Climate change and the urban heat island

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Abstract. Urban areas experience elevated temperatures compared to surrounding rural regions due to the urban heat island (UHI) effect, which amplifies the impacts of global climate change. This paper analyzes the relationship between rising atmospheric CO_2 levels, global temperature increase, and UHI intensity, focusing on Manchester, UK. Historical data from ice cores, meteorological records, and urban temperature measurements are used to quantify UHI trends and evaluate factors such as urbanization, wind speed, and cloud cover. The study highlights the influence of socioeconomic factors on carbon emissions and emphasizes climate justice in mitigation strategies. Results indicate that UHI in Manchester peaks at approximately 3–4 °C above surrounding rural areas, with seasonal variations reaching up to 5 °C during summer nights, highlighting the urgent need for urban mitigation strategies such as increased vegetation, reflective surfaces, and adaptive building design. Accelerated policy action, technological advances, and renewable energy adoption are essential to limit further temperature increases in urban environments.

1 Introduction

Climate change is already underway, with atmospheric CO_2 levels rising steadily due to human activities, primarily the combustion of fossil fuels. These changes can be quantified using the ratio of carbon-13 isotopes (^{13}C) in atmospheric CO_2, as fossil fuels are depleted in ^{13}C compared to natural atmospheric CO_2. Ice core analyses from Antarctica provide long-term records of atmospheric composition, showing a significant CO_2 increase since the Industrial Revolution around 1750 (Fig. 1).

Rising CO_2 levels contribute to global temperature increases and extreme weather events. Urban areas experience additional warming due to the UHI phenomenon, where dense infrastructure, reduced vegetation, and anthropogenic heat sources increase local temperatures compared to surrounding rural areas. Understanding the interaction between global climate change and local UHI effects is essential for developing mitigation strategies to protect public health and thermal comfort.

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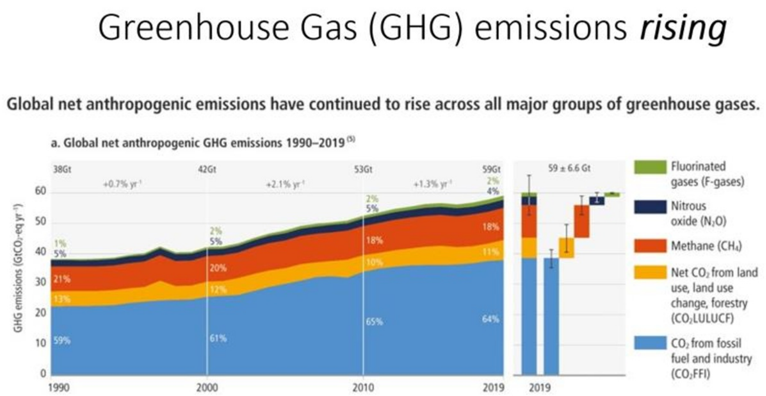

Figure 1. Greenhouse gas emissions rising

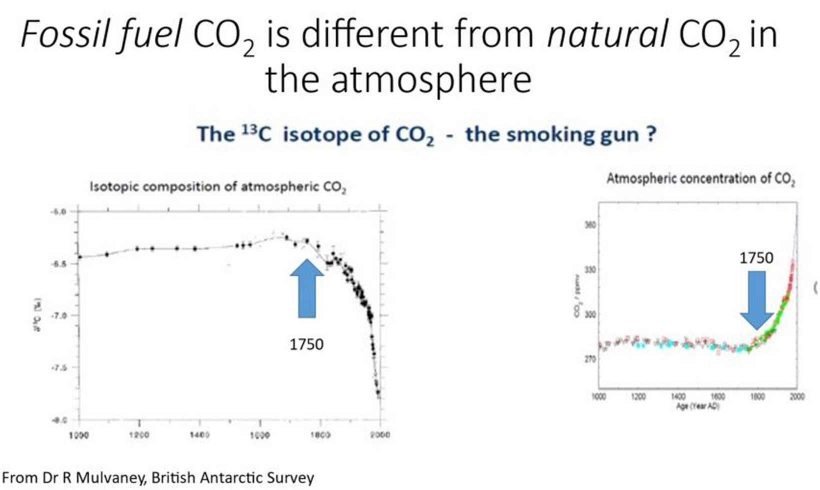

Figure 2. Carbon 13 isotope (13C) ratio indicating the increase in fossil fuel CO2 in the atmosphere and on the right the increase in carbon dioxide in the atmosphere.

