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Review

Co-benefits and synergies between urban climate change mitigation and adaptation measures: A literature review

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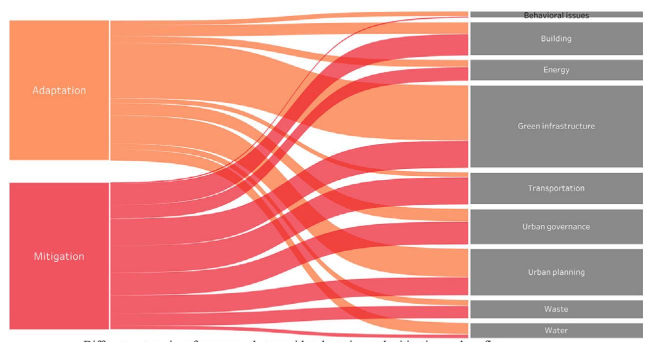
HIGHLIGHTS

- Adaptation needs to be considered at parity with mitigation.
- Co-benefits and synergies between adaptation and mitigation measures are explored.
- Relatively Extensive knowledge exists on co-benefits, but synergies are understudied.
- Green infrastructure measures show greater potential for offering co-benefits.
- Measures related to urban greening and transport are more likely to provide synergies.

GRAPHICAL ABSTRACT



Different categories of measures that provide adaptation and mitigation co-benefits

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ABSTRACT

Accounting for over 70% of global CO2 emissions, cities are major contributors to climate change. Acknowledging this, urban climate change adaptation and mitigation plans are increasingly developed to make progress toward enhancing climate resilience. While there is consensus that focusing on both adaptation and mitigation is necessary for addressing climate change impacts, better understanding of their interactions is needed to efficiently maximize their potentials. This paper, first, provides a bibliographic analysis to map existing knowledge regarding adaptation-mitigation interactions. This is done using methods such as bibliographic coupling, co-citation analysis, and co-occurrence analysis. Then, drawing on the literature, this study explores two types of interactions between adaptation and mitigation measures, namely co-benefits and synergies. These interactions are explored through analyzing evidence reported in the literature on different measures related to sectors such as energy, transportation, waste, water, green infrastructure, urban planning, and governance. Results of the bibliographic analysis show that there is a lack of research in the Global South. Results of the detailed content analysis show that many measures can provide co-benefits and synergies. Measures related to green infrastructure, buildings, energy systems, and, transportation are particularly capable of providing co-benefits. In addition, it was found that appropriate levels of density, promotion of public transportation, and urban greenery are measures that are more likely to provide synergistic benefits if combined with other adaptation and/or mitigation measures. This study highlights the need for more empirical research to better understand the magnitude of synergistic benefits between different measures.

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Contents

1. Introduction

Cities are home to most of the world population and account for over 70% of global CO2 emissions (Gurney et al., 2015). This share is expected to further increase as urbanization trends continue. Meanwhile, the high concentration of population in cities renders them more susceptible to environmental externalities caused by emissions, and to the climate change impacts (Creutzig et al., 2016). Accordingly, cities are key foci for adaptation and mitigation efforts (Grafakos et al., 2019). Adaptation is focused on limiting vulnerabilities and increasing coping capacity and is defined by the Intergovernmental Panel on Climate Change (IPCC) as “the process of adjustment to actual or expected climate and its effects” in human and/or natural systems (IPCC, 2014). In contrast, mitigation addresses issues related to the drivers of climate change and is defined by the IPCC as “a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)” (IPCC, 2014). Traditionally, mitigation has received more attention in climate change action plans developed by cities (Grafakos et al., 2019; Dovie, 2019; Papa et al., 2015). As a result, there is still imbalance between the focus on adaptation and mitigation (Grafakos et al., 2019; Dovie, 2019; Papa et al., 2015), and adaptation plans are often less advanced (Ford et al., 2018). In fact, in many cities, even in the developed world, better institutional arrangements exist for mitigation (Hoppe et al., 2016; Landauer et al., 2019). As a result, mitigation actions have also received the chunk of climate finance available by international donors and aid organizations (Grafakos et al., 2019). Even in the Paris Agreement, mitigation has received more attention; while there are clearly specified targets for mitigation, this is not the case for adaptation (Dovie, 2019).

The higher emphasis on mitigation reflects the relative effectiveness of decades of climate negotiations focused on developing policies to limit Greenhouse Gas (GHG) emissions. It is also argued that failure to limit global warming within 2 °C above pre-industrial levels will have significant ramifications for adaptation, as higher concentration of GHGs in the atmosphere is expected to increase the frequency and intensity of extreme events (e.g., storms, extreme temperature events, sea level rise, extreme precipitation, etc.), thereby making future adaptation more uncertain, costly, and challenging (Ford et al., 2018; UNFCCC, 2011; Chan et al., 2018). Despite this initial focus on mitigation, the importance of adaptation is increasingly acknowledged. This is driven by the increasing recognition of the fact that, due to historical emissions, certain levels of climate change are inevitable (Janetos, 2020; Ayers and Huq, 2009). In addition, uncertainties about the effectiveness of mitigation efforts necessitates improving adaptation capacities (Ayers and Huq, 2009; Laukkonen et al., 2009). As a result, there are now various initiatives such as the 100 Resilient Cities, the Covenant of Mayors, etc. that are fostering development of adaptation and resilience building plans (Papa et al., 2015).

Another issue is that climate action plans have traditionally tended to focus on either adaptation or mitigation. Geographically, mitigation has been considered as the priority responsibility of cities in the Global North, and adaptation of those in the Global South (Ayers and Huq, 2009). This could be explained by arguments that cities in the Global North have higher emissions and, therefore, more potential for mitigation. Also, they have more responsibility due to their larger contribution to historical emissions. In contrast, there are arguments that adaptation is particularly important in developing countries that contribute relatively less to GHG emissions (therefore, feature lower mitigation potentials), but are more vulnerable and face more climatic impacts (Dovie, 2019).

However, since the publication of the fourth assessment report of the IPCC (AR4) there has been a paradigm shift toward simultaneously addressing both mitigation and adaptation (Grafakos et al., 2019). This is driven by the increasing understanding that cities in the Global North need to deal with a large number of climatic impacts (e.g., some European countries have witnessed extensive flooding and heatwave events) and those in the Global South are growing rapidly, thus showing large potentials for mitigation (Ayers and Huq, 2009; Lwasa et al., 2018). Several studies have reported evidence confirming that the adaptation-mitigation divide has become blurred. For instance, an analysis of nine cities around the world shows that most of them integrate both adaptation and mitigation factors into their climate action plans (Grafakos et al., 2019). Similarly, survey analyses of 287 mid-size cities in the Great Lake region of the US (Kalafatis, 2017), and 350 municipalities around the world (Aylett, 2015) show that the adaptation-mitigation gap is becoming narrower.

A clear benefit of simultaneous integration of both adaptation and mitigation measures into climate action plans is better awareness about potential interactions that may exist between different measures due to multiple spatial and temporal dynamics and complexities (Aylett, 2015; Caparros-Midwood et al., 2019; Sharifi, 2020). Such enhanced awareness is needed for optimization of action plans

(Caparros-Midwood et al., 2019). The debates on interactions have significantly increased after being recognized in the Paris Agreement (Dovie, 2019). However, while in some cases, adoption of integrated approaches has resulted in better consideration of mitigation-adaptation interactions (Aylett, 2015), there are still claims that more improvements are needed. For instance, Caparros-Midwood, Dawson and Barr (Caparros-Midwood et al., 2019) report that even in Europe, where climate policies are relatively more advanced, only a small fraction of cities consider mitigation-adaptation co-benefits and synergies. Similarly, the analysis of mid-size cities in the US indicates that some local authorities are possibly not yet aware of the synergistic mitigation and adaptation opportunities that some policy actions may provide. For example, it was found that climate change adaptation benefits were not considered for measures aimed at increasing pedestrian transportation; or climate change mitigation was a missing link for measures aimed at transforming wastewater management (Kalafatis, 2017). The same study shows that mitigation and adaptation benefits of some policy actions such as improving tree canopy or building energy efficiency may still not be clear to policy makers. Therefore, better understanding of interactions is needed to enhance efficiency and effectiveness of action plans (Dulal, 2017). Considering co-benefits and synergies may also accelerate transition toward low-carbon and sustainable urban development (Ford et al., 2018).

Against this background, the main objective of this paper is to provide a better understanding of the existing research on the interactions between urban climate change adaptation and mitigation measures through reviewing the literature. Co-benefits and synergies are two specific types of interactions that will be explored in this paper. These two tend to be used interchangeably in the literature (Berry et al., 2015; Swart and Raes, 2007). However, they are different concepts and should be differentiated (Grafakos et al., 2019). Co-benefit is the more common term and is defined as an additional positive adaptation (mitigation) effect that can be achieved from a planning and/or policy measure aimed at improving mitigation (adaptation) (Grafakos et al., 2019; Berry et al., 2015). In contrast, synergies occur when interactions between adaptation and/or mitigation measures lead to greater benefits than when they are implemented separately (Landauer et al., 2019).

This work builds on the review by Landauer, Juhola and Söderholm (Landauer et al., 2015) that searches for interrelationships across different disciplines, with some major attention to urban studies. The work by Landauer, Juhola and Söderholm (Landauer et al., 2015) mainly focuses on drivers of co-benefits and synergies. It, however, does not provide details on different measures and how they may interact to provide co-benefits and synergies. The review by Berry, Brown, Chen, Kontogianni, Rowlands, Simpson and Skourtos (Berry et al., 2015) is another related work that lists several adaptation measures and examines their cross-sectoral interactions and impacts on mitigation. The list, however, only includes few measures and the potential synergies are also not discussed.

Results of this review are expected to enhance awareness about co-benefits and synergies. They can show which actions provide more co-benefits and synergies and, therefore, deserve further attention by planners and policy makers. They are also aimed to inform the assessment report that is currently under preparation by the Working Group III of IPCC (AR6).

The paper is organized as follows: the research methods and materials are explained in the next section; results, including bibliographic analysis and details on the most common types of interactions and potential linkages to resilience and sustainability are reported in Section 3; finally, Section 4 summarizes the findings, provides some policy recommendations, and highlights gaps to be addressed in the future research.

2. Methods and materials

Results reported in this paper are based on the review of 56 papers indexed in the Web of Science. To retrieve all relevant documents that deal with urban climate change mitigation and adaptation interactions, a broad-based initial search string was developed that includes different variants of terms such as mitigation, adaptation, resilience, urban, city, co-benefit, synergy, conflict, and trade-off (see the supplementary appendix). The terms trade-off and conflict were included, because papers dealing with them are also highly likely to address co-benefits and synergies. The initial search was conducted on 21 August 2019 and returned 86 items. The abstracts and conclusions of the retrieved documents were checked and papers dealing with adaptation-mitigation interactions at the city scale were selected for in-depth analysis. While reviewing the selected papers, it was noticed that other relevant terms such as interaction and inter-relationship could have also been included in the search string. Therefore, an updated literature search including those terms was conducted on 23 October 2019 (see the Appendix). The updated search string returned 156 items. The abstracts and conclusions of the newly added documents were checked, and documents that deal with interactions between adaptation and mitigation measures at the urban scale were added to the database. Also, during the review process, the alert function of Web of Science was activated to include recently-published papers in the work. The final database used for this study included 56 papers.

The VOSviewer software that is designed for text mining and bibliometric analysis was used to map the reviewed literature and identify highly influential documents, countries, and journals in this area (Van Eck and Waltman, 2009). Bibliographic coupling, co-citation, and co-occurrence were three main analyses done using VOSviewer. These will be further explained in the next section.

Information on adaptation and mitigation measures and their interactions were collected through detailed content analysis of the selected papers. A data extraction file was developed in Microsoft Excel to collect data on various items such as research methods, climatic impacts, geographic focus, major sectors, and types of interactions. This file included separate sheets to collect information related different planning/design measures. These sheets were also used to take note of different types of adaptation-mitigation interactions. When the database was complete, simple statistical analyses were conducted to prepare the results reported in the next section. Also, the Sankey diagrams were prepared using the Tableau software.[1]

3. Results and discussions

3.1. Overview of the literature

As shown in Fig. 1, the first paper on the interactions between urban climate change adaptation and mitigation was published in 2006 and an increasing trend can be observed ever since. The reviewed papers can be divided into three broad categories in terms of their focus on adaptation and/or mitigation. The majority (66%) are focused on both adaptation and mitigation, 19% addressed both issues but their focus is on adaptation, the rest are mainly focused on mitigation. The trends shown in Fig. 1 indicate the increasing recognition of the equal importance of both measures.

In terms of document type, 80% of the analyzed papers were research papers, 16% review papers, and the rest insight and letter. Regarding research methods, three major categories can be distinguished: social science methods (64%), science and engineering methods (29%), and economic methods (7%). Commonly used social science methods include literature review, content analysis, qualitative case study, grounded participatory research, and questionnaire and interview surveys. Modeling and simulation techniques such as integrated city models, the Weather Research and Forecasting (WRF) model, and integrated land use and transport model are examples of

[1] The template provided in the following website was used: https://www.flerlagetwins.com/2019/04/more-sankey-templates.html (Credits: Ken Flerlage, Jeffrey, and Olivier Catherin).

