

IPCC Reports and City Climate Change Plans: Proof of concept prototype

FSCI Hackathon Team

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Table of contents

1	Introduction	3
2	Mitigation & Cutting Emmisions?	4
2.1	Question: What measures can be taken by urban centers to mitigate and cut down on their emissions?	4
2.2	Query result: Climate Change 2022: Mitigation of Climate Change. Chapter 08 : Urban Systems and Other Settlements	4
2.3	Content:	4
2.3.1	Chapter 08 : Urban Systems and Other Settlements	4
2.3.2	Footnotes	8
3	Renewable energy?	9
3.1	Question: What role do renewable energy sources play in city climate plans? .	9
3.2	Query result: Box 6.8 100% Renewables in Net-zero Energy Systems (Page 675-676)	9
3.3	Content:	9
3.3.1	Box 6.8 100% Renewables in Net-zero Energy Systems	9
4	Question 3	13
5	Question 4	14
6	Question 5	15

1 Introduction

2 Mitigation & Cutting Emissions?

2.1 Question: What measures can be taken by urban centers to mitigate and cut down on their emissions?

2.2 Query result: Climate Change 2022: Mitigation of Climate Change. Chapter 08 : Urban Systems and Other Settlements

Chapter 8 Urban Systems and Other Settlements. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the 6th Assessment Report of the IPCC

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2.3 Content:

2.3.1 Chapter 08 : Urban Systems and Other Settlements

2.3.1.1 Executive Summary

Although urbanisation is a global trend often associated with increased incomes and higher consumption, the growing concentration of people and activities is an opportunity to increase resource efficiency and decarbonise at scale (very high

confidence). The same urbanisation level can have large variations in per capita urban carbon emissions. For most regions, per capita urban emissions are lower than per capita national emissions. {8.1.4, 8.3.3, 8.4, Box 8.1}

Most future urban population growth will occur in developing countries, where per capita emissions are currently low but expected to increase with the construction and use of new infrastructure and the built environment, and changes in incomes and lifestyles (very high confidence). The drivers of urban greenhouse gas (GHG) emissions are complex and include an interplay of population size, income, state of urbanisation, and how cities are laid out (i.e. urban form). How new cities and towns are designed, constructed, managed, and powered will lock-in behaviour, lifestyles, and future urban GHG emissions. Low-emission urbanisation can improve well-being while minimising impact on GHG emissions, but there is risk that urbanisation can lead to increased global GHG emissions through increased emissions outside the city's boundaries. {8.1.4, 8.3, Box 8.1, 8.4, 8.6}

The urban share of global GHG emissions (including carbon dioxide (CO₂) and methane (CH₄)) is substantive and continues to increase (high confidence). In 2015, urban emissions were estimated to be 25 GtCO₂-eq (about 62% of the global share) and in 2020, 29 GtCO₂-eq (67–72% of the global share).¹ About 100 of the highest emitting urban areas account for approximately 18% of the global carbon footprint. {8.1.6, 8.3.3}

The urban share of regional GHG emissions increased between 2000 and 2015, with much inter-region variation in the magnitude of the increase (high confidence). Globally, the urban share of national emissions increased 6 percentage points, from 56% in 2000 to 62% in 2015. For 2000 to 2015, the urban emissions share across AR6 WGIII regions increased from 28% to 38% in Africa, from 46% to 54% in Asia and Pacific, from 62% to 72% in Developed Countries, from 57% to 62% in Eastern Europe and West-Central Asia, from 55% to 66% in Latin America and Caribbean, and from 68% to 69% in the Middle East. {8.1.6, 8.3.3}

