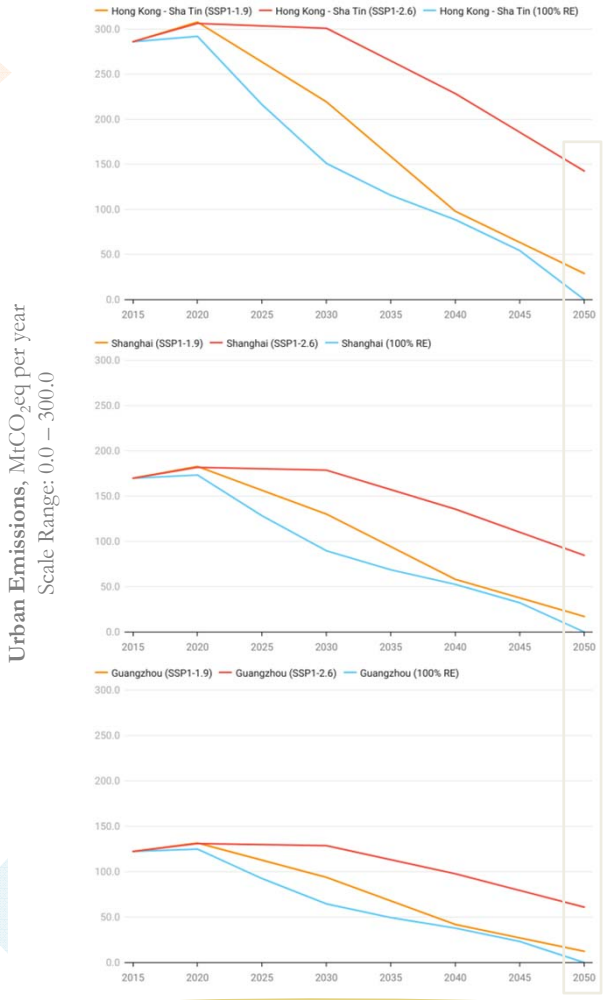
- Has a mechanism to **coordinate fragmented policy making** with RE policies increasing
- Implements **both a low-emission zone and vehicle ban** as part of mitigation efforts



Source: REN21 (2021)

- Can learn from other urban areas, including **2035 goals in Tianjin** to integrate RE in district networks, e.g. cooling for Guangzhou

Sources: REN21 (2021); Peng and Bai (2020); Tianjin Municipal People's Government (2021)



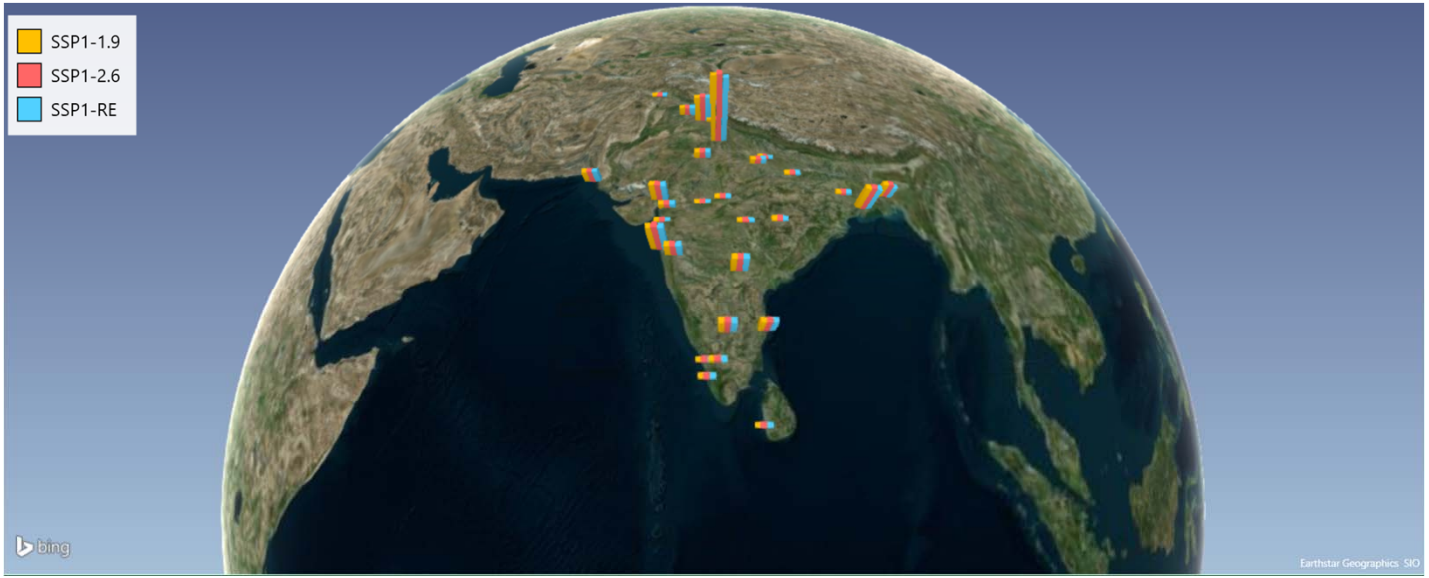
Making the complete shift for the urban energy system and beyond

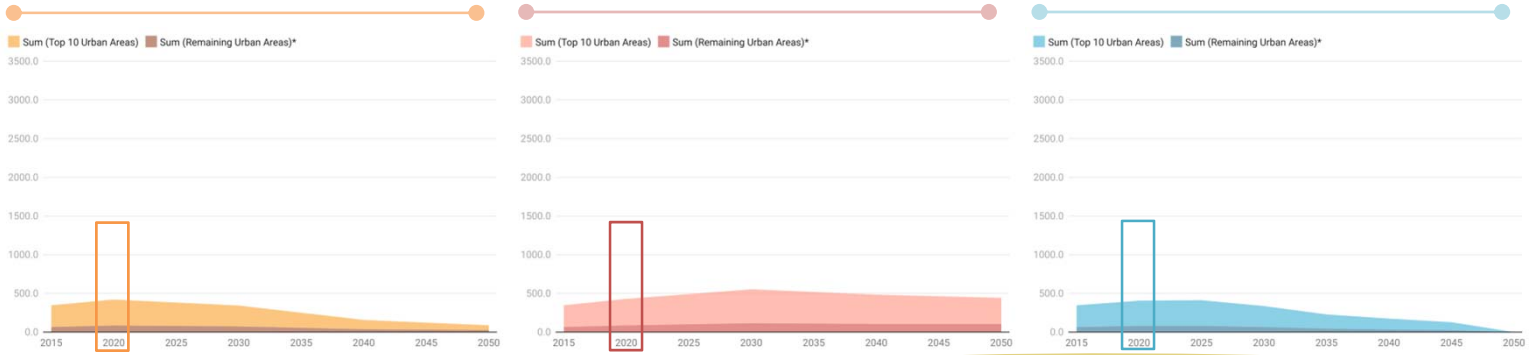
Co-benefits of 100% RE in these 3 urban areas:
~ 908 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

In Asia and Pacific (SAARC), urban emissions for 29 of the top 420 urban areas are 418.0 ± 11.5 $MtCO_2eq$ in 2020

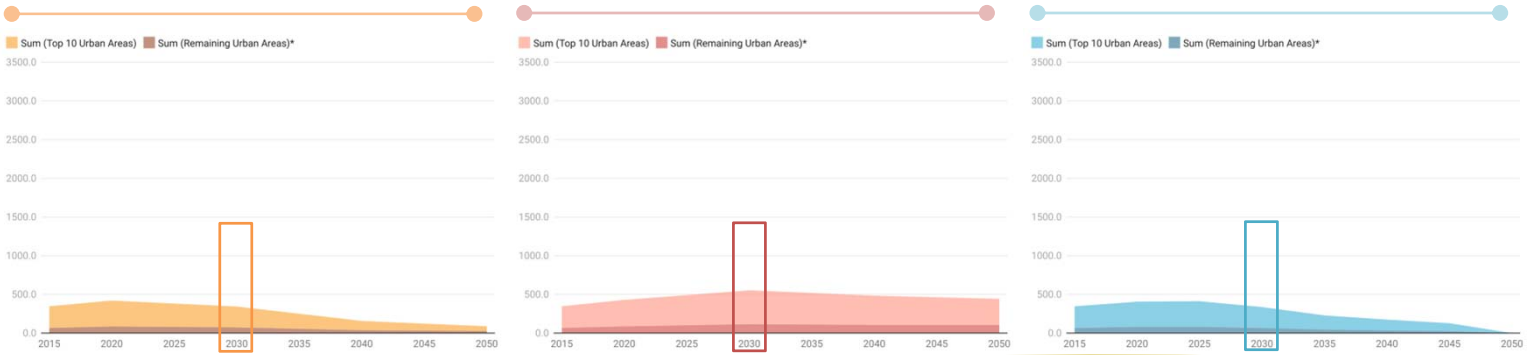




Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

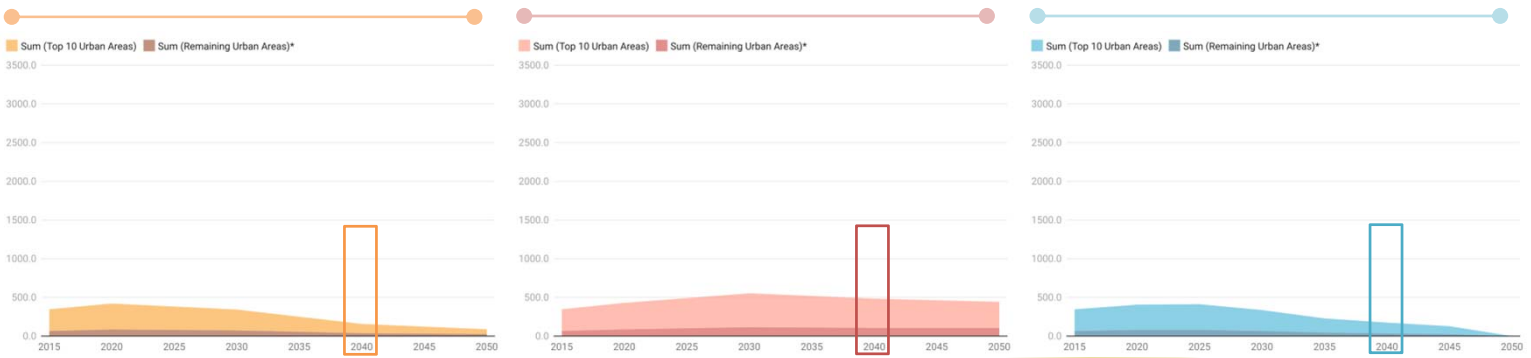
Across the SSP1 scenarios, urban emission pathways can lead to 343.5, 552.5 or 336.5 $MtCO_2eq$ in 2030



Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

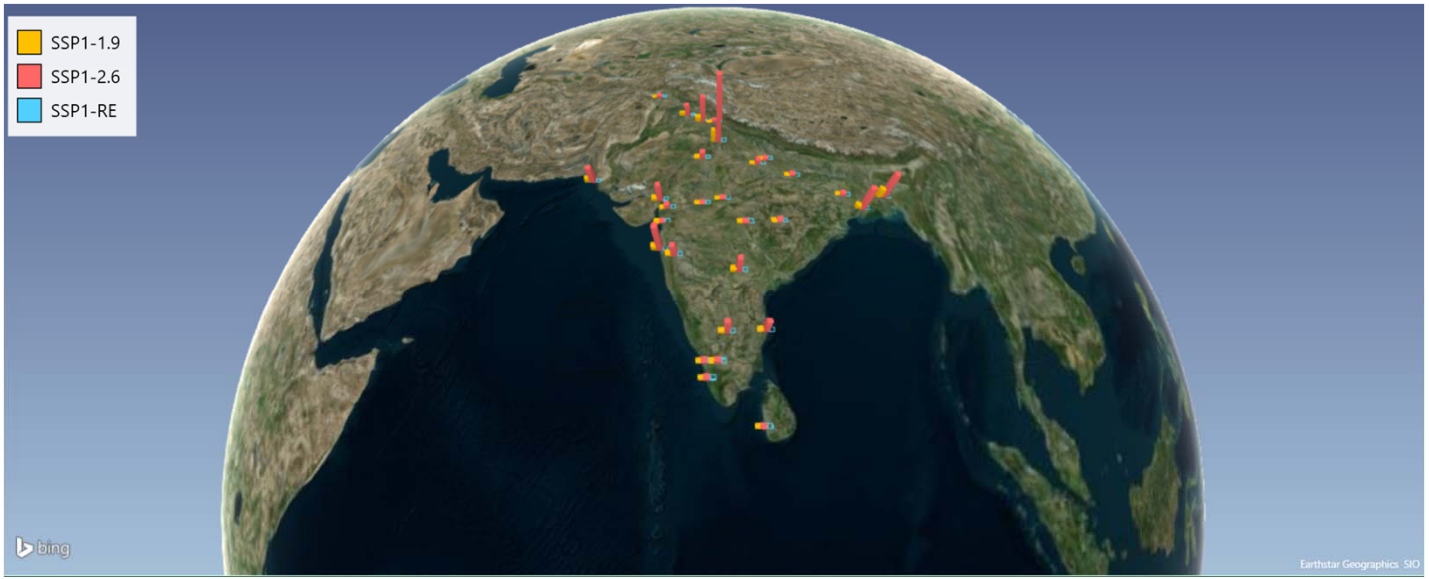
Across the SSP1 scenarios, urban emission pathways can lead to 156.9, 483.8 or 174.9 $MtCO_2eq$ in 2040

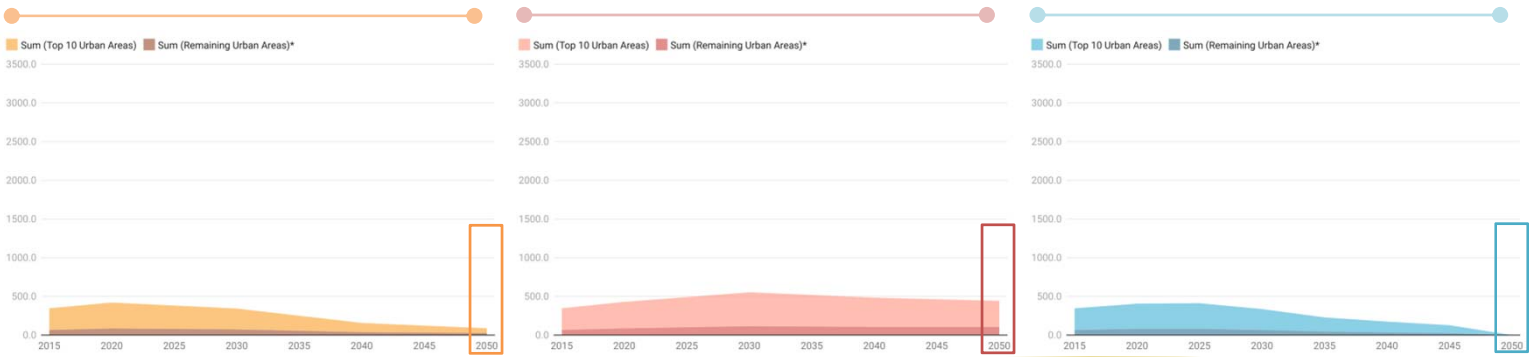


Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 87.7, 443.1 or ~0.0 $MtCO_2eq$ in 2050

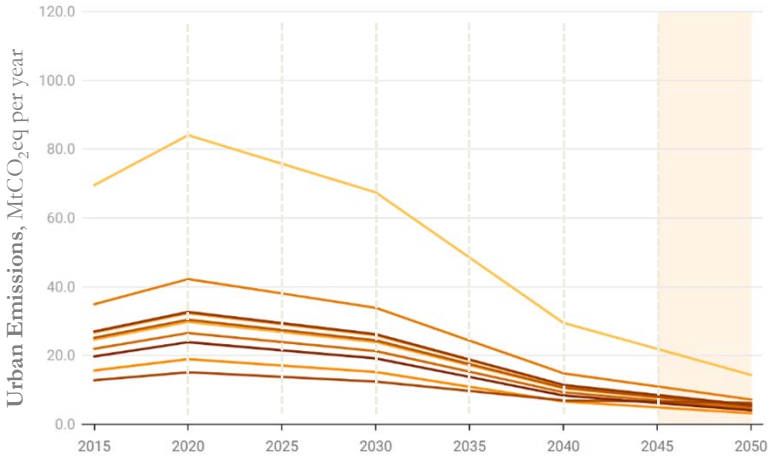




Urban Emissions
$MtCO_2eq$ per year

Top 10 Emitting Areas – Asia and Pacific (SAARC)

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 275.0 $MtCO_2eq$ by 2050



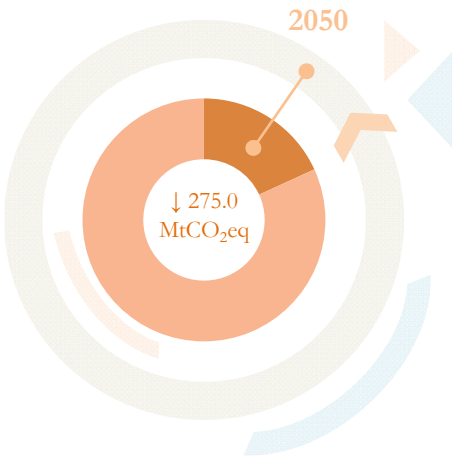
Search in table

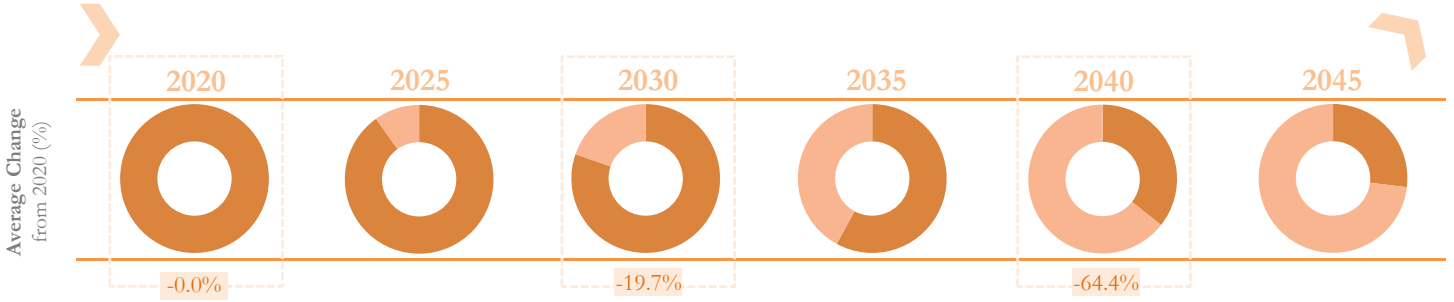
0.1 84.1

Region → Asia and Pacific (SAARC)

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Delhi	69.5	84.1	75.8	67.4	48.5	29.5	21.9	14.4
Mumbai	34.9	42.2	38.1	33.9	24.3	14.8	11.0	7.2
Bangalore	27.0	32.7	29.4	26.2	18.8	11.5	8.5	5.6
Kolkata	26.7	32.3	29.1	25.9	18.6	11.3	8.4	5.5
Ludhiana	25.2	30.4	27.4	24.4	17.5	10.7	7.9	5.2
Chennai	24.6	29.8	26.8	23.9	17.2	10.5	7.8	5.1
Hyderabad	22.0	26.6	23.9	21.3	15.3	9.3	6.9	4.5
Ahmadabad	19.8	23.9	21.5	19.2	13.8	8.4	6.2	4.1
Pune	15.7	19.0	17.1	15.2	10.9	6.7	4.9	3.2
Karachi	12.8	15.1	13.8	12.4	9.7	7.0	6.6	6.3

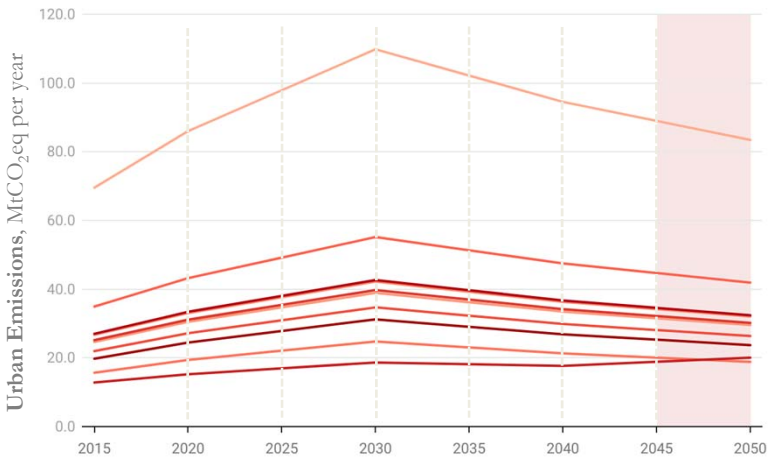
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Asia and Pacific (SAARC)

In SSP1-2.6, total emissions do not even start reducing until 2050 when there is only a 4.9 $MtCO_2eq$ reduction



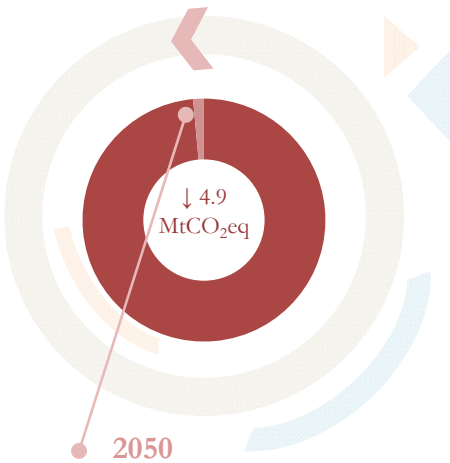
Search in table

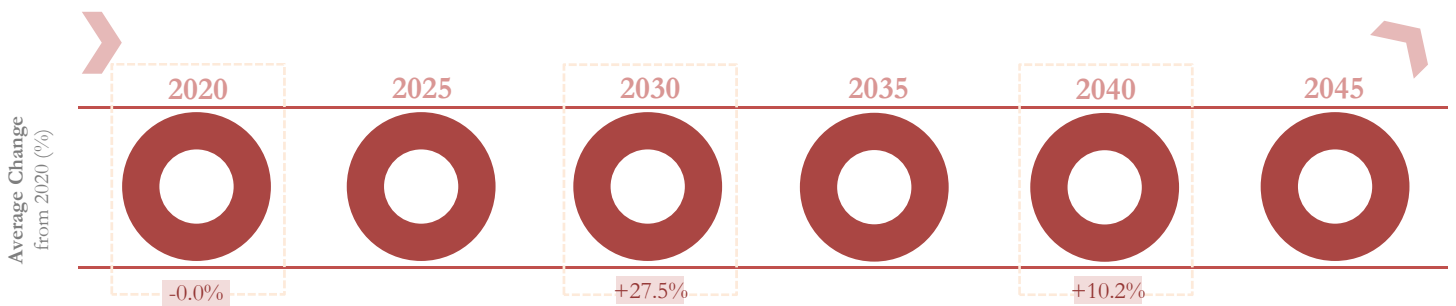
0.4 109.8

Region → Asia and Pacific (SAARC)

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Delhi	69.5	86.0	97.9	109.8	102.2	94.5	89.0	83.4
Mumbai	34.9	43.2	49.2	55.2	51.3	47.5	44.7	41.9
Bangalore	27.0	33.4	38.0	42.7	39.7	36.7	34.6	32.4
Kolkata	26.7	33.0	37.6	42.2	39.2	36.3	34.2	32.1
Ludhiana	25.2	31.1	35.4	39.7	37.0	34.2	32.2	30.2
Chennai	24.6	30.5	34.7	38.9	36.2	33.5	31.5	29.6
Hyderabad	22.0	27.2	30.9	34.7	32.3	29.8	28.1	26.4
Ahmadabad	19.8	24.4	27.8	31.2	29.0	26.9	25.3	23.7
Pune	15.7	19.4	22.1	24.8	23.0	21.3	20.1	18.8
Karachi	12.8	15.2	16.9	18.7	18.2	17.7	18.9	20.1

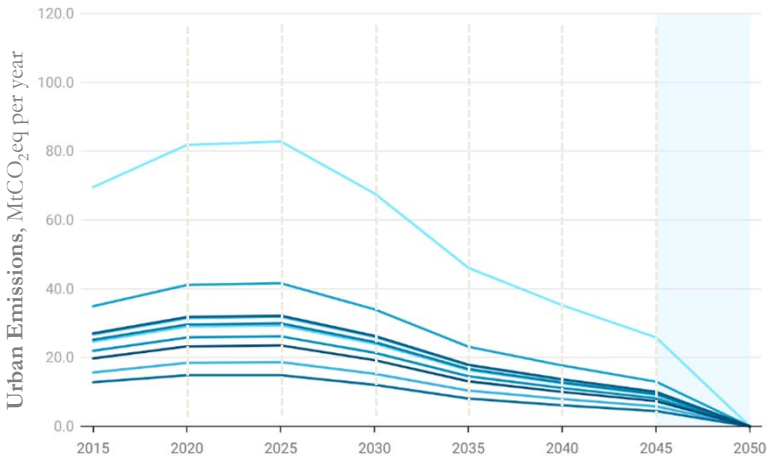
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Asia and Pacific (SAARC)

For these areas, 100% RE scenarios provide opportunities to eliminate 327.1 $MtCO_2eq$ of urban emissions in 2050



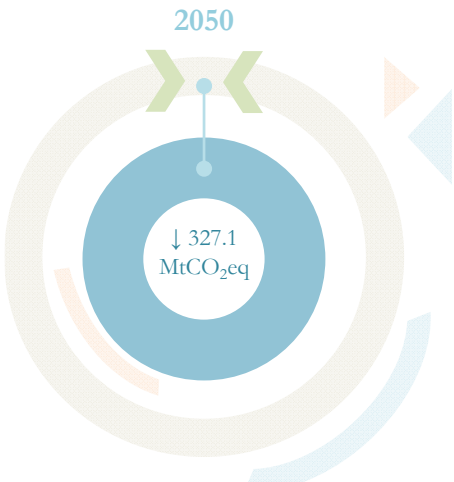
Search in table

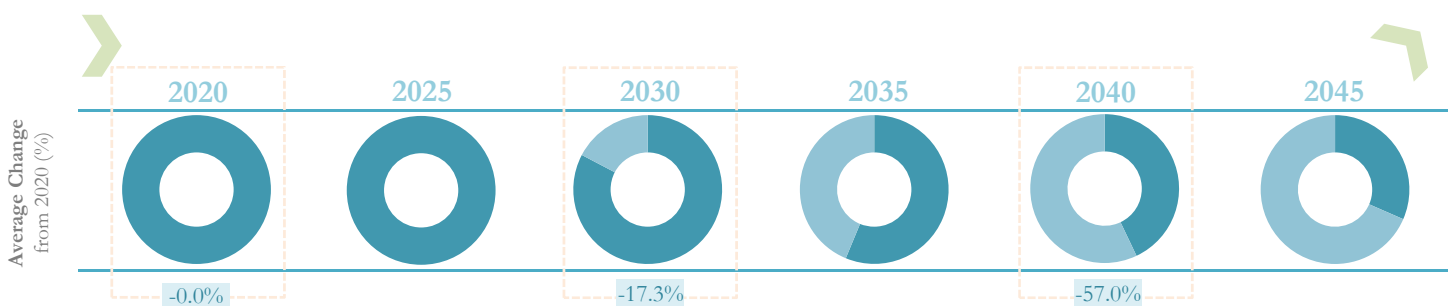
0.0 82.8

Region → Asia and Pacific (SAARC)

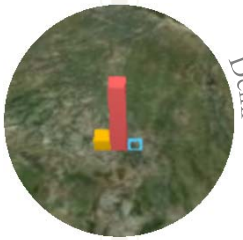
Uj	2015	2020	2025	2030	2035	2040	2045	2050
Delhi	69.5	81.8	82.8	67.7	46.1	35.2	25.8	0.0
Mumbai	34.9	41.1	41.6	34.0	23.1	17.7	13.0	0.0
Bangalore	27.0	31.8	32.2	26.3	17.9	13.7	10.0	0.0
Kolkata	26.7	31.4	31.8	26.0	17.7	13.5	9.9	0.0
Ludhiana	25.2	29.6	30.0	24.5	16.7	12.7	9.3	0.0
Chennai	24.6	29.0	29.3	24.0	16.3	12.5	9.2	0.0
Hyderabad	22.0	25.8	26.2	21.4	14.6	11.1	8.2	0.0
Ahmadabad	19.8	23.3	23.5	19.2	13.1	10.0	7.3	0.0
Pune	15.7	18.5	18.7	15.3	10.4	7.9	5.8	0.0
Karachi	12.8	14.9	14.9	12.1	8.1	6.1	4.5	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

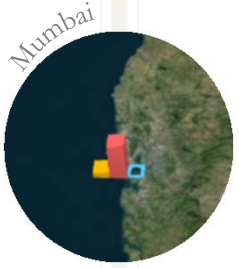




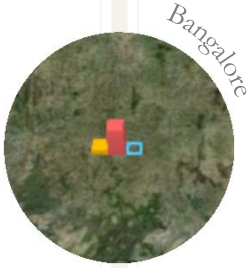
Actions Urban Areas Are Taking and Opportunities

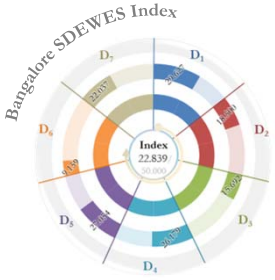


- **Aims to transition to clean and efficient cooling** within a city network alliance
- Delhi currently aims to increase city-wide installed capacity of RE by 2 GW by 2025



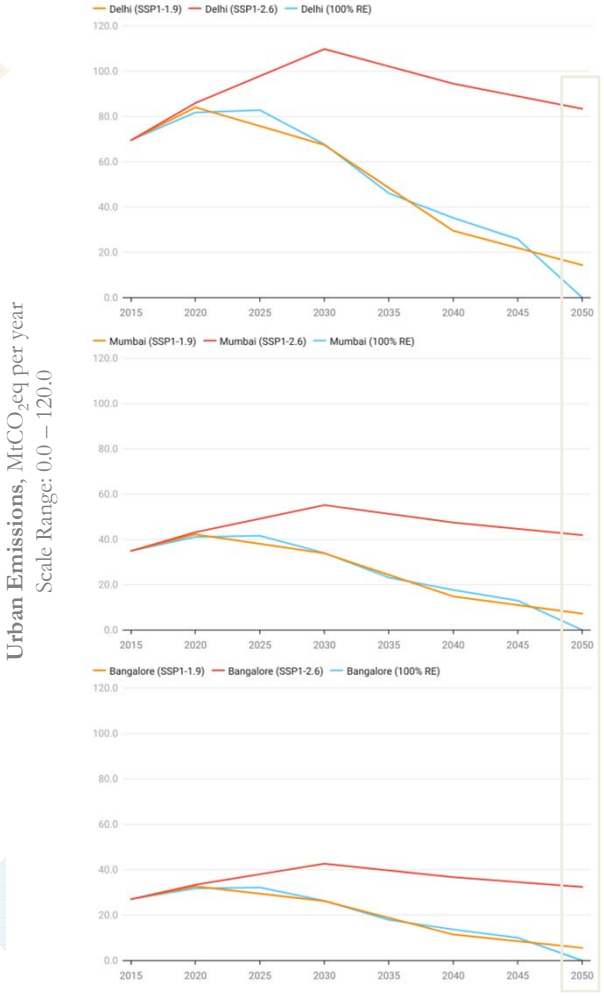
- Aims for **net zero CO_2 emissions by 2050**
- Also working to address water challenges due to climate change as a related initiative





- Bangalore and the region has a **6 GW wind/solar energy target for 2021**
- → SDEWES Index: Challenged City

Sources: Global Climate Action UNFCCC (2021); SDEWES Centre (2018)