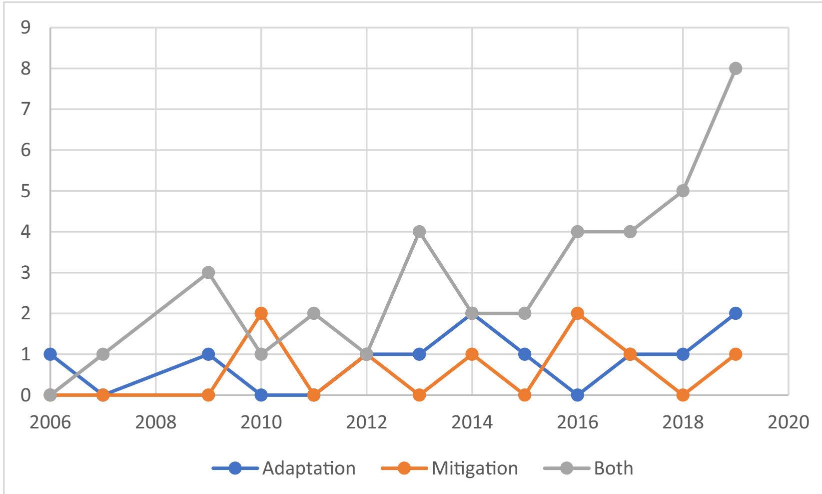

Fig. 1. Time evolution of the number of focus-specific papers dealing with urban adaptation and mitigation interactions.

science and engineering methods. Finally, cos-benefit analysis and multi-criteria analysis are two major types of economic methods. Fig. 2 of the Supplementary Appendix shows the distribution of the methods depending on the focus of the papers (i.e., either adaptation, mitigation, or both). It can be seen that in all cases social science methods are dominant, followed by science and engineering methods.

3.1.1. Bibliographic analysis

Co-citation is a bibliographic analysis method that indicates connection between two documents that are both cited by an identical third document (Van Eck and Waltman, 2009). This measure is used to identify the most influential publications and journals in an area. 'Co-citation by author' analysis for authors meeting the threshold of at least 6 co-citations shows that the following documents feature the highest link strength, indicating that they have had relatively higher influence: Hamin and Gurran (2009), Laukkonen et al. (2009), and Swart and Raes (2007). The influential documents can be divided into three major categories: first, those published by IPCC that have underscored the significance of simultaneously addressing both adaptation and mitigation (Seto et al., 2014; I. WGII, 2007). Obviously, these documents have been influential in fostering further research in this area. Second, articles that have discussed general issues related to interactions between adaptation and mitigation and have played a major role in clarifying the concepts of co-benefits, synergies, trade-offs, and conflicts (Laukkonen et al., 2009; Klein et al., 2005; Viguie and Hallegatte, 2012). Finally, articles that have discussed the interaction in the context of specific sectors such as urban form (Hamin and Gurran, 2009), spatial planning (Biesbroek et al., 2009), and green infrastructure (Gill et al., 2007). Results of the co-citation analysis are shown in Fig. 2. The supporting data is presented in Table 1 of the supplementary appendix.

'Co-citation analysis by source', setting the minimum number of citations of a source to 20, shows three major clusters of journals: planning and climate policy (e.g., Climatic Change, Global Environmental Change, and Environmental Science and Policy), natural and environmental science (e.g., Nature Climate Change, Science, and Proceedings of the National Academy of Sciences), and urban design and energy policy (e.g., Energy Policy and Landscape and Urban Planning). Journals such as Climatic Change, Global Environmental Change, and Nature Climate Change are more influential (see Fig. 3). Data on the number of citations and total link strength is presented in Table 2 of the supplementary appendix.

Another commonly used bibliographic analysis method is the 'term co-occurrence analysis'. Mapping co-occurrence of keywords can be used to identify key focus areas and common research topics. Output

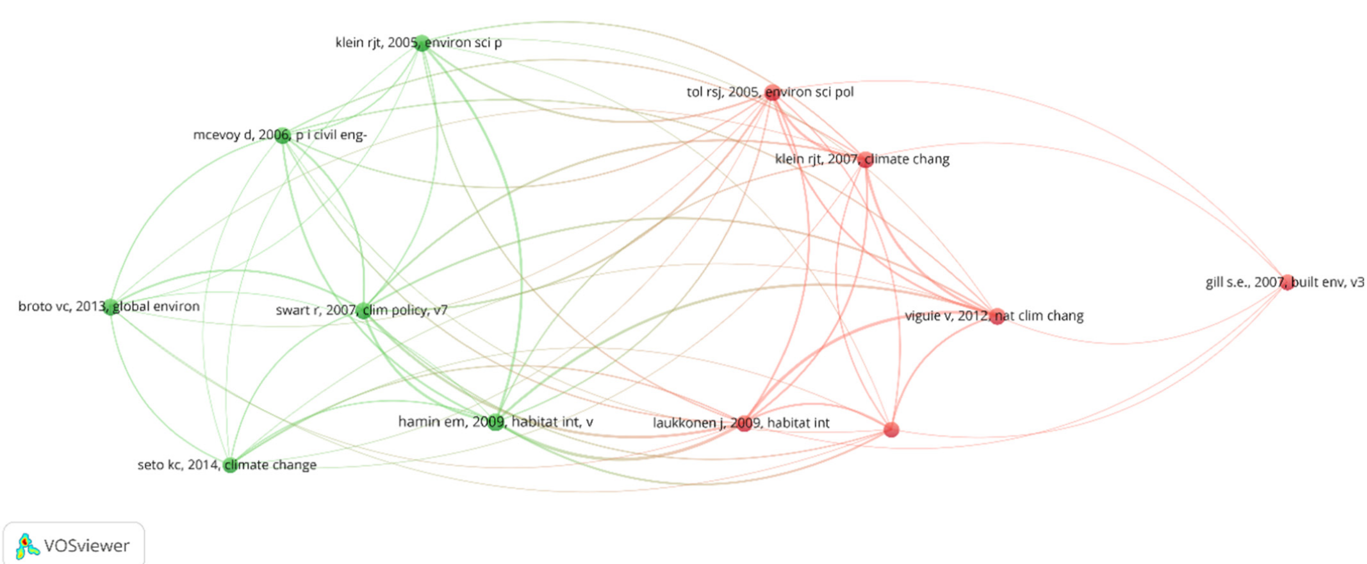

Fig. 2. Highly influential documents on urban climate change adaptation and mitigation interactions.

Table 1
The list of adaptation/mitigation measures. The third and fourth columns refer to the number of papers that have explicitly discussed each measure in relation to mitigation and adaptation, respectively.

Sector	Planning/policy measure	M	A	Primary objective	Major contribution(s) to mitigation	Major links to risks, or adaptive capacities improved
	Appropriate levels of density	16	2	Mitigation	Energy saving, sequestration	Flooding, wildfire, etc.
	Improved physical accessibility to amenities	1	1	Both	Energy saving	Generic response and adaptation capacities
	Land use mix	1	1	Both	Energy saving	Generic response and adaptation capacities
	Improved connectivity	1	1	Both	Energy saving	Generic response and adaptation capacities
	Relocating existing infrastructure to avoid risk-prone areas	–	2	Adaptation	–	Flooding, wildfire
	Risk zoning policy (e.g., flood zoning, restricting new developments)	1	2	Adaptation	Sequestration	Flooding, wildfire
	Development along riverbanks to reduce exposure to heat	1	1	Adaptation	Energy saving	Extreme heat
	Cool roofs and pavements	2	3	Both	Energy saving	Extreme heat
Urban design/Land use planning	Passive urban design (shading, orientation, natural ventilation, etc.)	2	1	Mitigation	Energy saving	Extreme heat/cold
	Appropriate design of streets, street networks, and street canyons	1	2	Both	Energy saving	Extreme heat/cold
	Transit-Oriented Development	2	1	Mitigation	Energy saving, sequestration	Indirect (response and adaptation capacities)
	Transportation demand management	5	1	Mitigation	Energy saving	Indirect (response and adaptation capacities)
	Promotion of public transport and active transport modes	7	3	Mitigation	Energy saving	Indirect (response and adaptation capacities)
	Congestion pricing	1	1	Mitigation	Energy saving	Indirect (through health benefits for adaptive capacity)
	Single tariff public transport policy	1	1	Mitigation	Energy saving	Indirect (equity benefits for adaptation)
	Car sharing	1	1	Mitigation	Energy saving	Indirect (response and adaptation capacities)
	Electrification of urban transportation	1	1	Mitigation	Energy saving	Generic (energy resilience, i
	Improvement of vehicle efficiency standards	1	1	Mitigation	Energy saving	Energy shocks
	Parking demand management	2	1	Mitigation	Energy saving	Indirect (through health benefits for adaptive capacity, etc.)
	Vehicles and fuel tax policies	1	1	Mitigation	Energy saving	Indirect (through health benefits for adaptive capacity)
Transportation	Adoption of high occupancy vehicle (HOV) lanes (e.g., BRT)	2	1	Mitigation	Energy saving	Indirect (response and adaptation capacities)
	Passive building design	2	1	Mitigation	Energy saving	Extreme heat/cold
	Insulation	4	1	Both	Energy saving	Extreme heat/cold
	Green building programs and policies	5	1	Mitigation	Energy saving, sequestration	Generic adaptation capacities
	Building retrofit	3	1	Mitigation	Energy saving	Generic adaptation capacities
	Enhance building energy efficiency (i.e., home appliances, light bulbs, etc.)	4	2	Mitigation	Energy saving	Energy chocks
	Improved air conditioning techniques	1	1	Both	Energy saving	Extreme heat/cold
	Providing smoke-free kitchens to poor household	1	1	Both	Energy saving	Indirect (through health benefits for adaptive capacity, etc.)
	Conventional air conditioning systems for maintaining thermal comfort	–	3	Adaptation	–	Extreme heat/cold
Building	Building material durability improvement	1	1	Both	Energy saving	Flooding, etc.
	Site/neighborhood level composting (reducing landfill)	3	1	Mitigation	Reduced CH_4 emissions	Land degradation
	Waste sorting, recycling, and reuse	2	1	Mitigation	Reduced CH_4 emissions	Generic adaptation capacities
	Waste to energy (gasification, community-based waste to energy)	4	1	Mitigation	Reduced CH_4 emissions	Energy shocks
Waste	Wastewater recycling and treatment/management	2	4	Both	Energy saving	Water stress
	Distribution and Decentralization of energy systems (district cooling and heating, CHP plants, microgrids, etc.)	10	4	Mitigation	Clean/renewable energy	Energy shocks, water stress
	Diversified energy profile based on renewable energies	1	1	Adaptation	Clean/renewable energy	Energy shocks
	Decarbonization of the energy sector/low carbon energy sources	2	1	Mitigation	Clean/renewable energy	Energy shocks
Energy	Electric power transmission and distribution management	1	1	Both	Energy saving	Energy shocks
	Green roof, roof garden, green façade	6	14	Adaptation	Energy saving, sequestration	Extreme heat, flooding
	Network of Parks, urban greenery and open spaces	5	12	Adaptation	Sequestration, energy saving	Extreme heat, flooding
	Urban nature protection (forests, green belt, protection of natural habitats, etc.)	5	8	Adaptation	Sequestration, energy saving	Extreme heat, flooding
	Wetlands and water bodies (including open stormwater systems)	2	5	Adaptation	Sequestration, energy saving	Water stress, flooding, extreme heat
	Urban agriculture and local food production	3	4	Both	Sequestration, energy saving	Food shortage, flooding, extreme heat
	Xeriscaping	1	1	Adaptation	Sequestration, energy saving	Water stress
Green Infrastructure	Water-sensitive urban design (permeable surfaces, bioswales, etc.)	2	5	Adaptation	Energy saving	Water stress, flooding

(continued on next page)

Table 1 (*continued*)