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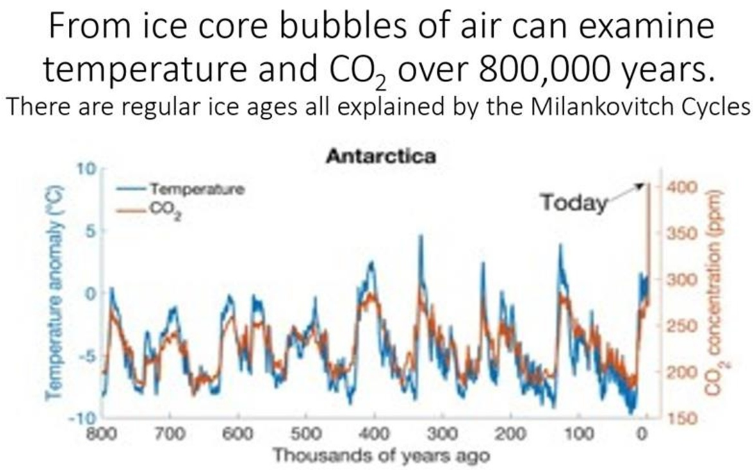

Figure 3. The variations over the years of temperature and CO2 levels

2 Achieving Net-Zero Carbon Emissions

Global energy policies aim to reach net-zero carbon emissions by 2050. Current trends indicate that, without additional interventions, fossil fuels will continue to contribute significantly to emissions (Fig. 4). However, renewable energy adoption is increasing exponentially worldwide (Figs. 5 and 6). Achieving net-zero emissions requires a combination of renewable energy expansion, carbon sequestration, and direct air capture technologies.

Technological solutions, including chemical absorption and engineered carbon capture, must complement natural processes. Effective policy, investment, and international cooperation are essential for global emissions reductions (Fig. 7). Natural sequestration through vegetation, such as forests and biomass, contributes to CO_2 removal but is insufficient alone due to limited uptake efficiency (Fig. 8).