Per capita urban GHG emissions increased between 2000 and 2015, with cities in the Developed Countries region producing nearly seven times more per capita than the lowest emitting region (medium confidence). From 2000 to 2015, global urban GHG emissions per capita increased from 5.5 to 6.2 tCO₂-eq per person (an increase of 11.8%); Africa increased from 1.3 to 1.5 tCO₂-eq per person (22.6%); Asia and Pacific increased from 3.0 to 5.1 tCO₂-eq per person (71.7%); Eastern Europe and West-Central Asia increased from 6.9 to 9.8 tCO₂-eq per person (40.9%); Latin America and Caribbean increased from 2.7 to 3.7 tCO₂-eq per person (40.4%); and Middle East increased from 7.4 to 9.6 tCO₂-eq per person (30.1%). Albeit starting from the highest level, Developed Countries had a decline of 11.4 to 10.7 tCO₂-eq per person (–6.5%). {8.3.3}

The global share of future urban GHG emissions is expected to increase through 2050, with moderate to low mitigation efforts, due to growth trends in population, urban land expansion, and infrastructure and service demands, but the extent of

the increase depends on the scenario and the scale and timing of urban mitigation action (medium confidence). In modelled scenarios, global consumption-based urban CO₂ and CH₄ emissions are projected to rise from 29 GtCO₂-eq in 2020 to 34 GtCO₂-eq in 2050 with moderate mitigation efforts (intermediate GHG emissions, SSP2–4.5), and up to 40 GtCO₂-eq in 2050 with low mitigation efforts (high GHG emissions, SSP3–7.0).

Urban land areas could triple between 2015 and 2050, with significant implications for future carbon lock-in. There is a large range in the forecasts of urban land expansion across scenarios and models, which highlights an opportunity to shape future urban development towards low- or net-zero GHG emissions and minimise the loss of carbon stocks and sequestration in the agriculture, forestry and other land use (AFOLU) sector due to urban land conversion (medium confidence). By 2050, urban areas could increase up to 211% over the 2015 global urban extent, with the median projected increase ranging from 43% to 106%. While the largest absolute amount of new urban land is forecasted to occur in Asia and Pacific, and in Developed Countries, the highest rate of urban land growth is projected to occur in Africa, Eastern Europe and West-Central Asia, and in the Middle East. The infrastructure that will be constructed concomitant with urban land expansion will lock-in patterns of energy consumption that will persist for decades if not generations. Furthermore, given past trends, the expansion of urban areas is likely to take place on agricultural lands and forests, with implications for the loss of carbon stocks and sequestration. {8.3.1, 8.3.4, 8.4.1, 8.6}

The construction of new, and upgrading of, existing urban infrastructure through 2030 will result in significant emissions (very high confidence). The construction of new and upgrading of existing urban infrastructure using conventional practices and technologies can result in significant committed CO₂ emissions, ranging from 8.5 GtCO₂ to 14 GtCO₂ annually up to 2030 and more than double annual resource requirements for raw materials to about 90 billion tonnes per year by 2050, up from 40 billion tonnes in 2010 (medium evidence, high agreement). {8.4.1, 8.6}

Given the dual challenges of rising urban GHG emissions and future projections of more frequent extreme climate events, there is an urgent need to integrate urban mitigation and adaptation strategies for cities to address climate change and withstand its effects (very high confidence). Mitigation strategies can enhance resilience against climate change impacts while contributing to social equity, public health, and human wellbeing. Urban mitigation actions that facilitate economic decoupling can have positive impacts on employment and local economic competitiveness. {8.2, Cross-Working Group Box 2, 8.4}

Cities can only achieve net-zero GHG emissions through deep decarbonisation and systemic transformation (very high confidence). Three broad mitigation strategies have been found to be effective in reducing emissions when implemented concurrently: (i) reducing or changing urban energy and material use towards more sustainable production and consumption across all sectors, including through compact and efficient urban forms and supporting infrastructure; (ii) electrification and switching to net-zero-emissions resources; and (iii) enhancing carbon uptake and storage in the urban environment (high evidence, high

agreement). Given the regional and global reach of urban supply chains, cities can achieve net-zero emissions only if emissions are reduced within and outside of their administrative boundaries. {8.1.6, 8.3.4, 8.4, 8.6}