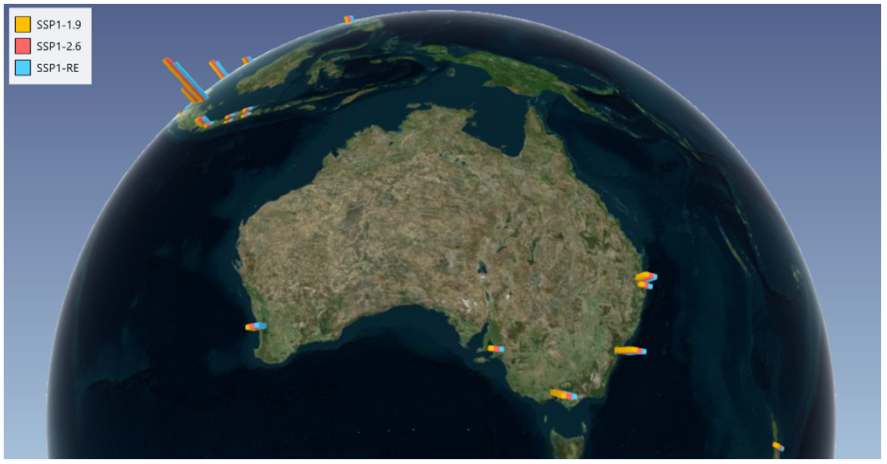
Making the complete shift for the urban energy system and beyond

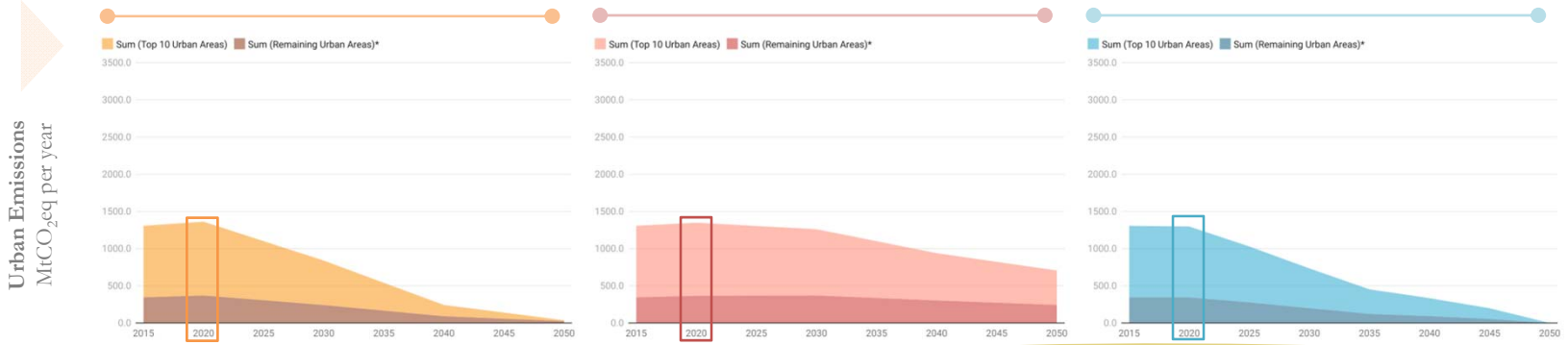
Co-benefits of 100% RE in these 3 urban areas:
~ 685 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

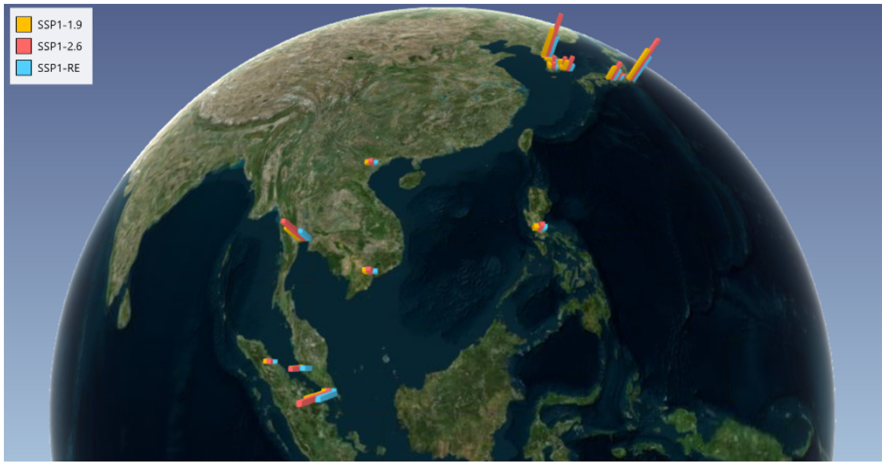
In other Asia and Pacific areas, urban emissions for 36 of the top 420 urban areas are 1329.4 ± 32.1 $MtCO_2eq$ in 2020

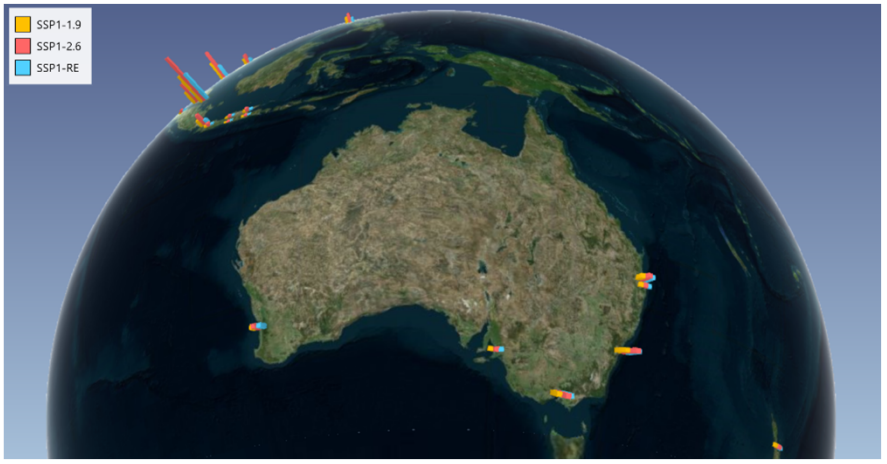


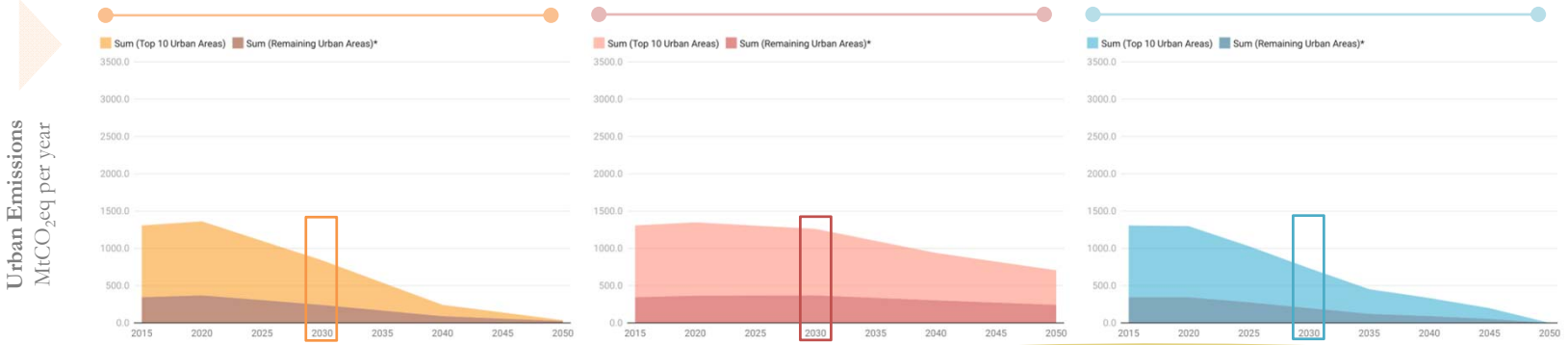


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 839.1, 1260.7 or 733.7 $MtCO_2eq$ in 2030

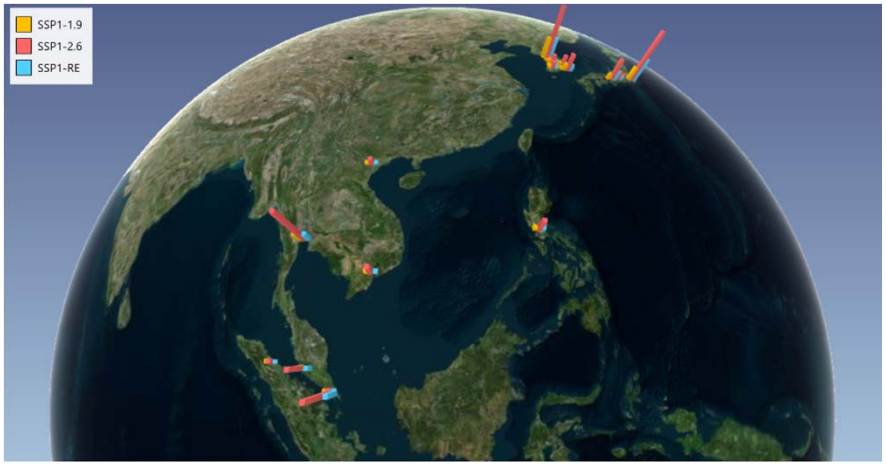


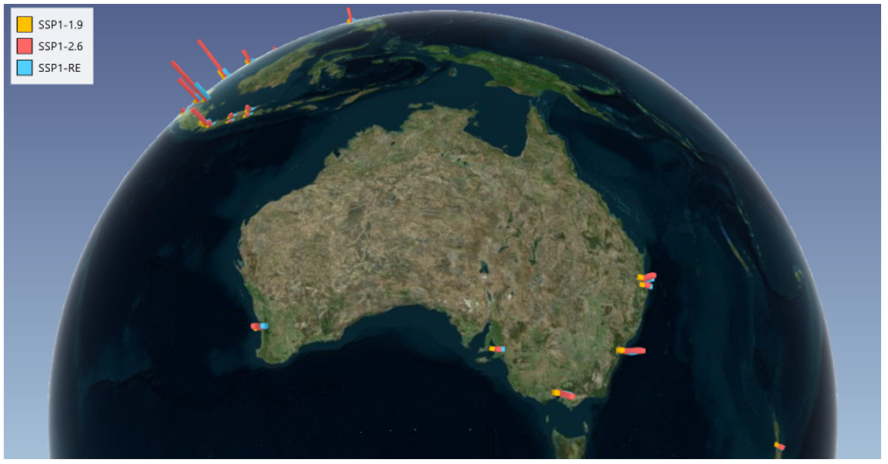


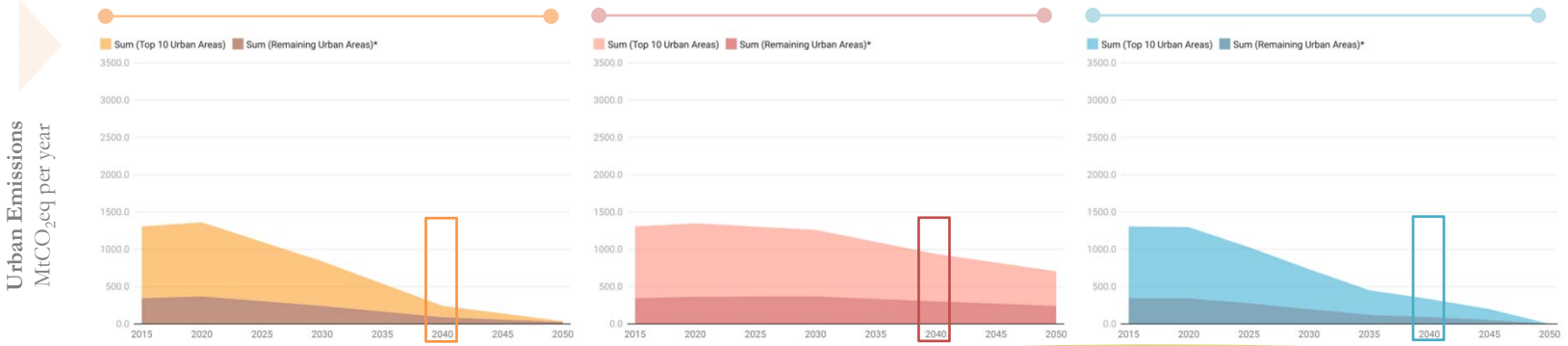


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 241.5, 938.6 or 333.6 $MtCO_2eq$ in 2040

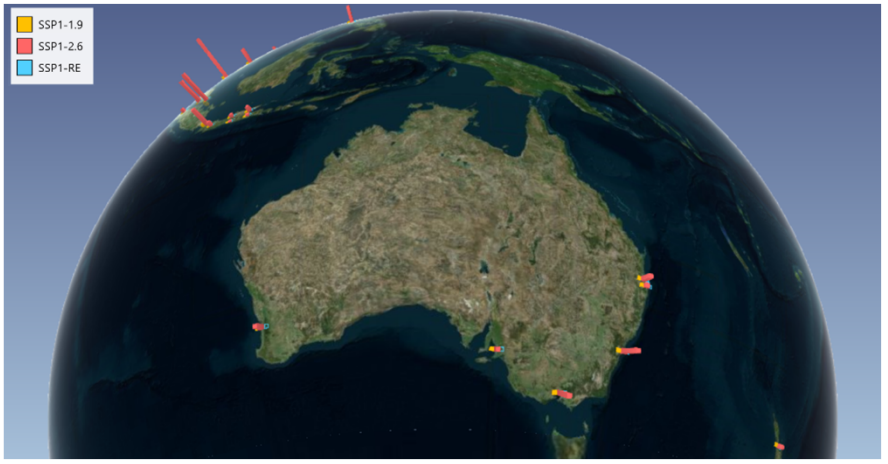


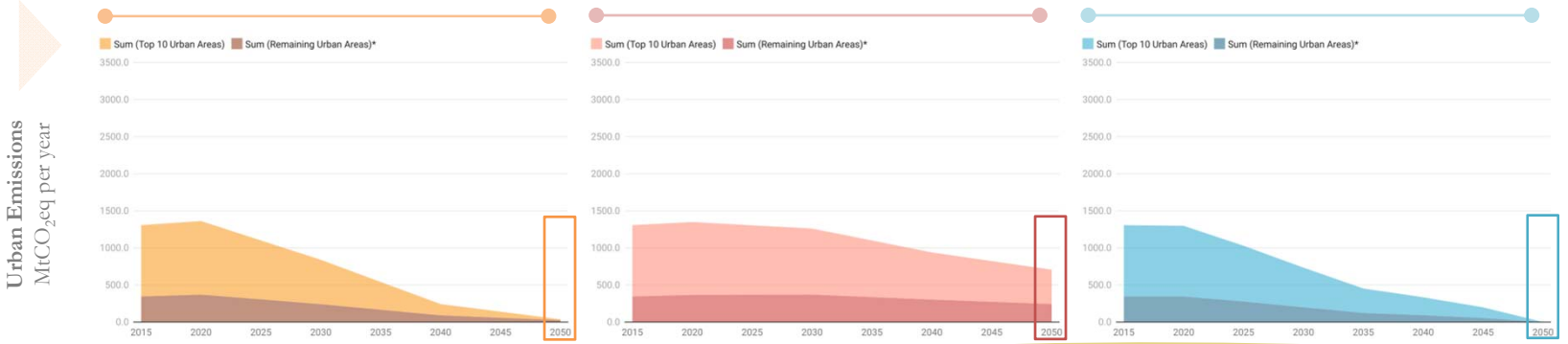




Future Outlook of Emissions for 420 Urban Areas

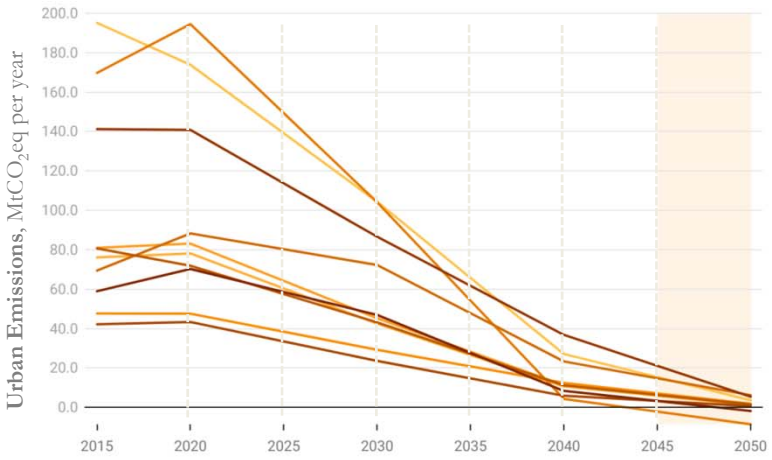
Across the SSP1 scenarios, urban emission pathways can lead to 36.5, 705.7 or ~0.0 $MtCO_2eq$ in 2050





Top 10 Emitting Areas – Asia and Pacific Countries*

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 980.6 $MtCO_2eq$ by 2050



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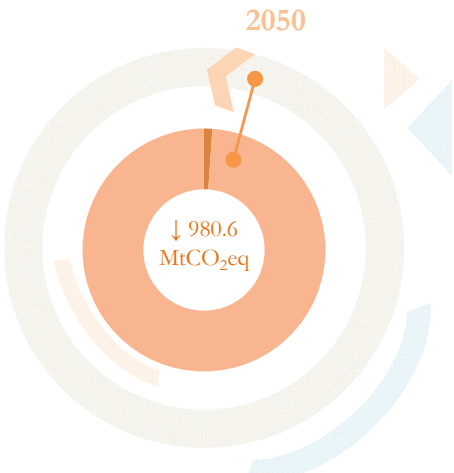
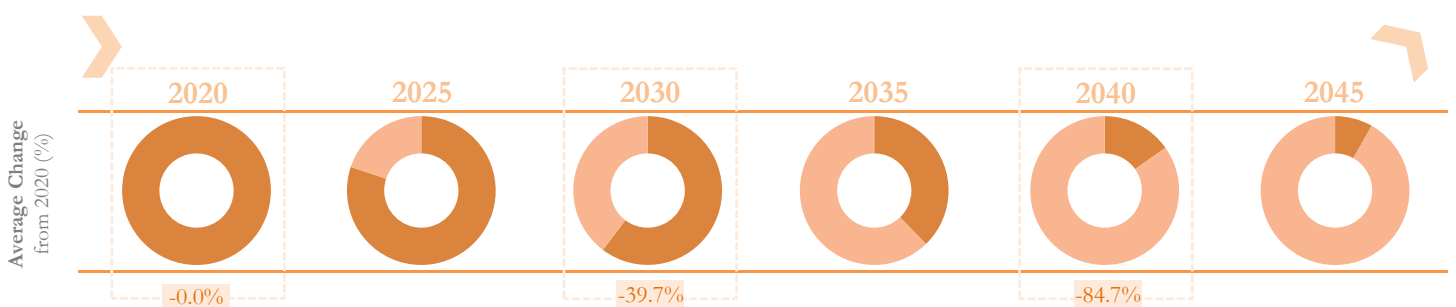
-8.6 195.2

Region → Asia and Pacific Countries*

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Tokyo	195.2	173.9	139.1	104.3	65.7	27.1	15.4	3.6
Singapore	169.8	194.5	149.3	104.1	54.2	4.3	-2.1	-8.6
Seoul	141.2	140.8	113.7	86.6	61.7	36.8	21.1	5.4
Sydney	81.0	83.1	64.2	45.2	28.3	11.3	6.3	1.2
Osaka	80.7	71.9	57.5	43.1	27.2	11.2	6.3	1.5
Melbourne	76.1	78.1	60.3	42.5	26.6	10.6	5.9	1.2
Bangkok	69.4	88.3	80.3	72.2	47.8	23.3	14.8	6.2
Kuala Lumpur	58.9	70.3	58.6	46.9	27.6	8.4	3.3	-1.8
Busan	47.7	47.5	38.4	29.2	20.8	12.4	7.1	1.8
Brisbane	42.2	43.3	33.4	23.6	14.7	5.9	3.3	0.6

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

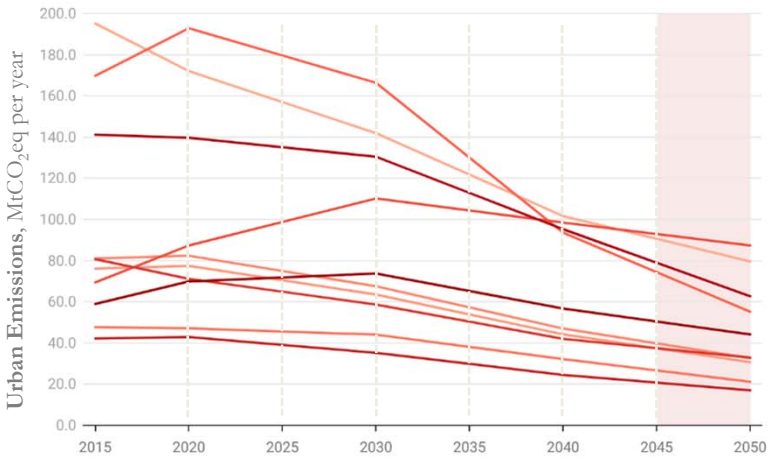




* Excluding urban areas in China and SAARC that are already shared.

Top 10 Emitting Areas – Asia and Pacific Countries*

While reductions in SSP1-2.6 remain limited at 519.5 $MtCO_2eq$ by 2050, largely forgoing a missed 1.5°C target



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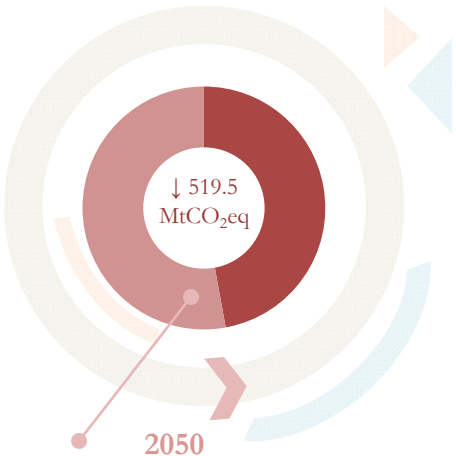
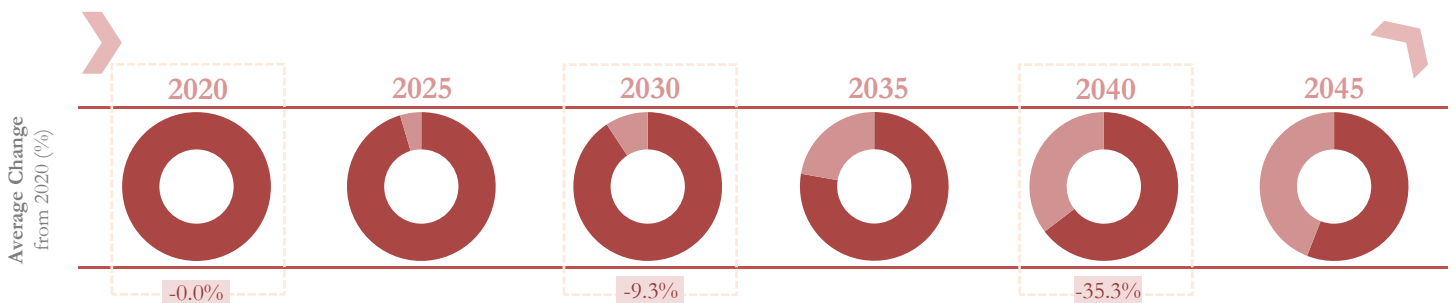
1.0 195.2

Region → Asia and Pacific Countries*

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Tokyo	195.2	172.0	157.0	141.9	121.8	101.6	90.6	79.6
Singapore	169.8	192.8	179.6	166.4	130.0	93.6	74.4	55.2
Seoul	141.2	139.7	135.1	130.5	112.9	95.3	79.0	62.7
Sydney	81.0	82.4	75.0	67.6	57.3	47.0	39.8	32.6
Osaka	80.7	71.1	64.9	58.7	50.3	42.0	37.5	32.9
Melbourne	76.1	77.4	70.5	63.5	53.9	44.2	37.4	30.7
Bangkok	69.4	87.3	98.8	110.2	104.3	98.5	92.9	87.3
Kuala Lumpur	58.9	69.9	71.8	73.8	65.2	56.7	50.4	44.1
Busan	47.7	47.1	45.6	44.0	38.1	32.2	26.7	21.2
Brisbane	42.2	42.9	39.1	35.2	29.9	24.5	20.7	17.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

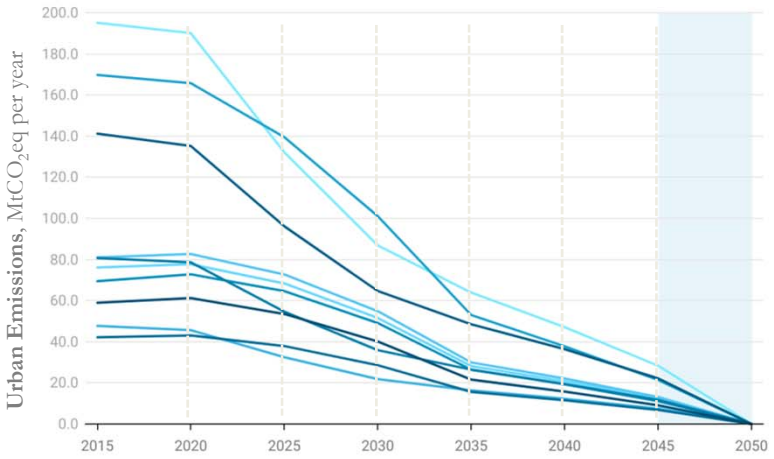




* Excluding urban areas in China and SAARC that are already shared.

Top 10 Emitting Areas – Asia and Pacific Countries*

For these areas, 100% RE scenarios provide opportunities to eliminate 952.7 $MtCO_2eq$ of urban emissions in 2050



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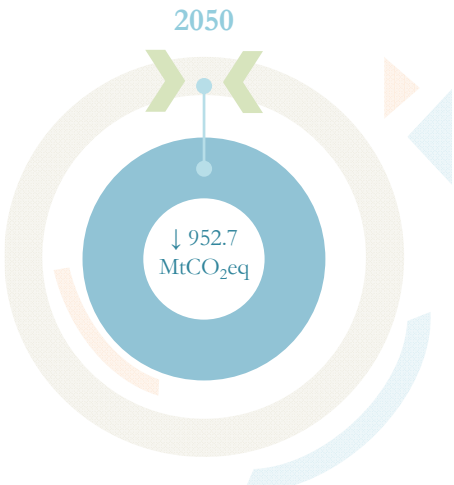
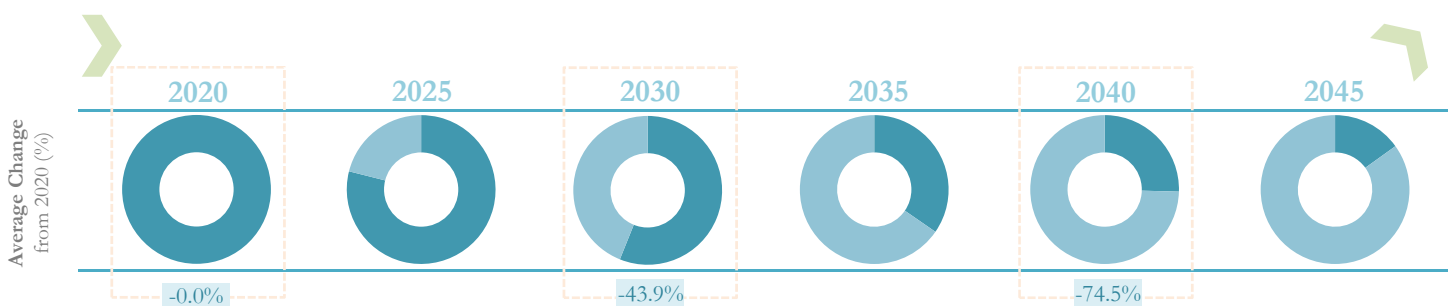
0.0 195.2

Region → Asia and Pacific Countries*

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Tokyo	195.2	190.1	132.1	86.8	63.9	47.1	28.3	0.0
Singapore	169.8	165.7	139.5	101.1	53.0	37.8	21.4	0.0
Seoul	141.2	135.2	96.2	64.7	48.5	36.4	22.2	0.0
Sydney	81.0	82.7	72.7	54.8	29.9	22.1	13.1	0.0
Osaka	80.7	78.6	54.6	35.9	26.4	19.5	11.7	0.0
Melbourne	76.1	77.7	68.4	51.6	28.1	20.8	12.3	0.0
Bangkok	69.4	72.8	64.6	49.1	26.4	19.3	11.1	0.0
Kuala Lumpur	58.9	61.2	53.5	40.1	21.6	15.7	9.1	0.0
Busan	47.7	45.6	32.5	21.8	16.4	12.3	7.5	0.0
Brisbane	42.2	43.1	37.9	28.6	15.6	11.5	6.8	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.





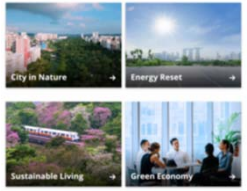
* Excluding urban areas in China and SAARC that are already shared.