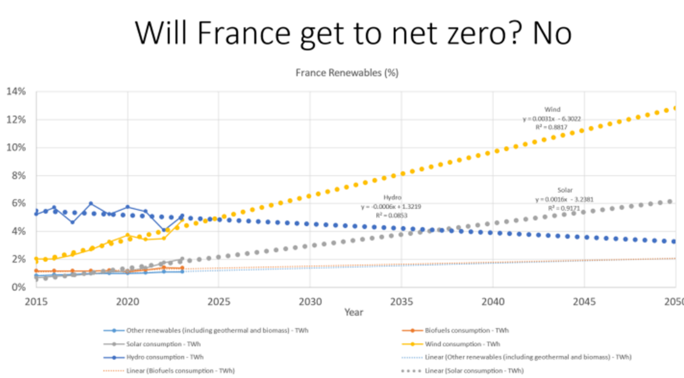

Figure 4. Linear projections of energy source use in France including renewables

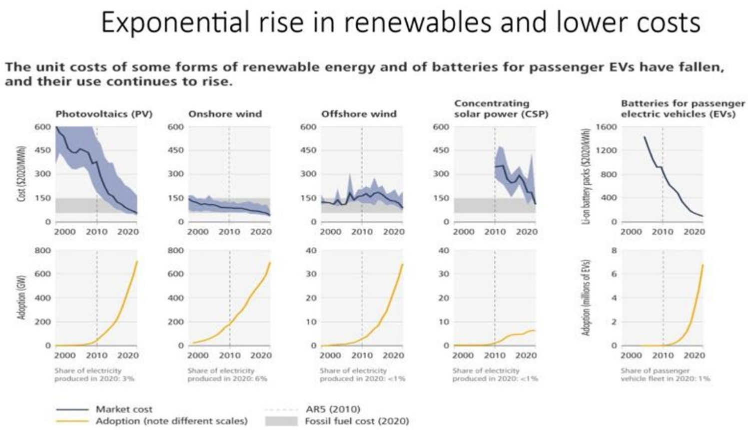

Figure 5. Exponential rise of renewables in the world

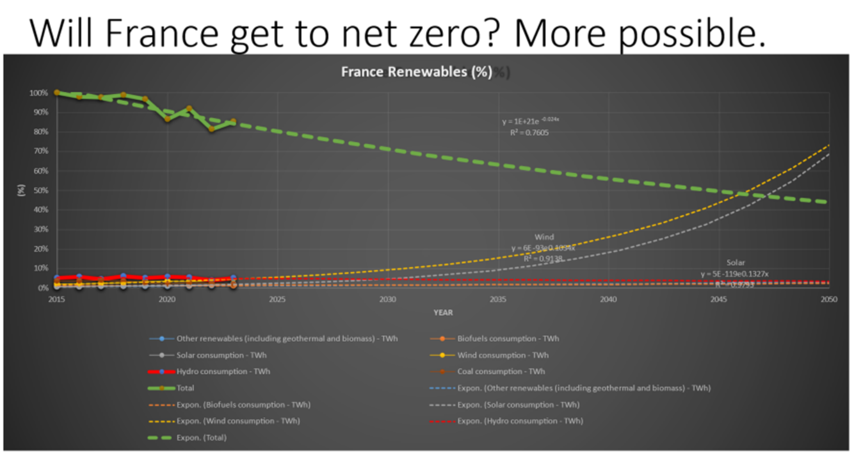

Figure 6. Exponential projection of renewables in France

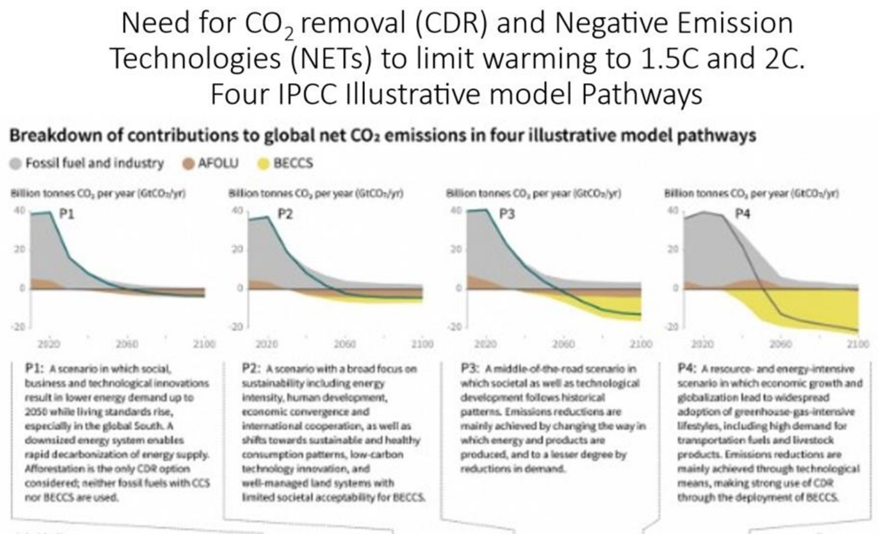

Figure 7. Pathways for global net emissions with carbon dioxide sequestration

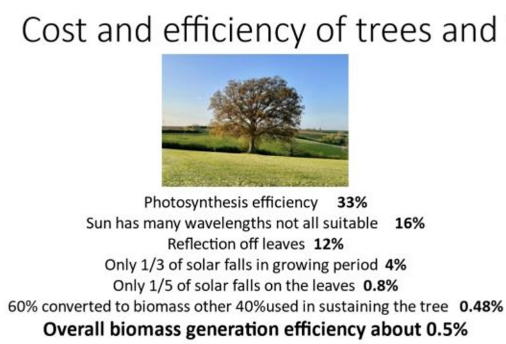

Figure 8. Biomass uptake of carbon dioxide from the atmosphere

3 The Urban Heat Island

The UHI effect causes urban areas to be warmer than surrounding rural regions, particularly during clear, calm nights (Fig. 9). Urbanization amplifies this effect: dense construction and reduced vegetation trap heat (Fig. 10).

In Manchester, UK, UHI intensity (UHII)—the temperature difference between urban and rural locations—has been measured at multiple city center sites. Diurnal patterns show peak UHII just before sunrise (Fig. 11), indicating that residents experience reduced nocturnal cooling, with implications for energy demand, public health, and thermal comfort.

Meteorological factors such as wind speed, cloud cover, and solar radiation influence UHII. An empirical equation was developed for Manchester to predict UHII based on these variables (Fig. 12). This model helps estimate urban temperature elevations where meteorological stations are limited or situated in rural areas.

Long-term UHII trends highlight the impact of urban development and extraordinary events such as the COVID-19 lockdown. Figure 13 shows UHII changes from 2013 to 2024 at five city center locations, with a temporary reduction in 2020–2021 followed by a resumption of the previous upward trend.

Figures 9–13 collectively demonstrate the role of urban structure and meteorology in driving UHI. Accurate measurements and empirical models provide essential guidance for mitigation strategies such as urban greening, reflective surfaces, and adaptive building design.