Sector	Planning/policy measure	M	A	Primary objective	Major contribution(s) to mitigation	Major links to risks, or adaptive capacities improved
	Rainwater harvesting (e.g., rain gardens, rainwater tanks, water retention)	1	5	Adaptation	Energy saving	Water stress, flooding
	Water efficiency improvement	1	2	Adaptation	Energy saving	Water stress
	Water demand management	1	1	Adaptation	Energy saving	Water stress
Water	Desalination water plants	–	2	Adaptation	–	Water stress
	Infill and brownfield (re-) development	1	1	Both	Energy saving, sequestration	Flooding
	Building codes that promote energy efficiency and support building safety	5	2	Both	Energy saving	Flooding
	Environmental pricing and regulation	1	1	Mitigation	Energy saving	Energy shocks, water stress
	Low carbon economy and sustainable investments	2	1	Mitigation	Energy saving	Indirect (response and adaptation capacities)
	Smart city plans and strategies and investment in high-tech industry	2	1	Both	Energy saving	Generic adaptation capacities
	Integration of both adaptation and mitigation into planning and policy making	1	2	Both	Energy saving	Generic adaptation capacities
	Increased stakeholder engagement	1	1	both	Energy saving	Generic adaptation capacities
	Efforts to overcome organizational or institutional barriers to implementing climate actions	1	1	Both	Generic	Generic adaptation capacities
	Efforts aimed at local air pollution management (e.g., car free days)	3	1	Mitigation	Direct emission reduction, energy saving	Indirect (through health benefits for adaptive capacity, etc.)
	Slum upgrading and reducing rate of urban poor	1	1	Adaptation	Energy saving	Flooding, extreme weather
	Promotion of innovative design	1	1	Both	Energy saving	Generic
	Investment on systems for monitoring energy production and consumption	1	1	Mitigation	Energy saving	Energy shocks
	Update of legislations and regulations to facilitate simultaneous integration	1	1	Both	Energy saving	Generic
Urban governance and planning	Consideration of the costs of mitigation measures in poor areas	1	1	Mitigation	Generic	Indirect (equity benefits for adaptation)
	Dietary changes	1	1	Both	Energy saving	Water stress, food shortage
	Citizen awareness	1	3	Both	Energy saving	Generic
Behavioral issues	Incentives for managing heating and cooling energy demand	1	1	Both	Energy saving	Energy shocks

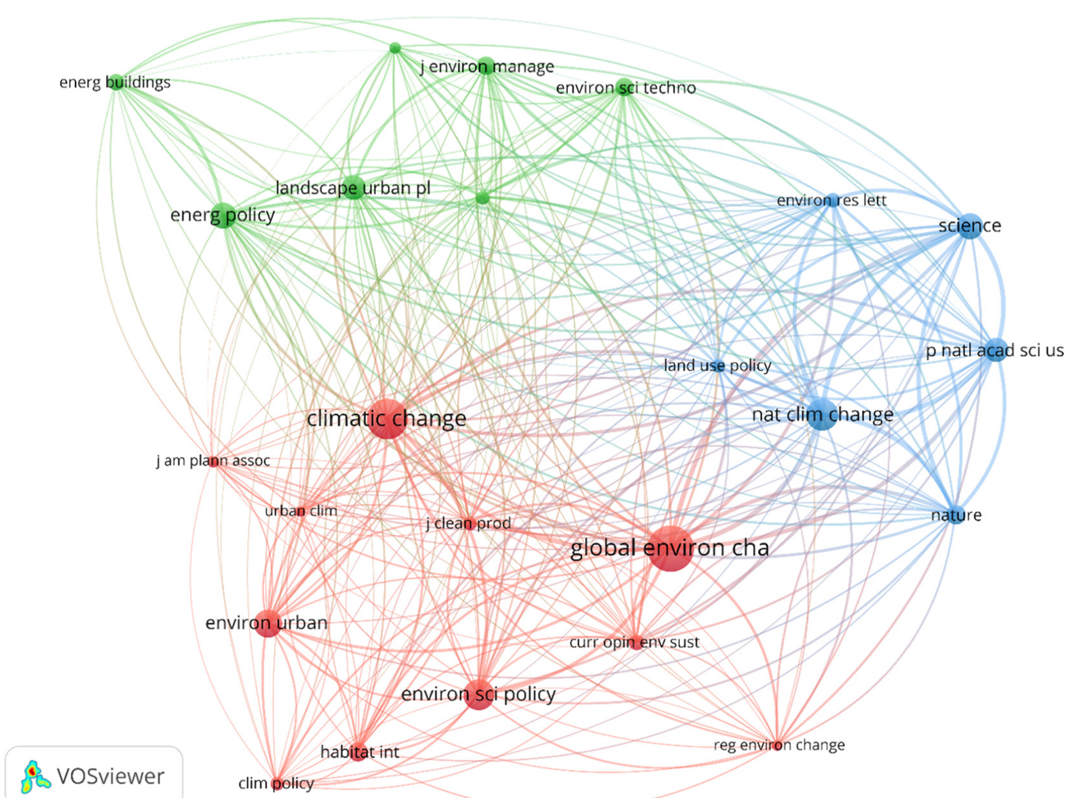

Fig. 3. Highly influential journals.

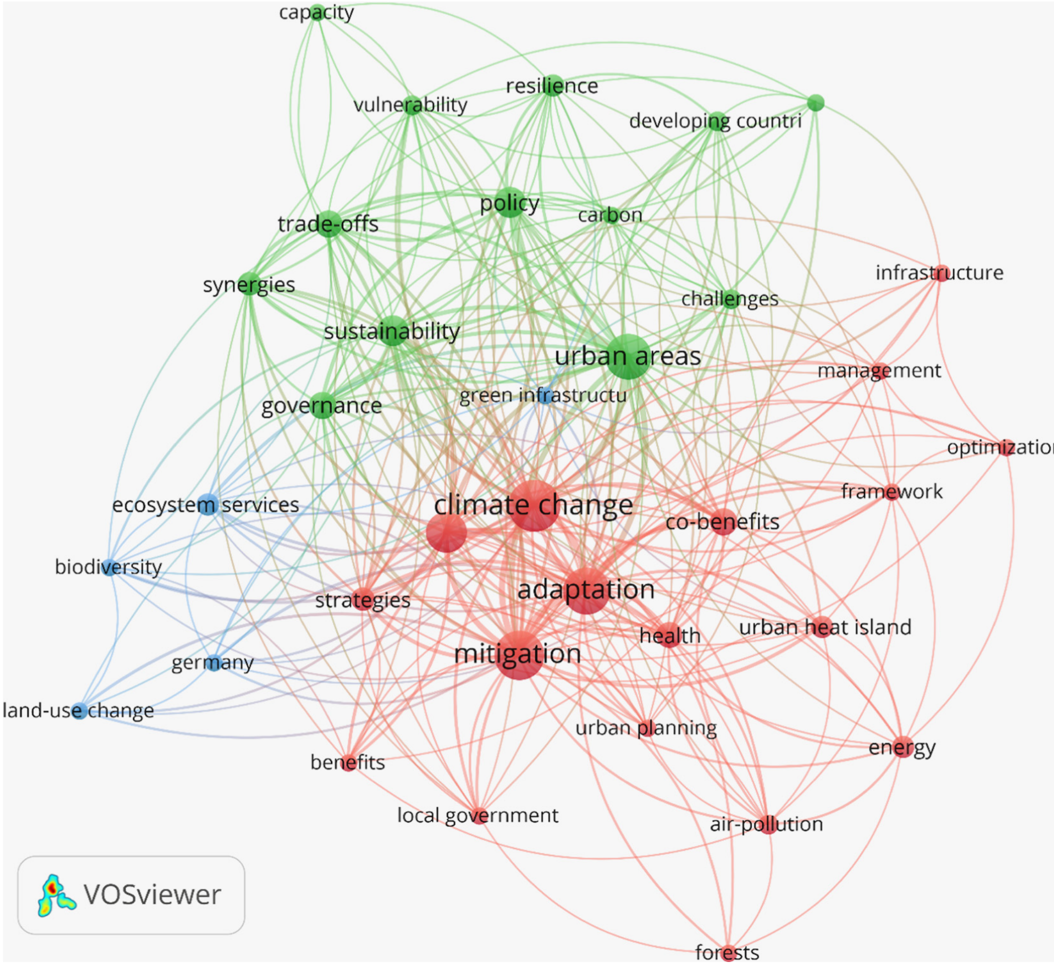

Fig. 4. The co-occurrence map.

of the co-occurrence analysis, for a minimum occurrence threshold of 3 keywords, is presented in Fig. 4. Larger node size corresponds to more frequently used terms. Quantitative data related to this co-occurrence map is shown in Table 3 of the supplementary appendix. The total link strength is used to understand the strength of connections between the terms. In this case, as expected, terms such as climate change, mitigation, adaptation, and impacts have the highest values of link strength and occurrence, indicating their high level of inter-relationship. An interesting finding is that mitigation and adaptation have similar values. This can be interpreted as the increasing acknowledgment of the importance of simultaneous consideration of them. The same argument can be made for the terms "co-benefits" and " synergies ". The analysis also shows that policy, health, and energy are major sectors that have higher values. This may indicate more focus on these sectors in the literature.

The co-occurrence analysis can also be used to create clusters of keywords, with each cluster including keywords that most frequently co-occur. In this case, the following four clusters can be identified. Policy-related keywords such as vulnerability, resilience, and adaptive capacity are grouped in the green colored cluster. Presence of the term 'developing country' in this cluster indicates more focus on topics such as resilience and vulnerability in developing countries. This is consistent with what was discussed in the Introduction section. The largest cluster that also includes terms 'mitigation' and 'adaptation' mainly includes keywords related to energy, micro-climate, and health. This can be interpreted as closer relationships between these terms in the literature, and shows the clear nexus between health, energy consumption, air pollution, and Urban Heat Island (UHI). The third cluster is focused on green infrastructure, land use, and biodiversity.

To identify the most prominent countries doing research in this area, the 'bibliographic coupling analysis', for a minimum threshold of four documents for a country, was used. Bibliographic coupling indicates connection between two documents that both cite the same third document (Van Eck and Waltman, 2009). As Fig. 5 shows, this area of research is mainly dominated by developed countries, particularly England and the USA. China and India are two developing countries that have shown connections with the developed countries. This is not surprising, given the magnitude of urbanization in these two countries. The two clusters show closer collaborations between the USA, Germany, and Australia (red cluster) and England, the Netherlands, Finland and Austria (green cluster). England has a central position in the network, indicating that its researchers have strong collaborations with their colleagues in other countries. Detailed content analysis of the reviewed papers provides further insights about the location of the authors and the geographic focus of the studies. Authors are mainly located in Europe, followed by North America, Oceania, South and South East Asia, and East Asia (Fig. 6). This figure also provides interesting insights regarding the geographic focus of the studies. Approximately 28% of the studies have a global focus and have mainly been done by researchers in Europe and North America. About 25% of the studies are focused on European cities. These studies have mainly been conducted by researchers based in Europe. Among the developing regions, South and South East Asia has received reasonable attention (~ 17%). Majority of studies on this region have been done by local and Europe-based

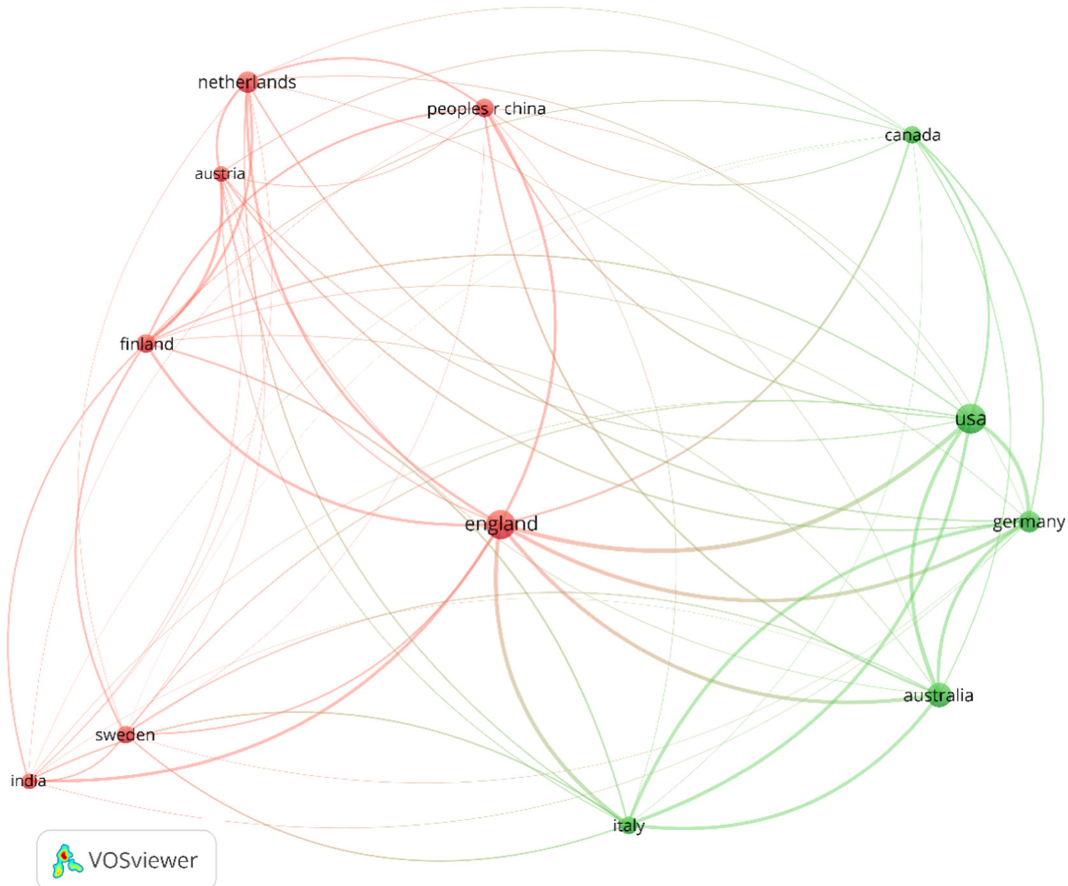

Fig. 5. The most prominent countries doing research on urban climate change adaptation and mitigation interactions.

researchers. This figure shows that some developing regions such as South America and Africa that are experiencing rapid rates of urbanization and are also argued to have lower adaptive capacities(UNDESA, 2018) have not received due attention.