Actions Urban Areas Are Taking and Opportunities

- **Urban rail line Setagaya** runs on 100% from hydropower and geothermal energy
- Zero Emission Tokyo Strategy for 2050

Source: Tokyo ZE Strategy

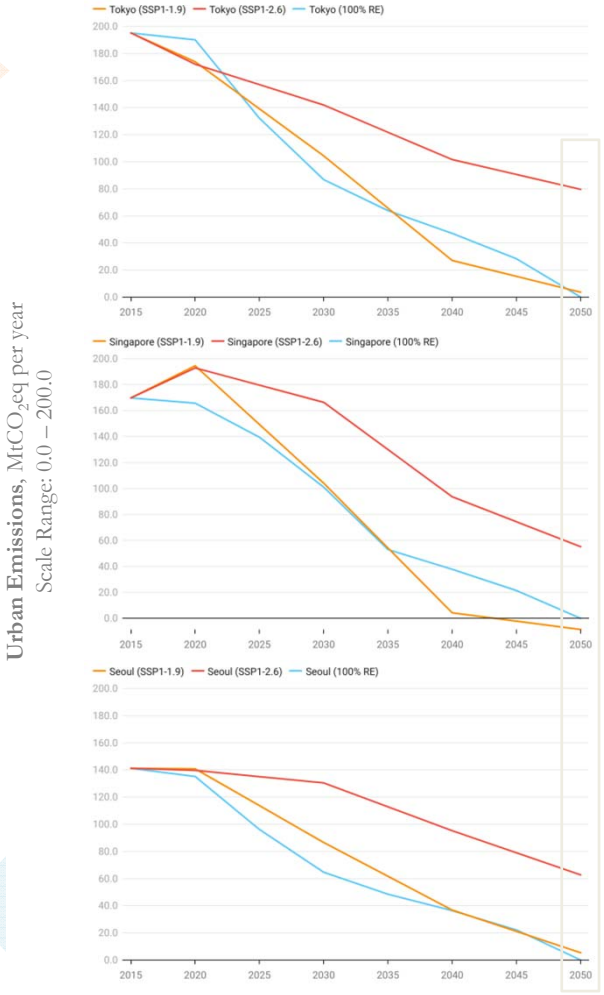
- Singapore Green Plan aims to **quadruple solar energy deployment by year 2025**
- Phasing out natural gas needs extra policies



Source: Singapore Green Plan

- Aims to reduce total city-wide emissions by 40% in 2030 compared to 2005 levels towards net-zero
- Designated city center as Green Transport Zone

Sources: Tokyo ZE Strategy; Singapore Green Plan; UNFCCC (2021)



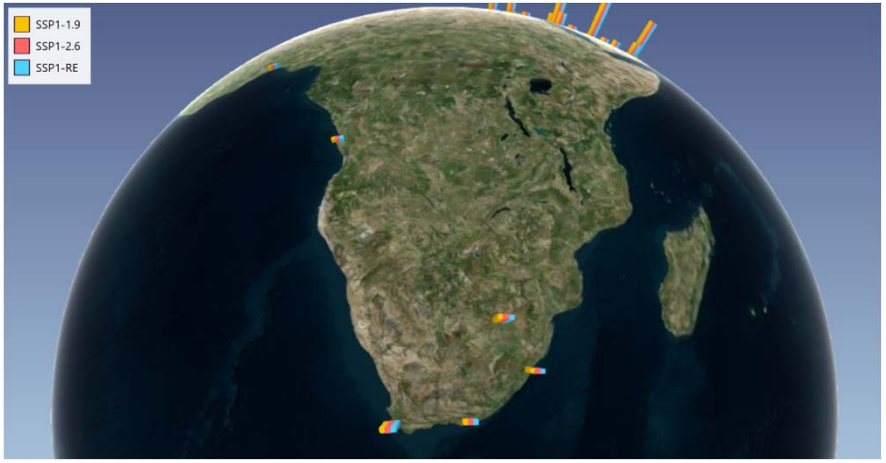
Making the complete shift for the urban energy system and beyond

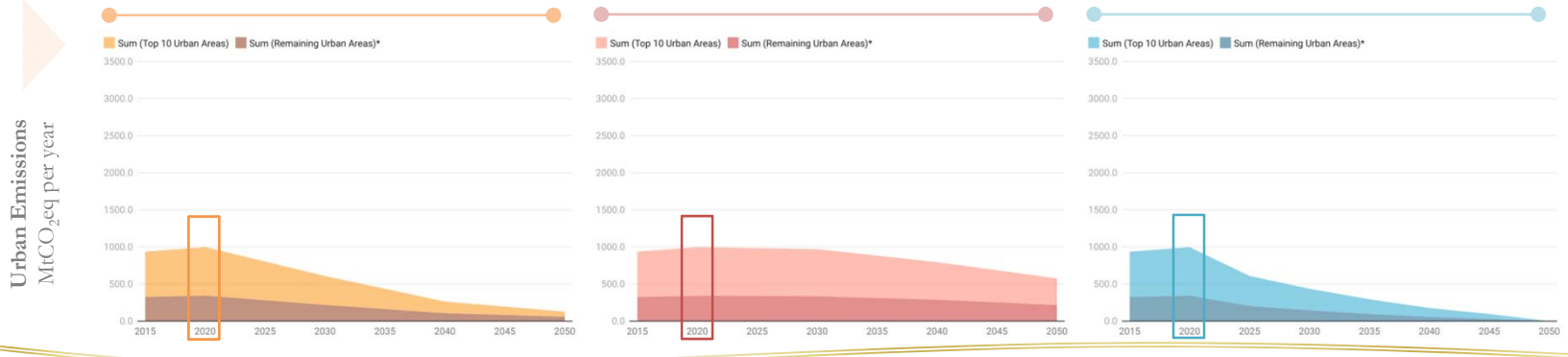
Co-benefits of 100% RE in these 3 urban areas:
~ 641 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

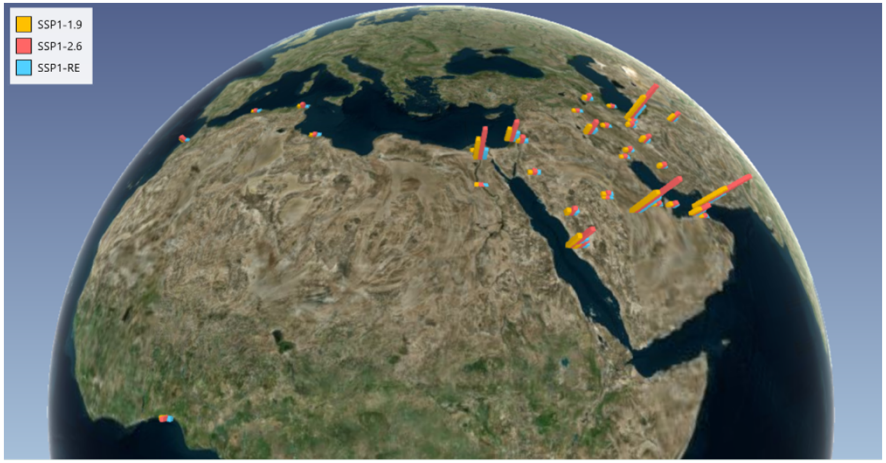
In Middle East and Africa, urban emissions for 42 of the top 420 urban areas are 967.1 ± 31.2 $MtCO_2eq$ in 2020

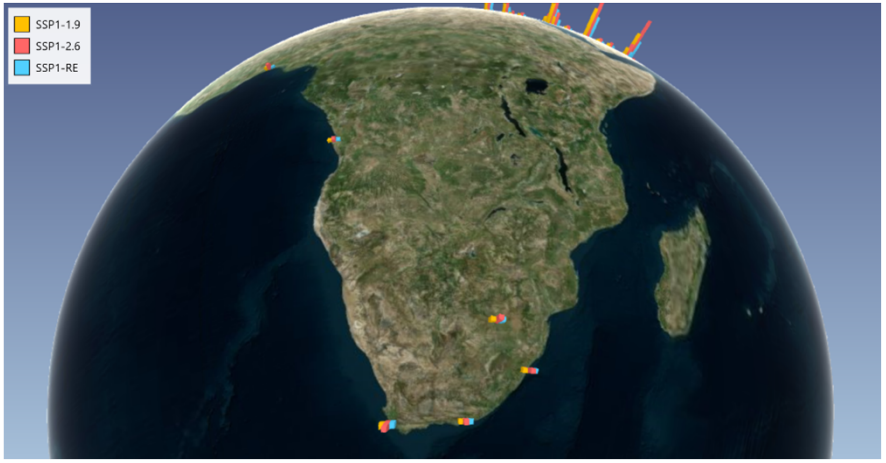


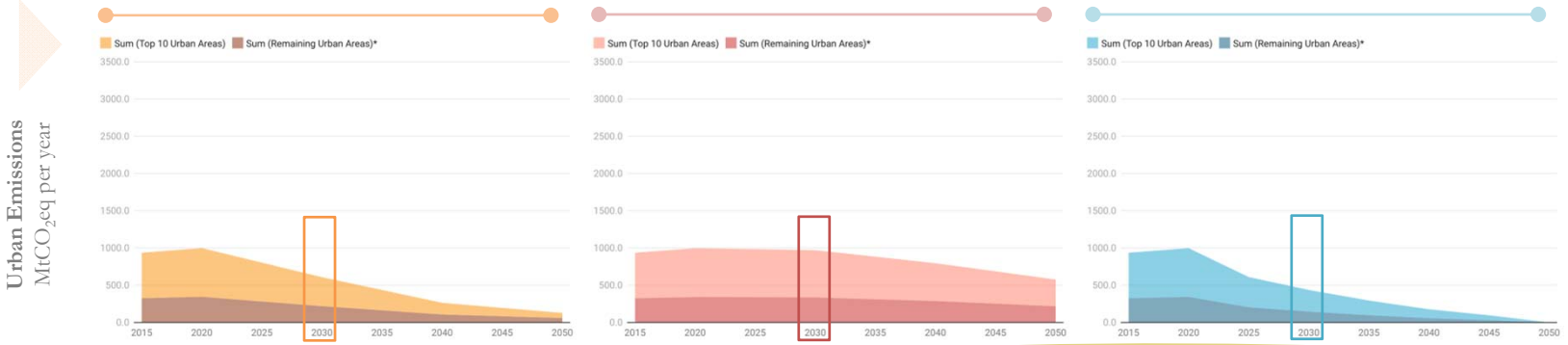


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 607.9, 970.9 or 436.0 $MtCO_2eq$ in 2030

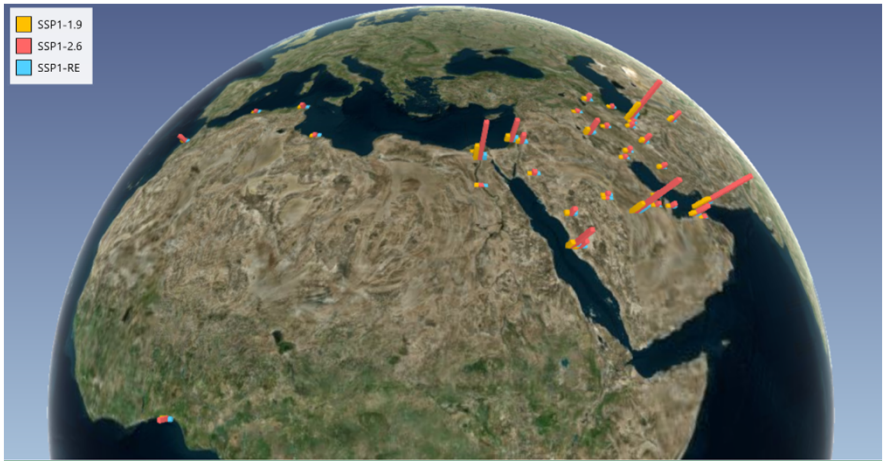


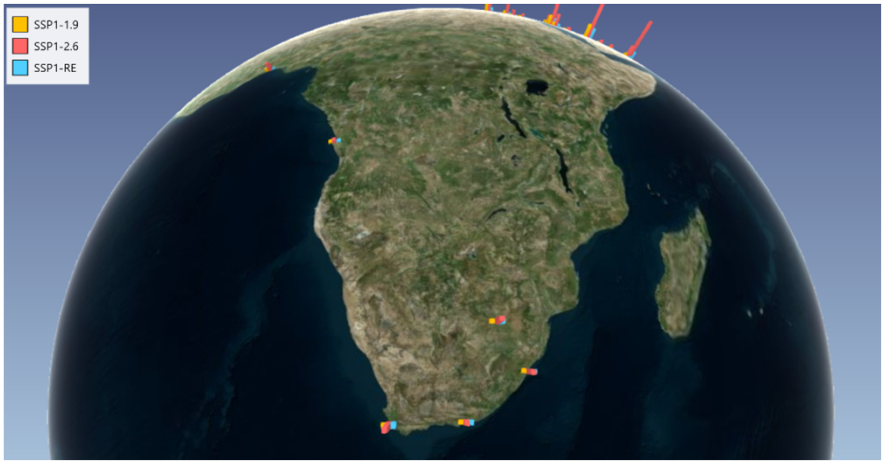


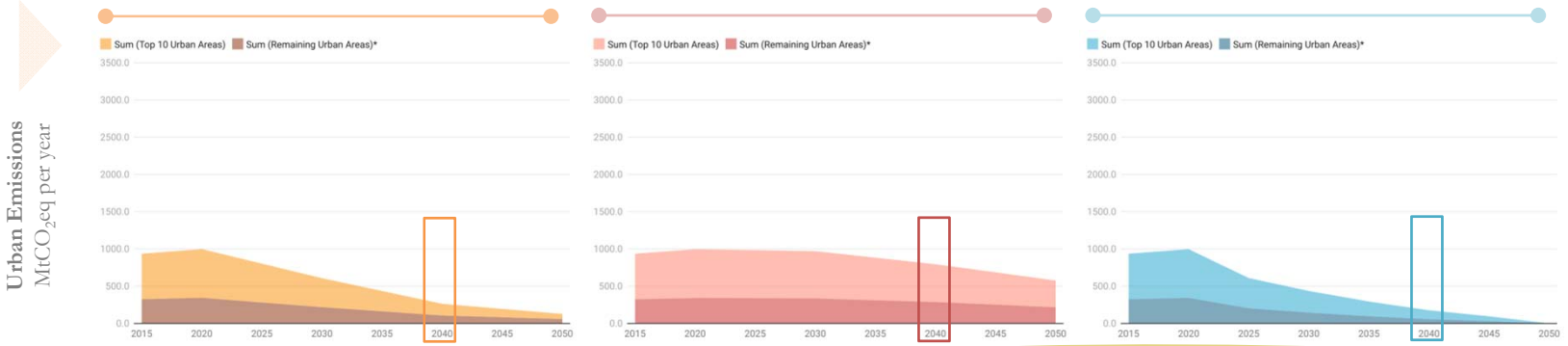


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 263.5, 795.7 or 176.9 $MtCO_2eq$ in 2040

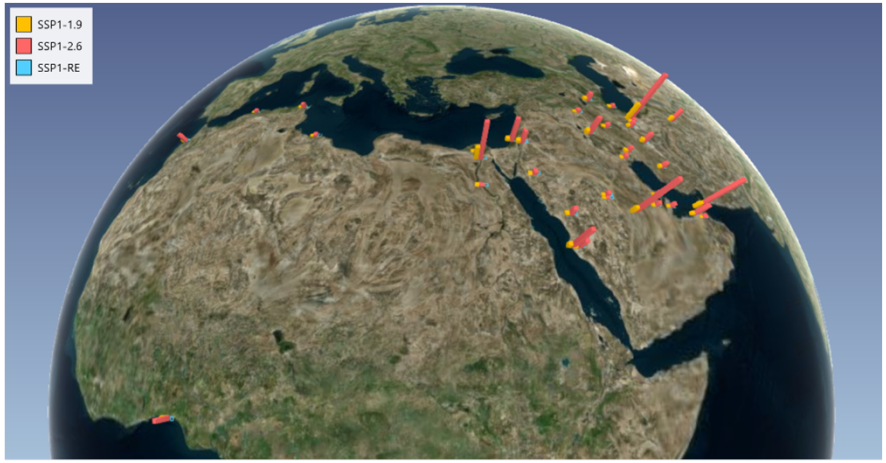


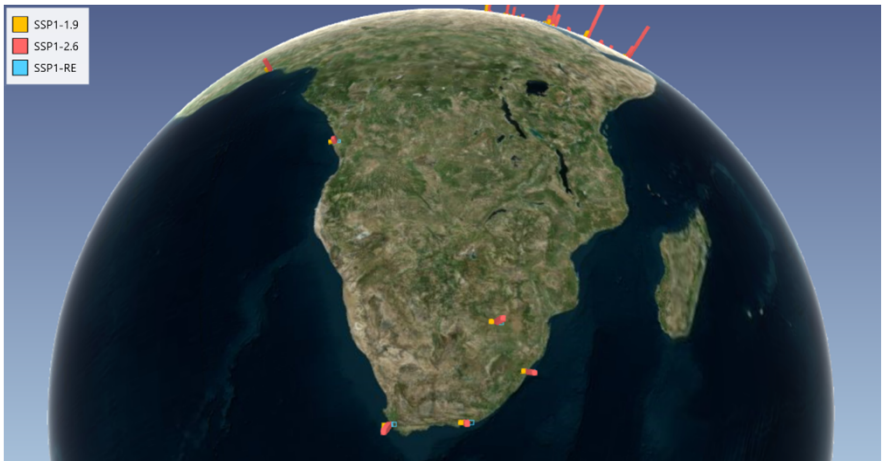


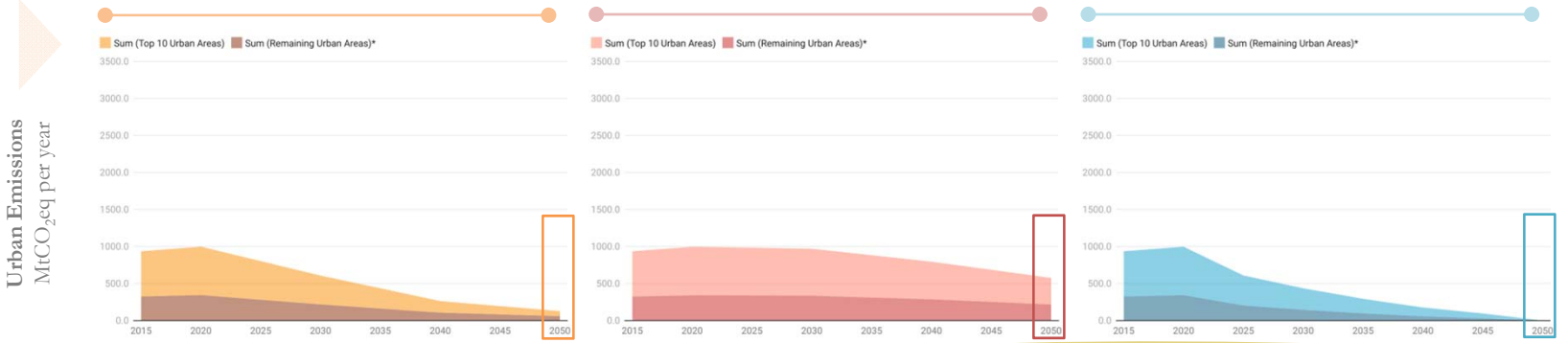


Future Outlook of Emissions for 420 Urban Areas

Across the SSP1 scenarios, urban emission pathways can lead to 127.6, 575.9 or ~0.0 $MtCO_2eq$ in 2050

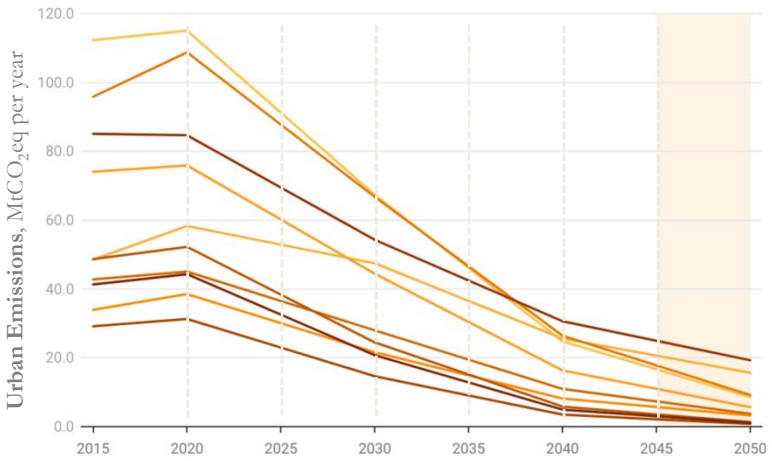






Top 10 Emitting Areas – Middle East and Africa

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 585.5 $MtCO_2eq$ by 2050



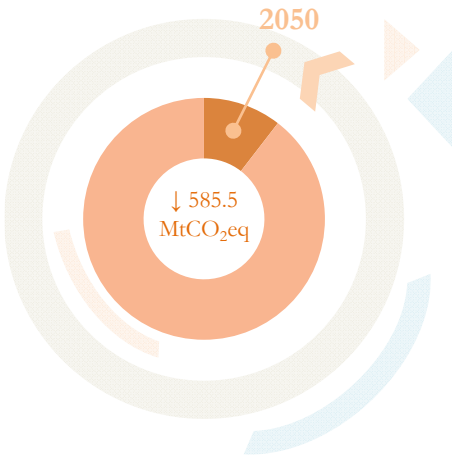
Search in table

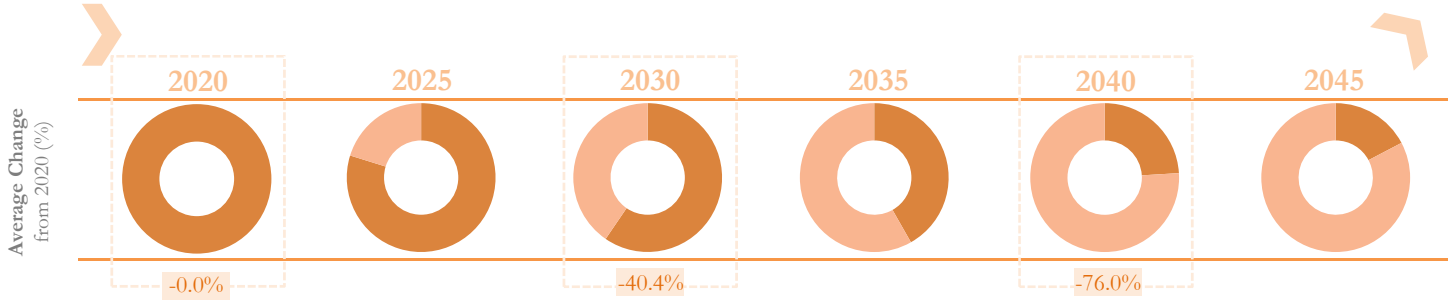
0.1 — 115.1

Region → Middle East and Africa

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Riyadh	112.3	115.1	91.2	67.3	46.1	24.8	16.7	8.6
Dubai	95.9	108.7	87.7	66.7	46.6	26.4	17.8	9.1
Tehran	85.1	84.7	69.5	54.3	42.4	30.6	24.9	19.3
Jiddah	74.1	75.9	60.2	44.4	30.4	16.3	11.0	5.7
Johannesburg	48.7	52.2	38.3	24.5	15.1	5.8	3.6	1.3
Cairo	48.5	58.3	52.9	47.5	36.5	25.6	20.6	15.7
Tel Aviv-Jaffa	42.8	45.0	36.5	28.0	19.5	10.9	7.3	3.7
Cape Town	41.3	44.3	32.5	20.7	12.8	4.9	3.0	1.1
Abu Dhabi	34.0	38.5	30.1	21.6	14.9	8.2	5.7	3.2
Durban (eThekwini)	29.2	31.3	23.0	14.6	9.1	3.5	2.1	0.8

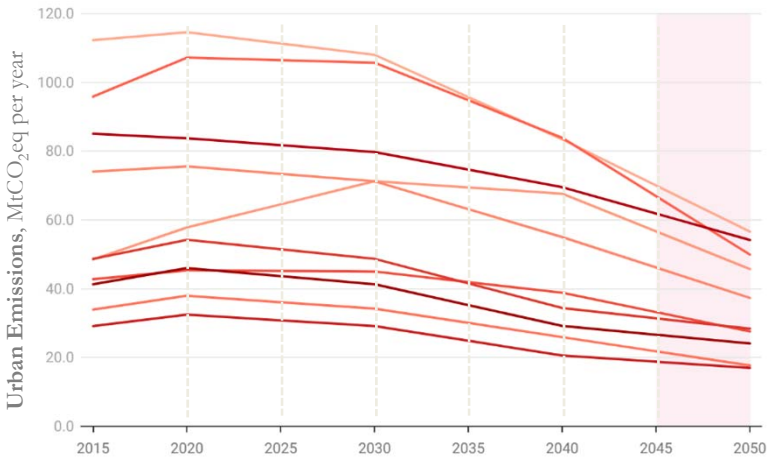
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Middle East and Africa

While reductions in SSP1-2.6 remain limited at 296.4 $MtCO_2eq$ by 2050, largely forgoing a missed 1.5°C target



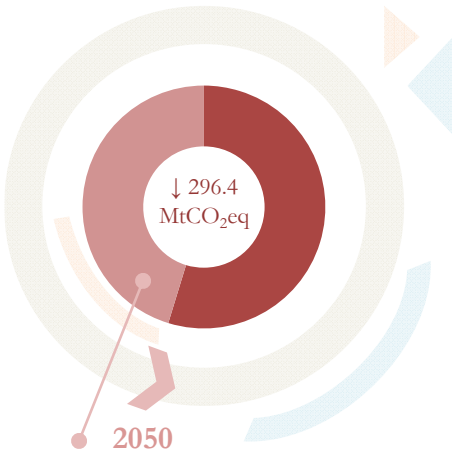
Search in table

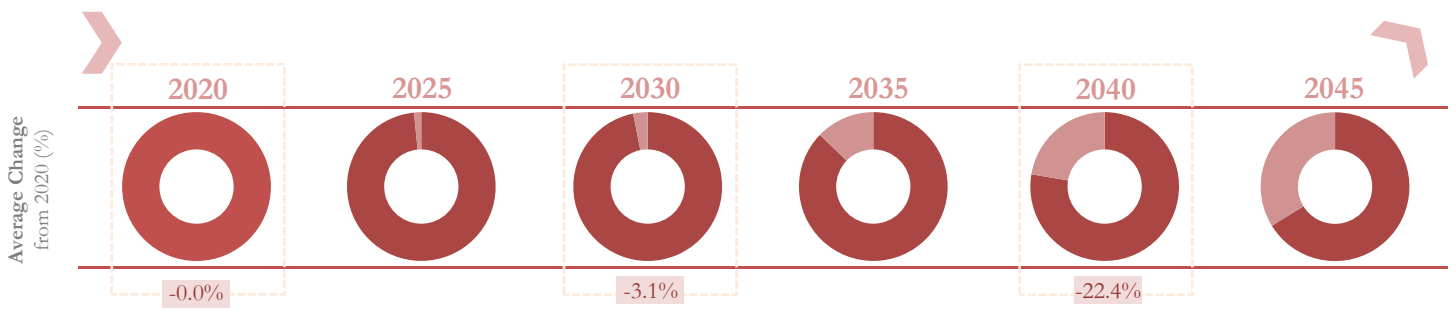
0.9 114.6

Region → Middle East and Africa

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Riyadh	112.3	114.6	111.3	108.0	95.7	83.4	70.0	56.6
Dubai	95.9	107.2	106.5	105.7	94.8	83.9	66.9	50.0
Tehran	85.1	83.8	81.8	79.8	74.6	69.5	61.9	54.2
Jiddah	74.1	75.6	73.4	71.2	63.1	55.0	46.2	37.4
Johannesburg	48.7	54.2	51.5	48.7	41.6	34.4	31.4	28.4
Cairo	48.5	57.8	64.6	71.3	69.5	67.6	56.7	45.7
Tel Aviv-Jaffa	42.8	45.4	45.2	45.0	41.9	38.9	33.2	27.6
Cape Town	41.3	46.0	43.7	41.3	35.2	29.2	26.6	24.1
Abu Dhabi	34.0	38.0	36.1	34.2	30.1	25.9	21.8	17.7
Durban (eThekwini)	29.2	32.5	30.8	29.2	24.9	20.6	18.8	17.0

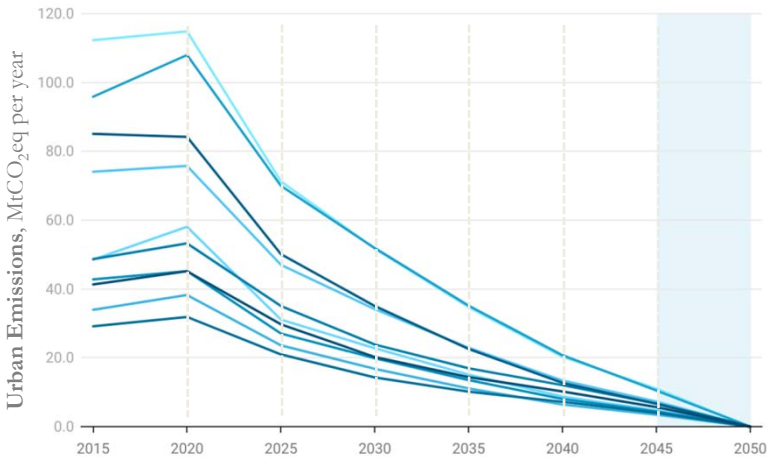
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Areas – Middle East and Africa

For these areas, 100% RE scenarios provide opportunities to eliminate 654.5 $MtCO_2eq$ of urban emissions in 2050



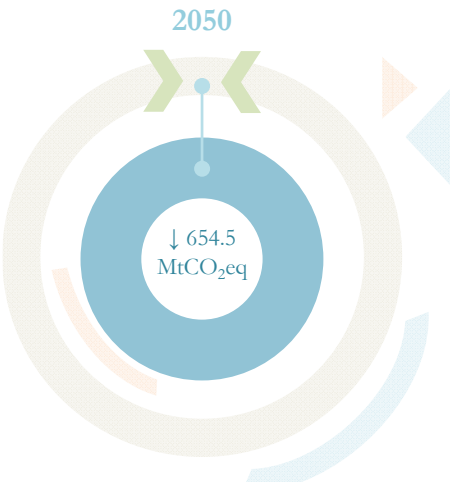
Search in table

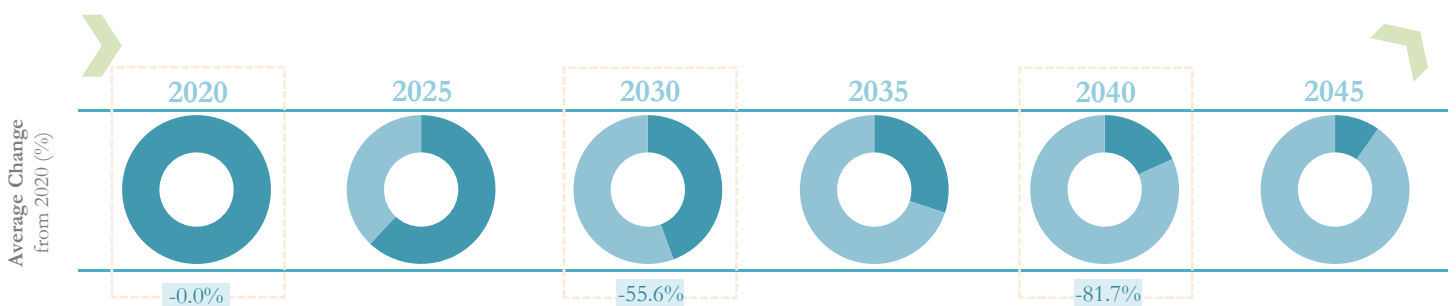
0.0 — 114.8

Region → Middle East and Africa

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Riyadh	112.3	114.8	71.3	51.7	34.7	20.3	11.0	0.0
Dubai	95.9	108.0	70.0	51.9	35.2	20.7	10.5	0.0
Tehran	85.1	84.2	50.1	35.0	22.6	12.7	6.6	0.0
Jiddah	74.1	75.7	47.0	34.1	22.9	13.4	7.3	0.0
Johannesburg	48.7	53.2	35.1	23.9	17.0	12.0	6.7	0.0
Cairo	48.5	58.1	31.1	22.8	15.1	8.7	4.7	0.0
Tel Aviv-Jaffa	42.8	45.2	27.1	19.9	13.5	8.0	4.4	0.0
Cape Town	41.3	45.2	29.7	20.2	14.4	10.2	5.7	0.0
Abu Dhabi	34.0	38.2	23.6	16.8	11.1	6.4	3.5	0.0
Durban (eThekwini)	29.2	31.9	21.0	14.3	10.2	7.2	4.0	0.0

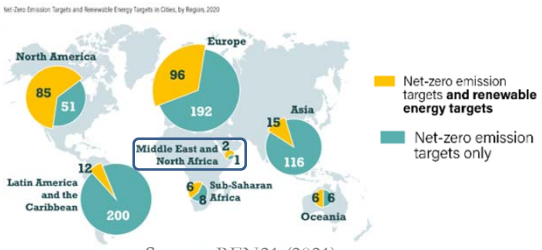
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





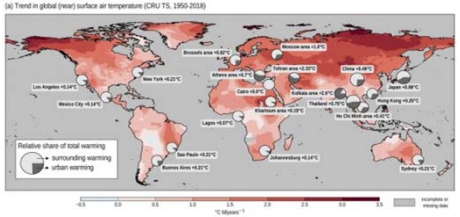
Actions Urban Areas Are Taking and Opportunities

- Overall, cities in the Middle East region **lag behind** adopting net-zero and RE targets



Source: REN21 (2021)

