Expanding Underground. Knowledge and Passion to Make a Positive Impact on the World – Anagnostou, Benardos & Marinos (Eds)

Urban underground space use in a climate neutral city

N.G. Bobylev
Saint Petersburg State University, Russia

D. Guo
Army Engineering University of PLA, China

A. Benardos
National Technical University of Athens, Greece

ABSTRACT: Sustainable, compact, green and climate neutral urbanization is essential in the context of tackling global environmental challenges such as biodiversity conservation and climate change. Cities are expanding in both developed and developing countries; the rate of this growth is much higher than the growth of population. Responsible cities are pursuing a compact city policy, striving to exclude new construction in undeveloped and green areas. The three-dimensional development of cities, and the use of underground space in particular, is a complex, multidimensional and interdisciplinary task. Urban climate agenda widens the above research area further, requiring detailing climate adaptation and mitigation issues. The paper will present analysis of opportunities and drawbacks that the urban underground space brings to an urban transition towards climate neutrality. This research contributes to a vision for urban underground space and integrated urban planning that enhance the quality of urban life while pursuing climate responsible development agenda.

1 INTRODUCTION

Cities are not climate neutral, they do have a significant impacts on local and global climate (IPCC, 2022; OECD, 2022). Most common local impact is known as Urban Heat Island (Oke, 1973), which constitute difference in temperature between the city centre and a reference area immediately outside the city. Usually city centres are a few degrees warmer than city surrounding area. This local warming is caused by heated surfaces and heat emissions from buildings ventilation systems, motor cars, and increased heat absorption and subsequent emission by variety of surfaces, like roofs and roads.

Global climate impacts of urban areas are primarily associated with energy consumption and carbon dioxide emissions; reducing these emissions is known as climate change mitigation. Urban areas are the largest territorial source of greenhouse gas emissions, accounting for up to 76% of global emissions (IPCC, 2022).

The concept of climate neutrality involves reducing greenhouse gas emissions and absorbing carbon from atmosphere that the total carbon emission - consumption balance would be zero or negative. Process of adsorbing carbon is known as carbon sink, green plants are natural carbon sinks.

Urban underground space and urban underground infrastructure plays an important role in a carbon neutral city (Bobylev et al, 2013; Guo et al, 2021), use of subsurface can increase or decrease city carbon emissions in different circumstances and time periods. Urban underground space and climate neutrality is a relatively new and yet scarcely explored subject; just a few

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scholarly publications attempted to conceptualise it and suggest approaches to calculate carbon balance (Wei et al, unpublished). This paper will summarise existing knowledge and provide new research questions for further studies. Analysis of opportunities and drawbacks that the urban underground space brings to an urban transition towards climate neutrality will be presented.

2 OPPORTUNITIES TO COOL CITIES USING UNDERGROUND SPACE

Urban underground space has been traditionally used to reduce high outdoor temperatures in hot climate, sunken courtyards in Iran can serve as an example. More recent example of combating urban heat can be using underground metro in Paris to host elderly during European summer heat waves in the past 10 years. Apart from providing heat relief in distinct underground facilities, urban underground infrastructure can contribute to reduction of Urban Heat Island effect by (1) frugal land use, (2) enabling greater energy efficiency and hence less local heat emissions. Placing infrastructure and facilities underground vacates land for urban green, which cools cities and acts as a carbon sink. Various types of linear infrastructure, placed underground are often more reliable in operations because of more protection from external factors, hence is more efficient in operations.

Figure 1 summarises opportunities for reducing local and global urban climate impacts by using underground space.

3 OPPORTUNITIES TO REDUCE URBAN CARBON FOOTPRINT USING UNDERGROUND SPACE

All Urban areas are at the forefront in driving global environmental change, and these areas are themselves heavily affected by global change, including climate change. Cities must become greener, smarter, more energy efficient and compact to address the climate challenge. Use of underground space is absolutely needed in most cities to address compact and energy efficient urbanisation. Ultimately, urban functions that do not require daylight should be placed underground, vacating space for green areas, which helps to adsorb carbon locally and reduce urban carbon footprint.