The detailed content analysis also showed that, in most regions, existing research addresses both adaptation and mitigation equally (Fig. 3 of the appendix). It can, however, be observed that some developing regions such as South and South East Asia have relatively more

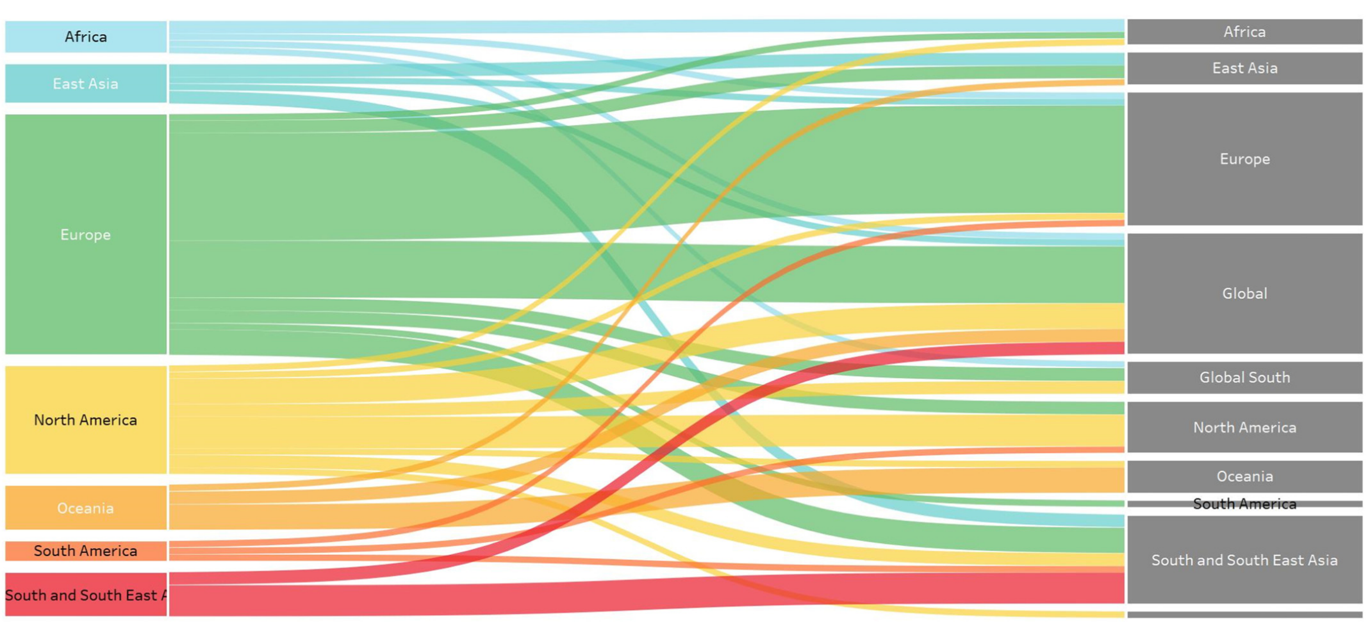

Fig. 6. Categorization by the origin of the authors (left panel) and geographic focus of the studies (right panel).

focus on Adaptation. This confirms the results of the VOSviewer software discussed earlier and is also in accordance with the claims in literature, that were discussed in the introduction, regarding the traditional belief that more attention to adaptation is needed in the Global South.

3.2. Adaptation and mitigation measures

A wide range of measures have been mentioned in the reviewed papers (see Table 1). These measures are divided into nine major categories, namely, urban design and land use planning, transportation, building, waste, energy, green and blue infrastructure, water, urban governance, and behavioral issues. As can be seen from Table 1 and Fig. 7, most categories include measures that are related to both mitigation and adaptation. More than 25% of the measures discussed in the reviewed papers are related to green infrastructure. It can be observed that, green infrastructure measures have been primarily discussed in relation to adaptation objectives. In other words, adaptation contributions of green infrastructure measures have received more attention. Similar patterns can be observed for measures related to urban planning and water categories. As will be discussed in the next sections, measures related to green infrastructure, urban planning, and water categories play essential roles in enhancing adaptation to climatic impacts such as flooding, extreme temperature events, and droughts. However, they also contribute to reducing GHG emissions. In contrast, measure belonging to building, transportation, energy, and waste categories are primarily related to climate change mitigation. This can be explained by significant energy saving benefits that can be achieved through efficiency improvements in these sectors. However, these measures also provide adaptation co-benefits.

3.3. Co-benefits

A summary of co-benefits related to each of the nine categories mentioned in Table 1 is provided here:

3.3.1. Urban design and land use planning

Measures related to compact urban development have received the highest amount of attention in this category. There are many studies demonstrating that compact urban development that features appropriate levels of density and is coupled with land use mix and improved accessibility and connectivity contributes to mitigation through promoting active and public transportation, thereby reducing per-capita travel demand and associated energy consumption (Caparros-Midwood et al., 2019; Yang and Goodrich, 2014; Pierer and Creutzig, 2019; Stokes and Seto, 2016). Compact development also reduces energy needs for cooling and heating of buildings, as housing size in high-density areas tends to be smaller and buildings can also benefit from the thermal efficiency contributions of shared walls (Pierer and Creutzig, 2019; Stokes and Seto, 2016). There is also evidence showing that water consumption is lower in compact cities and this can contribute to mitigation through reducing the energy demand for water (Yang and Goodrich, 2014). Moreover, higher feasibility of developing efficient large-scale community energy systems (e.g., district energy and cooling systems) in high-density areas provides additional mitigation opportunities. In addition, compact urban development can provide indirect mitigation opportunities through carbon sequestration benefits that can be achieved by nature preservation and wetland protection (Burley et al., 2012).

Also, multiple adaptation co-benefits have been reported for compact urban development that features enhanced accessibility, connectivity, and land use mix. Unlike urban sprawl, compact urban development reduces the demand for land, thereby enabling avoidance of risk-prone areas (Hoymann and Goetzke, 2016). In addition to reducing exposure to risks such as flooding and wildfire (Sharifi, 2019a), this will contribute to the protection of valuable ecosystems such as forests and wetlands. Ecosystem services offered by these natural assets are critical for adaptation to flood risk and heat events (Burley et al., 2012). Related to this, there is evidence showing that extreme heat events are less frequent in compact metropolitan areas compared with their sprawling counterparts (Dulal, 2017; Stone et al., 2010). As discussed above, water and energy consumptions are lower in compact areas, enabling them to better adapt to water stress and energy shocks (Yang and Goodrich, 2014; Sharifi, 2019b). Also, compactness entails less infrastructure development (Stokes and Seto, 2016). This allows better maintenance during periods of economic recession and provides sustainability co-benefits through reducing demand for resources.

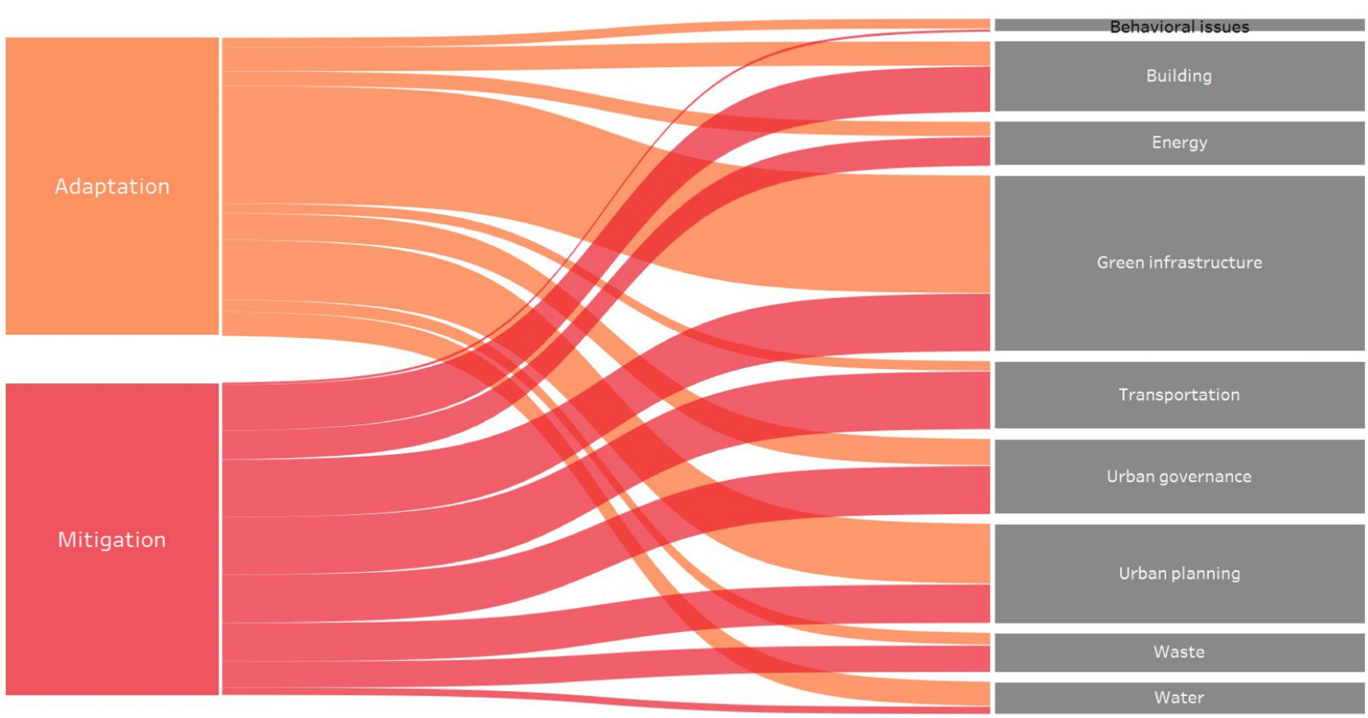

Fig. 7. Major categories of measures and their relationship with adaptation and mitigation.

Similar economy of scale benefits can be achieved in terms of disaster response as emergency teams can deal with high-density, mixed use, and well-connected areas in a faster and more efficient manner (Stokes and Seto, 2016; Sharifi, 2019a).

Regarding other measures in this category, passive design strategies related to albedo, shading, orientation, and natural ventilation are argued to be effective adaptation and mitigation measures. For instance, increasing albedo through cool roofs and pavements is a measure that contributes to mitigation as well as adaptation. Light-colored surfaces provide cooling benefits through reducing heat storage and increasing reflection of solar radiation. This, in turn, reduces cooling energy demand (Coutts et al., 2010). As for adaptation, high-albedo materials help achieving thermal comfort in the environment through mitigating the UHI effect (Coutts et al., 2010). This, in turn, can reduce pressure on the grid and, therefore improve energy resilience by lowering chances of black- and brown-outs (Li and Bou-Zeid, 2013).

3.3.2. Transportation

Transportation measures are mainly discussed in the context of mitigation, but can indirectly provide adaptation co-benefits. Evidence reported in the reviewed papers shows that investment in multi-modal public transportation and Transit-Oriented Development (TOD), if coupled with policy measures such as congestion charging, parking demand management, and vehicle and fuel tax schemes can significantly reduce Vehicle Kilometers Travelled (VKT) and associated emissions by discouraging vehicle-dependency and promoting public transportation ridership (Dulal, 2017). For instance, in their simulation study for Paris, Viguie and Hallegatte (2012) show how replacing "differentiated public transport tariff", wherein tariff increases as distance to city center increases, by a "single tariff for all destinations" can promote public transportation. Success stories have also been reported in other contexts such as Singapore and Southern California (Dulal, 2017). In the latter, evidence shows that adoption of High Occupancy Vehicle (HOV) lanes is an effective measure to reduce private car ownership and use, and per vehicle per mile emissions of HOV lanes are often lower than mixed flow lanes (on the order of 10–70%), as reported by Boriboonsomsin and Barth (2007) (cited in (Dulal, 2017)).

In terms of adaptation, public transportation infrastructure is more robust against adverse events (He et al., 2019). It is also demonstrated to be more effective for disaster absorption, as it can facilitate better emergency access and quicker and easier evacuation (Dulal, 2017). Public transportation can also strengthen coping and adaptive capacities of populations in other indirect ways. For instance, public health and capital assets are critical factors that influence coping and adaptive capacities. These factors can indirectly be linked to public transportation as it can contribute to enhancing public health and environmental quality and reducing household healthcare and transportation costs (Dulal, 2017; Viguie and Hallegatte, 2012; Jerneck and Olsson, 2013). Additional indirect economic resilience benefits can be accrued if public health and time-saving benefits lead to reduced productivity loss at the workplace (Jerneck and Olsson, 2013; Pasimeni et al., 2019). Public transportation can also contribute to improving economic capacity at the city level through improved performance facilitated by economic activities around walkable transport stations (Viguie and Hallegatte, 2012). Increased walkability, in turn, provides opportunities for social interactions that may strengthen social capital and, thereby, coping capacity of societies (Pasimeni et al., 2019). Other benefits of public transportation such as its abilities to reduce accessibility inequalities among neighborhoods (Viguie and Hallegatte, 2012) also strengthen social capital. Moreover, better resilience to energy shocks is an indirect co-benefit of public transportation that is achievable since public transportation tends to be more energy efficient (Pasimeni et al., 2019; Sharifi and Yamagata, 2016b).