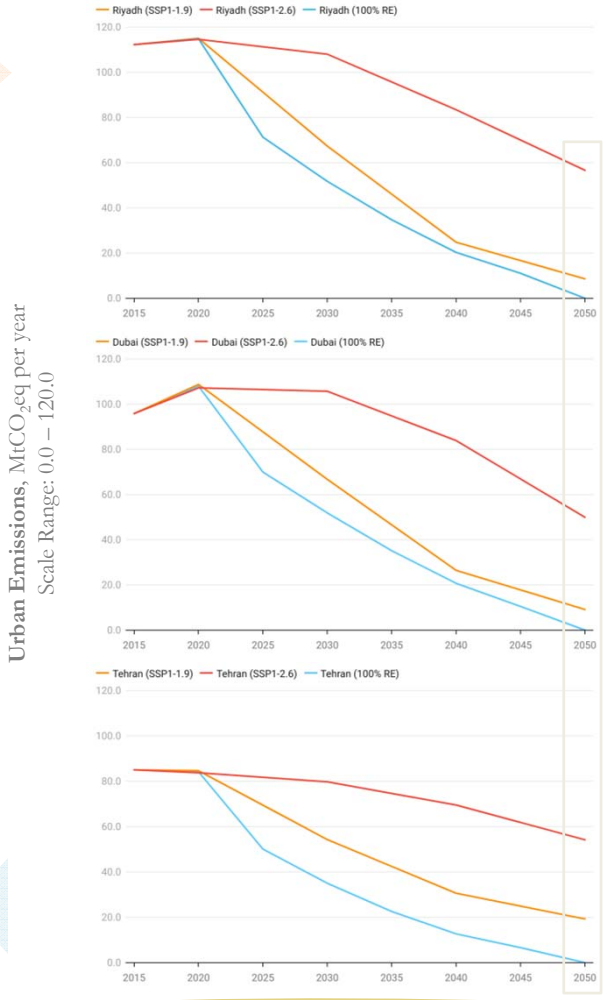
- Dubai is **involved in a city-wide net-zero CO_2 emissions** by 2050 with 75% RE target



Source: IPCC WGI (2021)

- **Total warming is +2.33 °C** due to urban and surrounding warming (IPCC WPI)

Sources: REN21 (2021); IPCC WGI (2021) Regional Fact Sheet Urban Areas



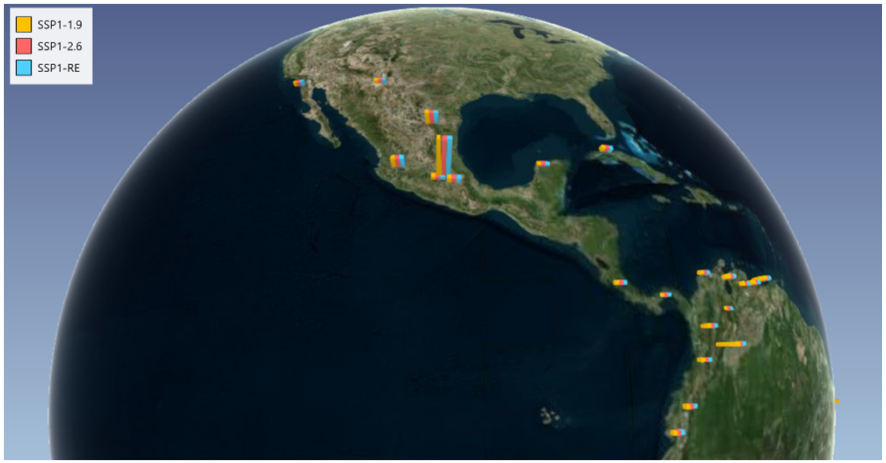
Making the complete shift for the urban energy system and beyond

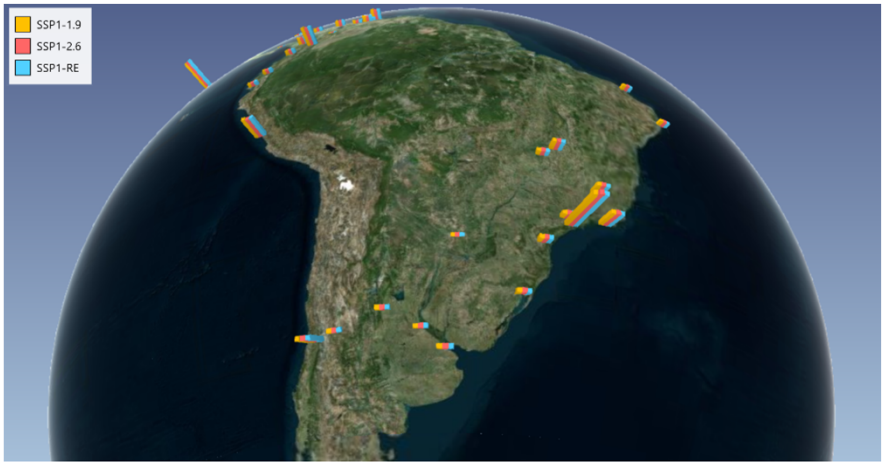
Co-benefits of 100% RE in these 3 urban areas:
~ 440 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

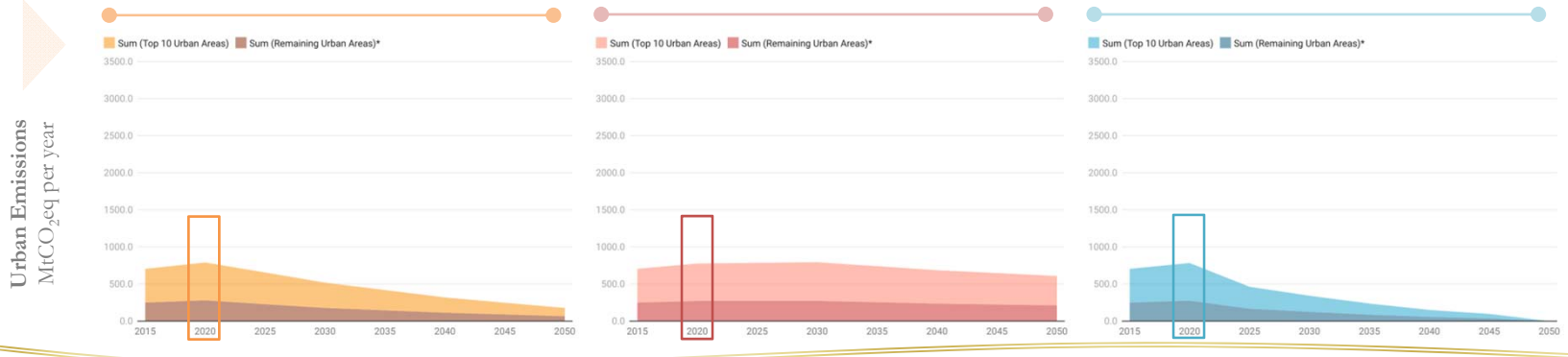
Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

In Latin America, urban emissions for 40 of the top 420 urban areas are 696.7 ± 94.4 $MtCO_2eq$ in 2020

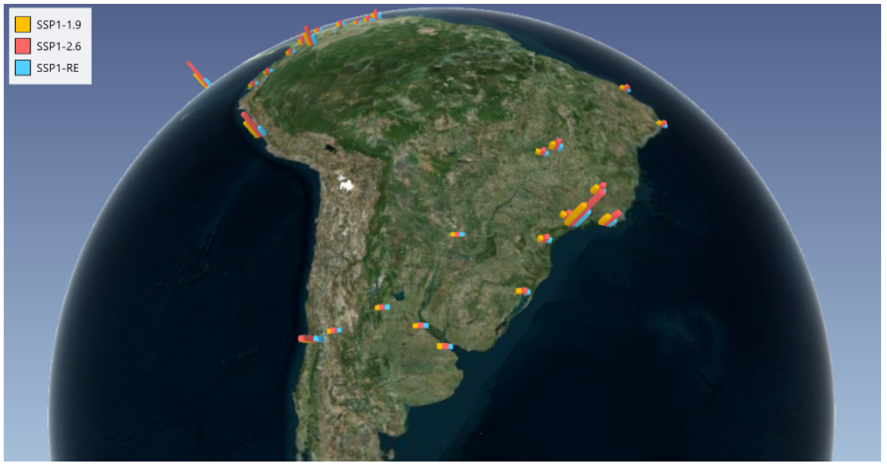


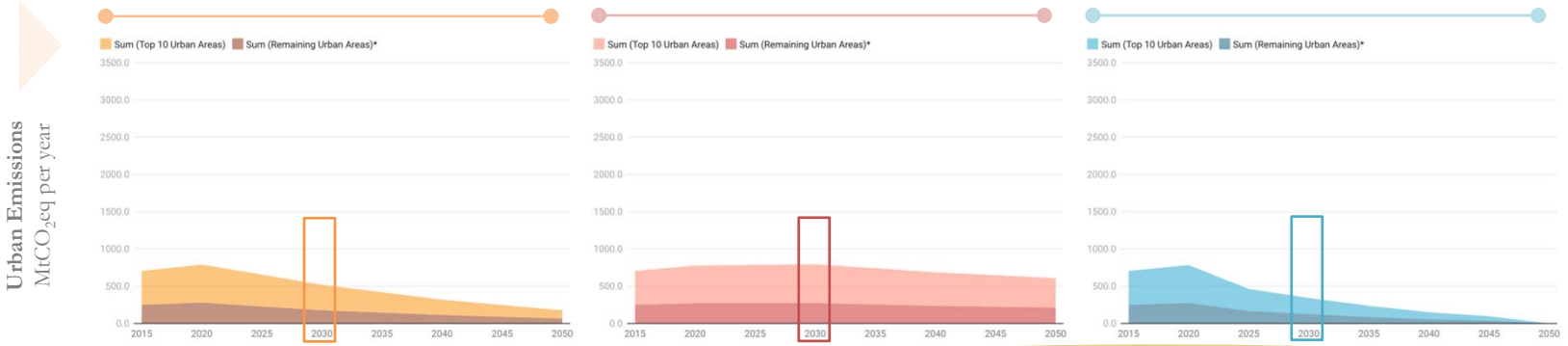




Future Outlook of Emissions for 420 Urban Areas

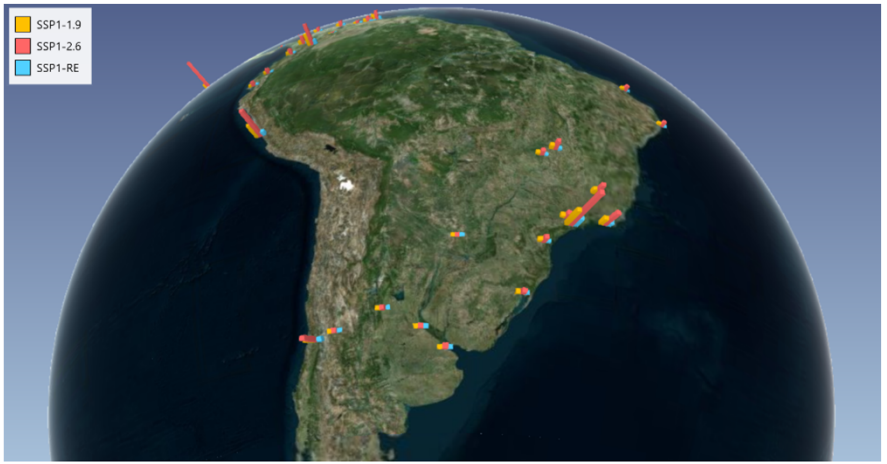
Across the SSP1 scenarios, urban emission pathways can lead to 518.8, 794.1 or 342.2 $MtCO_2eq$ in 2030

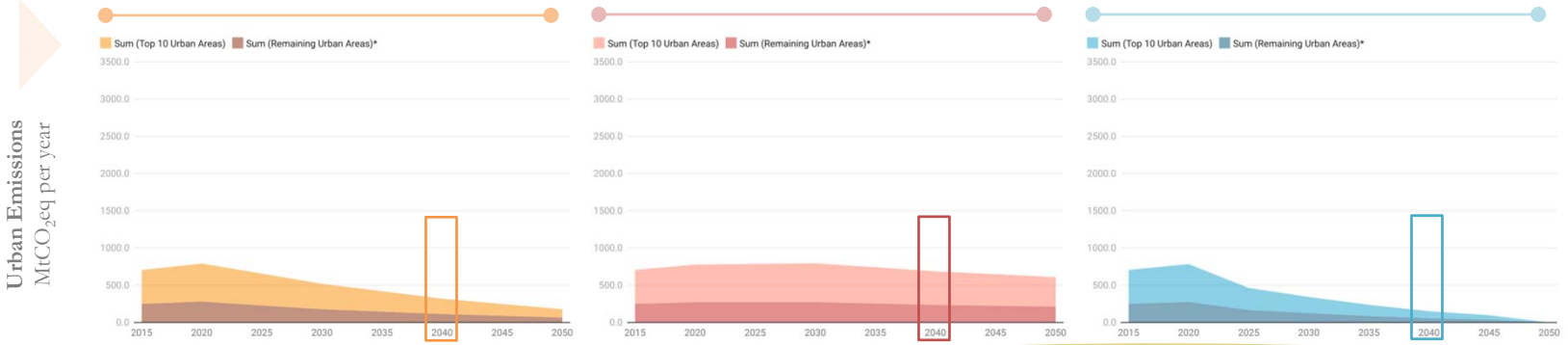




Future Outlook of Emissions for 420 Urban Areas

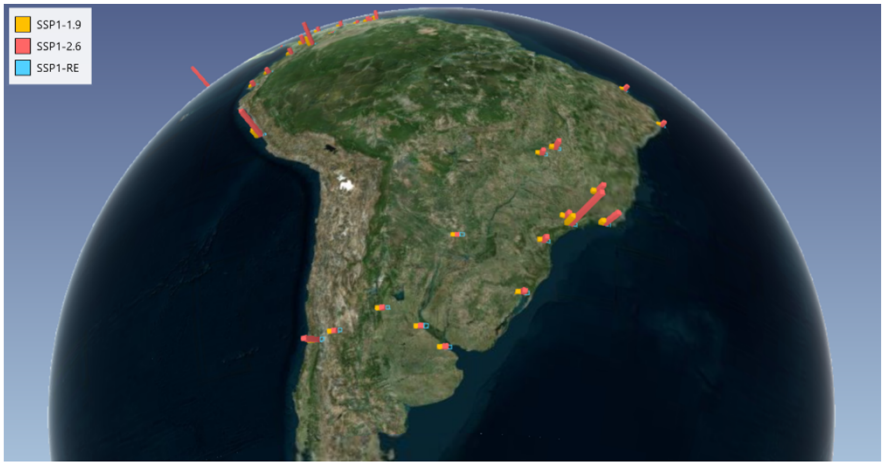
Across the SSP1 scenarios, urban emission pathways can lead to 318.8, 686.3 or 150.5 $MtCO_2eq$ in 2040

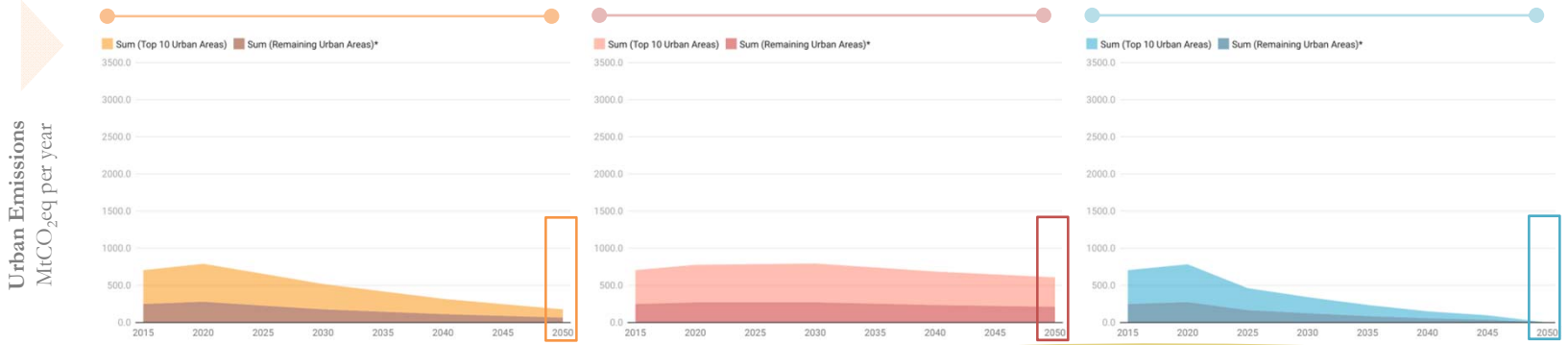




Future Outlook of Emissions for 420 Urban Areas

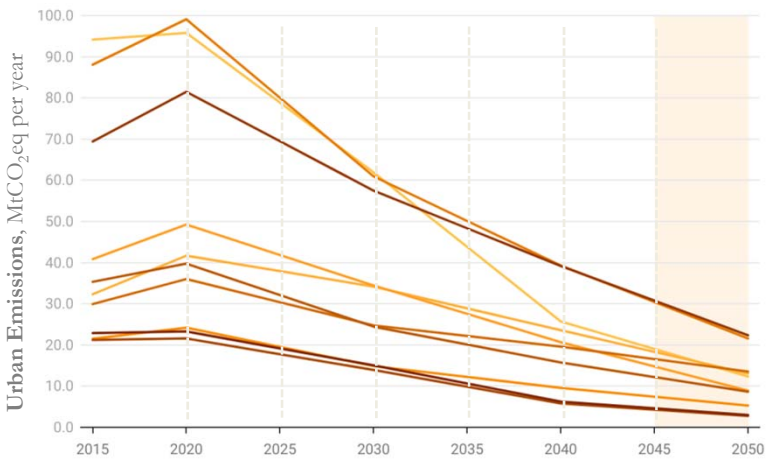
Across the SSP1 scenarios, urban emission pathways can lead to 176.9, 608.0 or ~0.0 $MtCO_2eq$ in 2050





Top 10 Emitting Urban Areas – Latin America

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their total footprint by 400.6 $MtCO_2eq$ by 2050



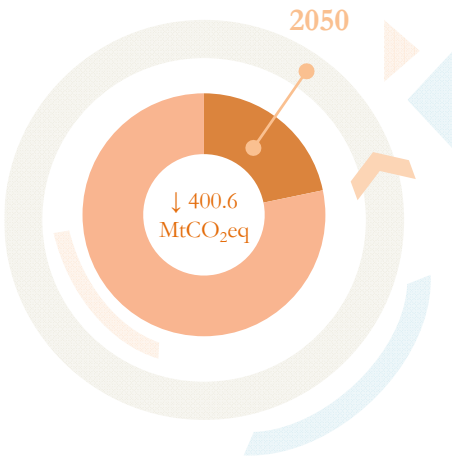
Search in table

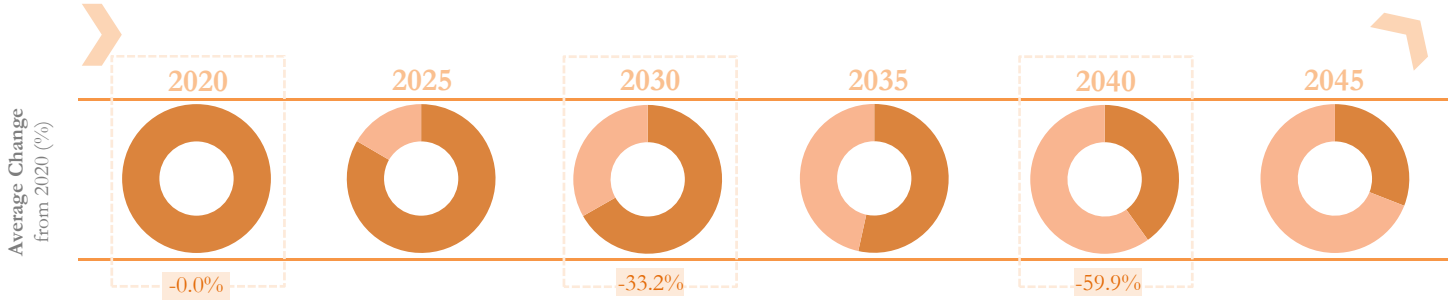
0.1 99.1

Region → Latin America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Mexico City	94.1	95.8	78.9	61.9	43.8	25.7	19.0	12.3
São Paulo	88.1	99.1	80.0	61.0	50.1	39.3	30.4	21.6
Buenos Aires	69.4	81.5	69.5	57.5	48.3	39.2	30.8	22.4
Santiago	40.9	49.2	41.8	34.5	27.6	20.7	14.8	8.9
Rio de Janeiro	35.3	39.8	32.1	24.5	20.1	15.8	12.2	8.7
Lima	32.3	41.7	37.9	34.2	28.9	23.6	18.3	13.1
Bogotá	29.9	36.0	30.4	24.8	22.2	19.6	16.6	13.6
Monterrey	22.9	23.3	19.2	15.1	10.7	6.3	4.6	3.0
Belo Horizonte	21.5	24.2	19.5	14.9	12.2	9.6	7.4	5.3
Guadalajara	21.2	21.6	17.8	13.9	9.9	5.8	4.3	2.8

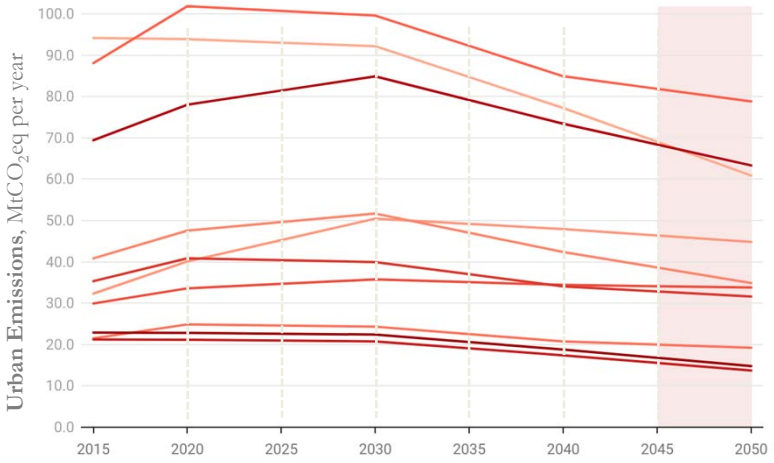
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – Latin America

Reductions in SSP1-2.6 are delayed and amount to 108.8 $MtCO_2eq$ in 2050, largely forgoing a missed 1.5°C target



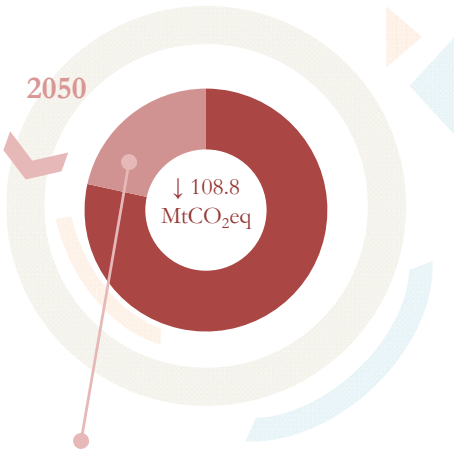
Search in table

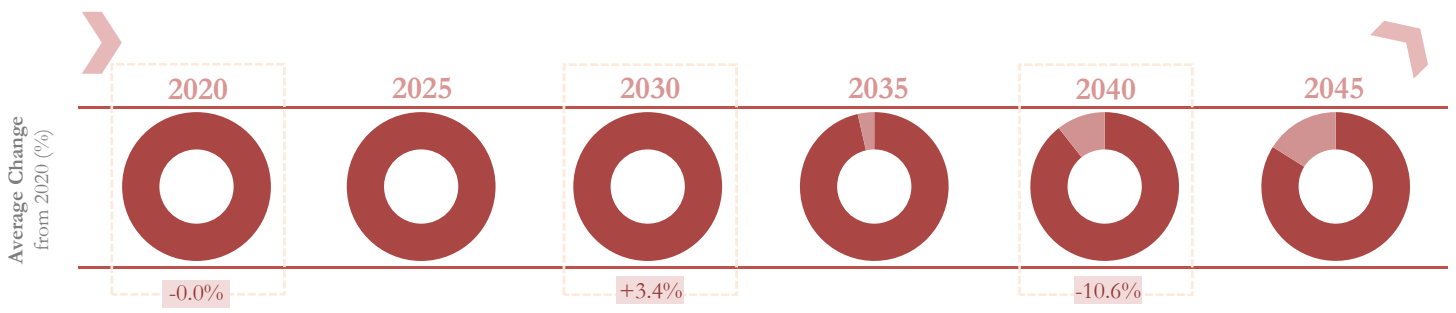
0.2 — 101.9

Region → Latin America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Mexico City	94.1	93.9	93.0	92.2	84.7	77.2	69.1	60.9
São Paulo	88.1	101.9	100.7	99.6	92.2	84.9	81.9	78.8
Buenos Aires	69.4	78.0	81.5	84.9	79.1	73.4	68.4	63.3
Santiago	40.9	47.6	49.6	51.7	47.0	42.4	38.6	34.9
Rio de Janeiro	35.3	40.9	40.4	40.0	37.0	34.1	32.8	31.6
Lima	32.3	40.1	45.3	50.5	49.2	47.9	46.4	44.8
Bogotá	29.9	33.6	34.7	35.8	35.1	34.4	34.1	33.8
Monterrey	22.9	22.8	22.6	22.4	20.6	18.8	16.8	14.8
Belo Horizonte	21.5	24.9	24.6	24.3	22.5	20.7	20.0	19.2
Guadalajara	21.2	21.1	21.0	20.8	19.1	17.4	15.6	13.7

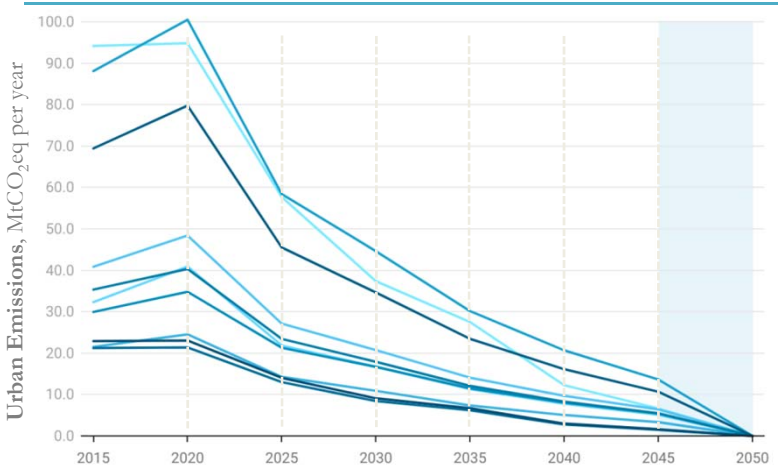
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – Latin America

For these areas, 100% RE scenarios provide opportunities to eliminate 508.4 $MtCO_2eq$ of urban emissions in 2050



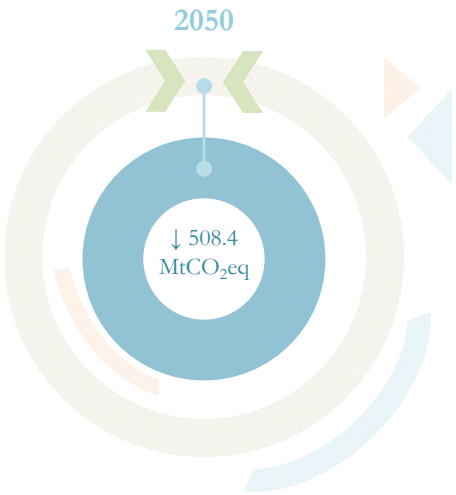
Search in table

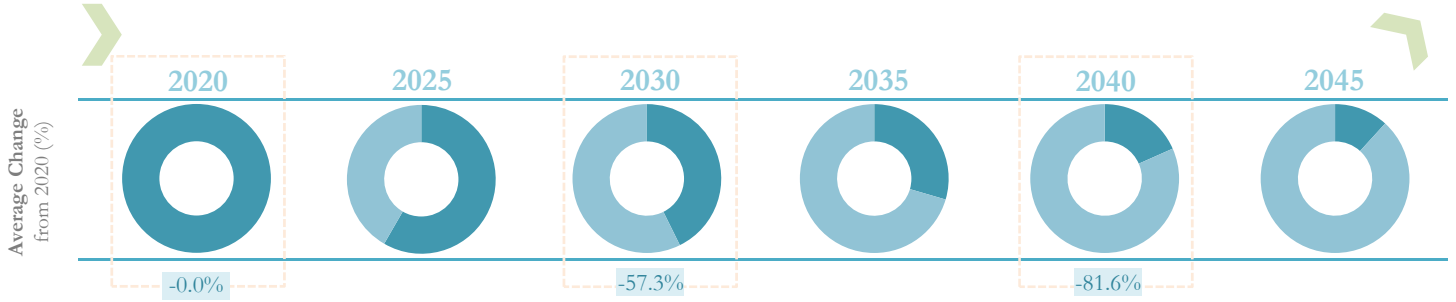
0.0 100.5

Region → Latin America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
Mexico City	94.1	94.8	57.7	37.4	27.5	12.3	6.6	0.0
São Paulo	88.1	100.5	58.4	44.6	30.1	20.7	13.6	0.0
Buenos Aires	69.4	79.7	45.5	34.6	23.4	16.1	10.7	0.0
Santiago	40.9	48.4	27.1	20.7	14.1	9.7	6.4	0.0
Rio de Janeiro	35.3	40.3	23.4	17.9	12.1	8.3	5.5	0.0
Lima	32.3	40.9	21.8	16.7	11.3	7.8	5.1	0.0
Bogotá	29.9	34.8	21.3	16.7	11.5	8.0	5.4	0.0
Monterrey	22.9	23.1	14.0	9.1	6.7	3.0	1.6	0.0
Belo Horizonte	21.5	24.5	14.3	10.9	7.4	5.0	3.3	0.0
Guadalajara	21.2	21.4	13.0	8.4	6.2	2.8	1.5	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.

