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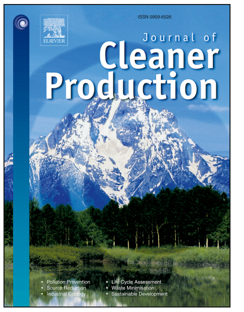

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Title page

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Trade-offs and conflicts between urban climate change mitigation and adaptation measures: A literature review

Ayyoob Sharifi, PhD[1]

Abstract

Many cities around the world are increasingly developing plans and policies for mitigation and adaptation to climate change. These plans and policies are often focused on either mitigation or adaptation. This dichotomized approach can be problematic and result in trade-offs. In other words, efforts aimed at enhancing mitigation (adaptation) may hinder achieving adaptation (mitigation) objectives. Additionally, conflicts may arise as there might be inconsistencies between some mitigation and adaptation measures. Since trade-offs and conflicts between adaptation and mitigation measures can undermine effectiveness and efficiency of municipal activities, efforts should be made to avoid or minimize them. This study aims to provide a better understanding of potential trade-offs and conflicts through reviewing literature on the interactions between urban adaptation and mitigation measures. This is done through bibliographic analysis and detailed content analyses of selected papers. Results of this review show that research on trade-offs and conflict has gained traction since the publication of the fourth assessment report of The Intergovernmental Panel on Climate Change. However, there is still a lack of empirical studies. In particular, limited research exists on the Global South cities. Also, according to the findings, existing research is mainly focused on trade-offs associated with measures related to energy, land use, transport, water, building, green infrastructure, and waste sectors. It is found that mitigation measures may have negative impacts on adaptation by increasing exposure to risks such as the urban heat island effect and flooding and/or by eroding livelihood options of poor and marginalized groups and causing equity concerns. In contrast, adaptation measures may increase greenhouse gas emissions by, among other things, reducing efficiency and increasing energy demand. It is discussed that integrated assessment frameworks should be utilized to deal with trade-offs and conflicts. Finally, some recommendations for better uptake of integrated frameworks are provided.

Keywords: Climate change; mitigation; adaptation; conflict; trade-off; interaction

1- Introduction

Accommodating more than 50% of the world population, cities account for about 70% of global CO_2 emissions and are major contributors to climate change (Division, 2018). Many cities, especially coastal ones are also exposed to a wide range of climate-related risks such as flooding, sea level rise and extreme temperature events. Moreover, as, for instance, population density of risk-prone coastal cities is projected to increase by 25% by 2050, future urbanization may also expose more people to the climate change impacts that are expected to be more frequent and intense (Aerts et al., 2014). Despite the daunting challenges caused by the compounded effects of climate change and rapid urbanization, it is increasingly recognized that cities can offer solutions to curb climate change and its impacts. Such solutions are often developed as part of climate action plans that set forth strategies and targets for adaptation and/or

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mitigation. Adaptation seeks to reduce vulnerability and enhance 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 is focused on 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). These definitions may imply that adaptation and mitigation are compartmentalized. However, it is argued that the ultimate goal of both is to minimize the undesirable consequences of climate change (Ayers and Huq, 2009). To this end, mitigation mainly focuses on the long-run reduction of risks, while adaptation is aimed at reducing the current risks that exist due to historical emissions and/or because of failure to achieve mitigation targets (Swart and Raes, 2007). Therefore, it can be said that adaptation and mitigation are not mutually independent, as more mitigation can reduce adaptation needs in the long run and more adaptation can lower the mitigation costs through improving coping and adaptive capacities (Endo et al., 2017; Swart and Raes, 2007). In other words, mitigation is needed for successful adaptation and vice versa. This is increasingly recognized in global policy frameworks. For instance, the need for developing action plans that include both mitigation and adaptation mechanisms is underscored in the Paris Agreement (UNFCCC, 2015) and the New Urban Agenda (Habitat, 2017). Similarly, the United Nations Sustainable Development Goals (particularly SDG 11 and SDG 13) recommend adopting integrated plans and policies towards mitigation and adaptation (UNSDG, 2015). Such integrated approaches also contribute to achieving the targets of the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015).

Table 1. Differences between climate change adaptation and mitigation measures (adapted from Dang et al. (2003)).

	Adaptation	**Mitigation**
Spatial focus	Local and regional	Global
Temporal focus	Short and medium term	Long term
Sectoral focus	A wider range of sectors	Energy-intensive sectors that are main sources of GHGs
Scale of cooperation	Mainly national and regional	Mainly international
Nature of action	Often in reaction to the real-world climate impacts; can be proactive if adaptation is based on projected climate impacts	Proactive, aimed climate stabilization
Level of uncertainty	More uncertain as frequency and uncertainty of future climate impacts is not well known	More certain as emission abatement targets are determined that can be updated regularly to reflect new projections
Justice issues	Less justice, as some areas are disproportionately affected by climate impacts, despite historically being less responsible for climate	Countries less vulnerable to climate impacts may not be motivated to contribute to achieving mitigation targets

change

Despite this, traditionally, adaptation and mitigation have been addressed separately in both research and practice. This dichotomous approach is even evident in the assessment reports prepared by the IPCC, where adaptation is addressed by Working Group II and mitigation by Working Group III. This could be explained by the typical understanding that adaptation and mitigation are different in many respects, for instance in terms of spatio-temporal focus and characteristics (Endo et al., 2017; Pasimeni et al., 2019). A summary of major differences mentioned in the literature is presented in Table 1 and is further explained here. An important difference is that actors involved in adaptation and mitigation efforts are often different. Mitigation targets are better defined and more objective and achieving them requires actions from major emitting sectors such as energy, transport, and building. Comparatively, adaptation target are more uncertain and require involvement of a wider range of stakeholders and sectors that may be at the risk of climate impacts (McEvoy et al., 2006; Swart and Raes, 2007). In other words, as adaptation has a short-medium term focus and climate change impacts are more easily and rapidly observed by a wider range of stakeholders. Somehow related to stakeholders, the beneficiaries of mitigation and adaptation can also be different. On the one hand countries and regions that are less vulnerable to climate impacts may not be motivated to contribute to achieving mitigation targets. On the other hand, some regions that historically are less responsible for climate change are disproportionately affected by its impacts. This raises issues related to equity and justice.

Another key difference is that mitigation is typically known as a global responsibility that is taken by nation states following international negotiations. It can offer global benefits in the long run; while also being able to provide immediate local co-benefits such as air pollution reduction. In contrast, adaptation is mainly practiced at local and regional levels and its vulnerability-reduction benefits can become apparent in the near term; although it can also provide medium- and long-term benefits (Landauer et al., 2019). However, it is increasingly recognized that the spatio-temporal scale mismatches are not in absolute terms and both adaptation and mitigation measures can be relevant at different spatial and temporal scales. For instance, spatially, mitigation measures related to low-carbon urban development are implemented at the local level (Berry et al., 2015) and adaptation measures aimed at achieving drought-resilient agriculture systems have consequences beyond the local level and can be coordinated at larger scales (Swart and Raes, 2007). Similarly, absolute differences in temporal scale are also challenged. For example, some adaptation efforts such as ‘building ecological networks’ need longer-term implementation strategies and lead to long-term benefits (Berry et al., 2015; Laukkonen et al., 2009).

The fact that both spatial and temporal scales of adaptation and mitigation measures can be similar has increased the interest in simultaneously addressing them in climate action plans. This interest is also driven by the fact that adaptation and mitigation are closely linked and can complement each other; failure to mitigate will make future adaptation more costly and challenging and better adaptation can reduce the mitigation needs (Berry et al., 2015; Ford et al., 2018). Survey analyses of urban climate action plans in Europe and the US show that the majority of cities consider both mitigation and adaptation (Aylett, 2015; Kalafatis, 2017).

Despite the increasing attention to simultaneous integration of adaptation and mitigation in urban climate action plans, evidence shows that only a small percentage of cities consider different interactions between adaptation and mitigation policies and measures. Co-benefits, synergies, conflicts, and trade-offs are four distinct types of interactions that may occur. Co-benefits occur when implementing an adaptation (mitigation) measure results in ancillary mitigation (adaptation) gains. A synergy refers to a situation when simultaneous implementation of two or more measures produces benefits greater than the sum of individual measures (Grafakos et al., 2019). Trade-offs occur when implementing an adaptation (mitigation) measure has negative effects on mitigation (adaptation) (Berry et al., 2015). In other words, some solutions developed to enable cities perform better under future climate change (i.e., adaptation actions), may have ramifications for the efforts aimed at reducing GHG emissions (i.e., mitigation) and vice versa (Paton et al., 2014). Finally, conflicts refer to situations when two measures are incompatible and their simultaneous implementation is not possible (Landauer et al., 2015).