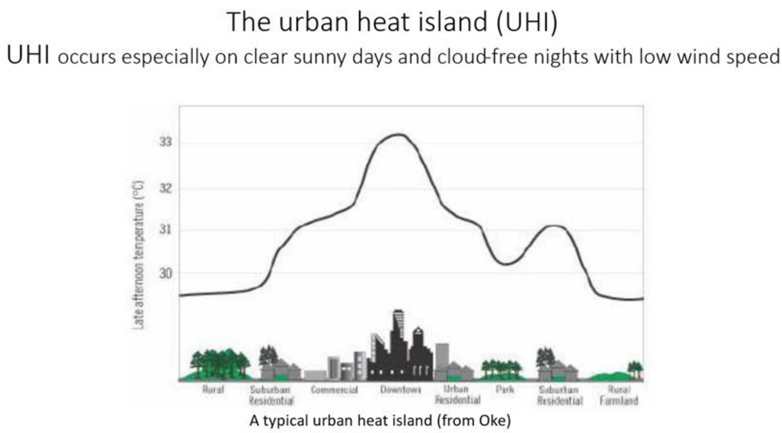

Figure 9. The urban heat island effect

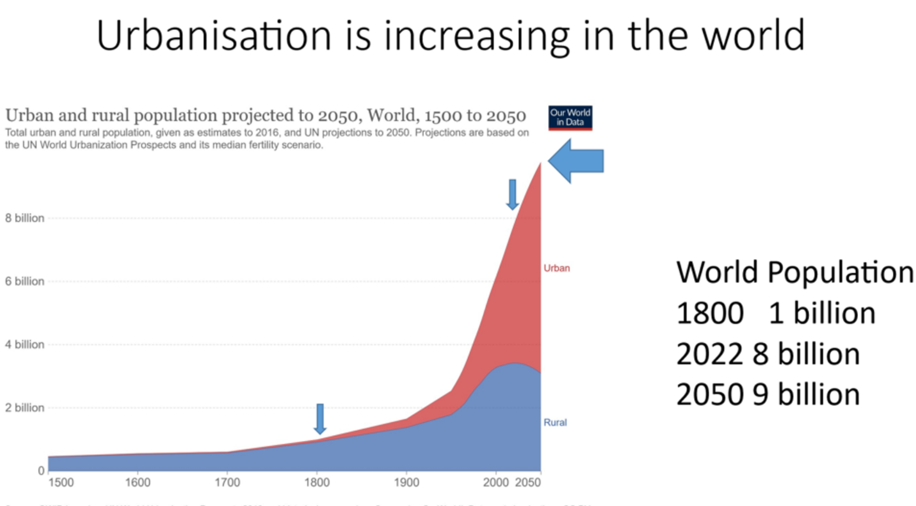

Figure 10. The increase in urbanisation in the world

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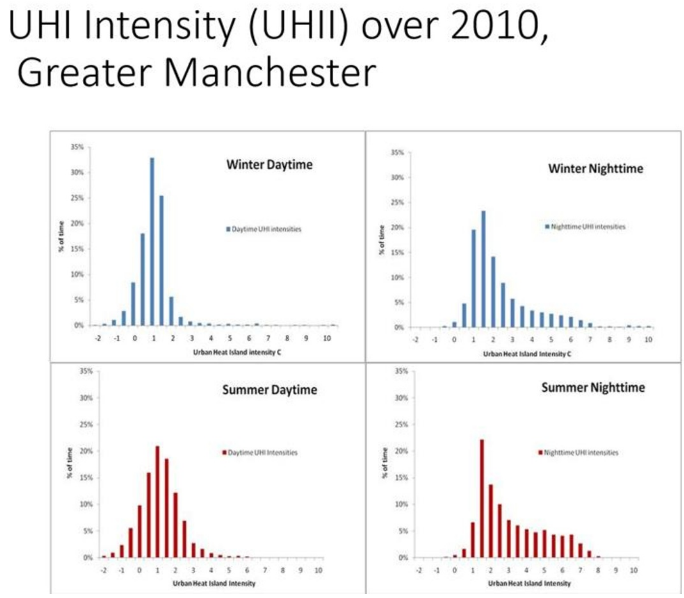

Figure 11. The urban heat island intensity for Manchester, UK

Empirical model (with initial weighted fitting factors) for predicting urban heat island intensity (UHII)

$$UHII = w\,AW + c\,AC + s\,AS + k$$

AW = (6 – WS), WS is the wind speed in knots.
If WS ≥ 6 AW = 0.