Qiao et all, 2019, have identified urban underground space contribution to a low carbon city as intervention to the following areas: transportation optimization, compact and mixed land use, green building and infrastructure, and renewable geothermal energy. Figure 1 further elaborates and details these ideas. Here we introduce five main categories for urban underground space reduction of urban climate impact. Apart from urban underground space use, there are of course, other ways and strategies to reduce urban carbon emissions. Linton et al, 2022, qualitatively analysed eight local government deep decarbonisation plans of cities and identified emerging technical pathways to deep decarbonisation: electricity, buildings, transportation, waste, carbon sinks and storage. This and similar studies neither single out nor even discuss urban compactness and underground space use as a factor in decarbonisation. However, comparing key policy intervention sectors for decarbonisation (Linton et al, 2022) and urban underground space contribution to the climate impact reduction (Figure 1), obvious correlations and alignment can be seen. Given that facilities, structures, and services in urban underground space are located in the same space continuum and in many cases have physical and functional connections and interaction, it is logical to consider urban underground space use as a city decarbonisation strategy in itself. This will ultimately help to draw conceptual connections between urban compactness, urban underground space, variety of urban infrastructure, and opportunities for urban climate neutrality.

4 URBAN UNDERGROUND INFRASTRUCTURE AND CARBON EMISSIONS

Urban underground space use and subsurface infrastructure contribute some carbon emissions (Figure 2). The main adverse impacts are associated with the construction process of facilities in the underground space, which contribute to global carbon emissions. Impacts of underground space use on local climate are insignificant and are associated with underground heat island effect, which is often secondary to surface heat island effect.

Urban resilience as a negative and positive contributing factor is featured in both diagrams (Figure 1 and 2). Urban resilience and underground space use is a significant question (ITA Working Group 20, unpublished). Underground facilities, on one hand, can help cities to adapt to climate change impacts, and, on the other hand, are themselves vulnerable to adverse local climate impacts. The same diverse description can be given about carbon emissions, required to provide urban adaptation to local climate change impacts. Urban underground space can provide benefits as well as drawbacks in this regard, depending on particular city vulnerabilities and state of infrastructure.

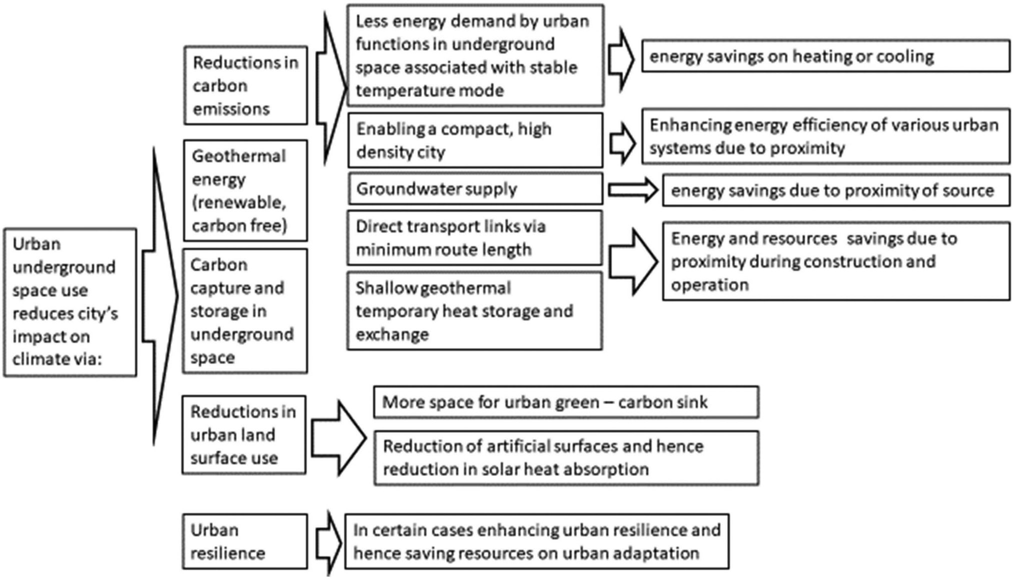

Figure 1. Urban underground space use and opportunities to reduce cities' climate impacts.