In addition to public transportation measures, improvement of vehicle efficiency standards, electrification of urban transportation and car sharing services are other noteworthy transportation-related measures that not only contribute to achieving mitigation targets, but also enhance adaptation capacities through cost savings that can lead to economic resilience and energy saving capacities that strengthen resilience to energy shocks.

3.3.3. Buildings

Several measures related to buildings have been discussed in the literature. In particular, strengthening the potentials of green building programs that promote the integration of energy-efficient systems, and passive design techniques have been emphasized. In combination, these can reduce energy loss and energy consumption and consequently decrease anthropogenic CO_2 emissions (Laukkonen et al., 2009; He et al., 2019; Santamouris, 2016). Since green building programs are mainly focused on newly-constructed buildings, building retrofit programs should also be promoted to increase energy efficiency of the existing building stock (Grafakos et al., 2019; He et al., 2019). Green building and retrofit programs also provide water efficiency co-benefits that can further reduce the energy demand, given the water-energy nexus (Grafakos et al., 2019; Sharifi and Yamagata, 2016b). This will also contribute to adaptation in areas dealing with water stress. Related to water, some green building features such as roof ponds and green roofs can further contribute to adaptation through stormwater retention. This not only contributes to flood resilience by reducing stormwater runoff, but also allows recycling the stored graywater (Grafakos et al., 2019; Landauer et al., 2019).

The most common adaptation co-benefit is, however, related to energy resilience and indoor thermal comfort. Green building programs can contribute to energy resilience through integrating energy generation systems such as micro wind turbines and photovoltaics, that enhance diversity and redundancy of energy supply (Santamouris, 2016). Green buildings are also more energy efficient. Being able to maintain thermal comfort in an energy-efficient manner is essential for reducing vulnerability to extreme heat events because of at least three reasons: first, it reduces household energy expenditure that is important for avoiding energy poverty; second, it reduces pressure on energy systems that is essential for maintaining energy supply during disasters; and third, better thermal properties allow maintaining some levels of thermal comfort even during blackouts (Ford et al., 2018; Laukkonen et al., 2009; Dulal, 2017; Sharifi and Yamagata, 2016b; Liu et al., 2016). In turn, enhanced thermal comfort provides health co-benefits that, as discussed earlier, can improve community and individual capacities in the long run (Liu et al., 2016). Furthermore, public health improvements and energy cost savings contribute to economic resilience by, among other benefits, reducing health sector costs, avoiding indirect costs associated with productivity loss due to extreme weather events, and enabling cities to allocate financial resources needed for the delivery of other societal services (Dulal, 2017; Jerneck and Olsson, 2013). Last, but not the least, building retrofit initiatives provide opportunities to reduce vulnerability of poor urban areas through building reinforcement programs (Sugar et al., 2013).

3.3.4. Waste

Measures in this category are mainly related to waste recycling and waste-to-energy technologies. Waste management measures such as composting, using energy from waste, and recovering landfill gas can enhance carbon sequestration and reduce GHG emission and particularly methane (Ayers and Huq, 2009; Dulal, 2017; Sugar et al., 2013). For instance, as the largest share of waste in developing countries is organic waste, there are many opportunities for composting. This contributes to reducing emissions, recycling waste, creating jobs, and providing additional revenues for municipalities as compost can be sold for use in agriculture and landscaping (Dulal, 2017; Gondhalekar and Ramsauer, 2017). Drawing on the waste management activities in Bangladesh, Ayers and Huq (Ayers and Huq, 2009) explain how composting of organic waste contributes to mitigation as well as adaptation. It provides mitigation benefits by reducing landfill methane emissions. Adaptation benefits can be accrued through using compost to reduce land degradation. Moreover, using compost as organic fertilizer improves drought resilience through enhancing soil moisture detention. Additionally, other sustainable development benefits such as ecosystem conservation and livelihood support can be achieved.

As decentralized energy generation sources that also provide efficiency improvements and reduce the need for waste treatment, waste-to-energy systems enhance energy security and resilience (Gondhalekar and Ramsauer, 2017; Colenbrander et al., 2017). They also reduce pressure on centralized waste treatment plants (Gondhalekar and Ramsauer, 2017). Waste to energy systems can also provide additional revenue sources to municipalities. These additional revenue sources improve economic resilience of municipalities and enable them to contentiously deliver municipal services, support local initiatives and provide amenities and healthcare services to all community groups, especially vulnerable ones, thereby improving their coping and adaptive capacities (Dulal, 2017). Arguing that in Dar es Salaam waste sector is the second highest contributor to the city's emissions, Sugar, Kennedy and Hoornweg (Sugar et al., 2013) show that waste management by implementing community-based waste-to-energy techniques not only reduces emissions (e.g., methane form landfills), but also provides multiple resilience benefits; for example, energy resilience by diversifying energy supply, and also reducing vulnerability of the poor communities in terms of energy poverty. In addition, it provides health co-benefits as uncollected waste can contaminate water supply (during floods) and cause health problems. Similar benefits have been reported for Kolkata, India (Colenbrander et al., 2017). There, the authors demonstrate that waste to energy can enhance economic resilience of the municipalities as the generated energy can provide redundant sources of income that can be used to cover the costs of urban management activities including waste management (Colenbrander et al., 2017).

3.3.5. Energy

Co-benefits related to energy systems are mainly attributed to decentralized and distributed energy supply systems that are based on a diverse array of renewable sources such as wind, solar, and hydropower. Distributed and decentralized energy systems reduce emissions by facilitating cleaner and more efficient energy supply. In addition, they can address the issue of efficiency loss that often occurs in conventional centralized plants, during transmission and distribution phases (Grafakos et al., 2019; Landauer et al., 2019; Pasimeni et al., 2019). As discussed earlier, water-energy nexus has major implications for adaptation and mitigation. Renewable-based decentralized systems can, therefore, play a significant role in reducing pressure on scarce water resources in water-stressed areas. For instance, Amman the capital city of Jordan relies on energy-intensive techniques, namely groundwater pumping and desalination for water service provision. Therefore, using photovoltaic electricity generation to meet the energy demands not only provides mitigation benefits, but also improves adaptation capacities by reducing pressure on water resources to ensure sustained access to water (Sugar et al., 2013).

Decentralization and diversification of the energy supply systems is also a measure that allows increasing resilience by reducing exposure to risk and ensuring that failure of some components does not result in total failure of the system (Sharifi and Yamagata, 2016b; Prior et al., 2018a). In contrast, centralized systems are likely to experience major power loss during severe storm events or due to peak power loads under extreme temperatures (Hamin and Gurran, 2009). Evidence from the post-Typhoon Haiyan experience shows that decentralized solar power generation is more resilient to extreme events than centralized energy systems. It proved effective for facilitating stable access to affordable energy in the immediate aftermath of the disaster, while the centralized systems failed to provide such functions (Solecki et al., 2019). Furthermore, traditionally, centralized energy infrastructure systems are dependent on water for cooling. Therefore, they are located near water sources, making them vulnerable to sea level rise and flooding under future climate scenarios (Sharifi and Yamagata, 2016b; McEvoy et al., 2006). Decentralization can, to a large extent, address this issue. Decentralized energy systems may also provide citizens with an additional source of revenue, and thereby, increase their economic resilience (Sugar et al., 2013).

3.3.6. Green infrastructure

As shown in Fig. 7, measures related to Green Infrastructure (UGI) have received the highest amount of attention among different categories. While attention has primarily been on adaptation benefits, considerable evidence has also been reported on the mitigation co-benefits that are mainly related to carbon sequestration, and cooling effects that indirectly lead to reduced energy consumption. For instance, green roofs and facades contribute to mitigation by functioning as carbon sinks, having longer lifespan than conventional roofs, improving insulation properties of buildings, and facilitating evapotranspirative cooling (Coutts et al., 2010; Alves et al., 2019). Longer lifespan is important for mitigation given the significant amount of emissions embodied in construction materials. Also, more lifecycle emission savings can be achieved through insulation properties of green roofs that reduce heat transfer and improve building energy efficiency (Coutts et al., 2010). Further, emission savings can be achieved through cooling effects that, indirectly, reduce energy consumption (Garshasbi et al., 2020).

Other green infrastructure options such as parks and urban green space, unpaved open space, and wetland and water bodies also provide sequestration and cooling benefits (Coutts et al., 2010). As expected, the relatively larger volume of urban greenery makes it the most suitable UGI option for carbon sequestration (Hoymann and Goetzke, 2016). Similarly, wetlands and water bodies are important carbon and nitrogen sinks. For instance, evidence from Riverside, California, shows that wetland systems are effective sinks and can provide atmospheric nitrogen renewal benefits at a much lower cost than conventional denitrification facilities (Dulal, 2017).

Shading by urban greenery provides cooling benefits. There is also robust evidence showing that urban greenery and water bodies facilitate latent heat dissipation and mitigate the UHI effect (Jerneck and Olsson, 2013). This, in turn, reduces demand for air conditioning that not only is energy intensive, but also intensifies the UHI effect as demonstrated in Taiwan (Dulal, 2017; Jerneck and Olsson, 2013). Urban nature protection (e.g., urban forest protection and green belt design) and ample provision of urban greenery and water bodies may also indirectly contribute to emission reductions through increasing density (and reducing dwelling size due to land scarcity) (Viguie and Hallegatte, 2012). For instance, modeling study for Paris shows that a greenbelt policy to regulate urban growth and prohibit sprawl provides multiple adaptation and mitigation benefits. It also contributes to ecosystem protection, thereby providing resilience benefits (Viguie and Hallegatte, 2012). Controlling urban sprawl is also an adaptation measure that reduces the number of houses located within forests and, therefore, exposed to wildfires (Hamin and Gurran, 2009; Sharifi, 2019a).

All the above-mentioned UGI measures improve adaptation capacity through improving microclimatic conditions, improving air quality, and enhancing indoor and outdoor thermal comfort (Coutts et al., 2010; Demuzere et al., 2014a). This reduces dependence on air conditioning, thereby improving energy resilience by reducing pressure on the grid and lowering chances of power cut during heat events (Li and Bou-Zeid, 2013). UHI mitigation and thermal stress relief have implications for health and economic resilience (Li and Bou-Zeid, 2013). As earlier discussed, improved health enhances long-term adaptive capacity and reduces household healthcare expenditure (Swart and Raes, 2007). Further economic benefits can also be achieved by avoiding productivity loss due to the lack of thermal comfort (Li and Bou-Zeid, 2013; Jerneck and Olsson, 2013).

Green infrastructure measures also generally contribute to flooding control and stormwater management by increasing the fraction of permeable surfaces that contribute to reducing peak flood discharge (Grafakos et al., 2019; Laukkonen et al., 2009; Hamin and Gurran, 2009). They also helps reduce pressure on the sewer system during heavy rainstorms and avoid overflow of combined sewers and the need for the energy-intensive pumping of the flooding water (Grafakos et al., 2019; Landauer et al., 2019; Georgescu et al., 2014).

UGI also improves water resilience by facilitating groundwater recharge and preventing encroachment on water reserves (Dulal, 2017; Ravindranath and Murthy, 2010). As a case in point, in Ulaanbaatar, Mongolia, green policies to protect the watershed have prevented development from encroaching water reserve areas and this will mitigate projected future water shortages. The net value of protecting the watershed is estimated to be about 560 million US dollars over 25 years. Such savings accrued from ecosystem service are specifically important in the context of developing country cities with low tax base and limited financial resources (Dulal, 2017). This is just an example of multiple ecosystem services that UGI can provide. Some others include, but are not limited to, regulating services (e.g., carbon sequestration and thermal comfort that were earlier discussed), supporting services (e.g., groundwater recharge, natural species protection), cultural services (e.g., providing space for recreation and social interaction that also contributes to social resilience), and provisioning services (e.g., timber, fuel wood, and food) (Dovie, 2019; Hamin and Gurran, 2009; Jerneck and Olsson, 2013; Demuzere et al., 2014b). Such services improve adaptive capacity of communities to climatic changes and variabilities (Ravindranath and Murthy, 2010).