Packages of mitigation policies that implement multiple urbanscale interventions can have cascading effects across sectors, reduce GHG emissions outside of a city’s administrative boundaries, and reduce more emissions than the net sum of individual interventions, particularly if multiple scales of governance are included (high confidence). Cities have the ability to implement policy packages across sectors using an urban systems approach, especially those that affect key infrastructure based on spatial planning, electrification of the urban energy system, and urban green and blue infrastructure. The institutional capacity of cities to develop, coordinate, and integrate sectoral mitigation strategies within their jurisdiction varies by context, particularly those related to governance, the regulatory system, and budgetary control. {8.4, 8.5, 8.6}

Integrated spatial planning to achieve compact and resourceefficient urban growth through co-location of higher residential and job densities, mixed land use, and transit-oriented development (TOD) could reduce GHG emissions between 23% and 26% by 2050 compared to the business-as-usual scenario (robust evidence, high agreement, very high confidence). Compact cities with shortened distances between housing and jobs, and interventions that support a modal shift away from private motor vehicles towards walking, cycling, and low-emissions shared and public transportation, passive energy comfort in buildings, and urban green infrastructure can deliver significant public health benefits and have lower GHG emissions. {8.2, 8.3.4, 8.4, 8.6}

Urban green and blue infrastructure can mitigate climate change through carbon sequestration, avoided emissions, and reduced energy use while offering multiple co-benefits (robust evidence, high agreement). Urban green and blue infrastructure, including urban forests and street trees, permeable surfaces, and green roofs³ offer potential to mitigate climate change directly through sequestering and storing carbon, and indirectly by inducing a cooling effect that reduces energy demand and reducing energy use for water treatment. Global urban trees store approximately 7.4 billion tonnes of carbon, and sequester approximately 217 million tonnes of carbon annually, although urban tree carbon storage and sequestration are highly dependent on biome. Among the multiple co-benefits of green and blue infrastructure are reducing the urban heat island (UHI) effect and heat stress, reducing stormwater runoff, improving air quality, and improving mental and physical health of urban dwellers. {8.2, 8.4.4}

The potential and sequencing of mitigation strategies to reduce GHG emissions will vary depending on a city’s land use, spatial form, development level, and state of urbanisation i.e., whether it is an established city with existing infrastructure, a rapidly growing city with new infrastructure, or an emerging city with infrastructure buildup (high confidence). New and emerging cities will have significant infrastructure development needs to achieve high quality of life, which can be met through energyefficient infrastructures and services, and people-centred urban design (high confidence).

The long lifespan of urban infrastructures locks in behaviour and committed emissions. Urban infrastructures and urban form can enable socio-cultural and lifestyle changes that can significantly reduce carbon footprints. Rapidly growing cities can avoid higher future emissions through urban planning to co-locate jobs and housing to achieve compact urban form, and by leapfrogging to low-carbon technologies. Established cities will achieve the largest GHG emissions savings by replacing, repurposing, or retrofitting the building stock, targeted infilling and densifying, as well as through modal shift and the electrification of the urban energy system. New and emerging cities have unparalleled potential to become low or net-zero GHG emissions while achieving high quality of life by creating compact, co-located, and walkable urban areas with mixed land use and transit-oriented design, that also preserve existing green and blue assets. {8.2, 8.4, 8.6}

With over 880 million people living in informal settlements, there are opportunities to harness and enable informal practices and institutions in cities related to housing, waste, energy, water, and sanitation to reduce resource use and mitigate climate change (low evidence, medium agreement). The upgrading of informal settlements and inadequate housing to improve resilience and well-being offers a chance to create a lowcarbon transition. However, there is limited quantifiable data on these practices and their cumulative impacts on GHG emissions. {8.1.4, 8.2.2, Cross-Working Group Box 2, 8.3.2, 8.4, 8.6, 8.7}

Achieving transformational changes in cities for climate change mitigation and adaptation will require engaging multiple scales of governance, including governments and non-state actors, and in connection with substantive financing beyond sectoral approaches (very high confidence). Large and complex infrastructure projects for urban mitigation are often beyond the capacity of local municipality budgets, jurisdictions, and institutions. Partnerships between cities and international institutions, national and regional governments, transnational networks, and local stakeholders play a pivotal role in mobilising global climate finance resources for a range of infrastructure projects with low-carbon emissions and related spatial planning programmes across key sectors. {8.4, 8.5}