This study only focuses on trade-offs and conflicts. More attention to these two interactions has been observed in science and policy domains following their recognition in the Paris Climate Agreement (Dovie, 2019). Despite this, there is still limited knowledge about trade-offs and conflicts between urban climate change adaptation and mitigation measures. These interactions warrant further attention to ensure that adaptation and mitigation measures are not counterproductive (Charoenkit and Kumar, 2014). This review also aims to clarify if trade-offs and conflicts are more dominant in some sectors and to provide some insights on how to minimize them. Furthermore, some methodological approaches for identifying and dealing with trade-offs and conflicts will also be discussed. This work builds on the paper by Mia Landauer et al. (2015) that mainly focuses on the cross-sectoral and cross-scale conflicts between mitigation and adaptation policies but does not specifically investigate various trade-offs between different measures at the urban scale.

Next section explains the review methods. Results, including a brief bibliographic analysis of the literature and a synthesis of evidence reported in the literature (on trade-offs and conflicts) are reported in

Section 3. Finally, Section 4 concludes the study by discussing some policy implications and highlights gaps that need to be addressed in future research.

2- Materials and methods

This desktop research involved bibliographic and content analyses of literature focused on trade-offs and conflicts between urban climate change adaptation and mitigation measures. The specific review questions were 'what is the major focus of the literature and what are the influential papers and journals?', 'what sectors and measures involve trade-offs and conflicts?' and 'what are possible methods and approaches for identifying and dealing with conflicts and trade-offs?".

Literature reviewed for the purpose of this paper was drawn from the following databases indexed in the Web of Science: Science Citation Index Expanded, Social Sciences Citation Index, and Emerging Sources Citation Index. Among different research databases, the Web of Science was selected because it covers all important and influential sources related to the topic. In addition, the article export format provided by it allows better bibliographic analysis using VOSviewer. The systematic review protocol included terms related to different interactions that may occur between urban climate change adaptation and mitigation measures. It also included the terms "co-benefits" and "synergies" because papers addressing these types of interactions may also have a secondary focus on trade-offs and conflicts (see the Supplementary Appendix for the review protocol). The latest search was conducted on 23 October 2019 and returned 156 documents. Abstracts and conclusions of these papers were examined to see if they address issues related to the review questions. At the end of this process 23 papers relevant to the review questions were selected for detailed content analysis. While reviewing these papers, references cited by them were also checked to add possibly relevant papers that were not retrieved from the literature search to the review database. In addition, the alert function of the Web of Science was activated to receive updates on recently published articles. Overall, 30 papers were reviewed for the purpose of this paper.

The first review question was addressed through different kinds of text mining and bibliographic analyses, including co-citation analysis, term co-occurrence analysis, and bibliographic coupling. Given the rapid increase in the number of publications, these methods are widely used for bibliometric analysis. For example, they have been used for mapping science related to environmental footprint (Martinez et al., 2019) or carbon emission (Su et al., 2020). However, there is still no such analysis of mitigation and adaptation measures in cities. These analyses were conducted using VOSviewer and will be further explained in the next section (Van Eck and Waltman, 2009). The latter two questions were addressed by content analysis of the selected papers. A Microsoft Excel sheet was developed to extract data related to the selected papers. This included data on items such as type of paper, geographic focus, research methods, thematic focus, sectoral focus, climatic impacts, and specific elements discussed. The excel file also included separate sheets (tabs) to collect evidence related to different planning/design measures and their associated trade-offs and conflicts. Results reported in the following section have been drawn through synthesizing data collected in these excel sheets. The Sankey diagrams used for data illustration have been produced using the Tableau software[2].

3- Results and discussions

3-1- Bibliographic analysis

One purpose of the bibliographic analysis was to identify influential journals and documents related to trade-offs and conflicts between adaptation and mitigation. 'Co-citation analysis by sources' is a method that can be used to identify most influential journals. It is an analysis used to calculate the number of times two documents are simultaneously cited by other identical documents (Van Eck and Waltman, 2009). Results of this and the other bibliographic analyses presented in this paper can also be used to determine the extent of similarity between documents. In all cases, the size of nodes indicates the relative importance of the items in question (e.g., specific journals in case of 'co-citation analysis by journal') and strengths of the links between items is determined by their proximity and the thickness of the link.

[2] 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).

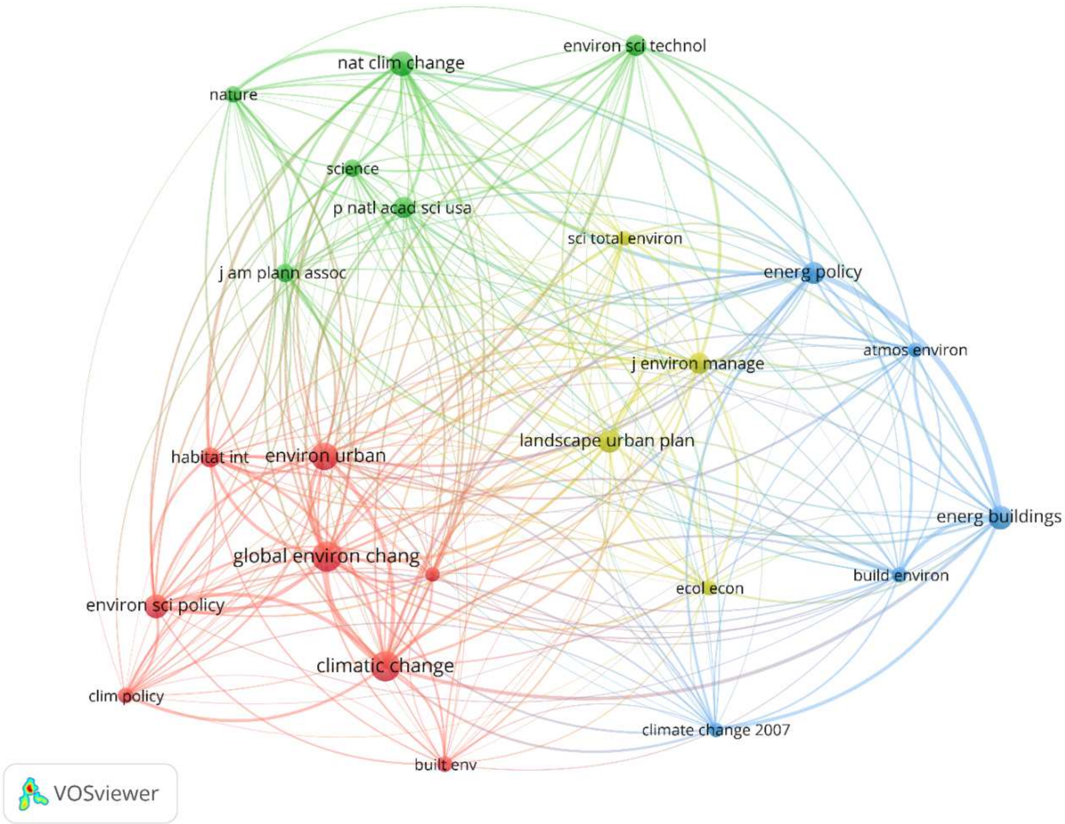

Figure 1. Co-citation analysis by source.

The ‘co-citation analysis by source’, with at least 11 citations for each source, shows four major clusters of journals. The dominant cluster (shown in red) is focused on urban climate policies. Other clusters are mainly focused on the science of climate change (green color), energy planning and policies (blue color) and urban planning and design (yellow color). The most influential journals are Climatic Change, Global Environmental Change, Environment and Urbanization, Nature Climate Change, and Environmental Science and Policy. For data on the number of citations and total link strengths see Table 1 of the supplementary appendix.

Two major clusters can be identified from the ‘co-citation analysis by cited references’ (for a minimum number of four citations). The green cluster includes documents that are mainly focused on issues related to integrating adaptation and mitigation into urban policies and climate actions. Highly influential documents in this cluster are Hamin and Gurran (2009) and McEvoy et al. (2006) .The cluster in red is also focused on both adaptation and mitigation, but has a clearer emphasis on trade-offs and conflicts. In this cluster, the following publications have proved more influential in advancing knowledge on adaptation-mitigation trade-offs and conflicts: Tol (2005), Viguie and Hallegatte (2012), and IPCC (2007). The latter confirms the key role that the Fourth Assessment Report of IPCC (AR4) has played in initiating and driving the research on inter-relationships between adaptation and mitigation. Figure 2 shows the results of this co-citation analysis. For supporting data see Table 2 of the supplementary appendix. Here it should be mentioned that, as earlier discussed, other policy frameworks such as the New Urban Agenda (Habitat, 2017), the Paris Agreement (UNFCCC, 2015), and the SDGs (UNSDG, 2015) have also played important roles in advancing awareness about the need for simultaneous inclusion of adaptation and mitigation in action plans. The likely reason is for their absence in Figure 2 is that they have only been released a few years ago.