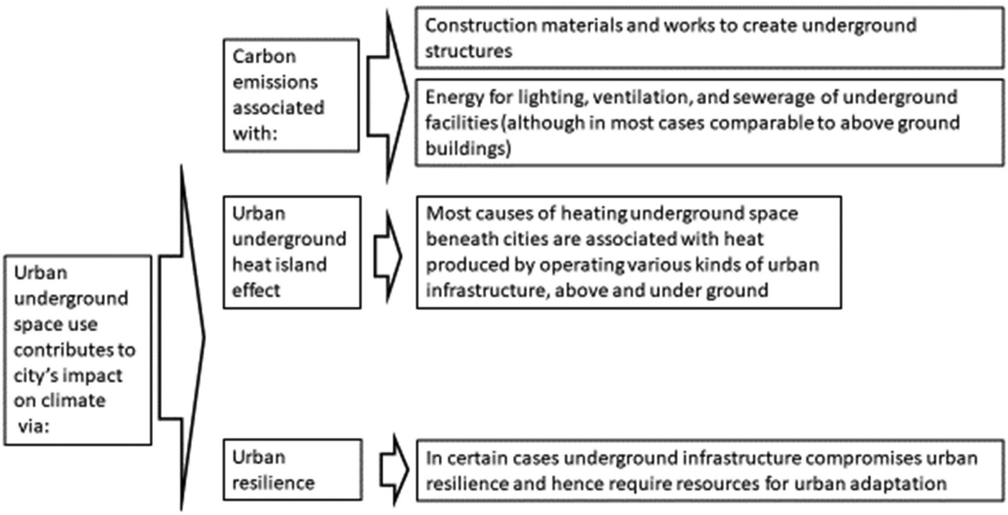

Figure 2. Urban underground space use possible contributions to cities' climate impacts.

5 IMPLEMENTATION PERSPECTIVES

Urban climate neutrality is a mainstream policy perused by many cities and recommended by professional community (UN-Habitat, 2022). However, our research have not identified any policy documents specifically addressing urban underground space use in a climate neutral city. There has been an active dialog between the International Tunneling and Underground Space Association designated Committee ITACUS and United Nations agencies concerned with urban carbon agenda. The ITACUS repeatedly advocated for distinct consideration of underground space in climate agenda with United Nations Office for Disaster Risk Reduction, United Nations Human Settlement Programme, United Nations Environment Programme (Agrawal et al, 2022). Carbon accounting methodologies informing policy and decision-making on climate neutrality are an important component of urban climate action agenda. Cheng et all, 2022, present a carbon accounting methodology for sustainable neighbourhood renewal from the perspective of carbon emission mitigation; detail policy for the construction of low-carbon neighbourhoods and low-carbon renewal projects. Similar to decarbonisation accounting, discussed in the previous section, urban underground space has been not mentioned or discussed in this and similar holistic methodologies for urban carbon accounting. Qiao et all, 2019, attempted to calculate carbon balance associated with underground space use in a case study of Shanghai Hongqiao central business district: low carbon contributions were categorized into underground rail transit, underground geothermal energy and underground building energy consumption.

Carbon accounting methodologies are clear challenge and opportunity to mainstream urban underground space use in to cities' climate policies.

6 FURTHER RESEARCH AGENDA

Climate neutrality strategies have been already developed in pioneering cities, however urban underground space have been barely mentioned in any of them. Most decarbonisation strategies include actions within industrial sectors: electricity, buildings, transportation, waste, carbon sinks and storage. Underground infrastructure is a part of these sectors and in this way has been considered in climate neutrality strategies. However, as underground space represent a continuum with distinctive features and interrelated infrastructure, there is a need to explicitly address subsurface in urban climate strategies.

To mainstream urban underground space in to climate neutrality strategies further research is needed on: (1) quantitative data on urban underground space, similar to urban sustainability indicators, (2) urban functions carbon emissions accounting while placing facilities in subsurface, (3) contribution of urban underground space to climate change adaptation and mitigation, (4) developing a theoretical framework for climate neutral city and urban underground space, (5) urban geothermal energy use, including shallow heat exchange.

The theoretical framework could be a cornerstone that would show indispensability of addressing urban underground space use in a climate strategy of any city. This framework can be based on gaining momentum concept of geosystem services, which argues for greater role of abiotic nature in urban planning (van Ree and van Beukering, 2016, Bobylev et al, 2022).

7 CONCLUSIONS

Urban Climate neutrality is a mainstream goal in urban development, cities' strategies, and planning. Climate neutrality faces conceptual and methodological challenges. Firstly, we have shown that decarbonisation strategies are usually focusing on a limited number of key industrial sectors, like energy, or even more narrow, electricity. Cities' decarbonisation strategies mostly ignore spatial development and urban form, and do not mention urban underground space. This is an obvious deficiency, since we have shown importance of urban underground space for reducing cities' climate impacts. As figure 1 details, wide opportunities lay in reducing global climate impacts by using urban underground space, and less so for reduction impacts on local climate.

Secondly, clear methodological challenges are associated with carbon emissions accounting, difficulty in including urban underground space into existing carbon balance assessments or using tailor made methodologies, of which we have identified just few.

A concept of urban underground space use in a climate neutral city should be developed further, as an initial step we have identified and systematised an array of impacts and opportunities, as well as drawbacks, of reducing cities' carbon footprint by developing urban underground space. Urban resilience and climate adaptation appears to be an issue where urban underground infrastructure can be an asset as well as liability.

This research contributes to a vision for urban underground space and integrated urban planning (Admiraal and Cornaro, 2018) that enhance the quality of urban life while pursuing climate responsible development agenda.

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