2.3.2 Footnotes

1 These estimates are based on consumption-based accounting, including both direct emissions from within urban areas, and indirect emissions from outside urban areas related to the production of electricity, goods, and services consumed in cities. Estimates include all CO₂ and CH₄ emission categories except for aviation and marine bunker fuels, land-use change, forestry, and agriculture. {8.1, Annex I: Glossary}

2 These scenarios have been assessed by WGI to correspond to intermediate, high, and very low GHG emissions.

3 These examples are considered to be a subset of nature-based solutions or ecosystem-based approaches.

3 Renewable energy?

3.1 Question: What role do renewable energy sources play in city climate plans?

3.2 Query result: Box 6.8 | 100% Renewables in Net-zero Energy Systems (Page 675-676)

Chapter 6 Energy Systems. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the 6th Assessment Report of the IPCC

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3.3 Content:

3.3.1 Box 6.8 | 100% Renewables in Net-zero Energy Systems

The decreasing cost and increasing performance of renewable energy has generated interest in the feasibility of providing nearly all energy services with renewables. Renewable energy includes wind power, solar power, hydroelectric power, bioenergy, geothermal energy, tidal power, and ocean power. There are two primary frames around which 100% renewable energy systems are discussed: 100% renewable electricity systems and 100% renewable energy systems, considering not only electricity but all aspects of the energy system.

It is technically feasible to use very high renewable shares (e.g., above 75% of annual regional generation) to meet hourly electricity demand under a range of conditions, especially when VRE options, notably wind and solar, are complemented by other resources (high confidence). There are currently many grids with high renewable shares and large anticipated roles for VRE sources, in particular wind and solar (Section 6.4), in future low-carbon electricity systems. An increasingly large set of studies examines the feasibility of high renewable penetration and economic drivers under different policy, technology, and market scenarios (Cochran et al. 2014; Deason 2018; Jenkins et al. 2018b; Bistline et al. 2019; Hansen et al. 2019; Dowling et al. 2020; Blanford et al. 2021; Denholm et al. 2021). High wind and solar penetration involves technical and economic challenges due to their unique characteristics such as spatial and temporal variability, short- and long-term uncertainty, and non-synchronous generation (Cole et al. 2017). These challenges become increasingly important as renewable shares approach 100% (Sections 6.6.2.2 and 6.4.3).

There are many balancing options in systems with very high renewables (Milligan et al. 2015; Jenkins et al. 2018b; Mai et al. 2018; Bistline 2021a; Denholm et al. 2021).

- **Energy storage.** Energy storage technologies like batteries, pumped hydro, and hydrogen can provide a range of system services (Balducci et al. 2018; Bistline et al. 2020a) (Section 6.4.4). Lithium-ion batteries have received attention as costs fall and installations increase, but very high renewable shares typically entail either dispatchable generation or long-duration storage in addition to short-duration options (Jenkins et al. 2018b; Arbabzadeh et al. 2019; Schill 2020). Energy storage technologies are part of a broad set of options (including synchronous condensers, demand-side measures, and even inverter-based technologies themselves) for providing grid services (Castillo and Gayme 2014; EPRI 2019a).
- **Transmission and trade.** To balance differences in resource availability, high renewable systems will very likely entail investments in transmission capacity (Mai et al. 2014; Macdonald et al. 2016; Pleßmann and Blechinger 2017; Zappa et al. 2019) (Section 6.4.5) and changes in trade (Abrell and Rausch 2016; Bistline et al. 2019). These increases will likely be accompanied by expanded balancing regions to take advantage of geographical smoothing.
- **Dispatchable (‘on-demand’) generation.** Dispatchable generation could include flexible fossil units or low-carbon fuels such as hydrogen with lower minimum load levels (Denholm et al. 2018; Bistline 2019), renewables like hydropower, geothermal, or biomass (Hirth 2016; Hansen et al. 2019), or flexible nuclear (Jenkins et al. 2018a). The composition depends on costs and other policy goals, though in all cases, capacity factors are low for these resources (Mills et al. 2020).
- **Demand management:** Many low-emitting and high-renewables systems also utilise increased load flexibility in the forms of energy efficiency, demand response, and demand flexibility, utilising newly electrified end uses such as electric vehicles to shape demand profiles to better match supply (Ameli et al. 2017; Hale 2017; Brown et al. 2018; Imelda et al. 2018a; Bistline 2021a).
- **Sector coupling:** Sector coupling includes increased