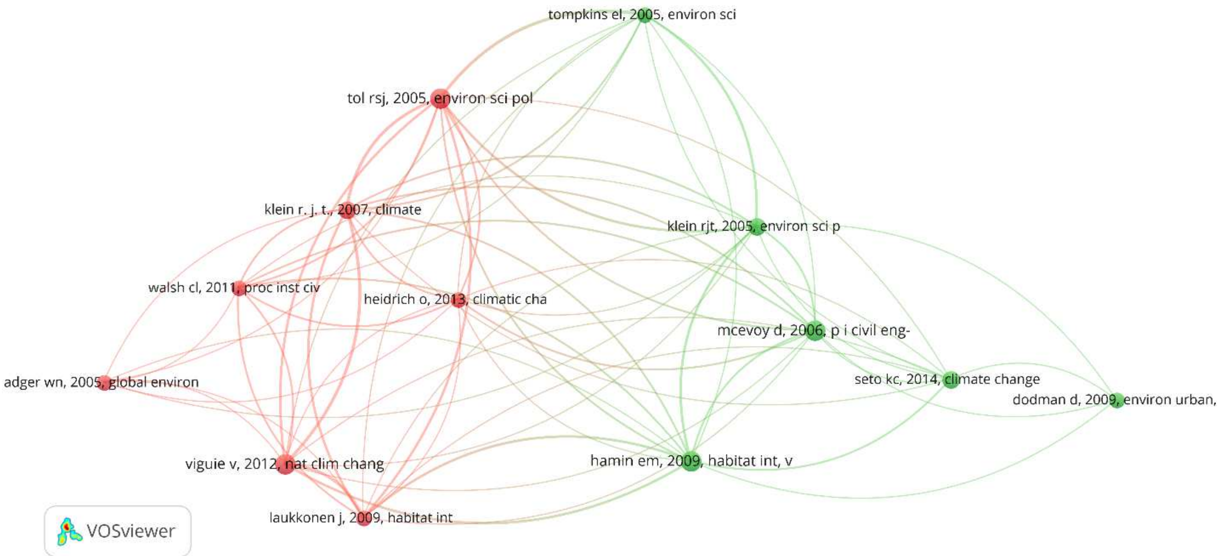

Figure 2. Co-citation analysis by cited references.

Bibliographic analysis can also provide information on the topical focus of the literature and the closely-related areas of research. For this purpose, the ‘term co-occurrence analysis’ can be used. Results of this analysis, for a minimum occurrence threshold of 2 keywords, is shown in Figure 3 (for supporting data on frequency occurrence of each keyword and the link strengths see Table 3 of the supplementary appendix). As can be expected, terms such as climate change, adaptation, and mitigation have appeared more frequently and have greater link strengths. Frequency and link strength of mitigation are greater than adaptation. This is in line with claims in the literature that there more attention has been paid to mitigation in climate action plans and adaptation plans are comparatively less advanced (Hoppe et al., 2016; Papa et al., 2015). The term ‘sustainability’ has occurred frequently and is strongly linked to both adaptation and mitigation. This may indicate the importance of adaptation and mitigation plans for achieving sustainability. These terms are also in proximity and strongly connected to the term ‘trade-offs’, that may indicate potential sustainability trade-offs of climate action plans. Such potential trade-offs will be further explored in the following sections. Among different adaptation-mitigation interactions, trade-offs, co-benefits, and synergies have received the most attention, but there is a lack of attention to conflicts. Regarding sectoral focus, it can be observed that policy, land use, energy, health, infrastructure, and transport have higher values, indicating that trade-offs related to them have been relatively more addressed in the literature.

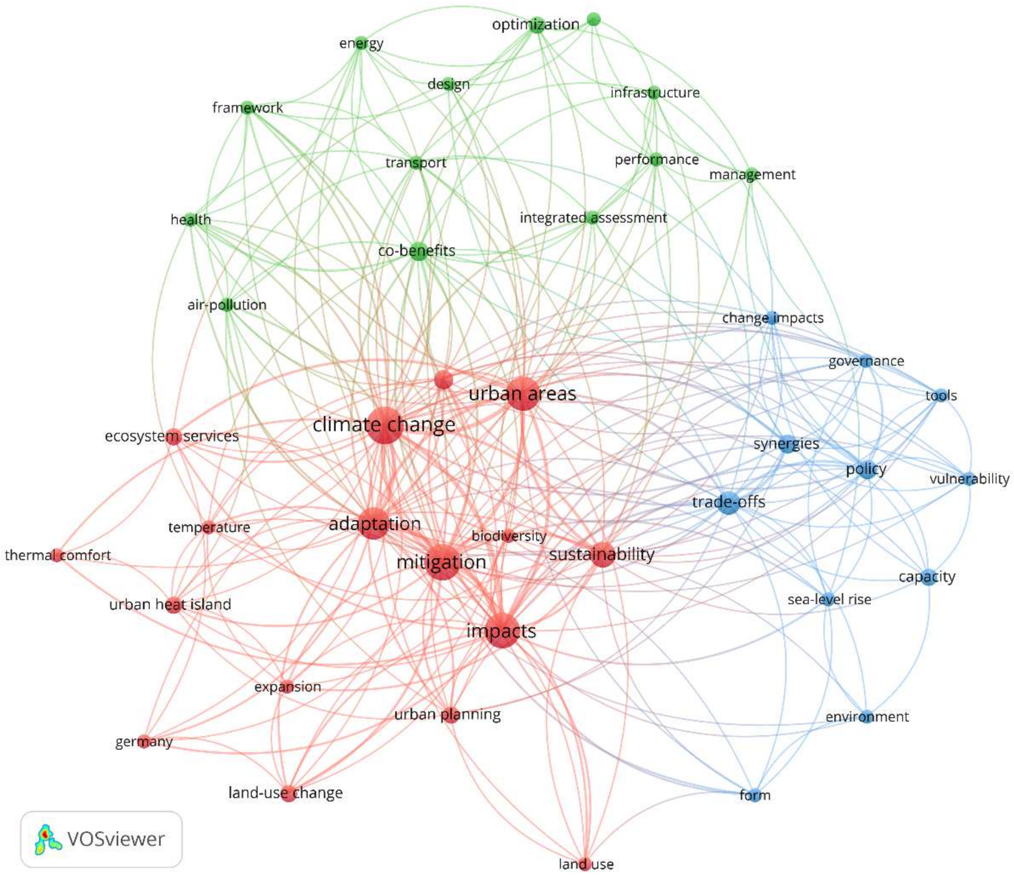

Figure 3. The term co-occurrence map.

In terms of subject matter similarity, three major clusters emerged from the co-occurrence analysis. Each cluster includes some major sectors and climatic impacts. A possible interpretation for each cluster could be that sector-specific adaptation and/or mitigation measures taken to deal with the climatic impacts are likely to involve trade-offs, conflicts, co-benefits, and synergies. The largest cluster (red) includes terms related to land use planning and design and climatic impacts associated with temperature changes. The next major cluster is dominated by energy and transport infrastructure and their possible linkages to air pollution and health. Finally, the cluster in blue is mainly related to governance/policy measures and vulnerability to sea level rise. More information related to these potential interactions will be provided in the analyses presented in the following sections.

Finally, ‘bibliographic coupling analysis’, for a minimum threshold of two documents per country, was used to find out which countries have conducted more research in this area. “A bibliographic coupling link is a link between two items that both cite the same document” (Van Eck and Waltman, 2009).