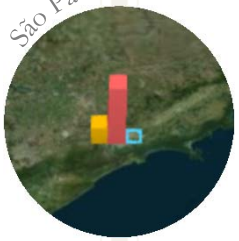




Actions Urban Areas Are Taking and Opportunities

- **One of the 733 cities aiming for net-zero**
- Climate Action Program of Mexico City (2021-2030) to coordinate carbon-neutrality goals

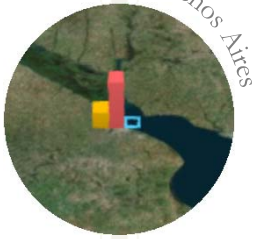
Source: PACCM (2021)



- **New PlanClima SP in 2021** with 43 priority areas guided towards zero carbon by 2050
- → SDEWES Index: Challenged City

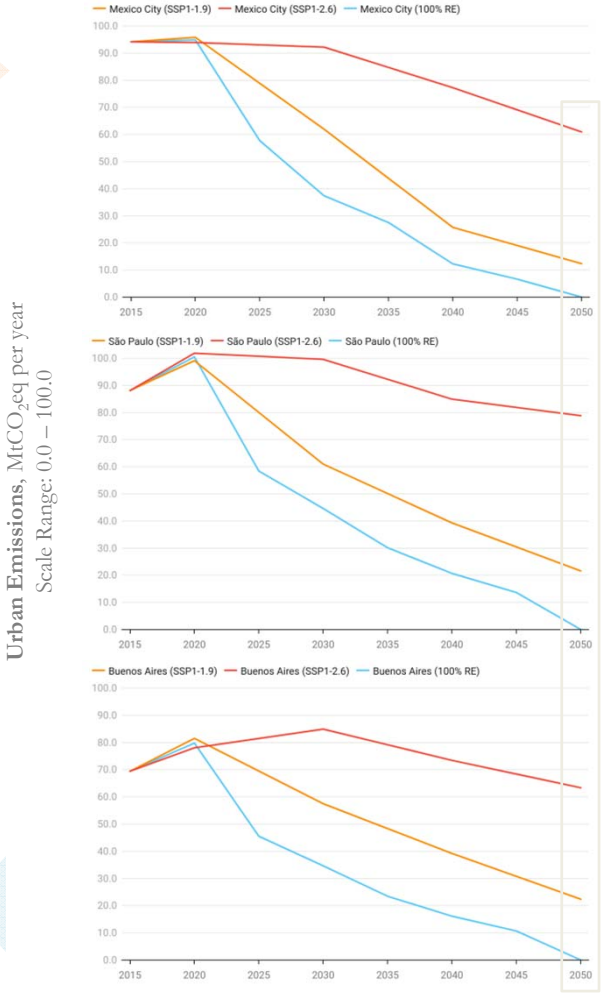
Source: PlanClima SP (2021)

Source: PAC (2021)



- New Climate Action Plan 2050 for reducing emissions **53% by 2030** and 84% by 2050
- Previous mitigation actions had focused on buildings, mass transit, private transport and waste from more sectoral perspectives

Sources: UNFCCC (2021); PACCM (2021); PlanClima SP (2021); C40 (2021); PAC (2021)



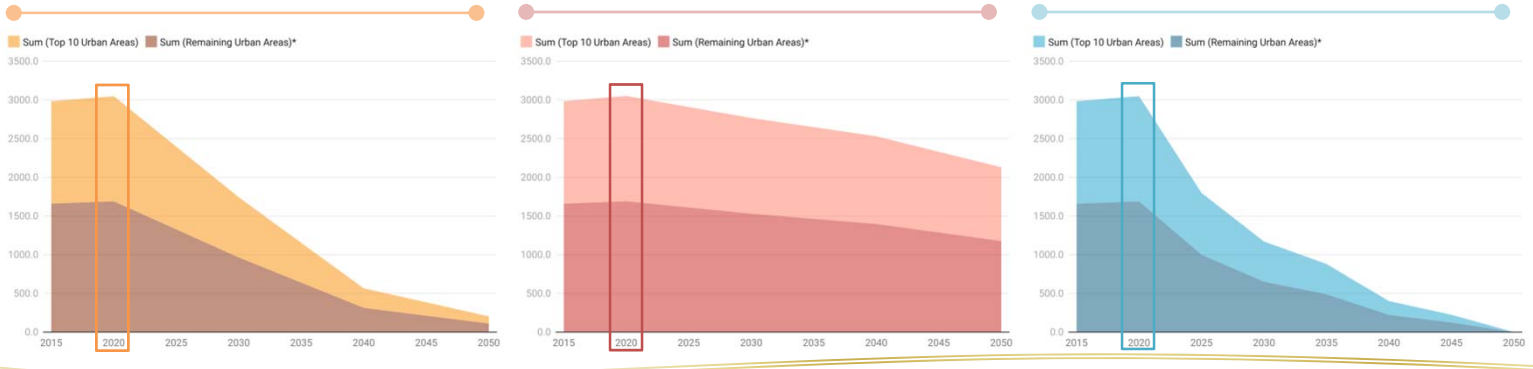
Making the complete shift for the urban energy system and beyond

Co-benefits of 100% RE in these 3 urban areas:
~ 380 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

Source: Calculated based on local per capita values for 2050 in Jacobson et al.(2020) with SSP1 urban population projection

Future Outlook of Emissions for 420 Urban Areas

In North America, urban emissions for 79 of the top 420 urban areas are 3024.9 ± 26.8 $MtCO_2eq$ in 2020

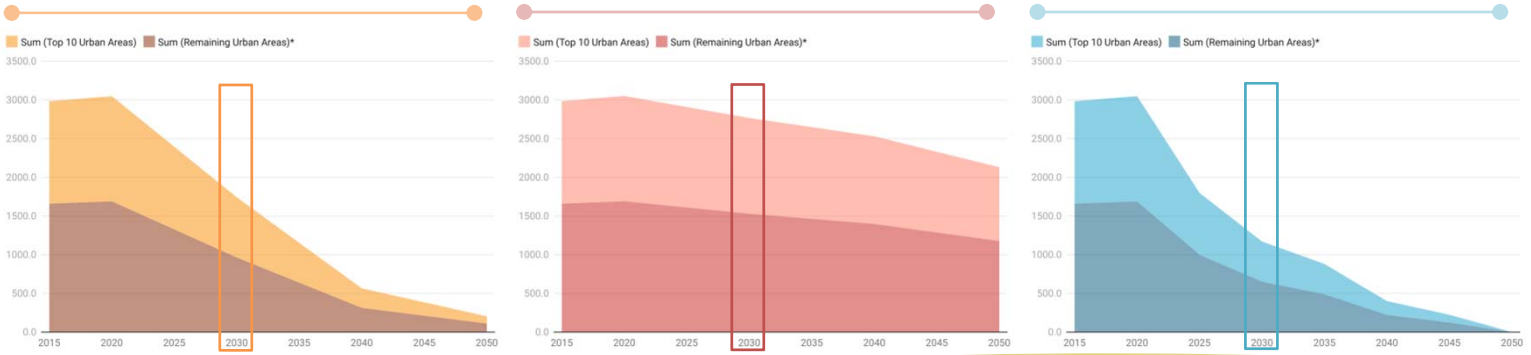


Urban Emissions
$MtCO_2eq$ per year

Future Outlook of Emissions for 420 Urban Areas

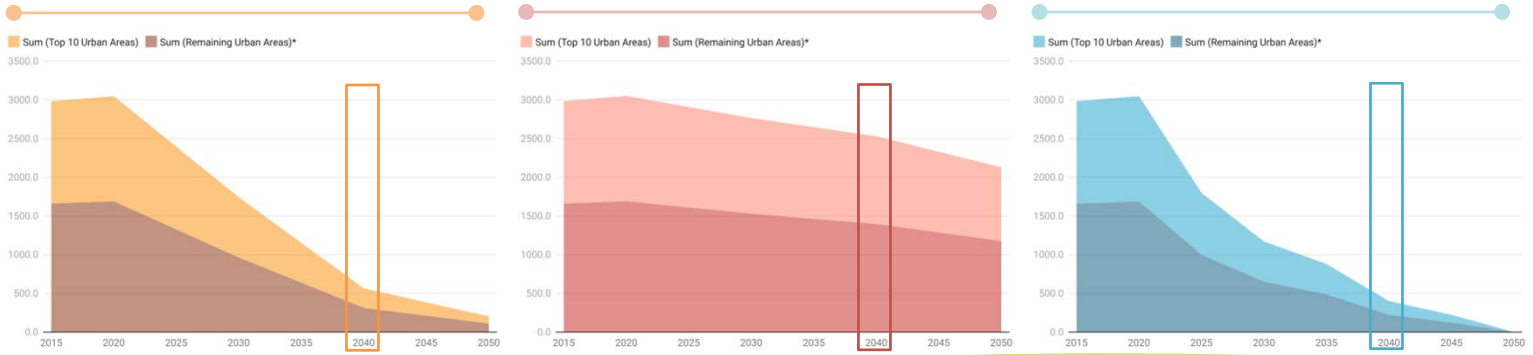
Across SSP1 scenarios, urban emission pathways can lead to 1742.2, 2766.0 or 1170.7 $MtCO_2eq$ in 2030

Urban Emissions
$MtCO_2eq$ per year



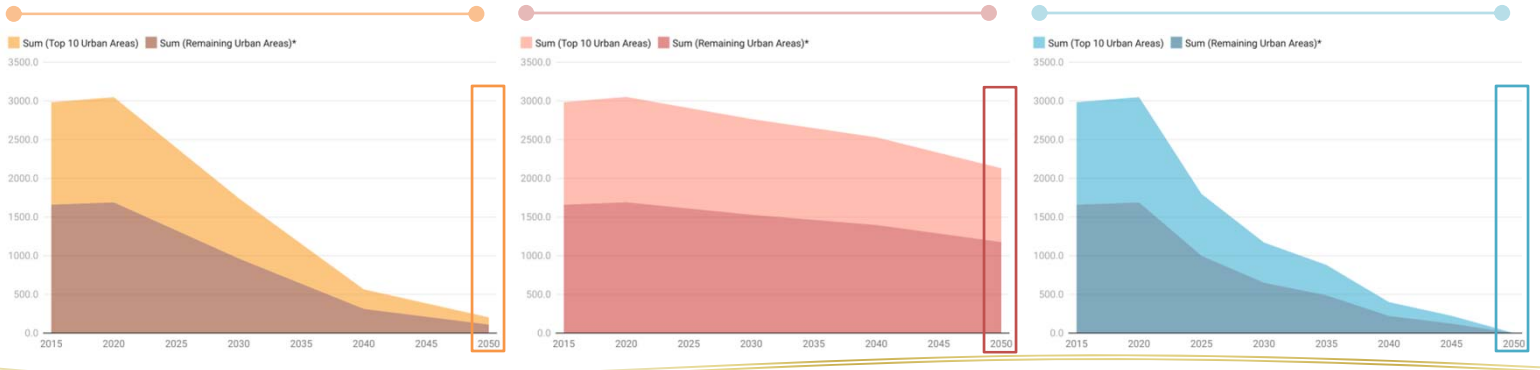
Future Outlook of Emissions for 420 Urban Areas

Across SSP1 scenarios, urban emission pathways can lead to 564.5, 2530.5 or 399.9 $MtCO_2eq$ in 2040



Future Outlook of Emissions for 420 Urban Areas

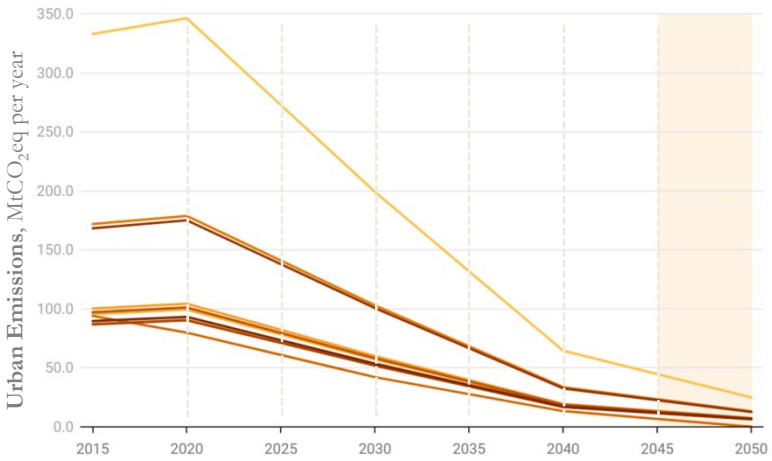
Across SSP1 scenarios, urban emission pathways can lead to 203.4, 2129.7 or ~0.0 $MtCO_2eq$ in 2050



Urban Emissions
$MtCO_2eq$ per year

Top 10 Emitting Urban Areas – North America

Under SSP1-1.9, the top 10 urban areas in this region will need to reduce their footprints by 1266.2 $MtCO_2eq$ by 2050



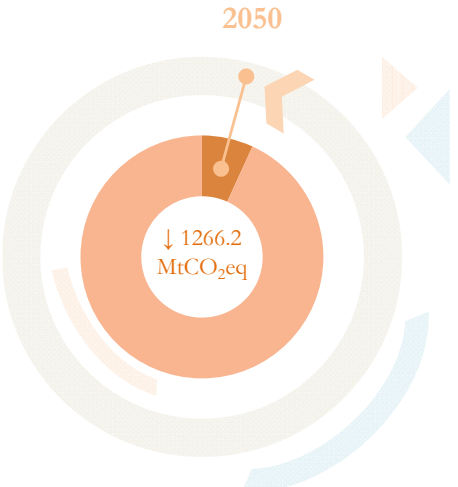
Search in table

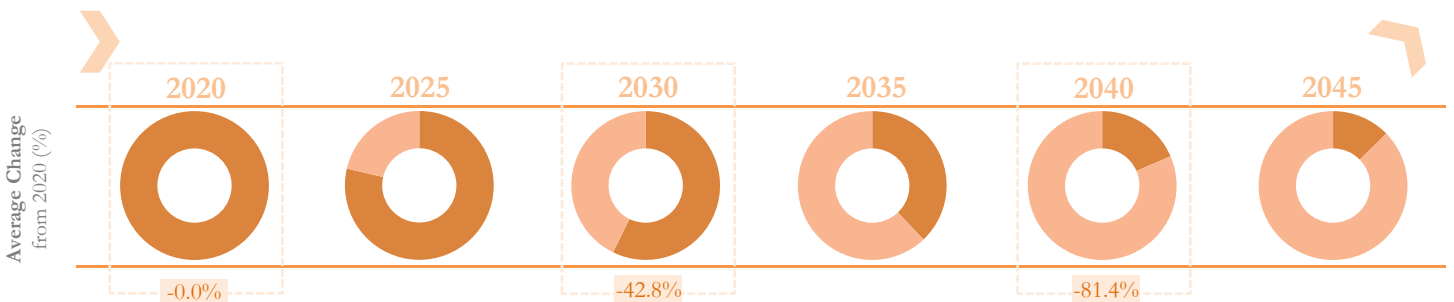
0.0 — 346.2

Region → North America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
New York-Newark	332.9	346.2	272.7	199.1	131.8	64.6	44.8	25.0
Los Angeles-L.B.-S.A.-S.C.	171.9	178.7	140.9	103.0	68.4	33.7	23.5	13.3
Chicago	168.3	175.1	137.9	100.7	66.7	32.7	22.6	12.6
Dallas-Fort Worth	100.3	104.3	82.2	60.0	39.7	19.5	13.5	7.5
Philadelphia	97.3	101.2	79.7	58.2	38.5	18.9	13.1	7.3
Miami	95.6	99.4	78.3	57.2	37.8	18.5	12.9	7.2
Toronto	94.0	79.8	61.0	42.1	27.8	13.4	6.8	0.1
Washington, D.C.	89.6	93.2	73.4	53.6	35.5	17.4	12.1	6.7
Houston	87.2	90.7	71.4	52.2	34.5	16.9	11.7	6.5
Atlanta	86.8	90.3	71.1	51.9	34.4	16.8	11.7	6.5

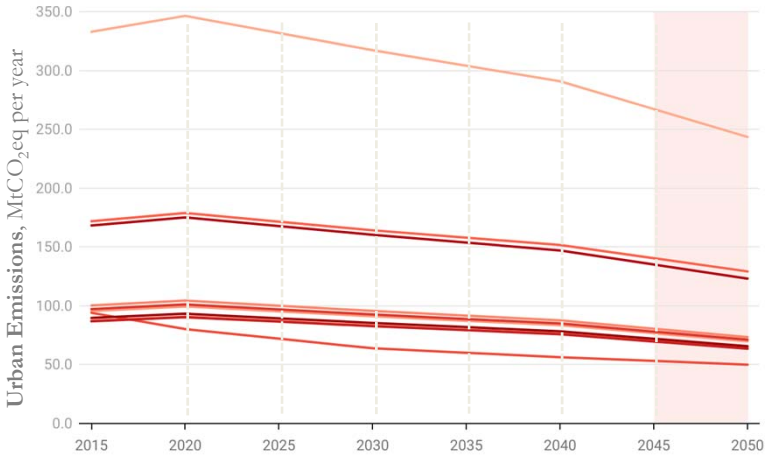
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – North America

While reductions in SSP1-2.6 remain limited at 406.9 $MtCO_2eq$ by 2050, again forgoing a missed 1.5°C target



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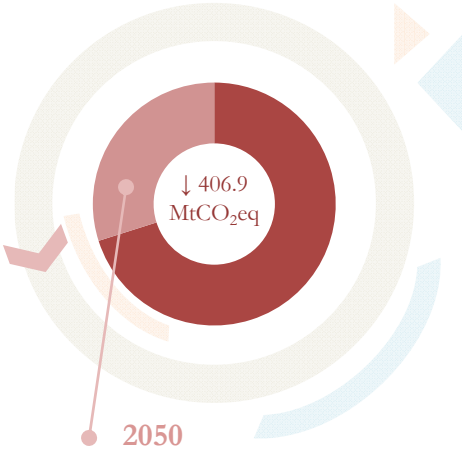
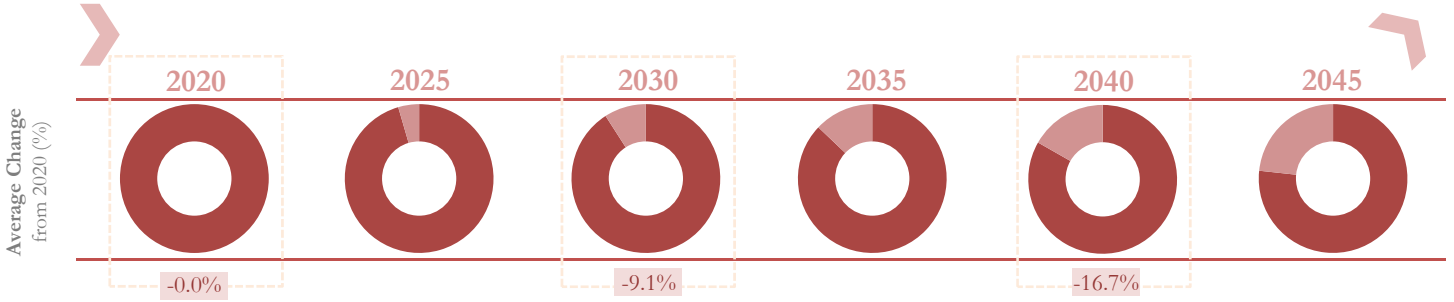
0.6 346.4

Region → North America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
New York-Newark	332.9	346.4	331.8	317.2	304.0	290.8	267.2	243.5
Los Angeles-L.B.-S.A.-S.C.	171.9	178.9	171.5	164.2	157.9	151.7	140.5	129.2
Chicago	168.3	175.2	167.8	160.4	153.7	147.1	135.1	123.1
Dallas-Fort Worth	100.3	104.4	100.0	95.6	91.6	87.7	80.5	73.4
Philadelphia	97.3	101.2	97.0	92.7	88.8	85.0	78.1	71.2
Miami	95.6	99.5	95.3	91.1	87.3	83.5	76.7	69.9
Toronto	94.0	80.2	72.1	63.9	60.1	56.3	53.2	50.0
Washington, D.C.	89.6	93.3	89.4	85.4	81.9	78.3	72.0	65.6
Houston	87.2	90.8	86.9	83.1	79.7	76.2	70.0	63.8
Atlanta	86.8	90.4	86.5	82.7	79.3	75.9	69.7	63.5

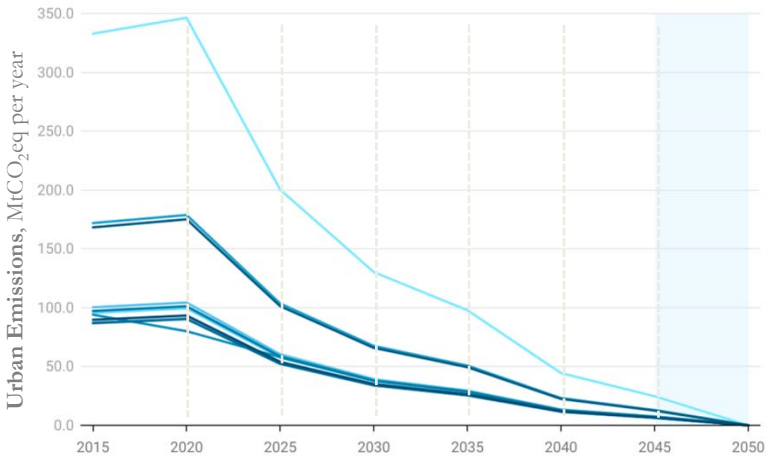
In units of $MtCO_2eq$ per year including CO_2 and CH_4.





Top 10 Emitting Urban Areas – North America

For these areas, 100% RE scenarios provide opportunities to eliminate 1359.6 $MtCO_2eq$ of urban emissions in 2050



Search in table

0.0 346.3

Region → North America

Uj	2015	2020	2025	2030	2035	2040	2045	2050
New York-Newark	332.9	346.3	200.2	130.2	97.8	44.4	24.7	0.0
Los Angeles-L.B.-S.A.-S.C.	171.9	178.8	103.5	67.4	50.8	23.2	13.0	0.0
Chicago	168.3	175.1	101.2	65.8	49.4	22.5	12.5	0.0
Dallas-Fort Worth	100.3	104.4	60.3	39.2	29.5	13.4	7.4	0.0
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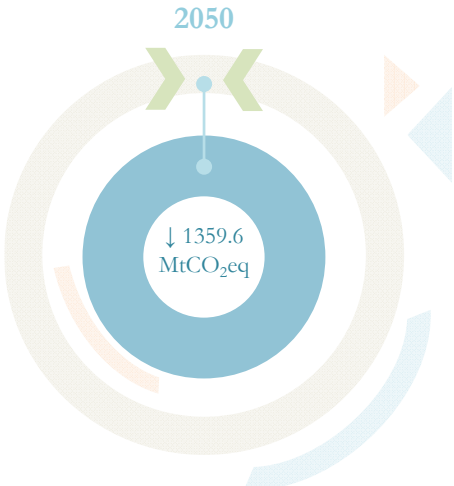
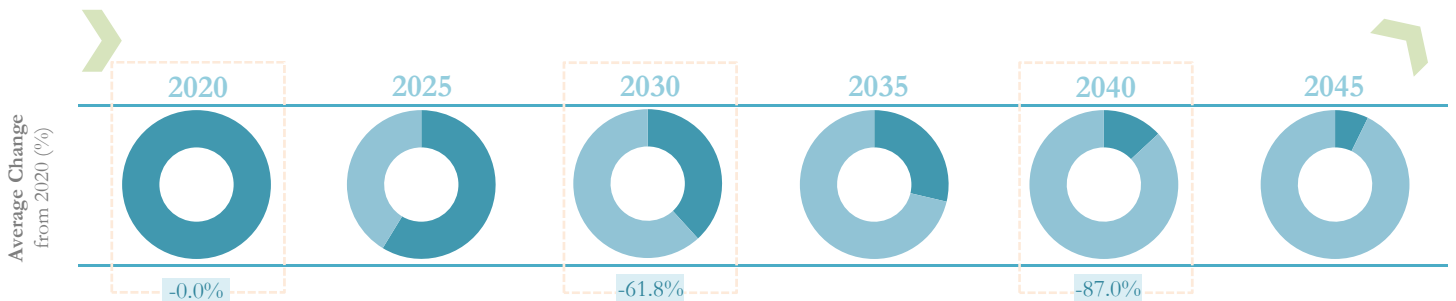
Miami	95.6	99.4	57.5	37.4	28.1	12.7	7.1	0.0
Toronto	94.0	80.0	57.9	38.0	28.7	13.1	7.4	0.0
Washington, D.C.	89.6	93.3	53.9	35.1	26.3	12.0	6.7	0.0
Houston	87.2	90.7	52.5	34.1	25.6	11.6	6.5	0.0
Atlanta	86.8	90.3	52.2	34.0	25.5	11.6	6.4	0.0

In units of $MtCO_2eq$ per year including CO_2 and CH_4.



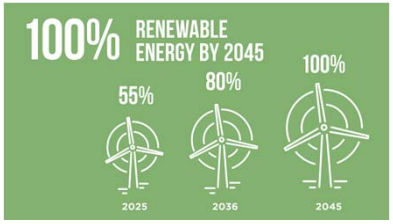


Actions Urban Areas Are Taking and Opportunities

- **100% RE for city operations** while having only a 8% share in total electricity emissions

Source: New York 1.5° Plan

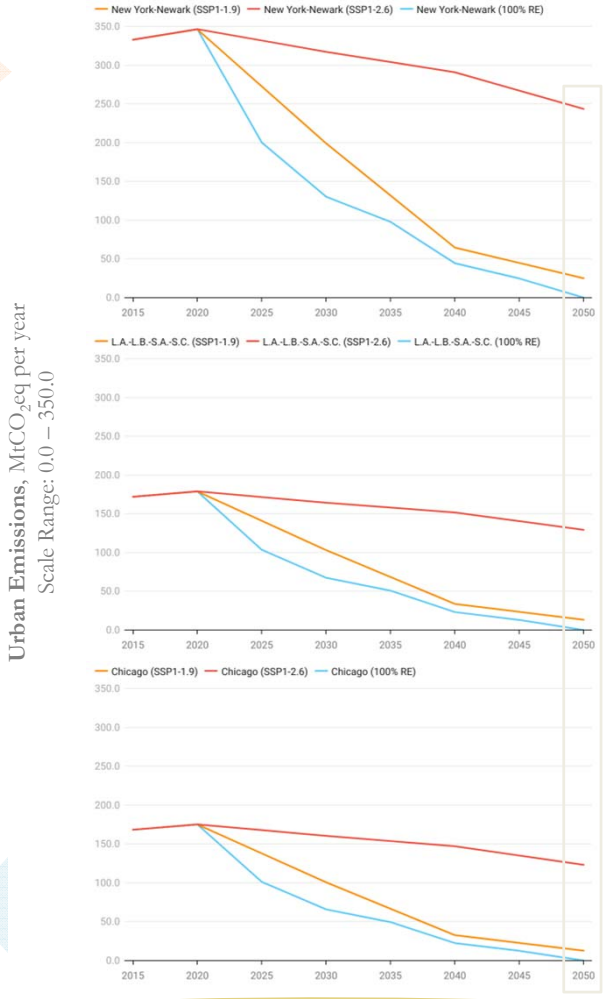
- **100% RE for energy supply by 2045** based on the Green New Deal Sustainability Plan



Source: Green New Deal Plan (2019)

- Target to reduce GHG emissions by 50% from 2005 levels by 2030 based on the **renewed regional climate action plan**
- Current regional level is ~120 $MtCO_2eq^*$

Sources: New York 1.5° Plan; Motyka et al. (2019) Renewables (Em)power Smart Cities; Green New Deal Plan (2019); Climate Action Plan for the Chicago Region (2021)



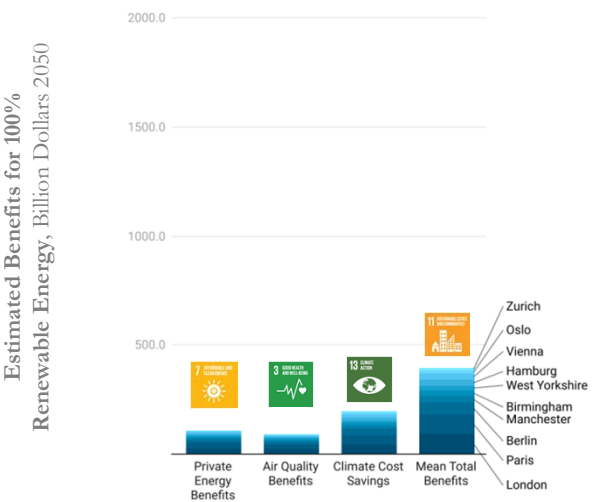
Making the complete shift for the urban energy system and beyond

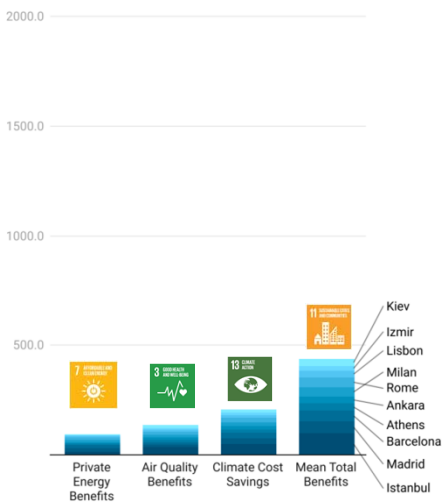
Co-benefits of 100% RE in these 3 urban areas:
~ 700 Billion
Energy, air quality and climate cost savings in 2050
Monetary units in USD

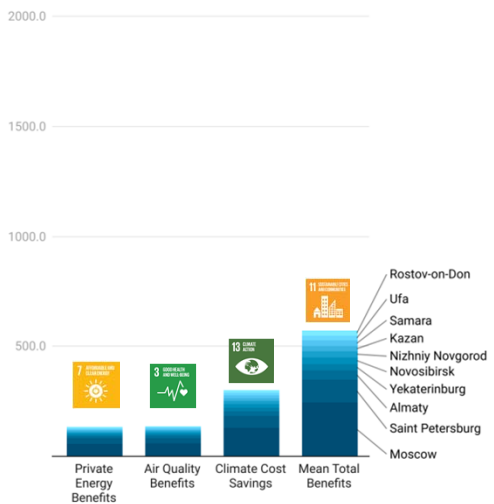
(*) Urban emissiona in this original analysis and local plans can differ based on the **boundary in the GHSL and/or scope of emissions**

What Kind of Urban Areas Do We Want to See in 2050?

Urban areas that are providing energy, health and climate related benefits for urban inhabitants are possible







Calculated based on local per capita values in Jacobson et al.(2020) with harmonized SSP1 urban population in 2050 based on Kii et al. (2021)

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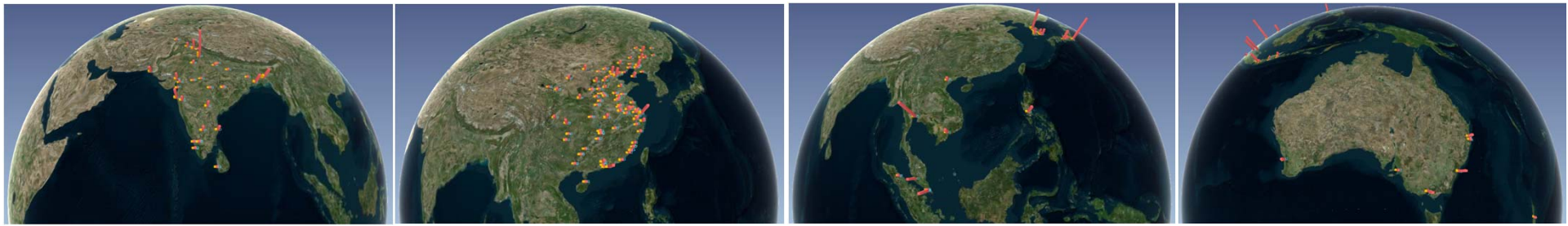

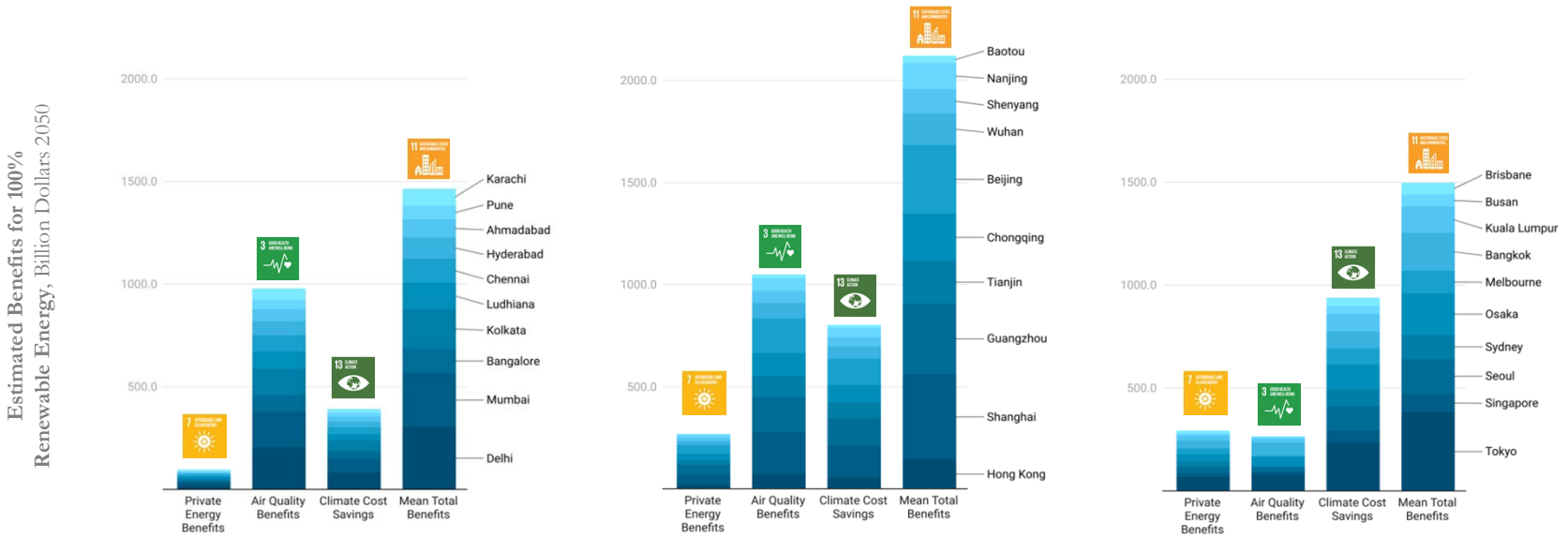

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What Kind of Urban Areas Do We Want to See in 2050?