end-use electrification and PtX electricity conversion pathways, which may entail using electricity to create synthetic fuels such as hydrogen (Davis et al. 2018; Ueckerdt et al. 2021) (Sections 6.4.3, 6.4., 6.4.5, 6.6.4.3, and 6.6.4.6).

Deployment of integration options depends on their relative costs and value, regulations, and electricity market design. There is considerable uncertainty about future technology costs, performance, availability, scalability, and public acceptance (Kondziella and Bruckner 2016; Bistline et al. 2019). Deploying balanced resources likely requires operational, market design, and other institutional changes, as well as technological changes in some cases (Denholm et al. 2021; Cochran et al. 2014). Mixes will differ based on resources, system size, flexibility, and whether grids are isolated or interconnected.

Although there are no technical upper bounds on renewable electricity penetration, the economic value of additional wind and solar capacity typically decreases as their penetration rises, creating economic challenges at higher deployment levels (Hirth 2013; Gowrisankaran et al. 2016; Cole et al. 2021; Denholm et al. 2021; Millstein et al. 2021). The integration options above, as well as changes to market design, can mitigate these challenges but likely will not solve them, especially since these options can exhibit declining value themselves (De Sisternes et al. 2016; Bistline 2017; Denholm and Mai 2019) and may be complements or substitutes to each other.

Energy systems that are 100% renewable (including all parts of the energy sector, and not only electricity generation) raise a range of technological, regulatory, market, and operational challenges that make their competitiveness uncertain (high confidence). These systems require decarbonising all electricity, using this zero-carbon electricity broadly, and then utilising zero-carbon energy carriers for all end uses not served by electricity, for example, air travel, long-distance transport, and high-temperature process heat. Broader questions emerge regarding the attractiveness of supplying all energy, and not just electricity, with renewables (Figure 6.22). Integrated assessment and energy systems research suggest large roles for renewables, but energy and electricity shares are far from 100%, even with stringent emissions reductions targets and optimistic assumptions about future cost reductions (Bauer et al. 2018; Bistline et al. 2018; Jenkins et al. 2018b; Huntington et al. 2020) (Section 6.7.1). Scenarios with 100% renewable energy systems are an emerging subset in the decarbonisation literature, especially at regional levels (Hansen et al. 2019; Denholm et al. 2021). Many 100% renewables studies focus more heavily on electrification for decarbonising end uses, and include less biofuels and hydrogen than the broader literature on deep decarbonisation (Bauer et al. 2018a). These studies typically assume a constrained set of available technologies to demonstrate the technical feasibility of very high renewable systems and do not optimise to find least-cost, technology-neutral decarbonisation pathways, and many 100% renewables studies focus on the electricity sector or a limited number of sectors (Jenkins et al. 2018a; Hansen et al. 2019). In addition to renewables, studies broadly agree that including additional lowcarbon options – including not only low-carbon electricity but also targeted use of fossil fuels with and without CCS (Section 6.6.2.1) and alternative fuels for sectors that are difficult to electrify (Section 6.6.2.4) – can lower the cost of decarbonisation, even with very high shares of renewables (Figure 6.22).

However, there is disagreement about the magnitude of cost savings from larger portfolios, which depend on context- and scenario-specific assumptions about technologies, markets, and policies.

4 Question 3

5 Question 4

6 Question 5