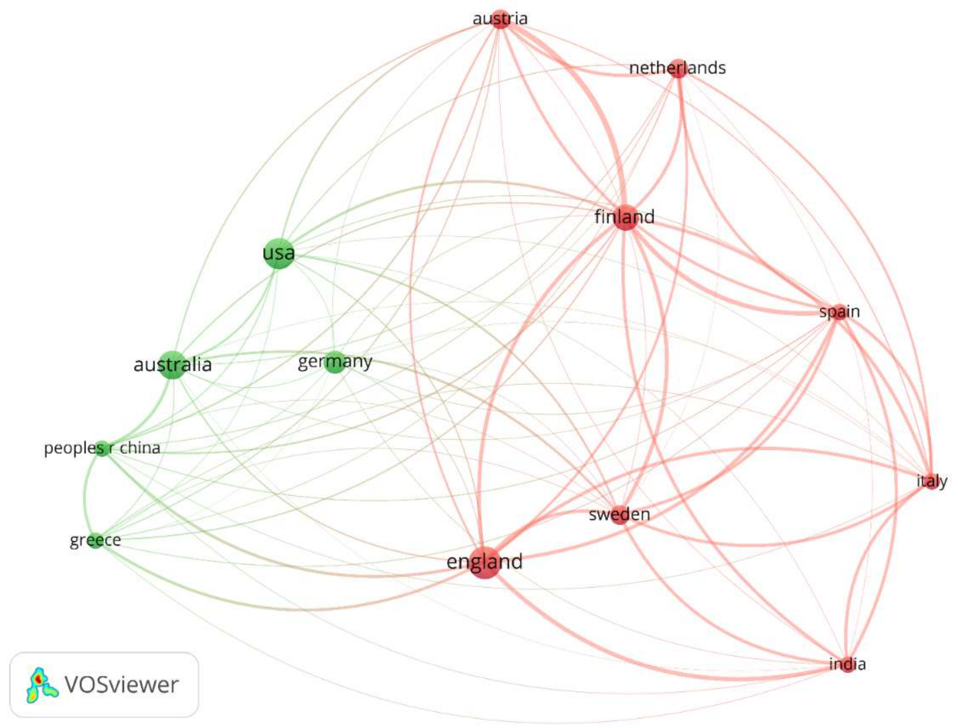

Figure 4. Bibliographic coupling by country.

Results show that research on conflicts and trade-offs between adaptation and mitigation has been mainly conducted by European and North American scholars. The European cluster is dominant and includes countries such as England, Finland, Austria, and the Netherlands. USA and Australia are two other influential countries that form the other cluster along with Germany, China and Greece. It can be noted that only two developing countries, namely, India, and China emerge from this analysis. This is despite the rapid rates of urbanization in the Global South that warrants further attention to urban climate change adaptation and mitigation in developing countries. As European and North American researchers may have focused on cities in other regions of the world, I also conducted a detailed manual analysis of the reviewed papers to better understand their geographic focus. Results confirm that most authors are located in Europe and North America (see Fig 1 of the supplementary appendix). However, most papers have global focus (~ 38%), followed by focus on Europe (~ 27%), and Oceania (~11%). It can be seen that, even when considering geographic focus, there is a lack of research on the Global South cities.

3-2- Adaptation and mitigation measures

As mentioned earlier, the main purpose of the detailed content analysis was to identify adaptation/mitigation measures discussed in the literature and to provide more clarity on trade-offs and conflicts associated with them. In terms of sectoral focus, the reviewed literature is mainly related to the energy sector (~ 27%), followed by land use (~18%), Transport (~13%), water (~13%), building (~12%), Green infrastructure (~8%), waste (~4%), and urban policy and governance (~3%) (see Figure 5). Accordingly, measures extracted from the literature are divided into eight main sectors as shown in Table 2. It should be noted that this table only includes measures that may involve trade-offs. Moreover, this is not intended to be an exhaustive list and only includes measures discussed in the literature.

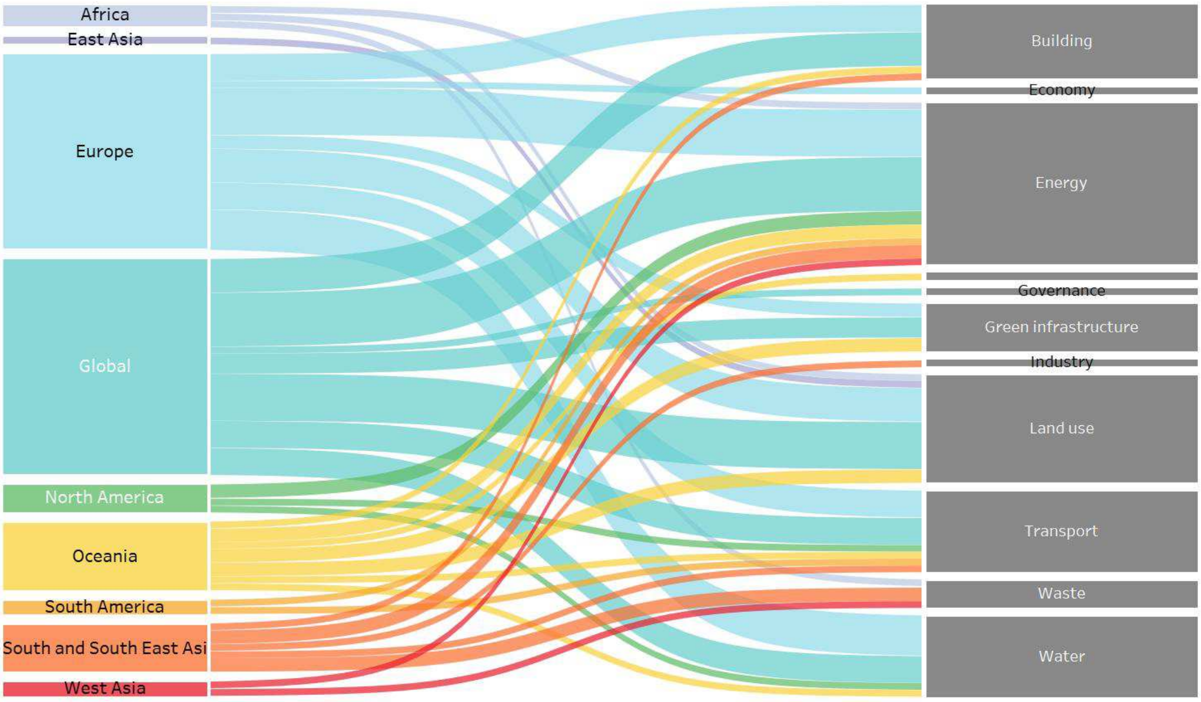

Figure 5. The geographic focus and sectoral relevance (right panel) of measures discussed in the literature (left panel).

Table 2 shows that mitigation is the primary objective of 50% of the measures; 30% are mainly related to adaptation, and the rest are related to both adaptation and mitigation. Mitigation is the primary objective of most of the measures belonging to the transport, building, waste, energy, and governance sectors. In contrast, measures related to water and green infrastructure sectors are primarily aimed at adaptation and the planning/land use is dominated by measures that are related to both adaptation and mitigation. As can be seen, most measures involve trade-offs for either mitigation or adaptation. But there are also measures that may lead to both adaptation and mitigation trade-offs. Trade-offs related to each of these eights sectors will further be discussed in the next section.

Table 2. Adaptation and/or mitigation measures that may involve trade-offs, as discussed in the literature.

Sector	Measure	Trade-off		Primary objective
		Mit.	Ad.	
Urban planning and land use	Compactness	✓	✓	Mitigation
	Land use mix		✓	Both
	Improved connectivity		✓	Both
	Risk zoning and relocating to avoid risk-prone areas	✓	✓	Adaptation
	Development along riverbanks to reduce exposure to heat		✓	Adaptation
	Cool roofs and pavements	✓		Both
Transport	Transit-Oriented Development	✓		Mitigation
	Transportation demand management		✓	Mitigation
	Congestion pricing		✓	Mitigation
	Single tariff public transport policy	✓		Mitigation
	Improvement of vehicle efficiency standards		✓	Mitigation
Building	Passive building design	✓		Mitigation
	Insulation		✓	Mitigation
	Building retrofit	✓		Mitigation
	Evaporative air coolers for air conditioning		✓	Both
	Conventional air conditioning	✓	✓	Adaptation
Waste	Site/neighborhood level composting		✓	Mitigation
	Waste to energy		✓	Mitigation
	Wastewater recycling and treatment	✓		Both
Energy	Decentralization of energy supply	✓	✓	Mitigation
	Diversified energy profile based on renewable energies		✓	Adaptation
Green and Blue Infrastructure	Green roofs and façades	✓	✓	Adaptation
	Network of parks, urban greenery and open spaces	✓	✓	Adaptation
	Urban nature protection	✓	✓	Adaptation
	Urban agriculture		✓	Both
Urban policy and governance	Environmental pricing and regulation		✓	Mitigation
	Low carbon investments		✓	Mitigation
	Implementing costly mitigation measures in poor areas		✓	Mitigation
Water	Rainwater harvesting		✓	Adaptation
	Desalination water plants	✓		Adaptation

3-2- Trade-offs

This section summarizes evidence, reported in the literature, on trade-offs related to each of the main eight sectors mentioned in the previous section.