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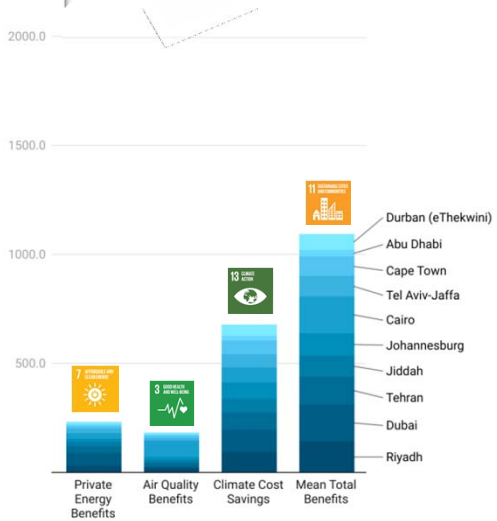
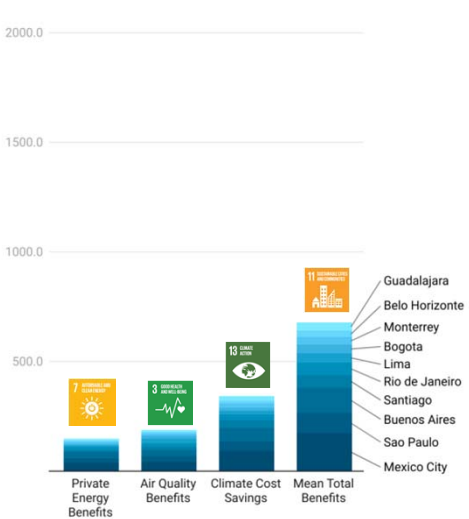
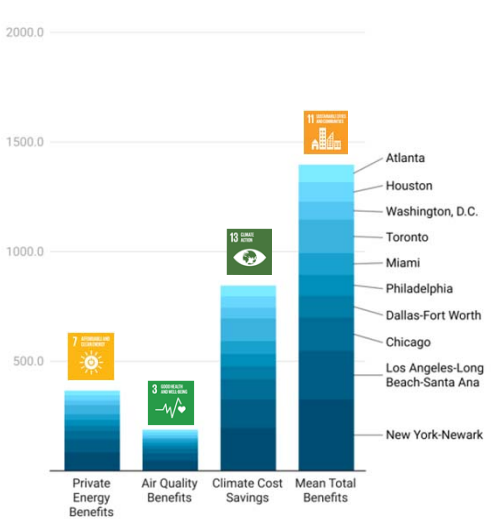
Contributions to sustainable development
based on the SDGs will continue after 2030

Estimated Benefits for 100% Renewable Energy, Billion Dollars 2050



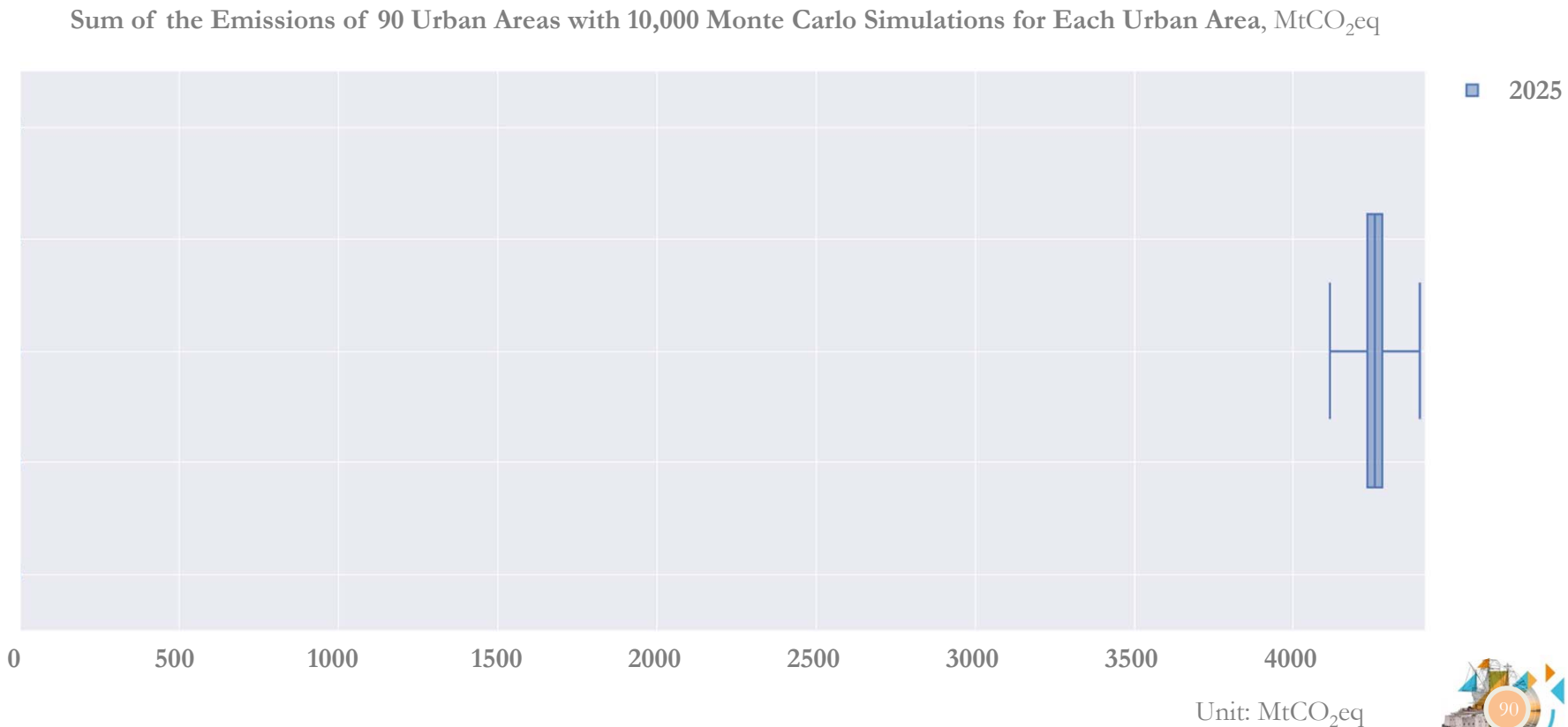




Calculated based on local per capita values in Jacobson et al.(2020) with harmonized SSP1 urban population in 2050 based on Kii et al. (2021)

Importance of the Success of Urban Governance

If each urban area reaches SSP1-RE values within ±10% randomly, progress towards net-zero can be still within sight



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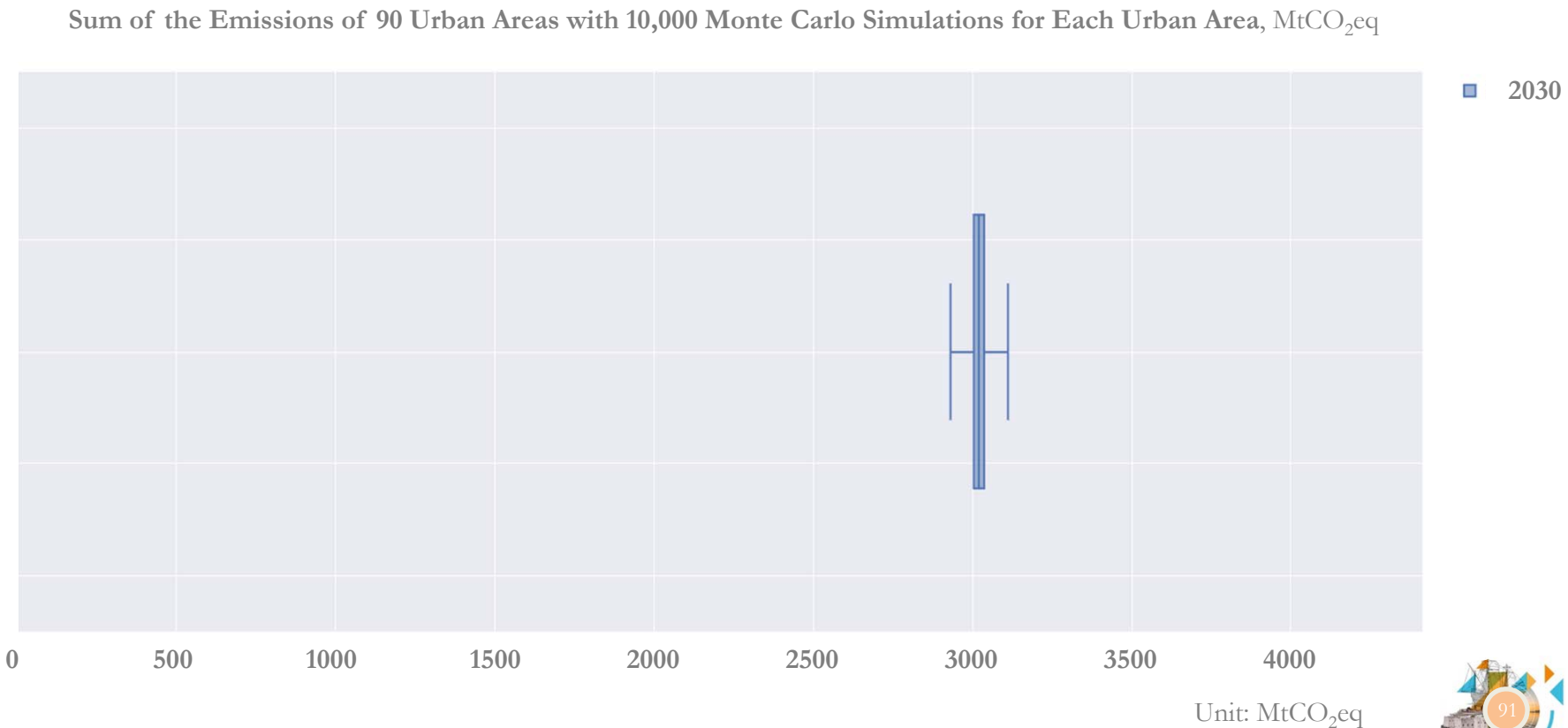

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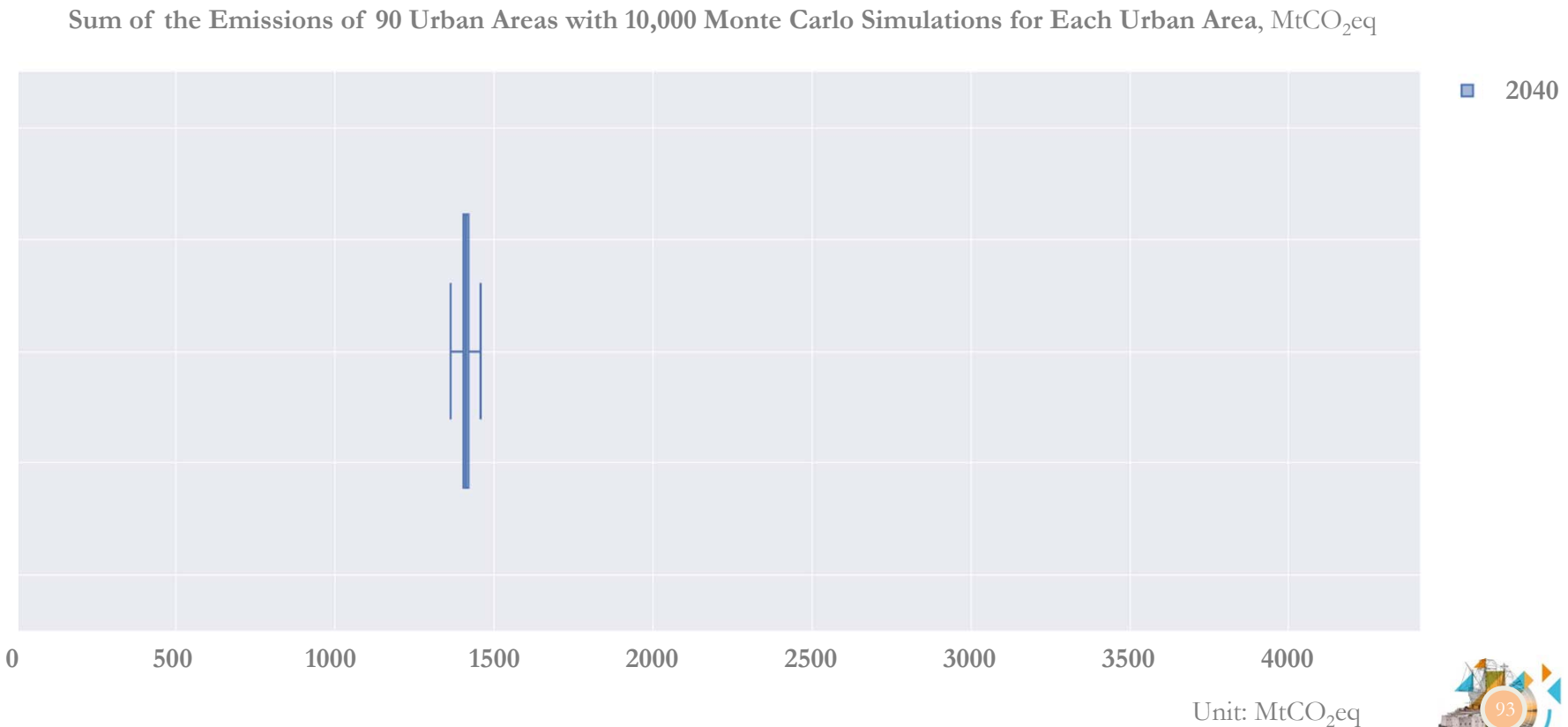

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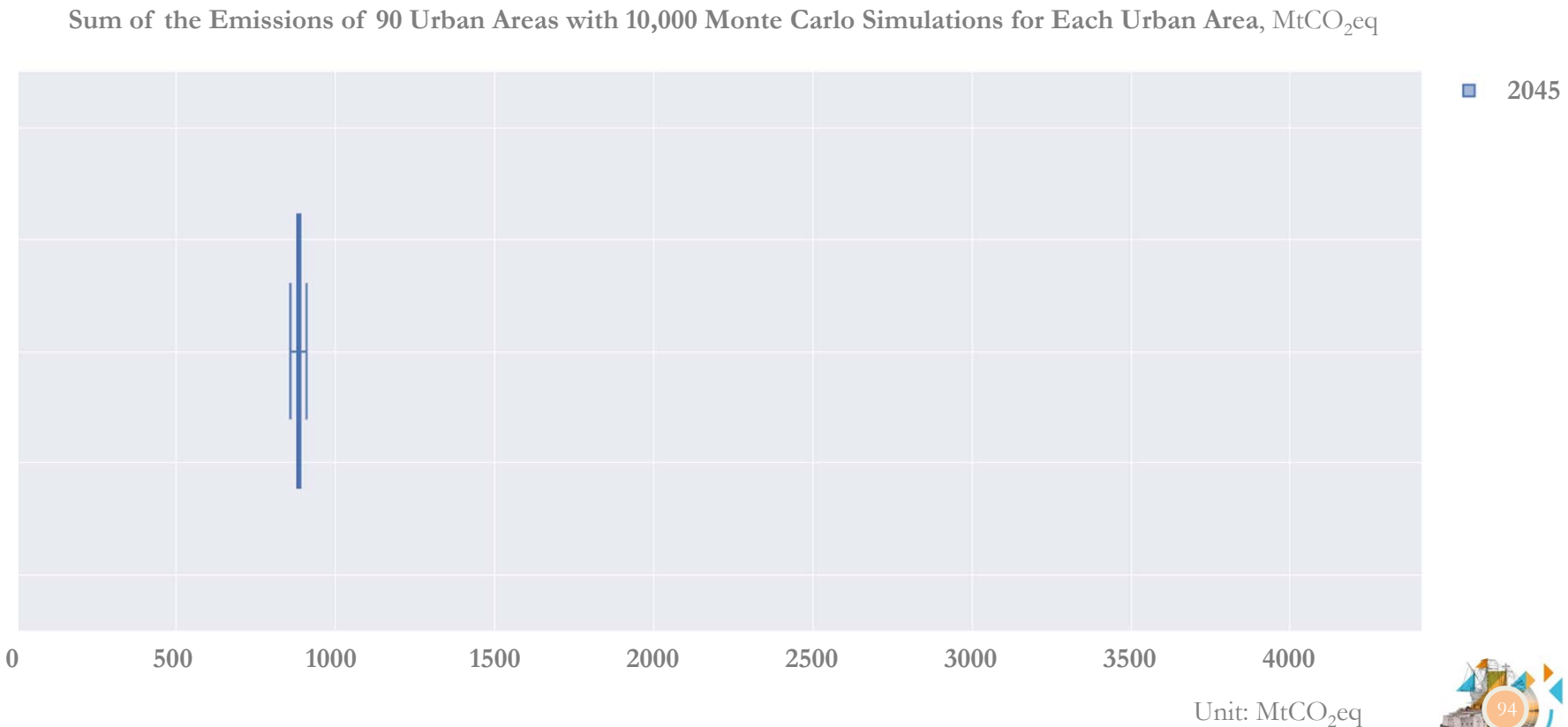

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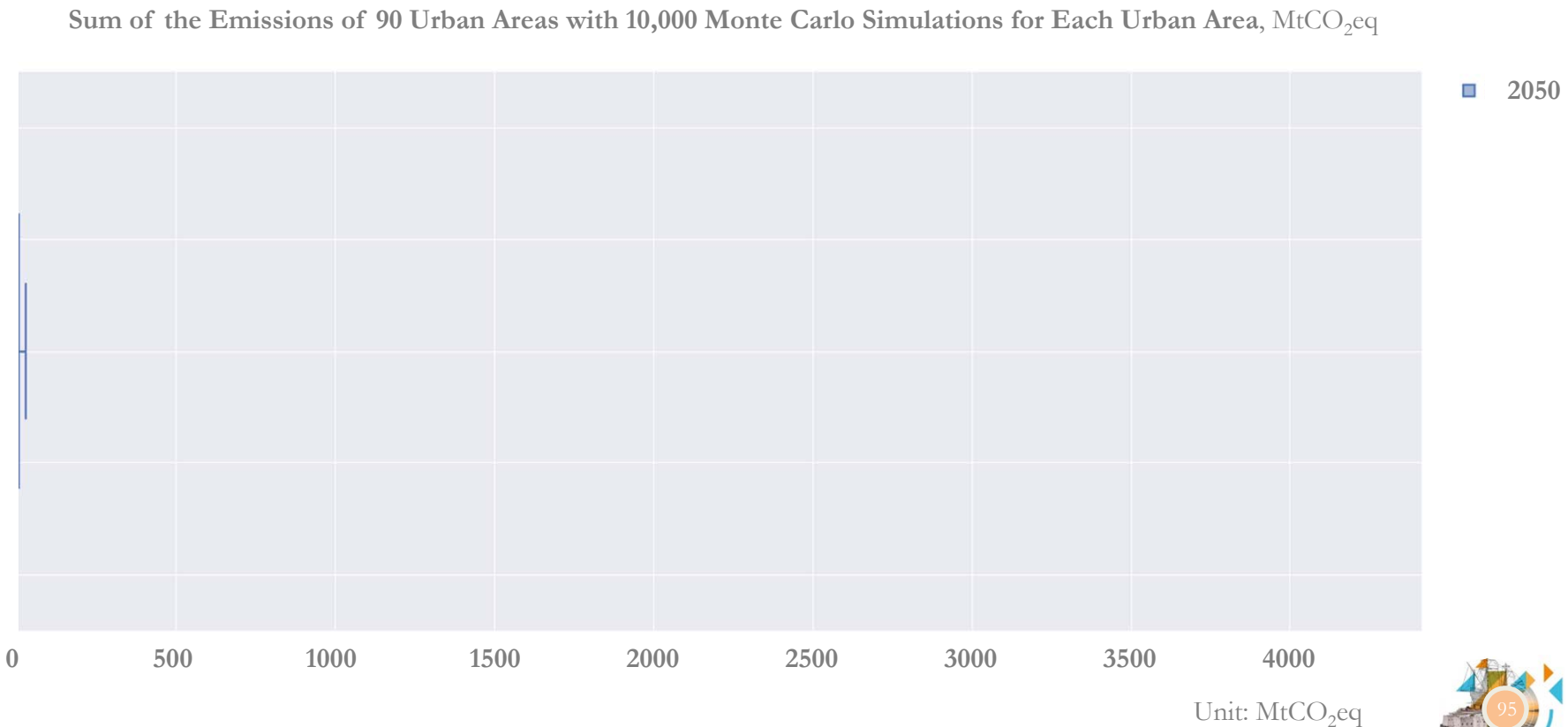


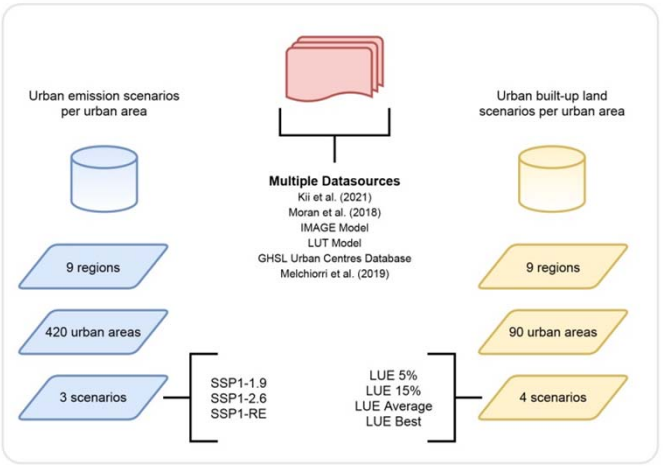
Integrated Scenarios Utilizing Land Use Efficiency

The three SSP1 scenarios for urban emissions are further coupled with scenarios considering land use efficiency

Data inputs – Urban emissions and trends

- Global Gridded Model of Carbon Footprints
- Global Human Settlement Layer GHSL-UCDB
  → **Land use efficiency (LUE) per urban cluster**
- Urban population by SSP per urban cluster

Land use efficiency is tracked per urban area for SDG11.3 (*) and is here used for extended scenarios



Overall method based on the **original research work** of the presenter

(*) SDG11.3: "By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, **integrated and sustainable human settlement planning and management** in all countries"

Scenario	Urbanization Qualities
SSP1-RE	Rapid / Relatively Compact
SSP1-1.9	Rapid / Relatively Compact
SSP1-2.6	Rapid / Relatively Compact

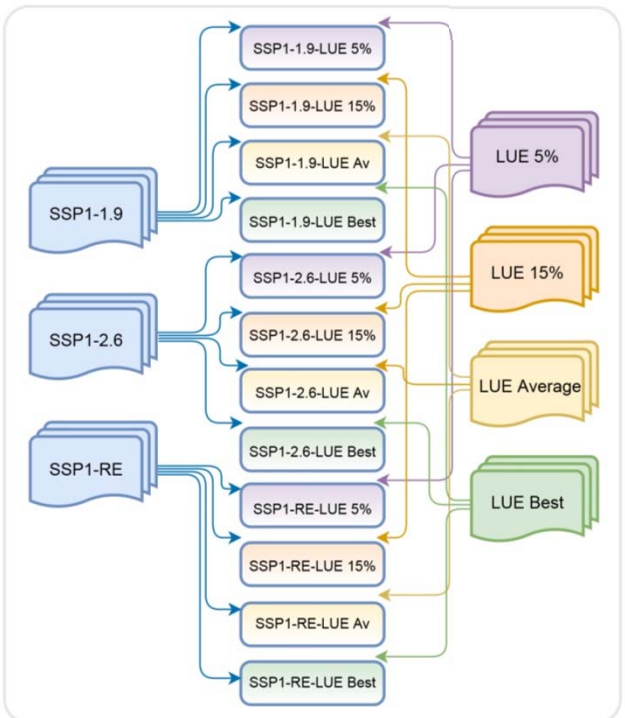
Scenario	Land Use Efficiency
LUE 5%	5% improvement every 5 years
LUE 15%	15% improvement every 10 years
LUE Av	Convergence to regional average LUE
LUE Best	Transition to the best regional LUE

Integrated Scenarios Utilizing Land Use Efficiency

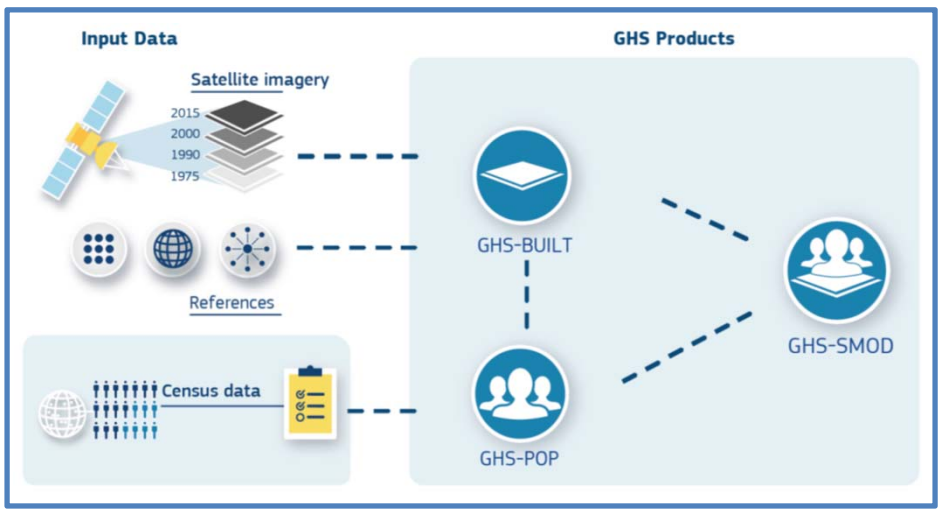
Together with the urban level SSP1 scenarios, land use efficiency scenarios for specific urban areas are obtained

Scenario values are solved based on the *LUE* equation per urban area U_j

$$LUE(U_j) = \frac{LCR(Uj)}{PGR(Uj)} = \frac{LN(L_{t+n})_{Uj}/LtUj * y^{-1}}{LN(P_{t+n})_{Uj}/LtUj * y^{-1}}$$



Based on the **original research work** of the presenter

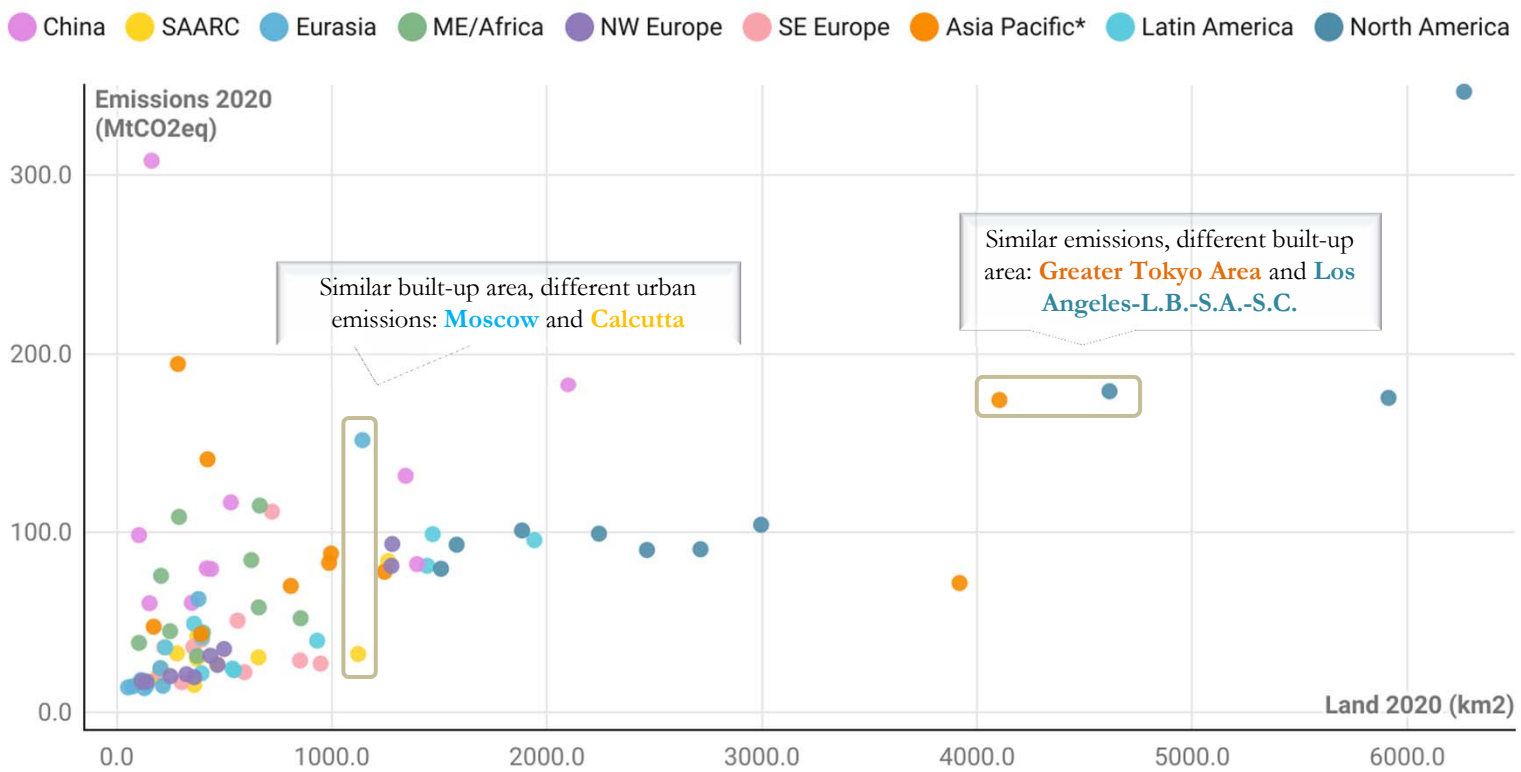


Source: JRC (2020), Atlas of the Human Planet; LUE equation adapted for scenarios for a specific urban area U_j from Melchiorri et al. (2019), Principles and Applications of the GHSL as Baseline for the LUE Indicator SDG11.3.1

- **LCR**: Rate of land consumption where *L* is built-up land
- **PGR**: Population growth rate where *P* is population

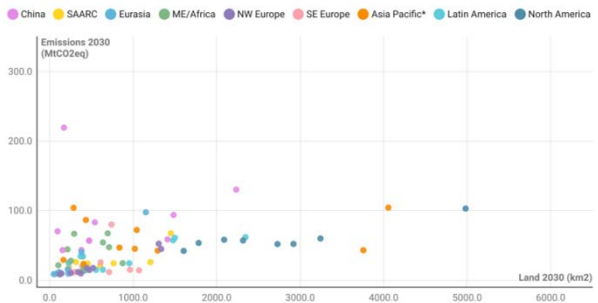
2-Dimensional Scenario Space – Emissions and Land

In 2020, 90 urban areas were responsible for 5.9 ± 0.3 $GtCO_2eq$ of emissions, covering 83.3 x 10^3 km^2 of built-up area

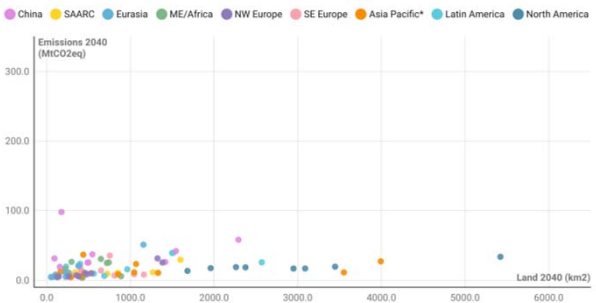


2-Dimensional Scenario Space – Emissions and Land

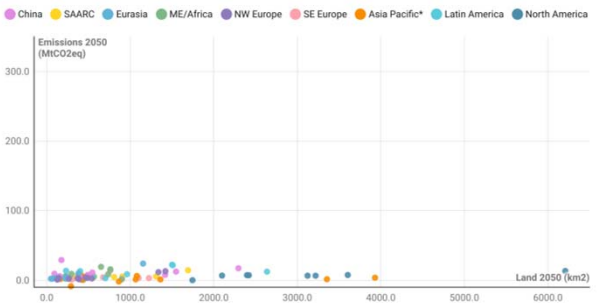
The SSP1-1.9 scenario with 5% improvement in LUE is <u>insufficient</u> to contain the growth of fast growing urban areas