Urban agriculture is a specific UGI measure that offers clear adaptation-mitigation co-benefits, as well as, multiple ecosystem services. Urban agriculture contributes to mitigation by reducing the need for energy-intensive food transportation, improving soil carbon sequestration capacity through promoting sustainable agriculture, improving microclimatic conditions, and facilitating transition toward low-carbon, plant-based and healthy diets (Grafakos et al., 2019; Prior et al., 2018a). Adaptation co-benefits are multiple, including improved thermal comfort, stormwater management, food security, economic resilience, and social resilience. Food security is enhanced since urban food production can cover some of the food needs of communities and make them less dependent on food transportation that might be disturbed in case of major disasters (Grafakos et al., 2019; Demuzere et al., 2019). Food production can also be a source of income for some groups and enhance their economic resilience (Gondhalekar and Ramsauer, 2017). Moreover, participation in urban farming programs can improve social resilience through enhancing social capital. This is achievable through opportunities for people from different income groups and cultural backgrounds to communicate and collaborate with each other, as shown in the case of Munich, Germany (Gondhalekar and Ramsauer, 2017).

3.3.7. Water

This category is closely related to the green infrastructure and energy categories. Water-related measures are primarily related to climate change adaptation, but also indirectly contribute to mitigation, given the water-energy nexus. As water sector is highly sensitive to climate change impacts, it is essential to take appropriate measures that ensure stability of water supply without significantly increasing the demand for energy (Paton et al., 2014).

It is suggested that rooftop tanks and basement cisterns can be used to harvest rainwater and use it for non-potable purposes (Gondhalekar and Ramsauer, 2017). Considering the water-energy nexus, rainwater and graywater recycling helps reduce pressure on the energy supply system, thereby reducing the amount of energy used for freshwater treatment (Berry et al., 2015; Alves et al., 2019; Paton et al., 2014). For Munich, Gondhalekar and Ramsauer (Gondhalekar and Ramsauer, 2017) estimate energy savings potential of 5.5 kWh per capita per year. The recycled water can be used for other purposes such as flushing and agriculture irrigation (Gondhalekar and Ramsauer, 2017). Additionally, wastewater recycling contributes to reducing vulnerability to floods (Landauer et al., 2019; Kalafatis, 2017). Also, through groundwater recharge and soil moisture recharge, it can restore ecosystem function and improve resilience to water scarcity and land subsidence (Berry et al., 2015; Gondhalekar and Ramsauer, 2017).

Significant energy savings can also be achieved through improving efficiency of water appliances (e.g., reducing leakages, using motion-sensitive faucets and adjustable showerheads, etc.), as well as, taking measures to reduce demand for water. This is especially needed in water- stressed areas with energy-intensive water supply sector. For instance, modeling study for California, US shows that applying water conservation measures during various stages of urban water management can help the state achieve its goal of 20% urban per capita water conservation by 2020. Among other measures, the conservation efforts involved reducing the amount of electricity and natural gas used for heating water and measures to reduce heated water usage. It is argued that these water conservation measures not only facilitate adaptation to the climate-induced threats on the water resources, but also contribute to the state's target of reducing emissions to 1990 levels by 2020. The modeling results indicate that statewide water conservation efforts that emphasize hot water saving could provide mitigation benefits of up to 3.53 Mt. CO_2e in 2020 (Haley et al., 2012).

3.3.8. Urban governance

This category includes a wide array of policy, investment, pricing, and regulatory measures that are primarily aimed at climate change mitigation but can also provide adaptation co-benefits. These include policies and measures to promote low-carbon urban development, as well as, those that motivate low-carbon innovation and lifestyle.

Urban policies that promote infill and brownfield (re-)development contribute to mitigation by reducing building and transportation energy demand through densification and by preserving carbon sinks through limiting land consumption (Hoymann and Goetzke, 2016). They can also contribute to adaptation. For instance, evidence from different areas in Germany shows that infill development improves resilience to extreme flood events. This can be explained by the fact that inner-urban development prevents expansion into flood-prone areas (Hoymann and Goetzke, 2016). Other adaptation and mitigation benefits that were earlier discussed for urban densification can also be achieved through infill and brownfield (re-) development.

The significance of updating legislations and regulatory frameworks to encourage simultaneous integration of adaptation and mitigation policies and encourage low-carbon development is well-recognized in the reviewed papers (Colenbrander et al., 2017; Prior et al., 2018b). Updated building codes can improve awareness about low-carbon standards and ensure efficiency improvements by setting minimum performance requirements regarding, for example, integration of renewable energy technologies, or rainwater harvesting equipment (Prior et al., 2018b). This will contribute to mitigation and provide adaptation co-benefits by improving energy, water, and economic resilience (Colenbrander et al., 2017).

Legislations and regulatory frameworks that encourage innovation and promotion and uptake of smart solutions are also likely to contribute to achieving mitigation targets. These could include mobility-related smart solutions such as e-bikes and mobility-as-a-service, energy-related solutions such as peer-to-peer electricity trading, electric vehicles-to-grid, and building-related mart solutions such as home energy management (Wilson et al., 2019). The main mitigation contributions of these solutions would be through efficiency improvements (Wilson et al., 2019). They can also strengthen adaptation capacities by, among other things, improving social capital through facilitating collaboration and sharing culture, and reducing reliance on centralized systems that as discussed earlier are more vulnerable to extreme events (Papa et al., 2015; Huang-Lachmann, 2019). In addition to ICT-based innovation, encouraging other types of innovative design is also emphasized in the literature. For instance, the Solar-Powered Floating

Pavilion in Rotterdam, the Netherlands, is an exemplary adaptive building that reduces emissions through integration of renewable energy technologies, and at the same time enhances resilience against floods (Papa et al., 2015).

Enhancing stakeholder engagement is another measure that strengthens partnership, thereby facilitating improved resource sharing and fundraising and providing opportunities to overcome institutional barriers to adaptation and mitigation (Landauer et al., 2019; Hamin and Gurran, 2009). It is also necessary to better identify priority areas and ensure that different societal groups equally benefit from adaptation and mitigation policies (Hamin and Gurran, 2009). Considering justice, in turn, provides additional benefits. For instance, improving building conditions can enhance energy efficiency or, efforts to reduce poverty contribute to the reduction of polluting fuel consumption, thereby decreasing emissions (Santamouris, 2016; Sugar et al., 2013). As a case in point, Santamouris (Santamouris, 2016) discuss that per capita per square meter heating energy consumption of low-income households is approximately 1.27 times higher than that of high-income households. Taking people out of poverty also contributes to adaptation by improving building robustness and tackling the energy poverty issue that leads to vulnerability to extreme weather events (Santamouris, 2016; Sugar et al., 2013).

Stakeholder engagement across different sectors is also essential for adopting an integrated governance approach that enhances adaptation-mitigation co-benefits. As a case in point, For the Silang-Santa Rosa subwatershed of the Philippines, Endo et al. (2017) demonstrated how developing an integrated participatory watershed land use management approach that improves comprehensive land use planning processes can facilitate synergistic opportunities for climate change adaptation and mitigation. Through applying measures such as regulating development in flood-prone areas to maintain and restore vegetation and forestry, revising building codes and other regulations to promote green roofs and permeable pavements, and afforestation measures, it was found that the number of people expected to be affected by flooding in 2025 will be reduced by 19% (compared to the BAU scenario). In addition, these measures can result in up to 528,142 tons of CO2 emissions reductions.

3.3.9. Behavioral issues

Behavior-related measures have not received enough attention in the reviewed papers. There are only some limited discussions on the importance of dietary changes, improved citizen awareness, and measures and incentives that may instigate behavioral changes and reduce energy demand. Transition toward less meat-based diets, especially red meat, contributes to climate change mitigation by reducing methane, and energy needed for water (Kjellstrom and McMichael, 2013). It also improves adaptation to water scarcity and provides other indirect adaptation co-benefits through promoting healthier diets that may reduce various types of cancers, obesity and cardiovascular diseases. In turn, this will improve long-term adaptive capacity of the population and reduce health sector economic costs (Kjellstrom and McMichael, 2013).

Evidence from different locations, for instance, Shuzu, China shows that increasing stakeholders' awareness about climate change and low-carbon living is an effective adaptation policy with mitigation and well-being co-benefits (Liu et al., 2016). Enhanced awareness can lead to better preparation, in turn, improving coping and response capacities of communities (Hoppe et al., 2016). Additionally, lack of awareness about the significance of adaptation and mitigation may influence the extent of public support needed for implementation of action plans (He et al., 2019). It may also hinder development of integrated urban governance approaches that as discussed in the previous sub-section can strengthen adaptation-mitigation co-benefits (Walsh et al., 2013).

3.4. Synergies

As discussed earlier, synergies refer to when the combined adaptation and/or mitigation effects of measures are greater than if they are implemented separately. Compared to co-benefits, synergies have received much less attention in the literature and have mainly been addressed implicitly. However, content analysis of the papers shows that, in addition to co-benefits, multiple synergies can also be achieved through interactions between different adaptation and/or mitigation measures (see Fig. 8 and Table 5 of the supplementary appendix). The figure shows that, for instance, coupling "Promotion of low-carbon public transportation systems" (on the left side) with "congestion pricing" and/or "transportation demand management" (on the right side) can provide synergies. While some synergistic benefits occur as a result of interactions between measures within certain categories (e.g., interaction between measures in the transportation category), cross-sectoral synergistic benefits are also common. In fact, about half of the interactions are cross-sectoral.

In terms of direct primary benefits that can be achieved from these synergistic interactions, about 70% are mitigation benefits (see Table 5 of the supplementary appendix). An important issue is that existing evidence is mainly implicit and, therefore, there is a lack of explicit evidence showing the magnitude of the synergistic benefits. Despite this shortcoming, results are useful for identifying measures that are likely to offer more synergies. As Fig. 8 shows, measures related to urban design and land use planning, transportation, buildings, green infrastructure, water, and energy show higher potential for offering synergies. The first two are particularly linked to each other and provide (primarily) synergistic mitigation benefits but can also (indirectly) lead to synergistic adaptation benefits. Promotion of low-carbon public transportation is, for instance, a measure that, if implemented as part of an integrated transportation and land use planning framework that considers measures such as appropriate levels of density, land use mix, and improved accessibility, can provide synergistic mitigation benefits (Caparros-Midwood et al., 2019). Synergistic benefits can also be achieved when policies aimed at promoting public/active transportation and urban greenery are coupled. For instance, in Rotterdam, the Netherlands, Tramways have been integrated with the green infrastructure. This Green Tramways project yields mitigation synergies by not only reducing transportation emissions, but also improving carbon sequestration and reducing demand for cooling (as greenery helps mitigate the UHI effect) (AMIA, 2020). Greening transportation corridors, if combined with nature conservation measures, can also offer adaptation synergies by reducing ecosystem fragmentation and enhancing biodiversity conservation (IEEP and Milieu, 2013). Transport-related synergies can also be achieved by combining TOD and public/active transportation policies with transportation demand management measures such as congestion pricing and vehicle quota system to limit private car use/ownership. Such strategies have been implemented in several contexts such as Singapore. As a result, mitigation synergies have been delivered through reductions in VKT, traffic congestion, and the UHI effect (AMIA, 2020). Another noteworthy transport-related measure is to combine transport electrification measures with renewable-based distributed energy generation systems (e.g., solar photovoltaics). In fact, evidence from the Netherlands shows that integrating photovoltaic panels and electric vehicles provides significant emissions savings (Mouli et al., 2016).