3-2-1- Energy

The energy sector is a major contributor to climate change. The literature indicates that decentralized and distributed energy systems based on a diverse array of renewable sources contribute to adaptation as well as mitigation (Sharifi and Yamagata, 2016; Sugar et al., 2013). However, appropriate measures need to be taken to avoid potential mitigation trade-offs. For instance, decentralization of energy supply often results in infrastructure redundancy that is critical for improving resilience and adaptive capacity of the system (Ko et al., 2019). However, this may result in mitigation trade-offs as redundant infrastructure may lead to less efficiency and more energy demand for construction and maintenance (Hamin and Gurran, 2009; Sharifi and Yamagata, 2016).

In addition, deployment of distributed and renewable energy systems still requires relatively significant amounts of capital investment. Therefore, mitigation benefits are likely to be achieved at high costs and undermine adaptive capacity of cities and urban households. For instance, Colenbrander et al. (2017) explain how transition from a system relying on fossil-fired power plants to one based on diverse renewable sources may erode adaptive capacity in Kolkata, India. Their study demonstrates that large-scale investment in renewable energy to replace coal-based energy sources provides significant mitigation benefits and also contributes to mitigating air pollution. However, until renewable energy technologies become more affordable and economically competitive, such developments require significant capital investment that may further strain limited resources, especially in the Global South cities. This raises the issue of distributional benefits of transition to renewable energy technologies, as authorities may prioritize using the capital investment for other purposes such as poverty alleviation and for improving sanitation conditions to improve adaptive capacity of the citizens. In addition, due to the high capital expenditure, the utility companies will make more effort to restrict electricity theft on which many low-income households rely for their livelihood and for maintaining reasonable levels of quality of life (Colenbrander et al., 2017). Lack of access to energy will, in turn, reduce their productivity that may eventually impact the economy (Colenbrander et al., 2017). It may also deteriorate indoor environmental conditions and cause health issues that in the long run will further erode the capacity to adapt to climate change impacts (Colenbrander et al., 2017; Liu et al., 2016). Therefore, appropriate care should be taken to ensure that adaptive capacity and equity, that are emphasized in several global/local policy frameworks such as the New Urban Agenda and the SDGs, will not be undermined due to applying mitigation-centered policies.

3-2-2- Land use

Adaptation and mitigation measures related to land use have frequently been debated in the literature. Overall, there is a general consensus that compact urban forms that feature moderate levels of density, connectivity, and land use mix are more desirable for climate change mitigation and can also provide some adaptation co-benefits (Sharifi, 2019a, c; Xu et al., 2019). Urban compactness, specifically, contributes to reducing building and transport GHG emissions (Pierer and Creutzig, 2019; Stokes and Seto, 2016). Highly dense urban areas with limited green and open spaces may, however, involve mitigation trade-offs as they can induce long-distance leisure travel (Holden and Norland, 2005), reduce the potential for renewable energy generation (Hamin and Gurran, 2009), increase energy demand for operation and maintenance, and intensify the Urban Heat Island (UHI) effect that may increase energy demand for air conditioning. Moreover, increasing density in some rapidly growing cities (e.g., those in

East Asia) has resulted in more use of steel for constructing high-rise buildings. This has negative impacts on mitigation as steel has higher embodied energy compared to concrete and wood (Stokes and Seto, 2016).

While compact urban development may result in mitigation trade-offs, negative impacts on adaptation are argued to be more prominent and have received further attention in the literature. Specifically, it is demonstrated that compact urban development can hinder adaptation efforts as high-density locations lack enough green and open spaces and are more prone to heat stress due to the UHI effect (Pierer and Creutzig, 2019). For instance, evidence from Melbourne, Australia shows that strategies that increase urban density and promote compact development through the Melbourne 2030 plan will increase night-time UHI in many parts of the city (Coutts et al., 2010). As a result, as future climate changes are likely to further intensify the UHI effects, a higher proportion of the population in the city will be exposed to heat stress risks (Coutts et al., 2010). Similar arguments have been made in other contexts. For example, a recent simulation study for Xiamen City, China shows that while population density, land use mix, and street connectivity significantly reduce per capita transportation GHG emissions, they will significantly increase vulnerability to the UHI effect (Xu et al., 2019). In addition to increasing exposure to the heat stress, high-density urban development may also put more pressure on the urban drainage system and increase the risk of flooding by reducing the fraction of permeable surfaces that are essential for surface run-off water management (Sharifi, 2019c). This will also cause additional economic burdens on cities as more investment on hard engineering solutions for stormwater management will be required (Landauer et al., 2015). Furthermore, it can negatively affect other ecosystem services such as air purification and recreation opportunities provided by green spaces (Koch et al., 2018). This may have negative consequences for human health and, in turn, further erode the capacity to adapt to climate change impacts in the long run (Liu et al., 2016).

Despite these issues, it is argued that smart design of compact cities can contribute to minimizing trade-offs (Koch et al., 2018). Smart design entails balanced use of spaces in land use planning to ensure that both adaptation and mitigation benefits are considered and focus on one objective does not hinder achieving the other. This will manifest itself in efforts such as allocation of appropriate levels of density, balanced distribution of uses, and optimal design of streets, neighborhoods, and urban blocks(Sharifi, 2019b). It also requires understanding interactions across different jurisdictional, management, sectoral, and spatial scales as demonstrated by Landauer et al. (2019) for Helsinki, Finland. More details about an integrated approach that can address such interactions will be provided in Section 3-4.

Other land use related measures mentioned in the literature that may involve trade-offs are ‘risk zoning and relocating to avoid risk-prone areas’, ‘development along riverbanks to reduce exposure to heat’, and passive design measures such as 'cool roofs and pavements'. Risk zoning and relocation is a measure that may lead to mitigation as well as adaptation trade-offs. It can increase GHG emissions as major relocations require building new infrastructure and may also increase commuting distance (Ford et al., 2018). In addition, policies that prohibit new developments in risk-prone zones reduce available land for development and, thereby, increase housing prices. As a result, dwelling sizes in the city center will become smaller. Here, although some mitigation benefits can be achieved and resilience to adverse events like floods increases, the economic affordability and Quality of Life (QOL) is undermined (Viguie and Hallegatte, 2012). Further, the reduced land options may require to significantly increase density in other locations, thereby increasing risk from heatwaves (Ford et al., 2018).

Development along riverbanks is a land use planning measure that contributes to adaptation to heat risk. This can also, indirectly, contribute to mitigation by reducing the need for mechanical cooling. However, as results of a spatial optimization framework for London, UK show, these riverbanks that function as cooling blue infrastructure are areas that have the highest level of flood vulnerability. As a result, in an optimal development scenario that considers both heat and flooding risks, about 75% of the available land in London will be designated as not suitable for development (Caparros-Midwood et al., 2019) .

Increasing albedo through cool roofs and pavements is another measure that ameliorates the UHI effect through reducing heat storage in the environment and reflecting high amounts of thermal energy. As demonstrated in Melbourne, Australia, this also effectively reduces energy demand and associated emissions (Coutts et al., 2010). However as modelling results for different regions in the US show, under some climatic conditions, cool roofs result in additional wintertime cooling, thereby increasing heating energy demand (Georgescu et al., 2014). The authors argue that addressing this issue requires developing cool roofs featuring reflective properties that can be adjusted depending on seasonal requirements. This study also shows that another adaptation trade-off may emerge since cool roof implementation results in noticeable summertime decrease in precipitation in some areas of southeastern US and Florida (between 2-4 mm per day). This may exacerbate water scarcity problems and, given the water-energy nexus, may also have implications for power generation (Georgescu et al., 2014).

3-2-3- Transport

Transportation is closely linked to land use. In fact, land use policies influence and are influenced by transportation policies. Therefore, as will be further discussed in Section 3-4, reaching optimal conditions requires integrated approaches that consider them simultaneously. However, for the purpose of simplicity, some trade-offs directly related to transportation measures are first discussed here.

Transportation measures that are likely to result in adaptation/mitigation trade-offs can be divided into three broad categories: investment in and expansion of public transport infrastructure, pricing mechanisms, and vehicle efficiency improvement schemes. Promoting active and public transportation through policies such as Transit-Oriented Development (TOD) and expansion of cycling and pedestrian routes is an effective strategy for reducing GHG emissions and provides multiple co-benefits such as health improvement through increasing physical activity and reducing air pollution (Dulal, 2017; Kjellstrom and McMichael, 2013). Health improvements and reductions in vehicle dependency can, in turn, improve adaptive capacity through cost savings and improved coping and response capacities (Dulal, 2017; Kjellstrom and McMichael, 2013; Viguie and Hallegatte, 2012). However, large-scale implementation of such policies may require significant physical reconfiguration of settlements and result in considerable operational and embodied emissions (Hamin and Gurran, 2009). Additionally, infrastructure development for transportation demand management may result in gentrification and eviction of poor and marginalized groups (Colenbrander et al., 2017). It may also lead to the loss of jobs of taxi or rickshaw drivers (Colenbrander et al., 2017). These trade-offs can be mitigated through social support measures such as facilitating training programs to diversify the working skills of the people that may be affected, developing community resettlement programs to help maintain livelihood abilities, and engaging informal settlement groups in the planning process and enabling them to negotiate their conditions with the authorities. Such practices have been conducted in countries such as India and Pakistan (Colenbrander et al., 2017).