AC = (8 – cloud cover in oktas).

AS = global short wave irradiance (KJ m^{-2} h^{-1})

w,c, s, k empirical constants

Figure 12. An empirical equation for estimating the UHII based on data for Manchester, UK

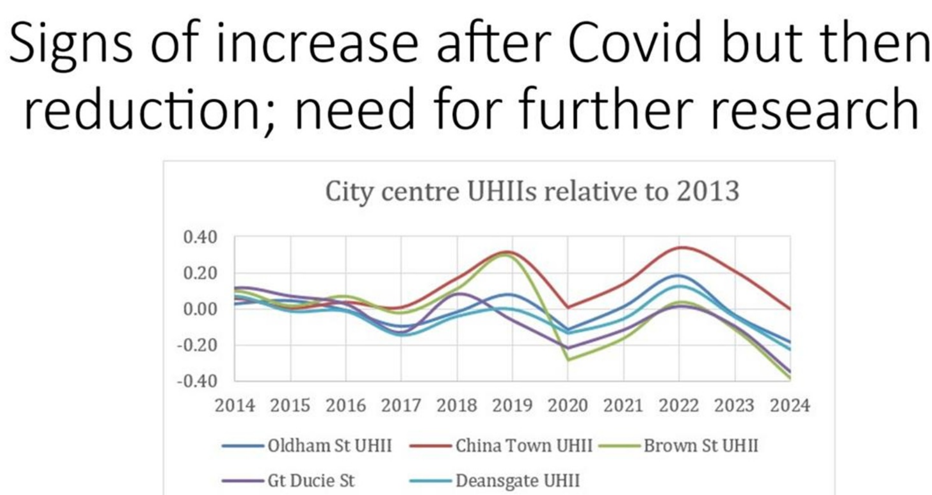

Figure 13. The UHII changes from 2013 to 2024 at Manchester for five city centre sites

4 Ethics and climate justice

Carbon emissions are unevenly distributed globally. The wealthiest 10% of the population are responsible for ~50% of emissions, while the poorest 50% contribute only ~10% (Fig. 14). This inequity highlights the ethical imperative for equitable access to renewable energy, particularly in rapidly growing developing countries.

Climate justice requires policies that support vulnerable populations while balancing global mitigation. Ethical considerations include protecting future generations, supporting low-carbon development in poorer nations, and prioritizing investments that provide both environmental and social benefits (Fig. 15).

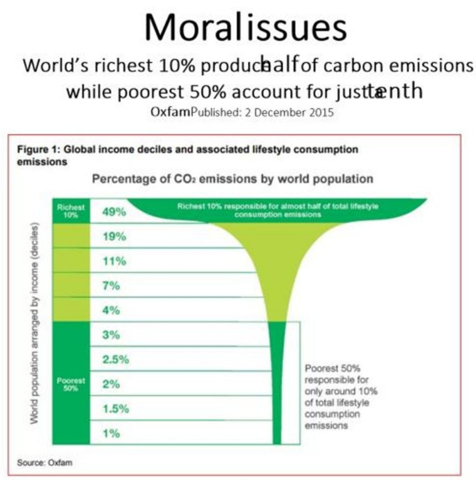

Figure 14. The inequality of carbon emissions from different strata of the world’s populations depending on wealth

Figure 15. A new level of morality

5 Conclusion

Human-induced climate change continues to raise global temperatures, with CO_2 levels increasing at unprecedented rates. Urban areas experience additional warming due to the UHI effect, driven by urbanization and local meteorological conditions.

Achieving net-zero emissions by 2050 requires accelerated adoption of renewable energy, carbon sequestration technologies, and international cooperation. Addressing global inequalities in emissions and energy access is critical to ensuring climate justice. Combining technological solutions with ethical policies can help mitigate climate change impacts and protect future generations. Urban planning interventions, such as increased vegetation, reflective surfaces, and heat-adaptive building design, are essential for reducing UHI effects.

Acknowledgements

The 2007 Nobel Peace Prize was jointly awarded to Al Gore and the Intergovernmental Panel on Climate Change (IPCC) in recognition of their efforts to build up and disseminate greater knowledge about man-made climate change.Professor Geoffrey Levermore, Head of the Built Environment Research Group at the University of Manchester at the time, contributed to the work of the IPCC as a Lead Author of the Fourth Assessment Report (Working Group III – Mitigation).

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