Δ Urban Emissions (2030) ↓ 2259 $MtCO_2eq$

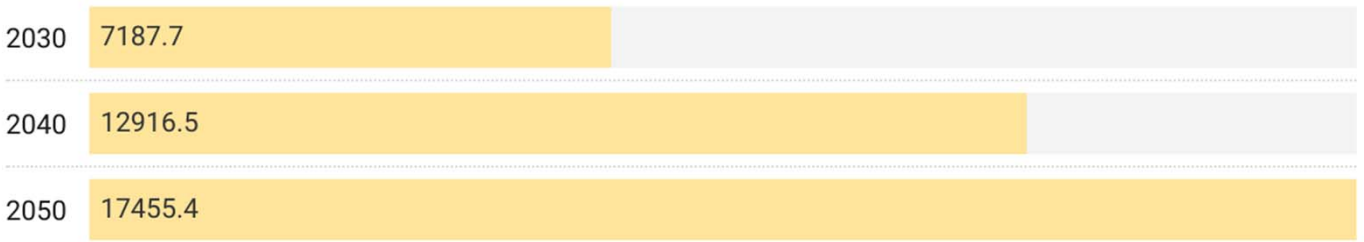


Δ Urban Emissions (2040) ↓ 4529 $MtCO_2eq$



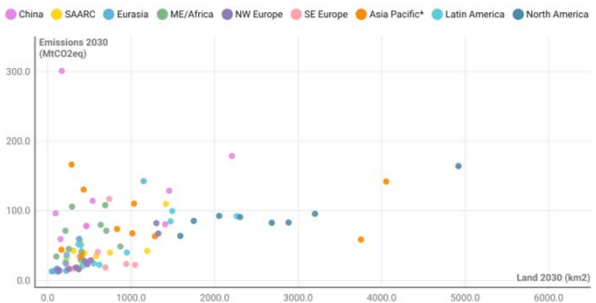
Δ Urban Emissions (2050) ↓ 5556 $MtCO_2eq$

Total Increase in Urban Built-Up Area Compared to 2020, Δkm^2

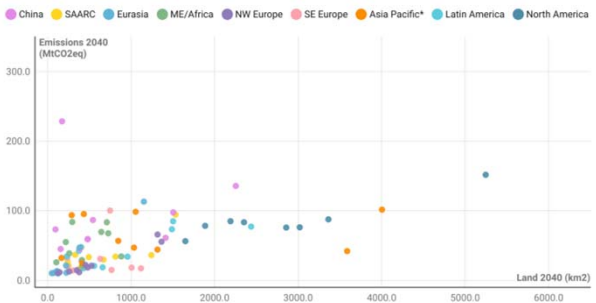


2-Dimensional Scenario Space – Emissions and Land

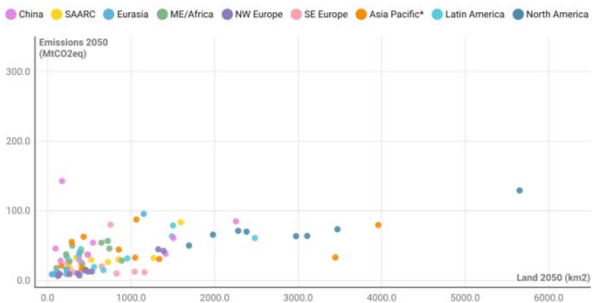
SSP1-2.6 with 15% improvement in LUE is only better in limiting built-up area while <u>insufficient</u> for urban emissions



Δ Urban Emissions (2030) ↓ 251 $MtCO_2eq$



Δ Urban Emissions (2040) ↓ 1346 $MtCO_2eq$

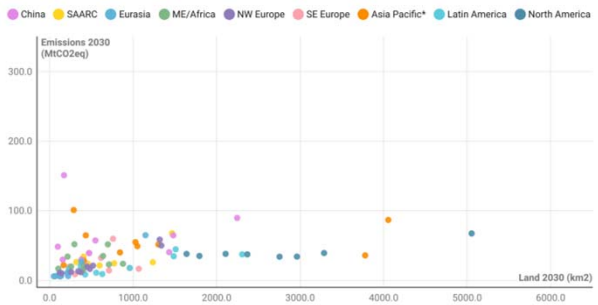


Δ Urban Emissions (2050) ↓ 2479 $MtCO_2eq$

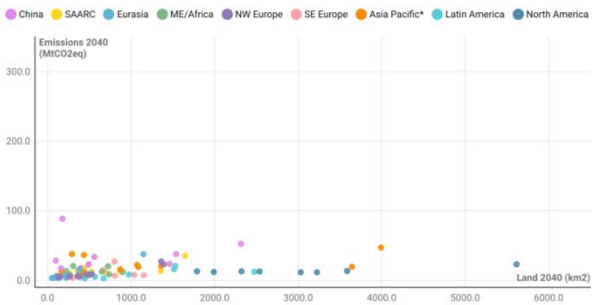
Total Increase in Urban Built-Up Area Compared to 2020, Δkm^2

2-Dimensional Scenario Space – Emissions and Land

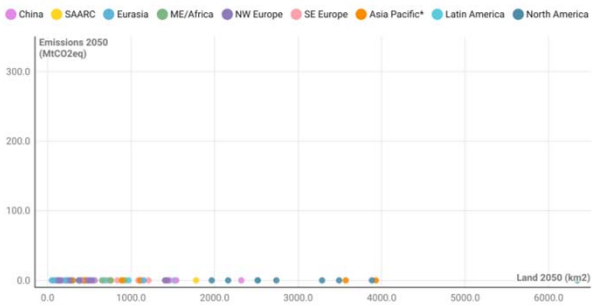
In comparison, SSP1-RE with LUE values converging to regional averages is better only for limiting urban emissions



Δ Urban Emissions (2030) ↓ 2567 $MtCO_2eq$

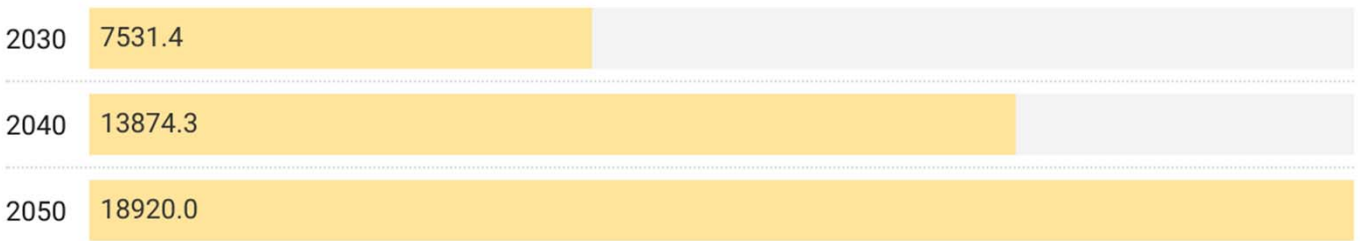


Δ Urban Emissions (2040) ↓ 4176 $MtCO_2eq$



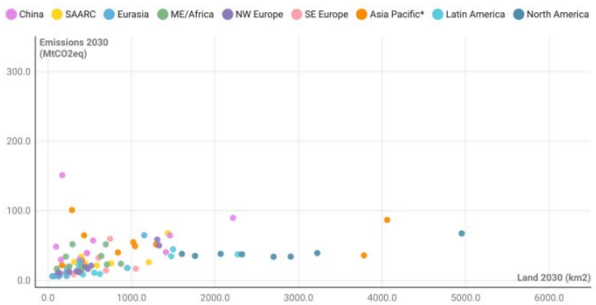
Δ Urban Emissions (2050) ↓ 5588 $MtCO_2eq$

Total Increase in Urban Built-Up Area Compared to 2020, Δkm^2

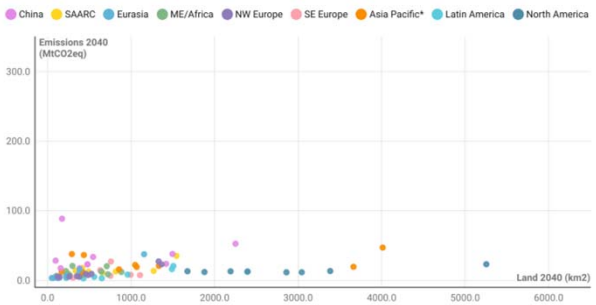


2-Dimensional Scenario Space – Emissions and Land

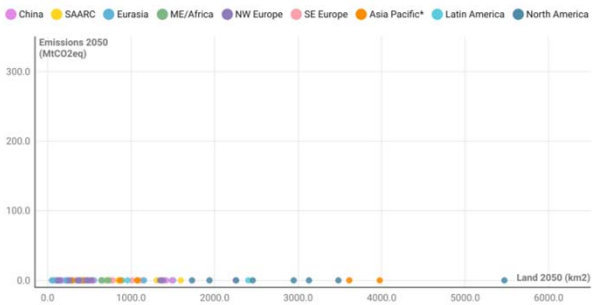
The SSP1-RE scenario with covergence to the regional best LUE values is <u>better in both dimensions simultaneously</u>



Δ Urban Emissions (2030) ↓ 2567 $MtCO_2eq$

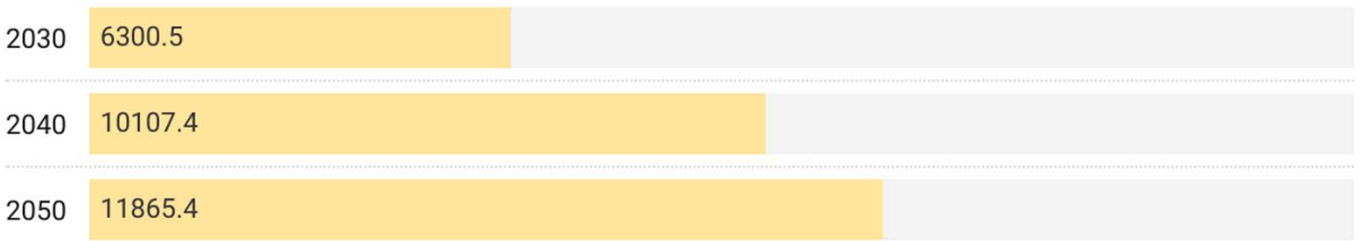


Δ Urban Emissions (2040) ↓ 4176 $MtCO_2eq$



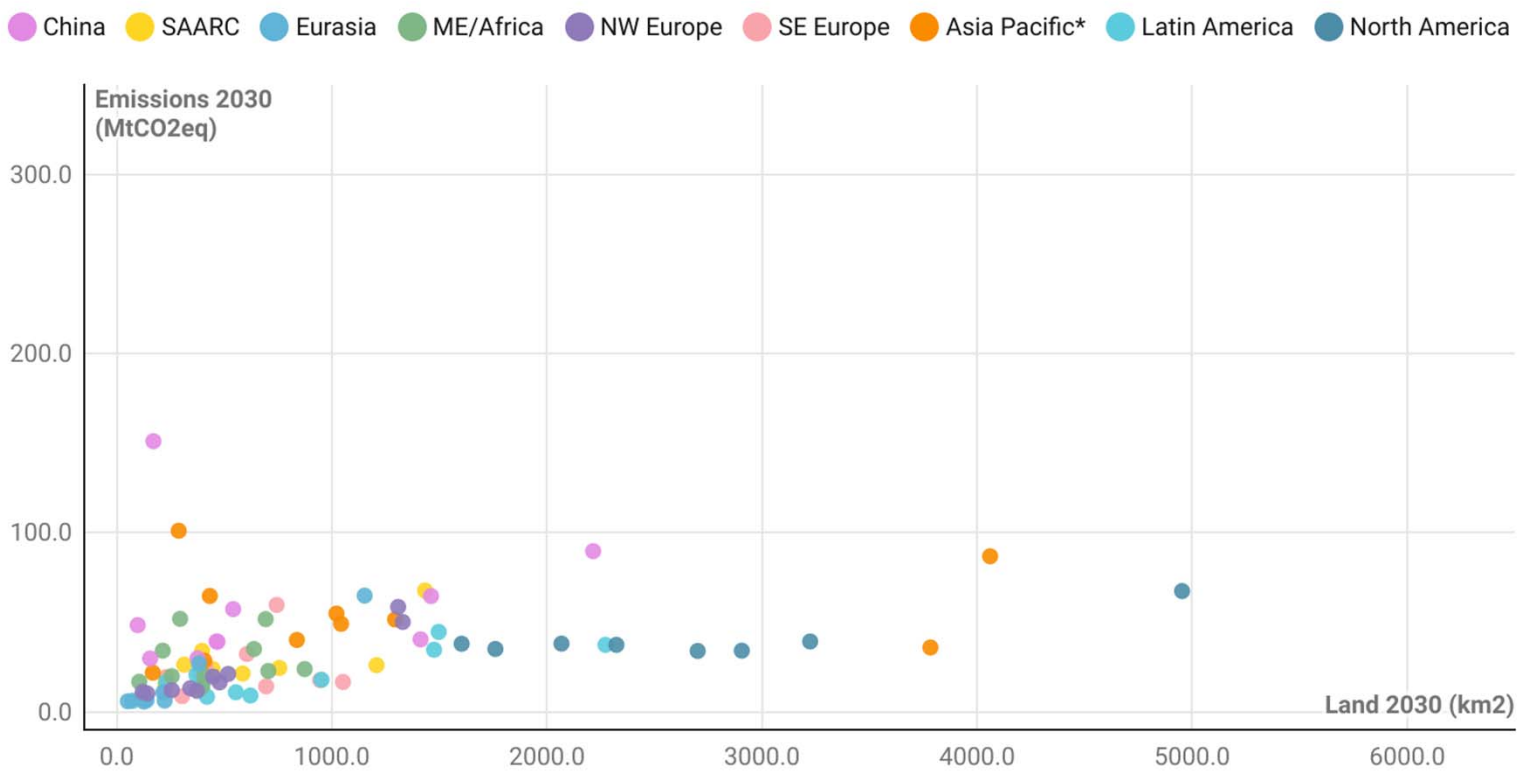
Δ Urban Emissions (2050) ↓ 5588 $MtCO_2eq$

Total Increase in Urban Built-Up Area Compared to 2020, Δkm^2



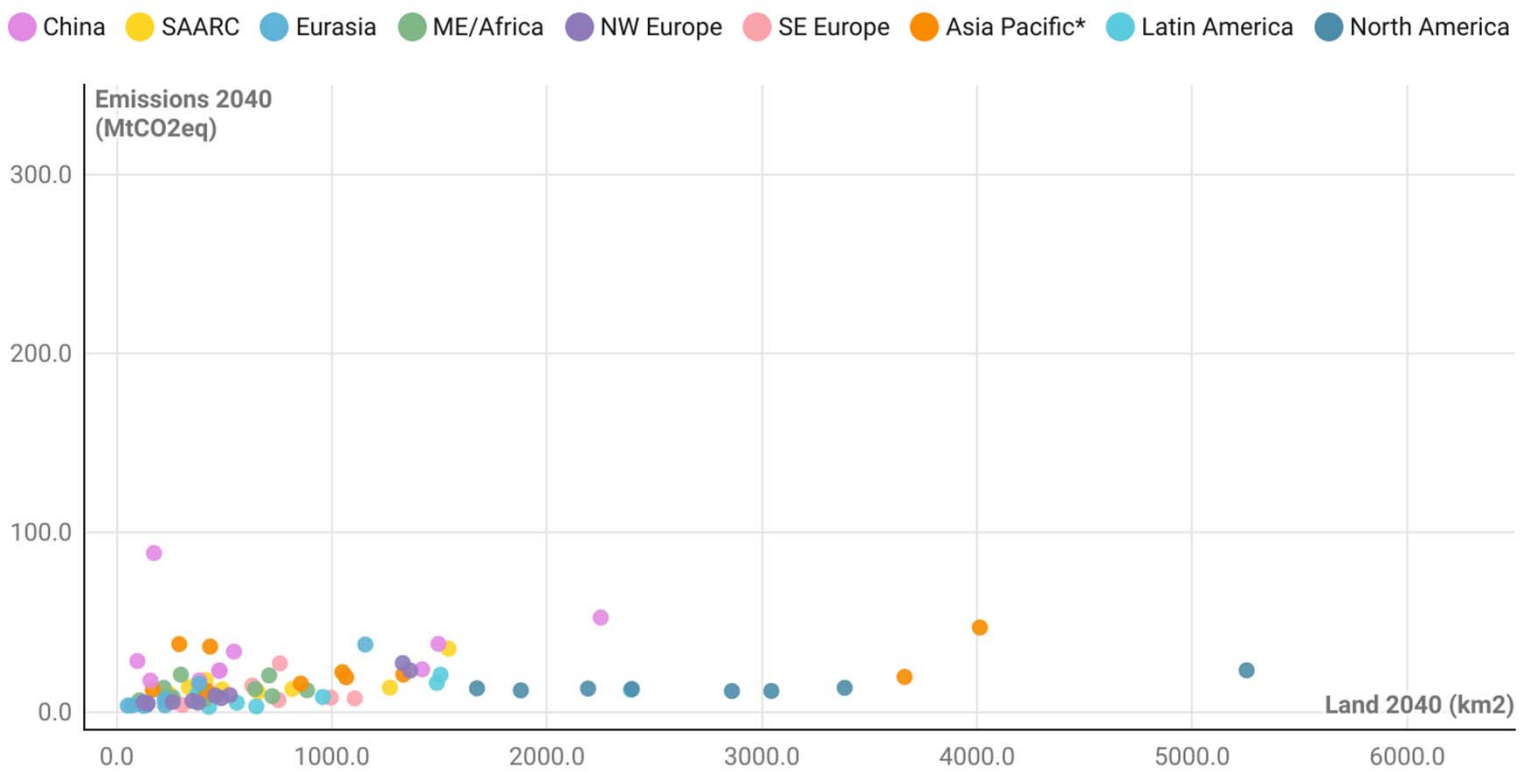
2-Dimensional Scenario Space – Emissions and Land

In 2030, the 90 urban areas progress toward 100% RE while limiting growth in built-up area to about 6.3 x 10^3 km^2



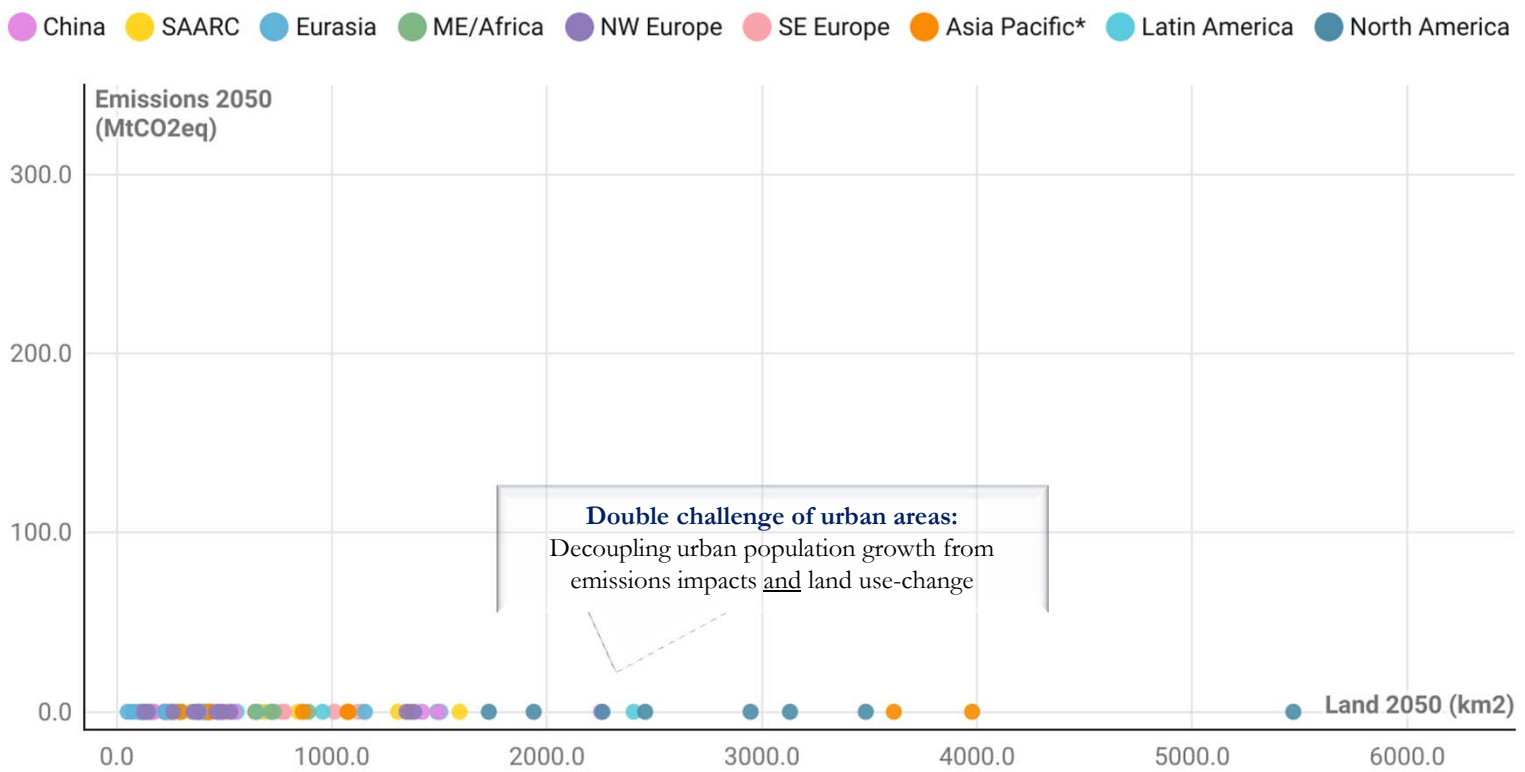
2-Dimensional Scenario Space – Emissions and Land

In 2040, the 90 urban areas progress toward 100% RE while limiting growth in built-up area to about 10.1 x 10^3 km^2



2-Dimensional Scenario Space – Emissions and Land

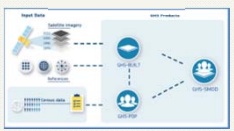
In 2050, the 90 urban areas reach the 100% RE target while limiting growth in built-up area to about 11.9 x 10^3 km^2



Cumulative Emissions from Urban Land Use Change

Even in the scenario with the best LUE, land use change in local biomes will have cumulative emissions penalties

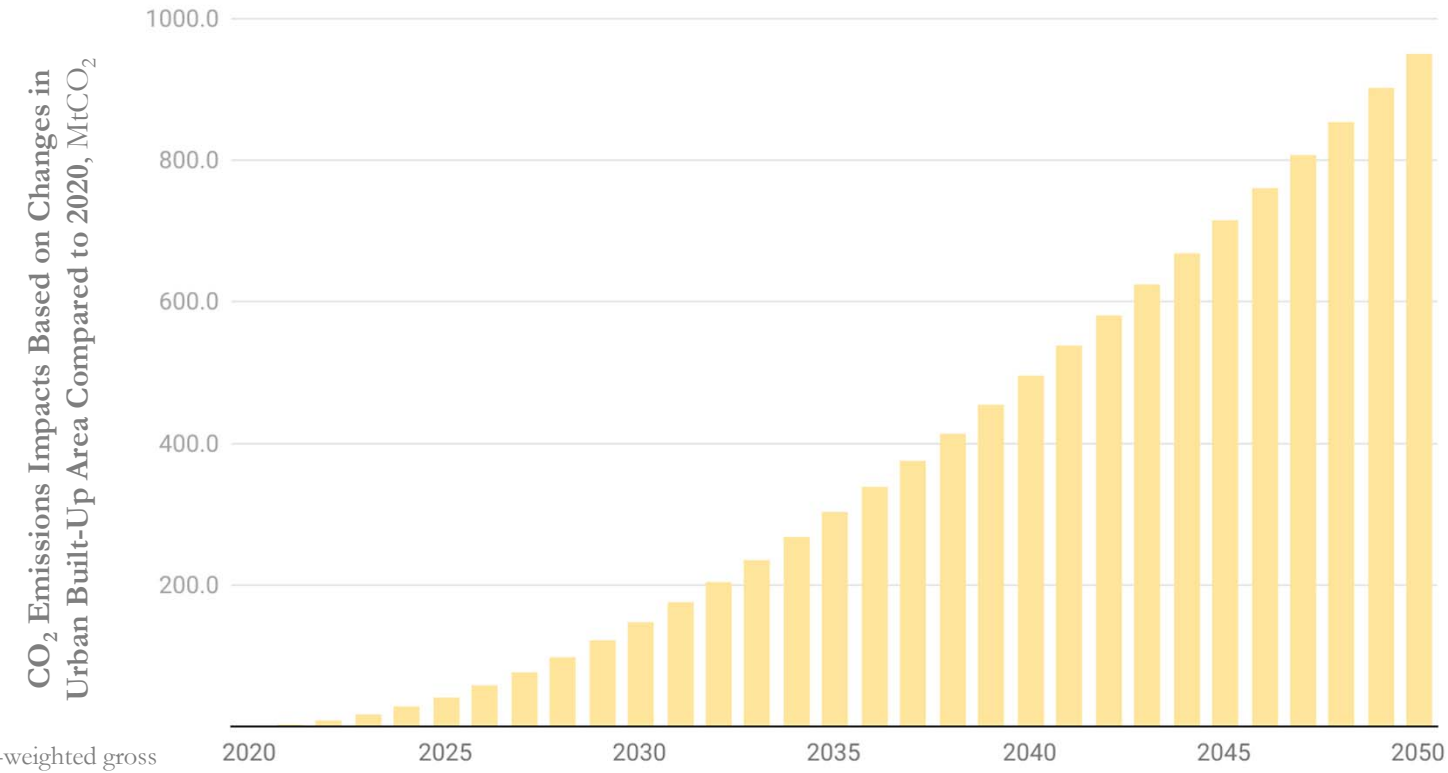
GHSL



Local Biomes (U_j)

CO_2 Sequestration Potential per Year

Cumulative Basis



Source: Based on area-weighted gross primary productivity per biome in Harper et al. (2016) using in JULES model.

Cumulative Emissions from Urban Land Use Change

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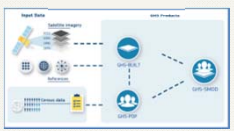

Local Biomes (U_j)

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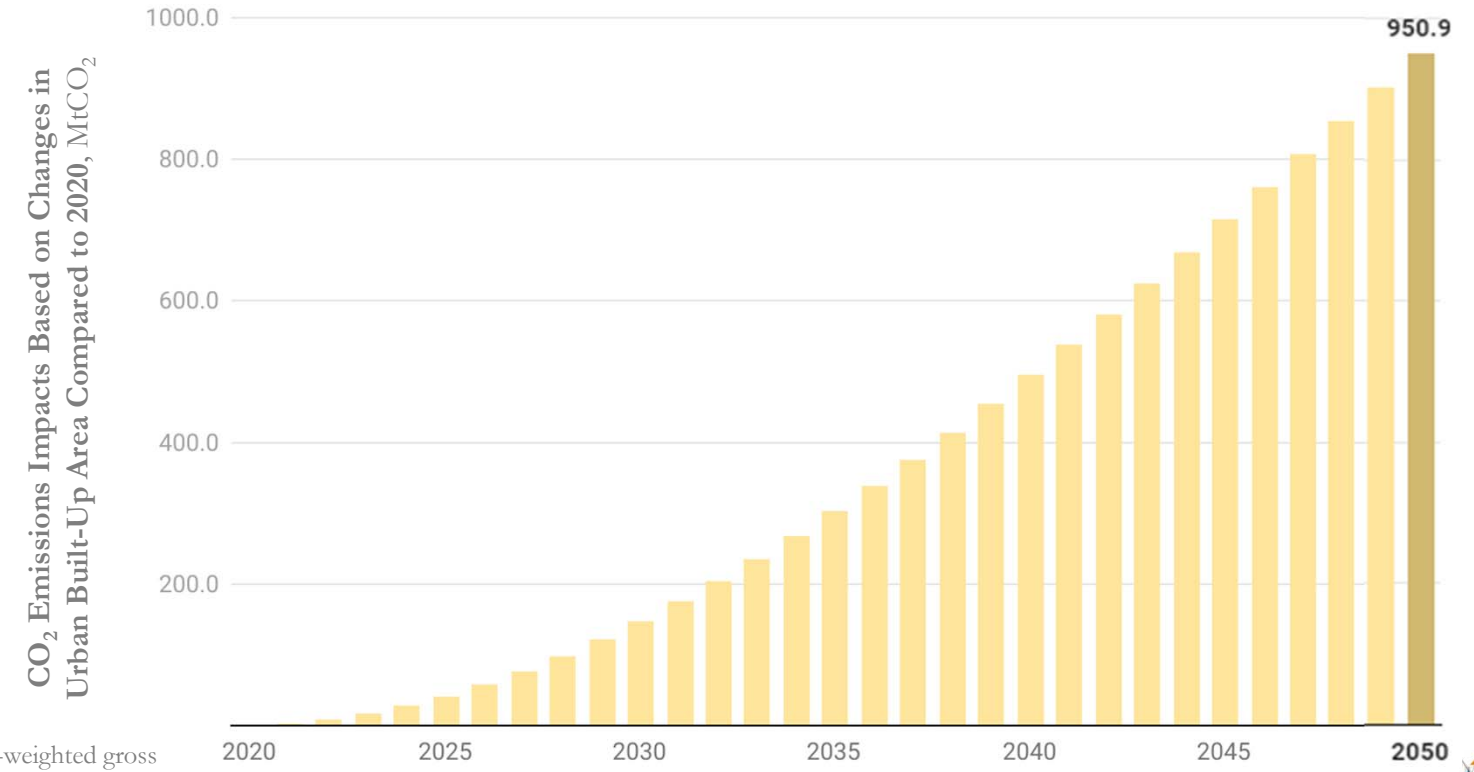
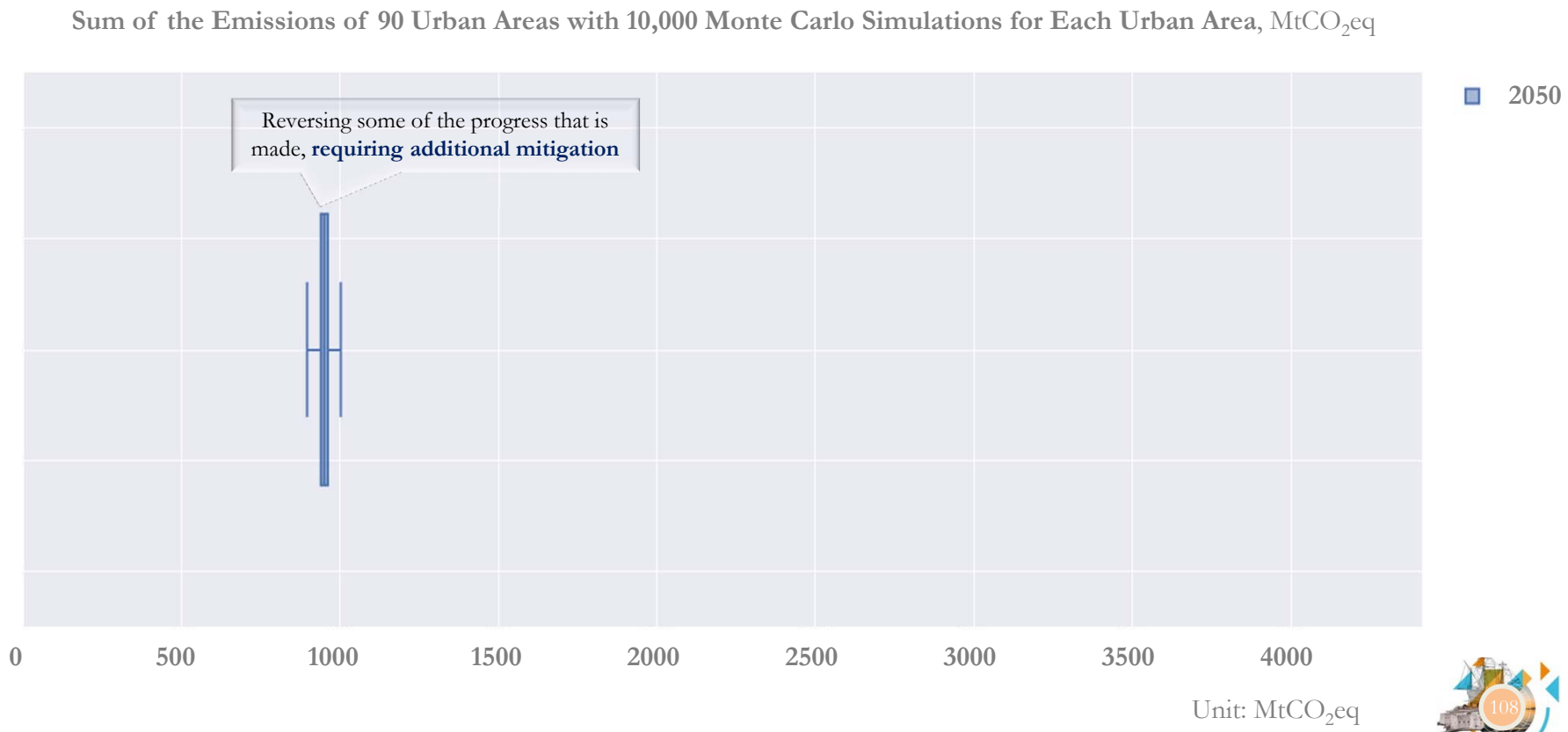


Source: Based on area-weighted gross primary productivity per biome in Harper et al. (2016) using in JULES model.