To maximize effectiveness of public transportation policies, they are often coupled with economic measures such as vehicle and fuel taxing, parking charge, regulating public transport tariffs, and congestion pricing. These measures can reduce emissions by improving efficiency and discouraging private vehicle usage (Dulal, 2017). In addition, they can contribute to adaptation through, among other things, improving health, contributing to household savings, and reducing societal costs of congestions such as productivity loss (Dulal, 2017; Kjellstrom and McMichael, 2013). Some of these policies such as vehicle and fuel taxing schemes may, however, cause adverse impacts on low-income households. It is suggested that such impacts can be mitigated through subsidy and “revenue recycling” programs (Dulal, 2017). Regulating public transport tariffs is another measure that needs to be implemented wisely. For instance, in their modeling 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 and make it more affordable for the less affluent suburban households. However, this policy may provide incentives for urban sprawl, thereby having detrimental impacts on biodiversity and increasing emissions.

Possible trade-offs involved in vehicle efficiency improvement programs should also be considered. For instance Colenbrander et al. (2017) explain how the environmental policy to achieve mitigation and health benefits by phasing out old vehicles can have adverse impacts on the livelihoods of poor and marginalized groups that economically rely on such vehicles. To deal with this issue, it is essential to employ social support mechanisms to ensure that low-income groups are not disproportionately affected by the negative impacts.

3-2-4- Water

Water sector is highly sensitive to climate change and cities in many areas need to develop appropriate adaptation policies to deal with water scarcity issues and ensure continuity of water supply. These policies may involve trade-offs as they can be costly and, given the water-energy nexus, they may also increase GHG emissions (Paton et al., 2014). For instance, water desalination is a climate-independent, but energy-intensive adaptation measure that has been discussed in the literature. Using the multi-objective evolutionary algorithm, Paton et al. (2014) explored the mitigation trade-offs that may occur when using desalination plants to increase adaptation of the urban water supply system in Adelaide, Australia to the impacts of climate change. They suggest that despite the fact that desalination plants are energy intensive and reliance on them should be minimized, it is essential to include some desalination plants in the water supply system to maintain system resilience and hedge against risks (because desalination plants are climate-independent and less vulnerable to risk). The study shows that rainwater tanks and stormwater harvesting may be better adaptation measures that also minimize mitigation trade-offs. Using desalination plants, sparingly and in combination with rainwater tanks that are ideally connected to the roof area and supply water for non-drinking purposes, can reduce the trade-offs and contribute to maintaining balance between adaptation and mitigation (Paton et al., 2014). However, rainwater harvesting systems are often expensive and cause cost-related trade-offs (Alves et al., 2019; Paton et al., 2014). To deal with this issue, it is suggested to combine rainwater harvesting systems with measures such as open detention ponds. Cost-benefit analysis by Alves et al. (2019) shows that total benefits of such synergistic measures outweigh the costs.

Investment in rainwater harvesting and other green infrastructure solutions also improves adaptation through enhancing the quality of water-related ecosystems and enhancing resilience to risks such as flooding and extreme heat. However, appropriate measures need to be taken in order to minimize the environmental footprint and life cycle impacts of green infrastructure to avoid mitigation trade-offs (Spatari et al., 2011). For instance, Xeriscaping can be used to reduce the demand for irrigation. It should be noted that promoting green infrastructure may also be in conflict with some mitigation measures. This will be discissed in Section 3-3. Overall, grey and green systems can complement each other to strike a proper balance between adaptation and mitigation (Alves et al., 2019). Therefore, integrated urban water management approaches that include both systems are needed. Such approaches also contribute to achieving sustainable development goals (e.g., SDG 6, 11, and 13).

3-2-5 Buildings

The building sector accounts for a large share of global emissions, indicating the significance of implementing mitigation measures that improve building energy performance. Moreover, as people spend most of their time indoors in either their homes or workplaces, proper adaptation measures are needed to maintain indoor thermal comfort. These adaptation and mitigation measures may, however, involve trade-offs. Review of the literature shows that although many building-level measures exist, their potential trade-offs have not been well explored.

Passive design measures are effective for reducing operational energy consumption. However, integrating them may increase construction costs, casting doubts on their affordability to all income groups (Hamin and Gurran, 2009). Also, some measures such as cavity wall insulation may increase flood vulnerability as shown by Walsh et al. (2011). Additionally, some passive design measures may increase embodied emissions as more energy-intensive materials might be needed (Hamin and Gurran, 2009).

The most notable trade-offs are, however, associated with air conditioning. Kjellstrom and McMichael (2013) explain how air conditioning of hospitals and the houses of elderly and vulnerable populations can be considered as an adaptation measure to climate change. This will provide health benefits and may also provide economic resilience benefits due to reducing the costs for treatment and improving workplace productivity. However, unless renewable energy sources are used for air conditioning, this may cause mitigation tradeoffs as it will increase energy demand. For instance, in response to the high mortality rates of the 2003 heat wave in France, air conditioners were installed in many homes (especially of elderly) and this has increased energy consumption (Kjellstrom and McMichael, 2013). Therefore, while building retrofit is important for maintaining thermal comfort, avoiding installation of energy-intensive air conditioners that are dependent on non-renewable energy sources is essential for achieving mitigation benefits (Ford et al., 2018). Furthermore, it should be noted that efficiency improvements from building retrofit may cause rebound effects and further increase energy demand (Santamouris, 2016).

While most trade-offs of air conditioning are related to mitigation, the adaptation trade-offs should also be noted. Over-reliance on air conditioners may erode adaptation capacity through reducing heat acclimatization. This is likely to cause major health risks under blackout and brownout conditions (Kjellstrom and McMichael, 2013). Finally, using evaporative air conditioning systems may also cause water-related trade-offs in areas facing water stress (Coutts et al., 2010).

3-2-6- Green infrastructure

A wide range of Urban Green Infrastructure (UGI) measures ranging from green roofs to parks and urban agriculture have been discussed in the literature that can provide multiple ecosystem services and benefits such as regulation of micro-climate, enhanced thermal comfort and UHI mitigation, stormwater management, air purification, recreational benefit, carbon sequestration, and health and educational benefits (He et al., 2019; Kabisch et al., 2016). Accordingly, UGI measures are important for adaptation and mitigation (De la Sota et al., 2019; Demuzere et al., 2014; Kabisch et al., 2016).

Despite this, proper design of UGI is needed to minimize potential trade-offs that may arise. Major adaptation trade-offs discussed in the literature include high costs of implementation and maintenance (Alves et al., 2019), health impacts associated with fertilizer and pesticide usage that may reduce air and water quality and increased presence of insects/animals that may be carriers of various diseases (Demuzere et al., 2014), and increased likelihood of concentration in risk-prone areas. Regarding the latter point, a modeling study for Paris, France shows that a greenbelt policy to regulate urban growth and prohibit sprawl provides multiple adaptation and mitigation benefits. For instance, it contributes to ecosystem protection and helps to reduce GHG emissions through limiting private vehicle usage, increasing density, and reducing dwelling size (due to land scarcity). However, this policy may result in adaptation trade-offs since land scarcity may lead to higher concentration of population in flood-prone areas (Viguie and Hallegatte, 2012).

Depending on the type of the UGI and how they are implemented, different mitigation trade-offs may also arise. For instance, construction and maintenance of intensive green roofs and urban forestry and agriculture involve considerable amounts of emissions (Demuzere et al., 2014). Regarding this, in their study of the ecological footprints of UGI in Lugo, Spain, De la Sota et al. (2019) show that implementation and management of urban forestry and urban agriculture emits CO_2 and measures should be taken to minimize the emissions. In the case of urban forestry, transport emissions and machinery-related emissions are dominant. The main emissions for urban agriculture come from fertilizer use and irrigation. Accordingly, in this case, using clean energy for machinery and transportation and also minimizing the use of chemical fertilizers could be effective measures to reduce emissions associated with implementation and management of green infrastructure (De la Sota et al., 2019).