One more effective way to gain synergies is to couple urban greenery measures with various measures related to buildings, passive urban design, energy systems, water and stormwater management, and risk zoning policy. For instance, a recent study considering the 2018 and 2050 climate and land use scenarios in Sydney, Australia shows that mitigation measures such as urban greenery and albedo enhancement can provide cooling energy savings of up to 18% in the building sector, compared to the business as usual scenario. Cooling energy savings achievable from (primarily mitigation) measures such as natural ventilation, shading, cool roof, and double glazing were much higher and up to about 62%. Modeling results showed that combining adaptation and mitigation measures yields significant synergistic benefits by providing a maximum of 70% reduction in the future building cooling demand

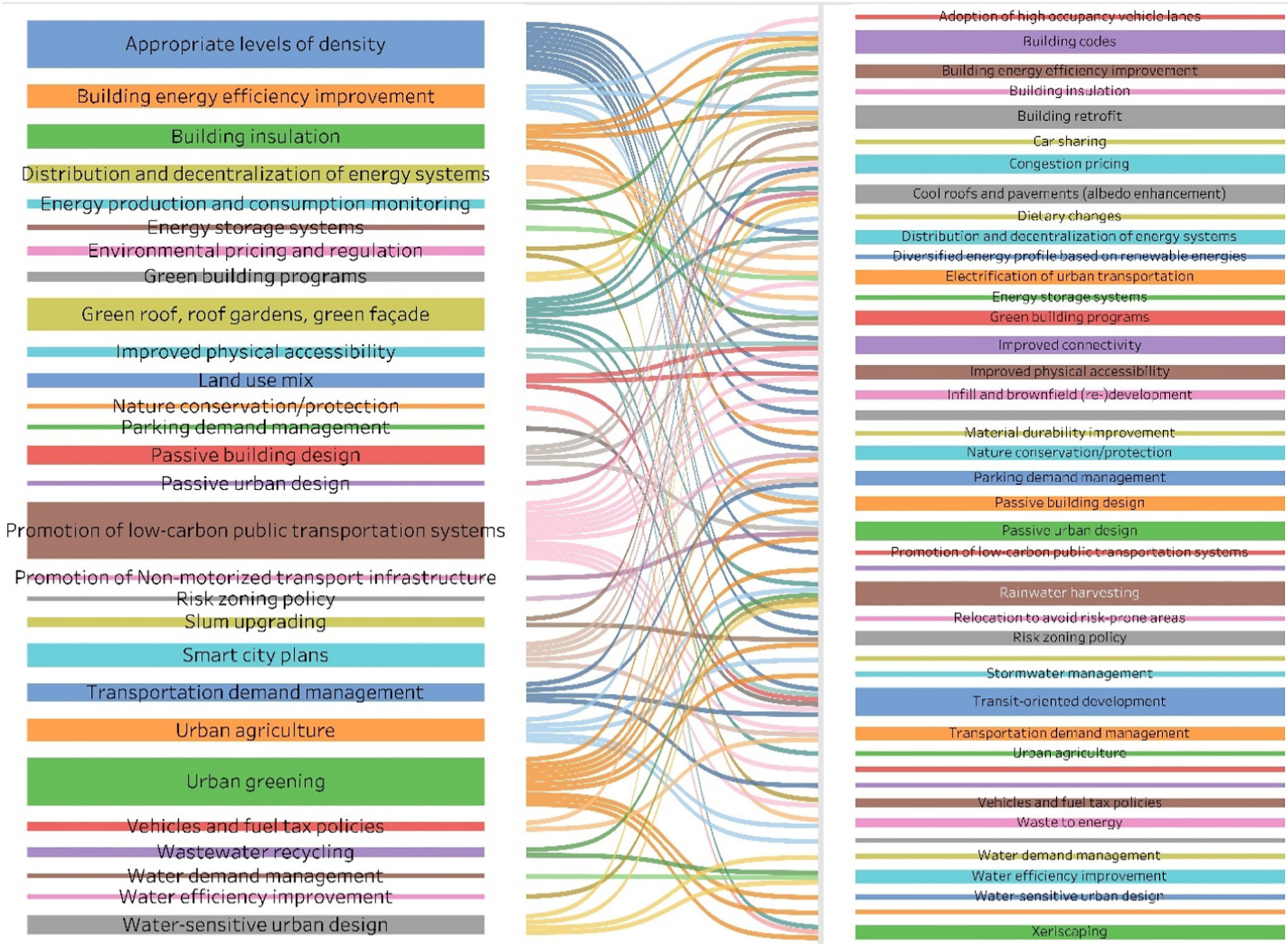

Fig. 8. Measure interactions that are likely to provide synergies. For more information on the interactions see Table 5 of the Appendix.

(Garshasbi et al., 2020). In Rio de Janeiro, Brazil, it is estimated that urban greenery in combination with risk zoning policies that prevent development on hilly and risky forests around the city has contributed to offsetting 11.6 metric tons of CO2e over about two decades (AMIA, 2020). There is still a lack of quantitative estimation of synergies obtainable from combining urban greening with other measures. However, some promising cases have been reported in the grey literature. For instance, in Rotterdam, the Netherlands, green roofs are combined with solar panels to create multifunctional roofs that provide mitigation synergies. Green roofs not only improve building energy efficiency, but also enhance efficiency of solar panels through their cooling effects. Accordingly, the combined mitigation benefits of multi-functional roofs is greater than if green or solar roofs were implemented separately (AMIA, 2020). Urban greenery can also be combined with stormwater flow management and water-sensitive design measures to deliver synergistic adaptation benefits. As a case in point, the Urban Forest Strategy of the City of Melbourne aims to couple urban greenery with water-sensitive design to enhance adaptation to heat and water stresses. Through increasing tree canopy cover, urban greenery provides cooling benefits. Additionally, water-sensitive design measures further enhance adaptation capacity by increasing water percolation and reducing the need to use potable water for irrigation (C.o. Melbourne, 2012).

Measures implemented across the building sector also provide synergistic opportunities. For example, improving material durability is an adaptation measure against flooding and enhancing insulation is a mitigation measure. Regulations that require compliance with both will provide synergistic mitigation benefits as not only operational emissions will be reduced, but also embodied emissions related to material extraction and use will be reduced (Landauer et al., 2019). Combining these two also provides synergistic adaptation benefits, as better insulation can also contribute to enhancing resilience (adaptation) to energy shocks (Landauer et al., 2019). There are also multiple opportunities for achieving synergistic benefits through city-wide implementation of mitigation measures associated with buildings. For instance, there are plans for integrating building-scale photovoltaics with building scale energy storage systems in New York City (NYC, 2017). This can improve efficiency improvements and contribute to the city's efforts toward decarbonization. Another well-known example is Masdar City in Abu Dhabi (United Arab Emirates) that aims to achieve deep decarbonization through a combination of measures including building energy efficiency improvement, passive building and urban design, rooftop photovoltaics, use of low-carbon and recycled construction materials, and water/energy efficiency improvement. The project is still ongoing, but it has achieved significant mitigation targets. In fact, the energy demand of buildings in Masdar City is 40% less than that of the average building in the neighboring Abu Dhabi(Masdar, 2020).

As discussed earlier, compared with co-benefits, synergies have received very limited attention in the literature. Accordingly, further elaborations on synergies can only be possible when more evidence on the nature of synergies becomes available. As Fig. 8 shows, there are some other measures that are likely to provide synergistic benefits when combined with each other. Further research is needed to understand the impacts of interactions between those measures.

4. Conclusions

To address climate change impacts in cities, adaptation needs to be considered at parity with mitigation. In addition, simultaneous consideration of both adaptation and mitigation is essential for efficient management of limited resources (Sugar et al., 2013). This review paper shows that the need to move away from compartmentalized approaches to adaptation and mitigation is well-recognized in the literature and there is a relatively extensive knowledge on the co-benefits between adaptation and mitigation. Knowledge about the importance of synergies is also growing but is, comparatively, limited. However, cities in the Global South are underrepresented in the peer-reviewed literature. This is despite the fact that they are places where the majority of future urban growth is expected to occur and are also more vulnerable to climate change impacts (UNDESA, 2018). Therefore, investigating adaptation-mitigation interactions in Global South cities merits further investigation.

Also, there is still a mismatch between rhetoric and reality and, as discussed in the Introduction section, despite the growing knowledge about the importance of simultaneous attention to mitigation and adaptation measures, some cities prioritize only one of them. This is due to various reasons such as challenges related to the coordination of activities of various departments with diverse and sometimes inconsistent priorities (Lwasa et al., 2018; He et al., 2019), or concerns about the feasibility of simultaneous consideration of adaptation and mitigation (Li et al., 2011). While, ideally, coordinated efforts across different sectors should be taken to ensure improving effectiveness and efficiency of actions, this might not be possible in all contexts. In the absence of such integrated and coordinated efforts for simultaneous consideration, prioritizing measures that facilitate co-benefits is recommended. This paper discusses a portfolio of measures across different urban sectors that can provide co-benefits and can be used by planners and decision makers to make better-informed decisions. It was found that, in all different nine categories, there are measures that can offer co-benefits. However, some measures are predominant and show greater potential. For instance, there is a lot of evidence showing that UGI provides multiple mitigation co-benefits in addition to its primary adaptation benefits. Comparatively, the literature shows that while measures related to building, transportation, energy, and waste are mainly targeting mitigation, their adaptation co-benefits are also significant. Overall, more evidence has been reported on the following measures that may indicate their greater potential for offering co-benefits: appropriate levels of density, public/active transport modes, building energy efficiency, green building programs, distributed and decentralized energy systems, green roofs and facades, and urban greenery and open spaces. These measures, therefore, deserve further attention.

There is a common understanding that there is a spatial mismatch between adaptation and mitigation. This implies that mitigation is more relevant at the national scale, while adaptation is mainly practiced at the local scale (Lwasa et al., 2018). Results of this review challenge this understanding by discussing a large portfolio of measures that provide direct and indirect mitigation benefits at the local scale. Suitability of the local level for achieving co-benefits has also been highlighted in Berry et al. (2015), where the authors argue that adaptation measures are dominant at the local level, but they also offer mitigation co-benefits. Results of this paper challenge this claim by showing that many primarily mitigation measures also exist at the local level.

Discussions presented in Section 3–4 also show the suitability of the local level for achieving synergistic benefits. In fact, the spatial proximity between different sectors in cities provides numerous opportunities for enhancing synergies. For instance, it was discussed that combining compact city and transportation measures offer greater mitigation benefits; or green infrastructure coupled with water-related measures multiplies adaptation benefits. Promoting synergistic measures is highly recommended as they can enable more efficient use of resources. Realizing such synergistic benefits, however, often requires cross-sectoral collaborations that are currently missing in many cities due to various challenges and obstacles (Landauer et al., 2019; He et al., 2019). It is suggested that more attention to integrated urban management approaches can facilitate cross-sectoral collaborations that can provide more synergistic benefits (Walsh et al., 2013).

Overall, this study has gone some way toward improving our understanding of the interactions between climate change adaptation and mitigation. However, further work is required to address several gaps highlighted in this review. In particular, more evidence from the Global South and more explicit evidence on the magnitude of synergistic benefits is needed. Also, currently attention is mainly on two-dimensional synergies and more research on synergistic benefits of combining multiple measures is needed. In addition, it should be acknowledged that only adaptation and mitigation measures mentioned in the peer-reviewed literature have been discussed in this study. Therefore, the list of measures is not comprehensive and other measures discussed in the grey literature should also be discussed in future research. Analysis of the grey literature may also provide more information on the Global South cities that, as mentioned earlier, are underrepresented in the peer-reviewed literature.

Finally, this paper has only focused on two types of interactions (i.e., co-benefits and synergies). As pursuing adaptation (mitigation) benefits may undermine achieving mitigation (adaptation) targets, it is also essential to be mindful of potential conflicts and trade-offs between adaptation and mitigation measures. Evidence on conflicts and trade-offs has been synthesized and discussed in a complementary review paper (Sharifi, 2020). It is hoped that these complementary studies will contribute to improved decision making toward achieving urban climate change adaptation and mitigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.141642.

References

Alves, A., Gersonius, B., Kapelan, Z., Vojinovic, Z., Sanchez, A., 2019. Assessing the co-benefits of green-blue-grey infrastructure for sustainable urban flood risk management. J. Environ. Manag. 239, 244–254.

AMIA, Adaptation and mitigation interaction assessment tool, C40 cities, https://resourcecentre.c40.org/resources/interaction-between-adaptation-and-mitigation-actions, Accessed on June 28, 2020., 2020.

Ayers, J.M., Huq, S., 2009. The value of linking mitigation and adaptation: a case study of Bangladesh. Environ. Manag. 43 (5), 753–764.

Aylett, A., 2015. Institutionalizing the urban governance of climate change adaptation: results of an international survey. Urban Clim. 14, 4–16.

Berry, P.M., Brown, S., Chen, M.P., Kontogianni, A., Rowlands, O., Simpson, G., Skourtos, M., 2015. Cross-sectoral interactions of adaptation and mitigation measures. Clim. Chang. 128 (3–4), 381–393.

Biesbroek, G.R., Swart, R.J., van der Knaap, W.G.M., 2009. The mitigation–adaptation dichotomy and the role of spatial planning. Habitat International 33 (3), 230–237.

Boriboonsomsin, K., Barth, M., 2007. Evaluating air quality benefits of freeway high-occupancy vehicle lanes in Southern California. Transport Res Rec 2011, 137–147.

Burley, J.G., McAllister, R.R.J., Collins, K.A., Lovelock, C.E., 2012. Integration, synthesis and climate change adaptation: a narrative based on coastal wetlands at the regional scale. Reg. Environ. Chang. 12 (3), 581–593.

C.o. Melbourne, Urban Forest Strategy: Making a Great City Greener 2012–2032. Retrieved from: https://www.melbourne.vic.gov.au/community/greening-the-city/urban-forest/Pages/urban-forest-strategy.aspx. Accessed on June 28, 2020., City of Melbourne Melbourne, 2012.

Caparros-Midwood, D., Dawson, R., Barr, S., 2019. Low carbon, low risk, low density: resolving choices about sustainable development in cities. Cities 89, 252–267.
Chan, F.K.S., Chuah, C.J., Ziegler, A.D., Dabrowski, M., Varis, O., 2018. Towards resilient flood risk management for Asian coastal cities: lessons learned from Hong Kong and Singapore. J. Clean. Prod. 187, 576–589.
Colenbrander, S., Gouldson, A., Roy, J., Kerr, N., Sarkar, S., Hall, S., Sudmant, A., Ghatak, A., Chakravarty, D., Ganguly, D., McAnulla, F., 2017. Can low-carbon urban development be pro-poor? The case of Kolkata, India. Environ. Urban. 29 (1), 139–158.
Coutts, A., Beringer, J., Tapper, N., 2010. Changing urban climate and CO2 emissions: implications for the development of policies for sustainable cities. Urban Policy Res. 28 (1), 27–47.
Creutzig, F., Agoston, P., Minx, J.C., Canadell, J.G., Andrew, R.M., Quere, C.L., Peters, G.P., Sharifi, A., Yamagata, Y., Dhakal, S., 2016. Urban infrastructure choices structure climate solutions. Nature Clim. Change 6 (12), 1054–1056.
Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014a. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manag. 146, 107–115.
Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014b. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manag. 146C, 107–115.
Demuzere, M., Bechtel, B., Mills, G., 2019. Global transferability of local climate zone models. Urban Clim. 27, 46–63.
Dovie, D.B.K., 2019. Case for equity between Paris climate agreement's co-benefits and adaptation. Sci. Total Environ. 656, 732–739.
Dulal, H.B., 2017. Making cities resilient to climate change: identifying "win-win" interventions. Local Environ. 22 (1), 106–125.
Endo, I., Magcale-Macandog, D.B., Kojima, S., Johnson, B.A., Bragais, M.A., Macandog, P.B.M., Scheyvens, H., 2017. Participatory land-use approach for integrating climate change adaptation and mitigation into basin-scale local planning. Sustain. Cities Soc. 35, 47–56.
Ford, A., Dawson, R., Blythe, P., Barr, S., 2018. Land-use transport models for climate change mitigation and adaptation planning. Journal of Transport and Land Use 11 (1), 83–101.
Garshasbi, S., Haddad, S., Paolini, R., Santamouris, M., Papangelis, G., Dandou, A., Methymaki, G., Portalakis, P., Tombrou, M., 2020. Urban mitigation and building adaptation to minimize the future cooling energy needs. Sol. Energy 204, 708–719.
Georgescu, M., Morefield, P.E., Bierwagen, B.G., Weaver, C.P., 2014. Urban adaptation can roll back warming of emerging megapolitan regions. Proc. Natl. Acad. Sci. U. S. A. 111 (8), 2909–2914.
Gill, S., Handley, J., Ennos, A., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environment (1978-) 115–133.
Gondhalekar, D., Ramsauer, T., 2017. Nexus City: operationalizing the urban water-energy-food Nexus for climate change adaptation in Munich, Germany. Urban Clim. 19, 28–40.
Grafakos, S., Trigg, K., Landauer, M., Chelleri, L., Dhakal, S., 2019. Analytical framework to evaluate the level of integration of climate adaptation and mitigation in cities. Clim. Chang. 154 (1–2), 87–106.
Gurney, K.R., Romero-Lankao, P., Seto, K.C., Hutyra, L.R., Duren, R., Kennedy, C., Grimm, N.B., Ehleringer, J.R., Marcotullio, P., Hughes, S., Pincetl, S., Chester, M.V., Runfola, D.M., Feddema, J.J., Sperling, J., 2015. Climate change: track urban emissions on a human scale. Nature 525 (7568), 179–181.
Haley, B., Gallo, J.B., Kehr, A., Perry, M., Siao, D., Smallen, W., Torn, M.S., Williams, J.H., 2012. The 2020 emissions reduction impact of urban water conservation in California. Journal of Water and Climate Change 3 (2), 151–162.
Hamin, E.M., Gurran, N., 2009. Urban form and climate change: balancing adaptation and mitigation in the U.S. and Australia. Habitat International 33 (3), 238–245.
He, B.J., Zhu, J., Zhao, D.X., Gou, Z.H., Qi, J.D., Wang, J.S., 2019. Co-benefits approach: opportunities for implementing sponge city and urban heat island mitigation. Land Use Policy 86, 147–157.
Hoppe, T., van der Vegt, A., Stegmaier, P., 2016. Presenting a framework to analyze local climate policy and action in small and medium-sized cities. Sustainability 8 (9).
Hoymann, J., Goetzke, R., 2016. Simulation and evaluation of urban growth for Germany including climate change mitigation and adaptation measures. ISPRS Int. Geo-Inf. 5 (7).
Huang-Lachmann, J.-T., 2019. Systematic review of smart cities and climate change adaptation. Sustainability Accounting, Management and Policy Journal 10 (4), 745–772.
I. WGII, Climate change 2007: impacts, adaptation and vulnerability, working group II, IPCC 4th assessment report, http://www. ipcc. ch (2007).
IEEP, Milieu, 2013. The Guide to Multi-Benefit Cohesion Policy Investments in Nature and Green Infrastructure. By Peter Hjerp, Patrick Ten Brink, Keti Medarova-Bergstrom, Leonardo Mazza, and Marianne Kettunen of IEEP, Together with Jennifer McGuinn, Paola Banfi and Guillermo Hernández of Milieu. A Report for the European Commission. Brussels.
IPCC, 2014. Annex II: Glossary. In: Mach, K.J., Planton, S., von Stechow, C. (Eds.), Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, pp. 117–130.
Janetos, A.C., 2020. Why is climate adaptation so important? What are the needs for additional research? Clim. Chang. 161, 171–176. https://doi.org/10.1007/s10584-019-02651-y.
Jerneck, A., Olsson, L., 2013. A smoke-free kitchen: initiating community based co-production for cleaner cooking and cuts in carbon emissions. J. Clean. Prod. 60, 208–215.
Kalafatis, S.E., 2017. Identifying the potential for climate compatible development efforts and the missing links. Sustainability 9 (9).
Kjellstrom, T., McMichael, A.J., 2013. Climate change threats to population health and well-being: the imperative of protective solutions that will last. Glob. Health Action 6, 1–9.
Klein, R.J.T., Schipper, E.L.F., Dessai, S., 2005. Integrating mitigation and adaptation into climate and development policy: three research questions. Environ. Sci. Pol. 8 (6), 579–588.
Landauer, M., Juhola, S., Söderholm, M., 2015. Inter-relationships between adaptation and mitigation: a systematic literature review. Clim. Chang. 131 (4), 505–517.
Landauer, M., Juhola, S., Klein, J., 2019. The role of scale in integrating climate change adaptation and mitigation in cities. J. Environ. Plan. Manag. 62 (5), 741–765.
Laukkonen, J., Blanco, P.K., Lenhart, J., Keiner, M., Cavric, B., Kinuthia-Njenga, C., 2009. Combining climate change adaptation and mitigation measures at the local level. Habitat International 33 (3), 287–292.
Li, D., Bou-Zeid, E., 2013. Synergistic interactions between urban heat islands and heat waves: the impact in cities is larger than the sum of its parts*. J. Appl. Meteorol. Climatol. 52 (9), 2051–2064.
Li, Y.F., Yang, X., Zhu, X.D., Mulvihill, P.R., Matthews, H.D., Sun, X., 2011. Integrating climate change factors into China's development policy: adaptation strategies and mitigation to environmental change. Ecol. Complex. 8 (4), 294–298.
Liu, M.M., Huang, Y.N., Hiscock, R., Li, Q., Bi, J., Kinney, P.L., Sabel, C.E., 2016. Do climate change policies promote or conflict with subjective wellbeing: a case study of Suzhou, China. Int J Env Res Pub He 13 (3).
Lwasa, S., Buyana, K., Kasaija, P., Mutyaba, J., 2018. Scenarios for adaptation and mitigation in urban Africa under 1.5 degrees C global warming. Curr Opin Env Sust 30, 52–58.
Masdar, Masdar city sustainability, Retrieved from: https://masdar.ae/en/masdar-city/the-city/sustainability. Accessed on June 27, 2020., 2020.
McEvoy, D., Lindley, S., Handley, J., 2006. Adaptation and mitigation in urban areas: synergies and conflicts. P I Civil Eng-Munic 159 (4), 185–191.
Mouli, G.R.C., Leendertse, M., Prasanth, V., Bauer, P., Silvester, S., Geer, S.v.d., Zeman, M., 2016. Economic and CO2 Emission Benefits of a Solar Powered Electric Vehicle Charging Station for Workplaces in the Netherlands, 2016 IEEE Transportation Electrification Conference and Expo (ITEC). pp. 1–7.
NYC, 1.5°C: aligning New York City with the Paris climate agreement, New York City Mayor's Office of Sustainability, Retrieved from: https://www1.nyc.gov/assets/sustainability/downloads/pdf/publications/1point5-AligningNYCwithParisAgrmtFORWEB.pdf. Accessed on June 28, 2020., 2017.
Papa, R., Galderisi, A., Majello, M.C.V., Saretta, E., 2015. European cities dealing with climate issues ideas and tools for a better framing of current practices. Tema-Journal of Land Use Mobility and Environment 63–80.
Pasimeni, M.R., Valente, D., Zurlini, G., Petrosillo, I., 2019. The interplay between urban mitigation and adaptation strategies to face climate change in two European countries. Environ. Sci. Pol. 95, 20–27.
Paton, F.L., Maier, H.R., Dandy, G.C., 2014. Including adaptation and mitigation responses to climate change in a multiobjective evolutionary algorithm framework for urban water supply systems incorporating GHG emissions. Water Resour. Res. 50 (8), 6285–6304.
Pierer, C., Creutzig, F., 2019. Star-shaped cities alleviate trade-off between climate change mitigation and adaptation. Environ. Res. Lett. 14 (8).
Prior, J.H., Connon, I.L.C., McIntyre, E., Adams, J., Capon, A., Kent, J., Rissel, C., Thomas, L.E., Thompson, S.M., Westcott, H., 2018a. Built environment interventions for human and planetary health: integrating health in climate change adaptation and mitigation. Public Health Research & Practice 28 (4).
Prior, J.H., Connon, I.L.C., McIntyre, E., Adams, J., Capon, A., Kent, J., Rissel, C., Thomas, L.E., Thompson, S.M., Westcott, H., 2018b. Built environment interventions for human and planetary health: integrating health in climate change adaptation and mitigation. Public Health Research & Practice 28 (4), 5.
Ravindranath, N.H., Murthy, I.K., 2010. Greening India Mission. Curr. Sci. 99 (4), 444–449.
Santamouris, M., 2016. Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change. Sol. Energy 128, 61–94.
Seto, K.C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G.C., Dewar, D., Huang, L., Inaba, A., Kansal, A., Lwasa, S., 2014. Human Settlements, Infrastructure and Spatial Planning.
Sharifi, A., 2019a. Resilient urban forms: a macro-scale analysis. Cities 85, 1–14.
Sharifi, A, 2019b. Urban form resilience: A meso-scale analysis. Cities 93. https://doi.org/10.1016/j.cities.2019.05.010.
Sharifi, A., 2020. Trade-offs and conflicts between urban climate change mitigation and adaptation measures: a literature review. J. Clean. Prod. 276, 122813. https://doi.org/10.1016/j.jclepro.2020.122813.
Sharifi, A., Yamagata, Y., 2016b. Principles and criteria for assessing urban energy resilience: a literature review. Renew. Sust. Energ. Rev. 60, 1654–1677.
Solecki, W., Grimm, N., Marcotullio, P., Boone, C., Lobo, J., Luque, A., Romero-Lankao, P., Young, A., Zimmerman, R., Breitzer, R., Griffith, C., Aylett, A., 2019. Extreme events and climate adaptation-mitigation linkages: understanding low-carbon transitions in the era of global urbanization. Wiley Interdisciplinary Reviews-Climate Change 16.
Stokes, E.C., Seto, K.C., 2016. Climate change and urban land systems: bridging the gaps between urbanism and land science. J. Land Use Sci. 11 (6), 698–708.
Stone, B., Hess, J.J., Frumkin, H., 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Environ. Health Perspect. 118 (10), 1425–1428.
Sugar, L., Kennedy, C., Hoornweg, D., 2013. Synergies between climate change adaptation and mitigation in development: case studies of Amman, Jakarta, and Dar es Salaam. International Journal of Climate Change Strategies and Management 5 (1), 95–111.
Swart, R., Raes, F., 2007. Making integration of adaptation and mitigation work: mainstreaming into sustainable development policies? Clim. Pol. 7 (4), 288–303.

UNDESA, 2018. World Urbanization Prospects: The 2018 Revision. United Nations Department of Economic and Social Affairs, United Nations, New York.

UNFCCC, 2011. Assessing the Costs and Benefits of Adaptation Options. An Overview of Approaches.

Van Eck, N., Waltman, L., 2009. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538.

Viguie, V., Hallegatte, S., 2012. Trade-offs and synergies in urban climate policies. Nat. Clim. Chang. 2 (5), 334–337.

Walsh, C.L., Roberts, D., Dawson, R.J., Hall, J.W., Nickson, A., Hounsome, R., 2013. Experiences of integrated assessment of climate impacts, adaptation and mitigation modelling in London and Durban. Environ. Urban. 25 (2), 361–380.

Wilson, C., Pettifor, H., Cassar, E., Kerr, L., Wilson, M., 2019. The potential contribution of disruptive low-carbon innovations to 1.5 degrees C climate mitigation. Energy Efficiency 12 (2), 423–440.

Yang, Y.J., Goodrich, J.A., 2014. Toward quantitative analysis of water-energy-urban-climate nexus for urban adaptation planning. Curr. Opin. Chem. Eng 5, 22–28.