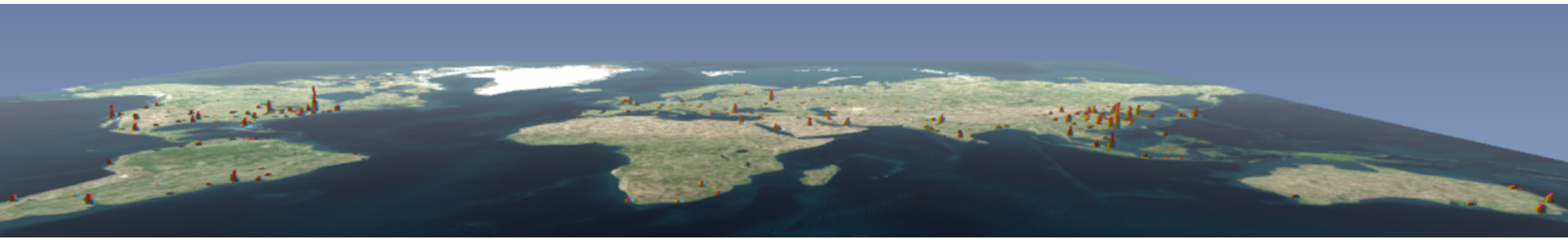
Cumulative Emissions from Urban Land Use Change

Cumulative emissions from land use change can alter a net-zero status in 2050 by ~1 $GtCO_2eq$ for the 90 urban areas

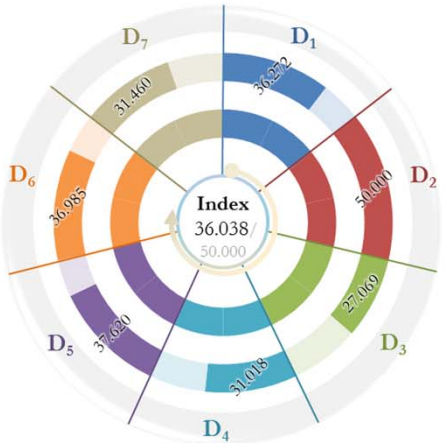


Urban Enablers of Action for Smart Energy Systems

Beyond the top emitting 420 urban areas, other urban areas can be pioneers for net-zero emissions much earlier



SDEWES Index for Copenhagen
(Rank 1 / 120)



Sources: SDEWES Centre (2018); Kılkış (2019) <https://www.sdewes.org/sdewes_index.php>

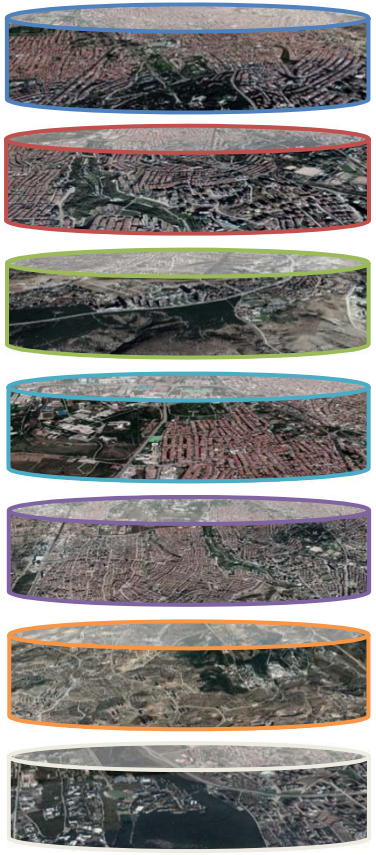
Source: Copenhagen 2025 Climate Plan Roadmap 2021-2025

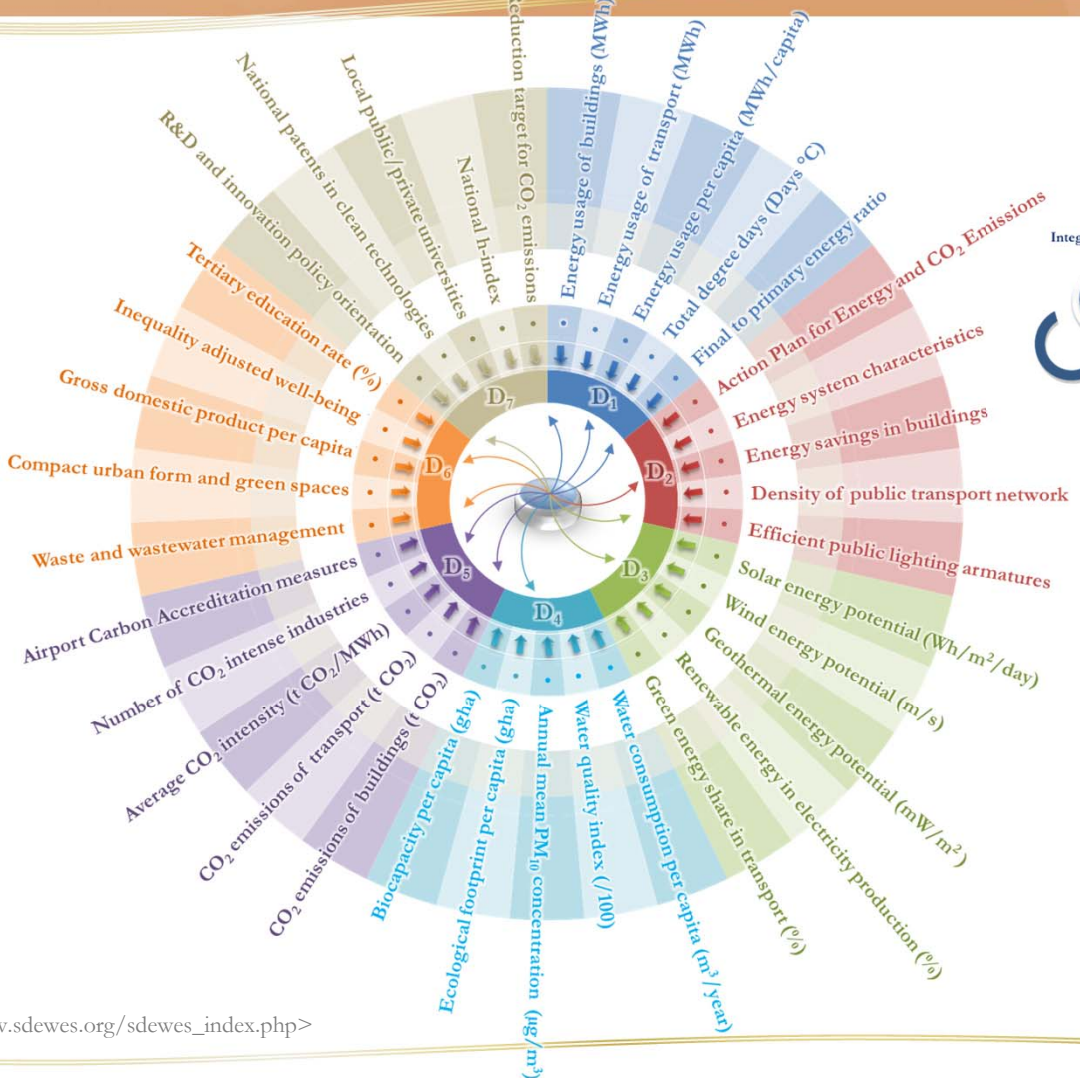
Urban Enablers of Smart Energy Systems

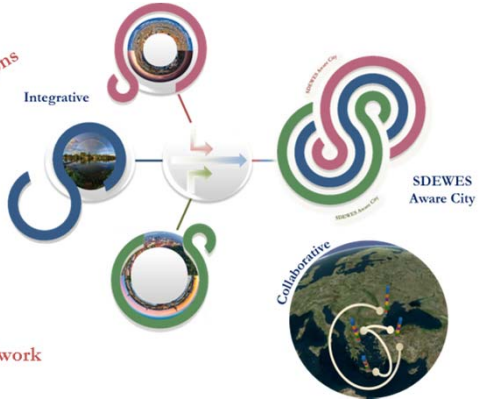
- Emphasis on carbon-neutral district heating by 2025 and **energy system flexibility** based on integration for future energy systems with heat pumps and power-to-X
- **Partnerships** for flexible electricity use at large scale

Multi-Dimensional Approach of the SDEWES Index

SDEWES Index







- Supporting **renewable energy penetration**
- Integration of **urban and energy planning**
- **Decoupling** of emissions from greater wellbeing

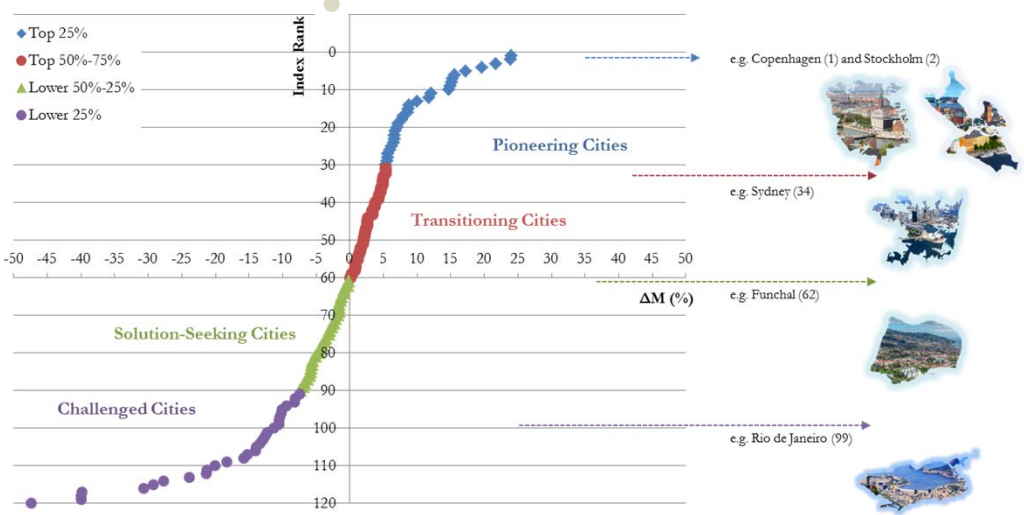
Source: SDEWES Index <https://www.sdewes.org/sdewes_index.php>

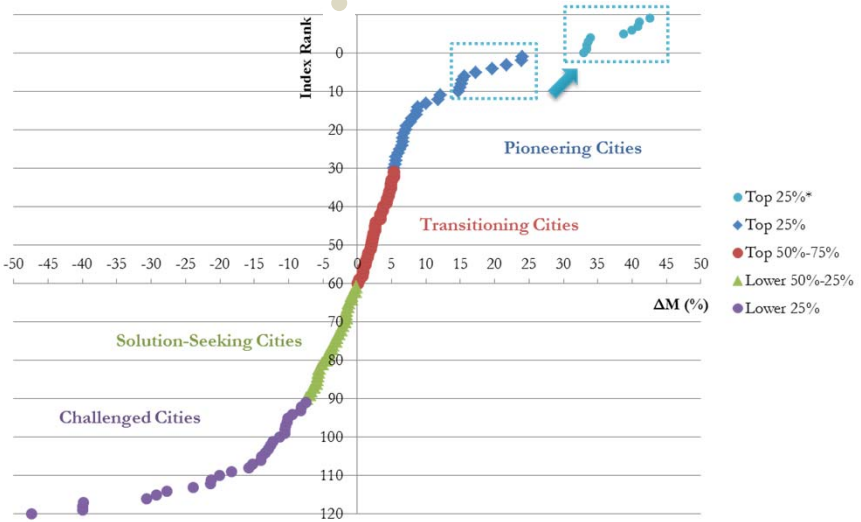
Even Pioneers Can Improve – Advancing Together

All urban areas can improve their performances and even the pioneers can improve by advancing urban integration

Achieving collectively, even the pioneers

- Zeroing energy emissions
- 100% renewable electricity
- All cities with lowest PM_{10}
- Low ecological footprint
- Additional urban planning





Source: Kılkış (2019), Benchmarking the sustainability of urban energy, water and environment systems and envisioning a cross-sectoral scenario for the future, *Renewable and Sustainable Energy Reviews* 103: 529-545

Source: Kılkış (2020), Integrated approach for climate neutrality in urban areas with correct timing and response, *Climate Neutrality in Cities Panel*

Integrated Approach for Net-Zero GHG Emissions

The mission on 100 climate-neutral cities will involve an integrated approach to support net-zero GHG emissions

- **Reducing the amount of total waste generated** and halving the amount of residual (non-recycled) municipal waste by 2030

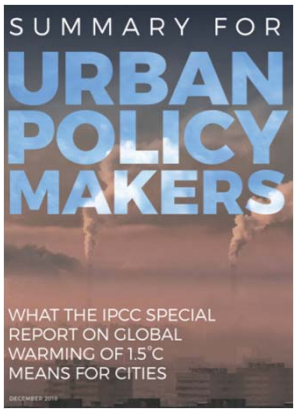
- **Coordinated planning and operation of the energy system as a whole**, across multiple energy carriers, infrastructures, and consumption sectors

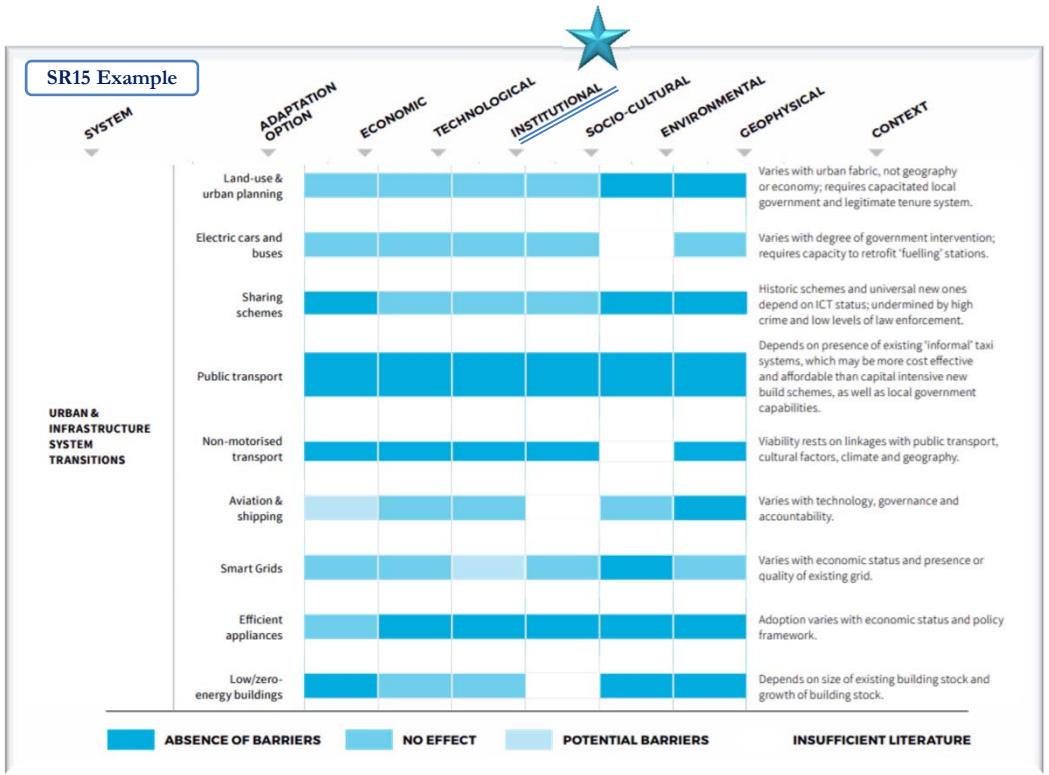
- Modern, renewable based **smart district heating and cooling systems**
  - **Twin green and digital transitions**, new forms of cooperation
  - Systemic adaptation beyond sectors and **nature-based solutions**

Sources: EC (2019); EC (2020); EC (2021)

Multi-Dimensional Feasibility Aspects and Enablers

Feasibilities of urban options are multi-dimensional and malleable, including cross-sector coordination as enablers





- **First chapter dedicated to Urban Systems** during an assessment cycle in AR6
- Provides a basis for a **Special Report on Cities and Climate Change** in AR7

Sources: IPCC (2018), Special Report on Global Warming of 1.5 °C (SR15); Innovate4Cities (2018); Innovate4Cities (2019)

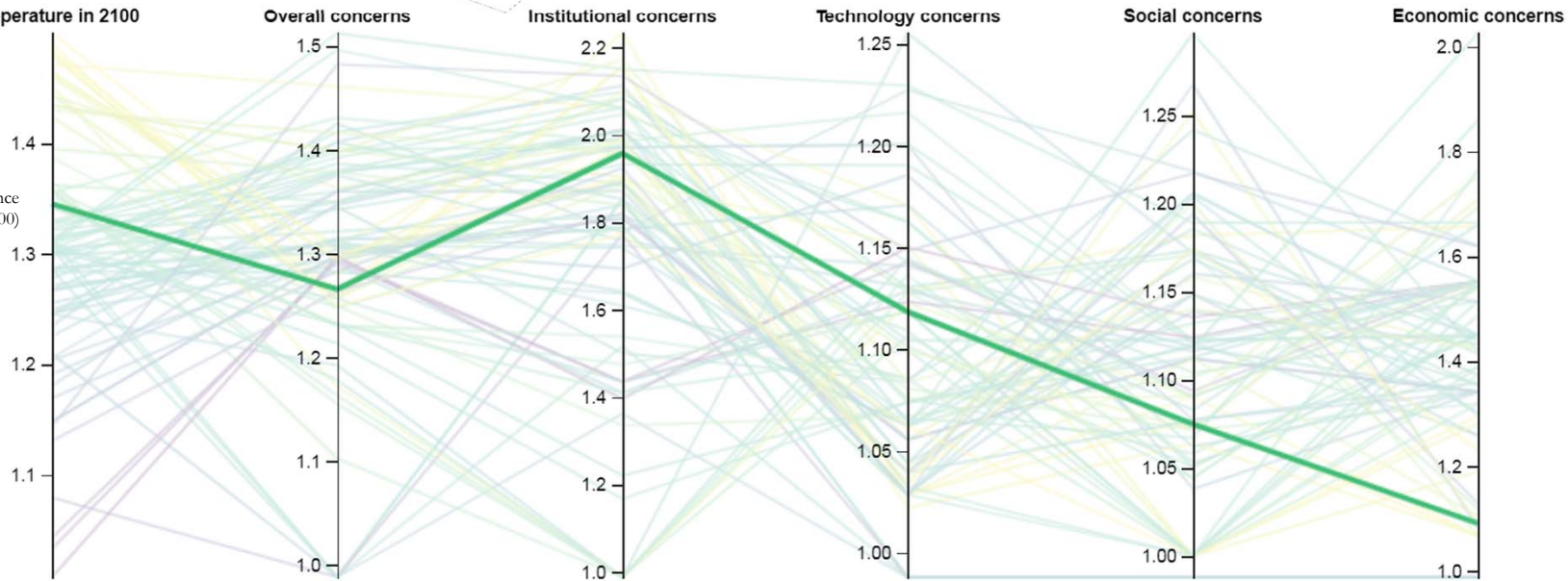
System Level Feasibility Assessments of Scenarios

Strenghtening cross-sector coordination can avoid feasibility concerns later on, also applying to the local level

Temporal trade-off between early institutional transformation, including **cross-sector collaboration, with fewer challenges and risks later on**

(*) Represents normalized values

Example:
IMAGE Advance 2020 (1.5°C 2100)



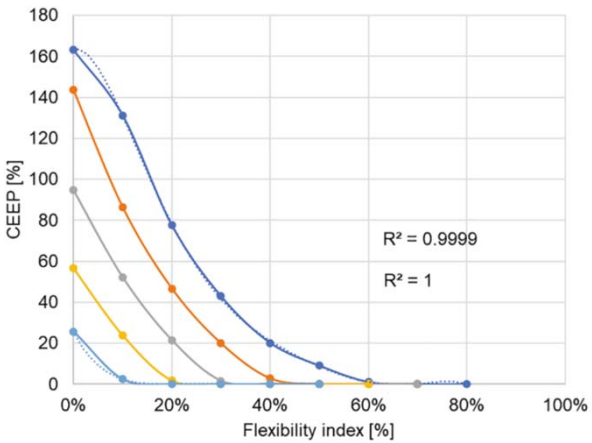
Temperature in 2100 (°C)	Overall Concerns (*)	Institutional Concerns (*)	Technological Concerns (*)	Social Concerns (*)	Economic Concerns (*)
1.35	1.27	1.96	1.12	1.07	1.09

Sources: Brutschin et al. (2021), A multidimensional feasibility evaluation of low-carbon scenarios, *Environ. Res. Lett.* 16: 064069;
IIASA Multidimensional Feasibility Dashboard <https://data.ece.iiasa.ac.at/climate-action-feasibility-dashboard/>

Beyond Scenarios – Time to Realize the Pathways

Enhancing system flexibility for the highest penetration of renewable energy requires urban level contributions

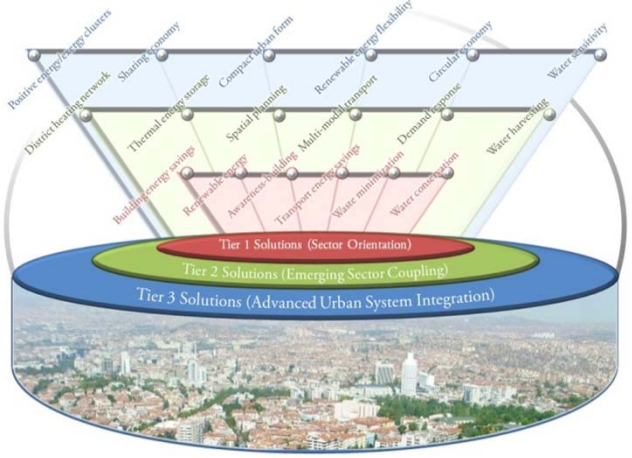
Demand flexibilization as an enabler, e.g. vehicle to grid and power to heat



Source: Pfeifer et al. (2021), Flexibility index and decreasing the costs in energy systems with high share of renewable energy, *Energy Conversion and Management* 240: 114258

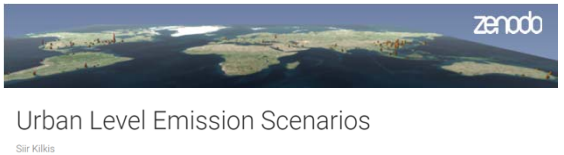
The 420 urban areas **can mobilize** to realize the pathways with wider views of integrated action!

Advancing from sector orientation to emerging sector coupling and **urban system integration**



Urban areas can search for their emission scenarios based on SSP1-RE for action!

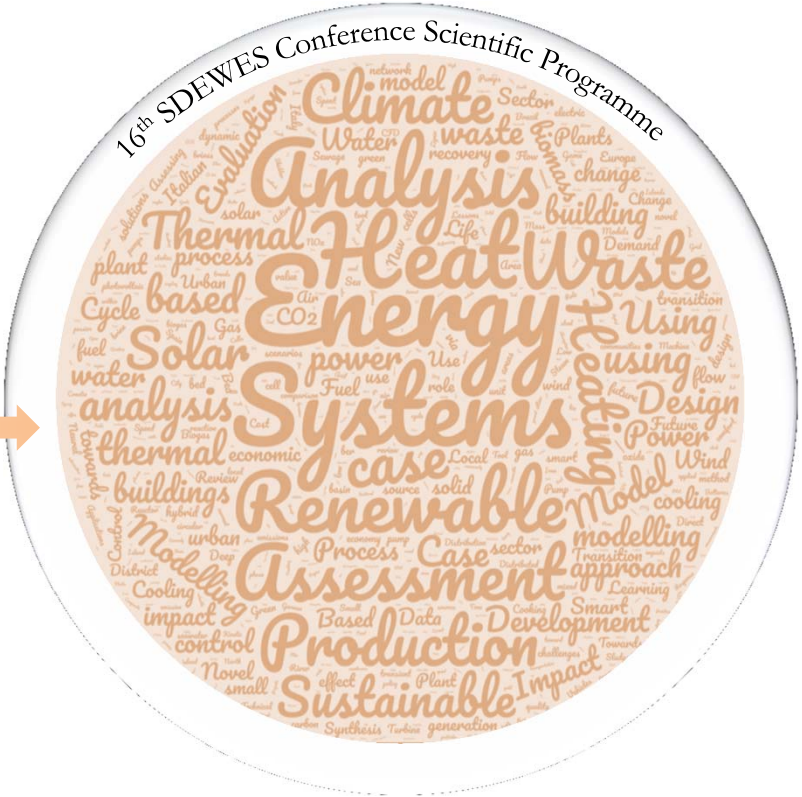
Source: Kilkis (2021), Urban Level Emission Scenarios
https://github.com/ClimateSiir/Urban-Level-Emission-Scenarios
https://github.com/ClimateSiir/Urban-Level-Emission-Scenarios/wiki



* Due to the time dimension of balancing supply and demand, can also **save exergy from being destroyed in the overall system**

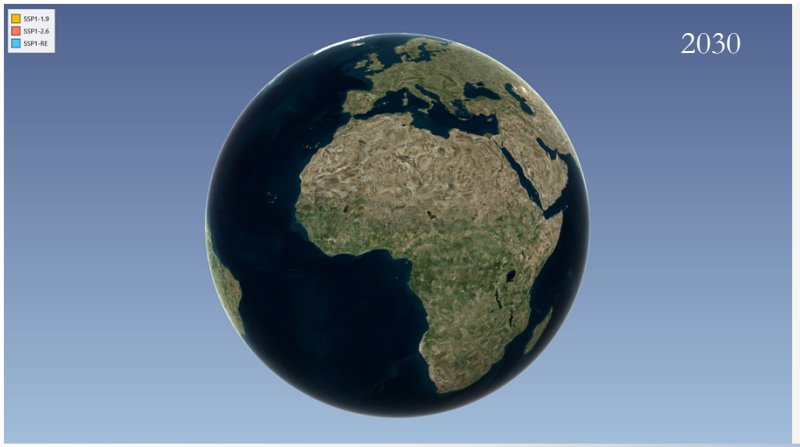
Source: Kılkış (2021), Transition towards urban system integration and benchmarking of an urban area to accelerate mitigation towards net-zero targets *Energy* 236:121394

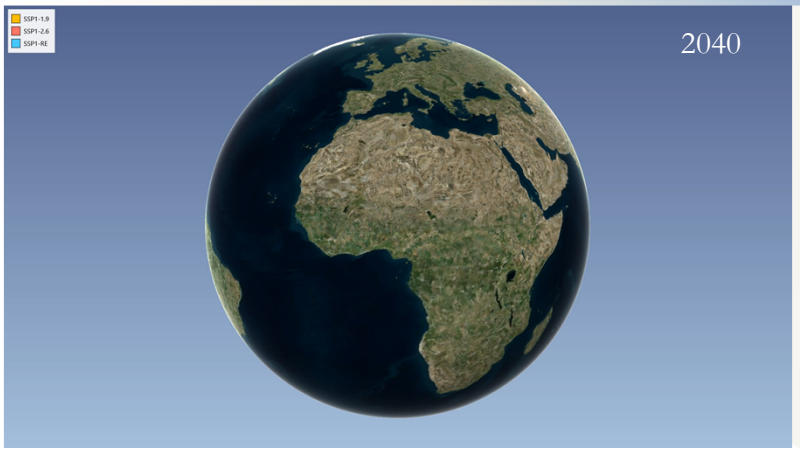
SDEWES Research Community and Sustainability



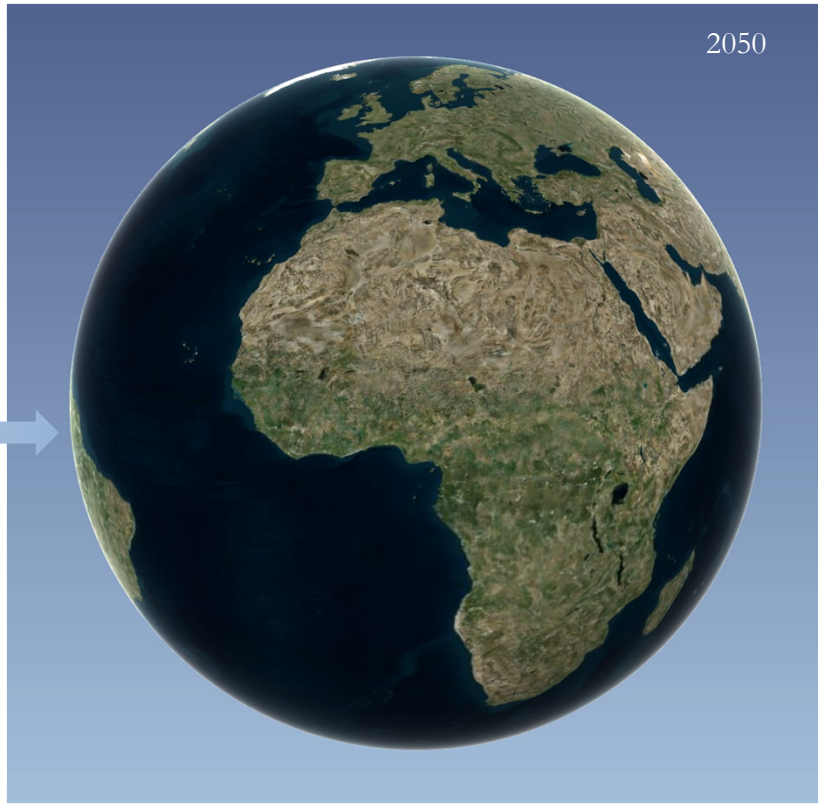
Based on: SDEWES (2021)
<https://www.dubrovnik2021.sdewes.org/programme>

No Other Time to Act and Scale Up Than Now





Outcomes will depend on enabling a shift to sustainability



Represents the **original data analysis** that is included in this presentation

Targeting Sustainable Urban Systems Across the World

Collective action across all regions for more sustainable urban systems can support making a world of a difference!

2050 Scenario Comparisons for the Top 3 in Each Region