Efforts aimed at extensive provision of green spaces may also, indirectly, increase emissions by reducing urban density and increasing automobile dependency. As a case in point, Hamin and Gurran (2009) demonstrate how urban nature protection in Port Stephens, on the mid northern New South Wales coast, results in energy-intensive low density development. Similar results have been reported for Germany, where examining different urban development scenarios showed that protection and development of urban green space in a manner that improves accessibility to green infrastructure, results in (larger) expansion of the urban area and this may have implications for energy consumption (Hoymann and Goetzke, 2016). These trade-offs can be to some extent mitigated by using local renewable energy sources to meet energy demands of households.

Selection of appropriate tree species is another way of reducing trade-offs. For instance, in seasonal climates using deciduous trees is recommended as they can contribute to reducing energy consumption by providing shading benefits during summer days, while allowing penetration of solar radiation during winter days. Proper choice of trees also matters for adaptation. For example, in some contexts planting large trees on both sides of streets may limit air circulation and thereby increase street-level air pollution and UHI effect (Demuzere et al., 2014).

3-2-7- Waste

This is a relatively under-explored sector in the reviewed literature. The discussed trade-offs are mainly related to health and distributional effects. For instance, site-level composting is a measure that contributes to mitigation through reducing emissions from transporting waste, as well as, methane emissions from landfill (Ayers and Huq, 2009). It may, however, cause health impacts, and thereby affect adaptive capacity of local communities (Hamin and Gurran, 2009).

Waste to energy is another measure that its primary objective is mitigation. This is mainly achieved through enhancing efficiency, reducing waste treatment requirements, reducing emissions from organic waste decay, and replacing energy generated from fossil fuels (Colenbrander et al., 2017). However, in some contexts, implementation of waste-to-energy programs may negatively affect livelihoods of some income groups, thereby diminishing their adaptive capacity. As a case in point, in Kolkata, India, many people rely on waste picking/scavenging for their livelihood. Large-scale investment in the waste-to-energy technologies and other measures such as landfill gas utilization will limit opportunities for waste picking, thereby affecting livelihoods of poor and marginalized communities and making them more vulnerable to economic shocks (Colenbrander et al., 2017). It is suggested that collaborating with waste pickers and formalizing their activities may provide opportunities to address this trade-off. For instance, it may be possible to develop waste sorting mechanisms, wherein poor and marginalized groups can be employed to sort waste and extract items with potential value that can be separated.

One possible mitigation trade-off that has been discussed is related to wastewater recycling and treatment. This can enhance water efficiency and contribute to adaptation to water stress risks. However, mitigation trade-offs may arise. For instance, using groundwater pumps for wastewater treatment (to avoid flooding) is an energy-intensive practice and increases emissions, unless efficiency of the equipment is improved and/or renewable and clean energy sources are used (Landauer et al., 2019).

3-2-8- Policy and governance

Trade-offs associated with urban policies are not well-explored in the literature. The limited discussions are mainly related to potential adaptation trade-offs of environmental pricing and investment strategies that are aimed at climate change mitigation. Environmental pricing provides mitigation benefits by 'internalizing environmental externalities', thereby improving efficiency. However, such policies may affect socio-economic resilience and adaptive capacity of the poor. In fact, the negative impacts of such policies may outweigh the benefits as the poor often don't have enough human capital and economic resources to afford the higher premiums and/or use costlier resources and technologies (Dercon, 2014).

Similarly, low-carbon investments can provide mitigation benefits by reducing energy demand and associated GHG emissions. However, the poor may not accrue such benefits. For instance, although low-carbon energy generation may create more job opportunities, it might not be feasible for the poor to get involved due to the limitations in terms of subsidies and public investments (i.e., subsidies are not enough to enable them to participate) (Dercon, 2014). Additionally, implementing costly low-carbon policies in poor contexts may add strains on municipal budgets and leave limited resources for adaptation (Swart and Raes, 2007).

3-3- Conflicts

Simultaneous implementation of some of the measures discussed in the previous section, that involve trade-offs, may not be possible due to compatibility issues. Under such conditions, depending on various factors such as strategic and policy goals and priorities, preferences of stakeholders and beneficiaries, and the stage of development (Landauer et al., 2015), it may be necessary to either make a choice between conflicting measures, or adopt smart planning and design approaches that minimize the conflicts.

Table 3. Conflicts between different adaptation and/or mitigation measures.

Measure 1	**Measure 2**	**Cross-sectoral**
Compact urban development	Urban parks and open spaces	Yes
Compact urban development	Decentralization of energy supply	Yes
Compact urban development	Diversified energy profile based on renewable energies	Yes
Compact urban development	Urban agriculture	Yes
Compact urban development	Site/neighborhood level composting	Yes
Compact urban development	Passive building design	Yes
Risk zoning and relocating to avoid risk-prone areas	Development along riverbanks to reduce exposure to heat	No
Urban parks and open spaces	Infill and brownfield (re-)development	Yes
Transportation demand management	Infill and brownfield (re-)development	Yes
Evaporative air coolers for air conditioning	Water demand management	Yes

While many adaptation/mitigation measures exist, only few possibly conflicting measures have been discussed in the literature (see Table 3). This may indicate that conflicting conditions are not frequent.

However, it may also be due to limited empirical research on interactions between adaptation and mitigation measures. Results show that increasing density is a specific measure that is likely to particularly conflict with the UGI measures such as provision of parks and open spaces and urban agriculture. This conflict will have significant consequences as it may increase vulnerability to risks associated with the UHI effect and urban flooding and may also reduce access of all citizens to ecosystem services provided by UGI. Increasing density may also conflict with other measures such as neighborhood level composting, some types of passive building design, and decentralization of energy supply to promote uptake of renewable energy. Regarding renewable energy generation, the per-capita roof space is limited in dense urban areas and, as a result, per-capita energy that can be produced from renewable sources is lower than that of low-density areas (Hamin and Gurran, 2009).

Infill and brownfield development are measures that contribute to compact urban development but may conflict with other measures. For instance, evidence from a spatial optimization study for London, UK shows that brownfield development in inappropriate and less accessible areas, that are not in proximity of employment zones, conflicts with efforts aimed at transport demand management by minimizing distance to town centers (Caparros-Midwood et al., 2019). If implemented inappropriately, infill and brownfield development may also result in extremely dense areas that leave limited space for providing green and open spaces that are necessary for adaptation to flooding and the UHI effect (Hoymann and Goetzke, 2016). However, as demonstrated for a district in Leipzig, Germany, smart planning and design measures can be utilized to reduce potential conflicts involved in brownfield development (Koch et al., 2018).

Another noteworthy conflict may arise between measures that are aimed at reducing vulnerability to different types of risks. For instance, measures aimed at reducing vulnerability to flooding by avoiding development near riverbanks conflict with efforts to utilize cooling benefits of rivers to minimize heat risk. In their scenario analysis for London, Caparros-Midwood et al. (2019) elaborate on the importance of addressing this conflict through using spatial optimization models. Some other useful methods and approaches for dealing with conflicts and trade-offs will be discussed in the following section.

3-4- Methods and approaches for addressing conflicts and trade-offs

The discussions up to this point indicate the complexity of interactions between adaptation and mitigation measures. Accordingly, if implemented separately, different sectors/actors may take measures that involve conflicts/trade-offs and some of their effects cancel each other. In addition to climate change adaptation and mitigation, these conflicts/trade-offs can have significant implications for achieving equity health, and disaster risk reduction targets specified in local/global policy frameworks such as the New Urban Agenda, the SDGs and the Sendai Framework for Disaster Risk Reduction. Therefore, integrated approaches that can facilitate communication between different actors and sectors with different interests are needed to enable a balanced attention to mitigation and adaptation (Landauer et al., 2015; Lwasa et al., 2018). Integrated approaches that enable coordination between different actors and sectors allow taking holistic approaches that consider spatio-temporal dynamics between different measures (Demuzere et al., 2014; Endo et al., 2017).

Two somewhat distinct but related approaches for holistic accounting of adaptation and mitigation measures have been discussed in the literature: first, integrated policy making wherein different scenarios are compared to understand which measures provide win-win solutions (Viguie and Hallegatte, 2012; Xu et al., 2019), and second, Urban Integrated Assessment Frameworks (UIAFs) (Caparros-Midwood et al., 2019; Ford et al., 2018; Walsh et al., 2011).

A good example of the first approach is the study by Viguie and Hallegatte (2012), showing that isolated implementation of three different policy measures (i.e., green belt policy, flood zoning policy, and public participation policy) in Paris can result in trade-offs. Green belt policy can reduce GHG emissions but may lead to higher population concentration in flood-prone areas; flood zoning policy can contribute to mitigation and reduce flooding risk but may have negative effects on equity and housing affordability; the public transportation policy improves equity but may increase GHG emissions by promoting urban sprawl. The study shows that although each policy entails certain levels of trade-offs, the combination of all policies may provide opportunities for minimizing the trade-offs. For instance, the flood zoning policy can reduce the trade-offs entailed in the greenbelt policy (i.e., population concentration in risk-prone areas). Therefore, it is suggested that taking account of different policies and combining them in an integrated policy making approach can provide win-win solutions by maximizing synergies and minimizing trade-offs (Viguie and Hallegatte, 2012).

Taking a similar scenario-making approach, Xu et al. (2019) examine adaptation-mitigation trade-offs for four different scenarios related to urban form and green infrastructure in Xiamen, China. The business as usual scenario (BAU) assumes that historical trends of land use will continue; the Adaptation Scenario (AS) promotes decentralized and low-density development that allows adequate inclusion of green open spaces to improve adaptation to flooding and the UHI effect; the Mitigation Scenario (MS) aims at reducing GHG emissions and is characterized by compact development and land use mix; finally, the Combined Scenario (CS) promotes polycentric urban form that is characterized by moderate levels of density and green open space and seeks to achieve adaptation-mitigation balance. Results of their modelling analyses showed that the adaptation scenario reduces vulnerability to the UHI effect and flooding compared to the BAU scenario. However, it can increase GHG emissions. In contrast, the mitigation scenario reduces emissions compared to the BAU but intensifies the UHI effect and increases exposure to flood risks (Xu et al., 2019). It is demonstrated that the combined scenario that considers adaptation and mitigation simultaneously is effective for reducing per capita GHG emissions, minimizing exposure to flood risk, and reducing the UHI intensity compared to the BAU scenario (Xu et al., 2019).

The second approach is focused on using UIAFs. Global scale integrated assessment models for informing climate change planning have been studied for several decades, resulting in a robust literature. However, UIAFs are still nascent. Some examples related to this approach are introduced here. A pioneering UIAF has been developed by the Tyndall Centre for Climate Change Research that improves understanding of long-term adaptation-mitigation interactions through simultaneous consideration of various processes related to socio-economic and population dynamics, land use, and transportation under different future climate projections (Dawson et al., 2009; Walsh et al., 2011). A preliminary case study in London confirms that this city-scale integrated framework enables examination of conflicts and trade-offs, as well as, co-benefits and synergies between different planning and design measures (Dawson et al., 2009; Ford et al., 2018).

Taking a similar approach, Caparros-Midwood et al. (2019) introduced a multi-objective spatial optimization framework that enables planners and policy makers to appropriately examine different alternatives, provide simultaneous evaluation against different objectives, and better deal with trade-offs between various measures and objectives. Applying the framework to London, UK, it was found that obtaining maximum performance across all objectives is highly unlikely for a single plan because some objectives cannot be simultaneously optimized. Their results show that several trade-offs emerge when making efforts to meet different objectives related to ‘minimizing risk from future flooding risk’ ‘minimizing exposure to future heat risk’, ‘minimizing distance of new development to town centers to minimize travel’, ‘minimizing expansion of urban sprawl’, ‘maximizing development on brownfield sites’, and ‘preventing development of greenspace’. Results also show that containing urban sprawl and reducing transport emissions may increase heat risk. However, it is argued that exposure to heat risk can be minimized by requiring new developments (in the inner high-density areas) to integrate green infrastructure elements such as green roofs and green spaces and high albedo materials that improve cooling benefits (Caparros-Midwood et al., 2019).

Another noteworthy example of UIAFs is the Ruhrgebiet simulation model that has been developed to explore how different factors related to demography, employment, land use, transport, environment, and urban structure interact and how such interactions may influence efforts seeking to achieve energy transition from fossil fuels to renewable energies in the Ruhr area of Germany ((Schwarze, 2017) cited in Ford et al. (2018)).

Overall, it can be observed that good efforts have been made to develop UIAFs that clarify interactions between adaptation and mitigation. However, empirical evidence is still scarce and limited to few major urban areas in Europe.

4- Conclusions

Cities around the world are increasingly developing action plans to facilitate climate change adaptation and/or mitigation. Improved understanding of interactions between adaptation and mitigation measures is essential for maximizing synergies and minimizing conflicts and trade-offs. The main aims of this paper were to provide more clarity on potential conflicts and trade-offs that may occur and to discuss possible approaches that can be taken to balance adaptation and mitigation.

The bibliographic analysis showed that more attention to adaptation-mitigation interactions has been made since the publication of the fourth assessment report of the IPCC. The literature is, however, still limited and this may be interpreted as a confirmation of arguments that adaptation and mitigation have often been studied separately (Xu et al., 2019). The reviewed literature is mainly focused on cities from the Global North and more attention to the Global South cities is needed. Additionally, while trade-offs have been relatively well discussed, only limited research on potential conflicts is available. Detailed content analysis of the selected papers confirmed imbalance between research on trade-offs and conflicts.

Results showed that energy, land use, transport, water, building, green infrastructure, waste, and policy are dominant sectors that may involve trade-offs. Efforts aimed at reducing GHG emissions may diminish adaptive capacity in various ways such as increasing exposure to the UHI effect and flooding and amplifying negative health impacts. The most recurring trade-offs of mitigation efforts were, however, related to equity. In other words, in some contexts, mitigation efforts may indirectly affect adaptive capacity of poor and marginalized groups through, among other things, affecting affordability of urban services and eroding livelihood options. Therefore, equity concerns should receive due attention in mitigation plans. Trade-offs may also arise when making efforts to enhance adaptation. It was discussed that such efforts may increase GHG emissions due to various issues such as the need for significant physical reconfiguration that increases embodied emissions, increased energy demand for construction and maintenance of infrastructure, increased energy demand for air conditioning, and reduced efficiency associated with the utilization of redundant and/or energy intensive technologies.

Unlike trade-offs, conflicts have not been well explored in the literature. The only exceptions are measures related to increasing density that may conflict with measures across other sectors such as green infrastructure, distribution and decentralization of energy supply, neighborhood level composting, and some forms of passive building design. The fact that increasing density conflicts with several other measures indicates that planners and policy makers need to pay attention to contextual factors and also consider other potentially influential adaptation/mitigation measures when making decisions regarding appropriate levels of density. Future research should further explore potential conflicts between adaptation and mitigation measures.

Dealing with conflicts and trade-offs requires adopting integrated approaches that simultaneously consider adaptation and mitigation and enable balancing multiple objectives. It was discussed that Urban Integrated Assessment Frameworks (UIAFs) that take account of various socio-economic, environmental and physical factors under different climate scenarios can be used to inform smarter planning and design interventions that overcome trade-offs and provide win-win solutions. While such integrated frameworks are desirable, there are several barriers to their development and uptake that need to be addressed. Development of UIAFs often requires certain levels of technical expertise that may not always be available. Such expertise is also necessary for analyzing the results. Another challenge is regarding data availability that may be easier to deal with in the future given rapid advances in crow-sourced data platforms and open-source mapping (Walsh et al., 2013). Institutional barriers should also be addressed. Specifically, it is essential to shift away from silo-based approaches and strengthen inter-sectoral collaboration -across multiple jurisdictional, spatial, institutional, and management scales- to facilitate simultaneous consideration of adaptation and mitigation in climate action plans (He et al., 2019; Landauer et al., 2019; Lwasa et al., 2018). This may be challenging given that objectives of different sectors are not always consistent (Landauer et al., 2019). One way to address this barrier could be redesigning regulatory frameworks to encourage integrated approaches. This is important because legal barriers and restrictions may hinder integration of adaptation and mitigation measures (Landauer et al., 2019). These barriers should be further explored in future research.

Finally, it should be emphasized that while simultaneous consideration of adaptation and mitigation provides opportunities for designing balanced climate actions that maximize co-benefits and minimize trade-offs, as Xu et al. (2019) argue, the window for action is narrow and rapidly closing due to rapid rates of urbanization and intensifying climate change trends. Given the inertia in urban infrastructure, delays in simultaneous integration of adaptation and mitigation into climate action plans may result in undesirable pathways that will not be easily reversed in the future.

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Highlights

- Conflicts and trade-offs between urban adaptation and mitigation measures are explored.
- Conflicts and trade-offs have received more attention since publication of IPCC AR4 report.
- Most trade-offs are related to energy, land use, transport, water, and building sectors.
- The most recurring trade-offs of mitigation measures are related to equity and adaptive capacity.
- Integrated assessment frameworks should be used to deal with conflicts and trade-offs.

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: