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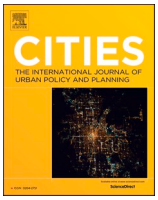

Empirical evidence of urban climate adaptation alignment with sustainable development: Application of LDA

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ABSTRACT

Cities are critical sites for climate action. Population and infrastructure are concentrated in urban areas and their susceptibility to climate change impacts makes them a pivotal place to embark on adaptation plans and strategies. In the Fifth Assessment Report (AR5) the Intergovernmental Panel on Climate Change (IPCC) affirms that urban adaptation allows sustainable development and resilience. However, without evidence, this affirmation fails to acquire credibility and objectivity. As an attempt to provide the evidence for the assertion, this study examines the current actions in urban centers to determine if there is an alignment between adaptation and development. The study employs text mining techniques to analyze 400 urban project descriptions from Cities100 reports (2015–2019) of the C40 network. With Latent Dirichlet Allocation (LDA), a machine learning algorithm for topic model analysis, the study identifies 17 major topics. Using multidimensional scaling and cluster analysis to further characterize the findings, it finds an alignment of adaptation with urban sustainable and resilient development in several major cities. In this way, the paper makes a contribution to a global understanding of urban adaptation as well as demonstrates a way of adopting the grey literature into the urban adaptation studies.

1. Introduction

Cities are playing a growing role in the introduction of climate change adaptation (CCA) actions into their ongoing policy framework. Cities are motivated to take adaptation actions due to their geographical vulnerability (Boussalis et al., 2019; Hallegatte et al., 2013) and the interconnectedness of urban infrastructure, population, and assets (Carter et al., 2014; Geneletti & Zardo, 2016). They have become 'early adapters' to climate change impacts not only due to their vulnerabilities but because of expected benefits from taking adaptation measures within their boundaries (Perry World House, 2019). Another positive aspect of urban adaptation is presented in the eighth chapter of the Fifth Assessment Report (AR5) of the IPCC. The report makes 25 assertions in the *Executive Summary*, which support the linkage between urban climate adaptation and sustainable development. Among these findings, however, only 4 statements are supported by *robust* evidence while more than half are based on *medium* evidence and 5 are supported by *limited* evidence. One of these latter assertions, made based on limited evidence but around which there was strong agreement, addresses the relationship between climate change adaptation and development (IPCC, 2014: 538–540).

> "Urban adaptation provides opportunities for incremental and transformative adjustments to development trajectories toward resilience and sustainable development via effective multilevel urban risk governance, alignment of policies and incentives, strengthened local government and community adaptation capacity, synergies with the private sector, and appropriate financing and institutional development. Opportunities to do so are high in many rapidly growing cities where institutions and infrastructure are being developed, though there is limited evidence of this being realized in

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practice *(medium confidence, based on limited evidence, high agreement)*. {8.4} (IPCC, 2014)".

Sustainable development is an approach to development that ensures the sustainability of environmental, economic, and social dimensions of natural and human systems. The concept of sustainable development, originated from the field of forest management, has developed to include not only environmental but economic and social dimensions as well. The established definition on sustainable development that IPCC also follows is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" from Brundtland Report (WCED, 1987). The United Nations declared Sustainable Development Goals (SDGs) in 2015 for the next 15 years as a successor to the Millennium Development Goals (MDGs). Its sustainable development agenda emphasizes the balance of three pillars: economic growth, social inclusion, and environmental protection (UN, 2015).

Adaptive capacity is the ability to respond to challenges through managing risk, managing impacts, developing new knowledge, learning, and developing innovative, novel, flexible and effective approaches (Gunderson, 2000; Levin et al., 1998). Recognition of the human dimensions of changes; appreciating the role of local knowledge for strengthening adaptive capacity; focusing on the scale at which impacts are experienced; and linking action with pro-poor development outcomes is known as community-based adaptation (McNamara & Buggy, 2016). In the meantime, IPCC's definition on adaptation or adaptive capacity is wider. IPCC (2014) defines adaptation as "the process of adjustment to actual or expected climate and its effects" in its glossary and it further adds an explanation to the concept with two possible expected outcomes – to "exploit beneficial opportunities" as well as to "moderate or avoid harm" (IPCC, 2014). Also, in its definition of adaptive capacity, both the aspect of facing potential damage and that of taking advantage of opportunities are mentioned.

In adaptation discourse, the meaning of adaptation has been open to debate. Its interpretation in development projects is often unclear (Klepp & Chavez-Rodriguez, 2018). According to Klepp and Chavez-Rodriguez, following adaptation's reintroduction into policy and social sciences debates at the 1992 Rio Summit (Pelling & Manuel-Navarrete, 2011), Bassett and Fogelman (2013) identified adjustment, reformist, and transformation adaptation approaches as three key concepts in climate change literature. Adjustment includes top-down solutions. The more radical solutions include reform through sustainable development and societal transformation. Schipper (2007) advocates that transformation is the most viable way to reduce vulnerability and strengthen adaptation capacity. Bassett and Fogelman (2013) found the adjustment approach to be the most influential.

In 2006, the United Nations Department of Economic and Social Affairs (UNDESA) and the Energy and Resources Institute (TERI) hosted a workshop to strengthen the research and understanding of climate change and sustainable development (TERI, 2006). The work group noted that there were several varying links between climate change and sustainable development (Banuri & Gupta, 2000; Cohen et al., 1998; Robinson & Herbert, 2001). They also noted that human induced climate change poses a threat to MDGs. They noted that in 2003, the OECD published that adaptation to climate became part of programs that further sustainable development planning (OECD, 2003). In 2005, the OECD noted that embedding CCA into industry sector policies, programs and projects expands opportunities to address climate change impacts and reduce vulnerability (OECD, 2004). The UNDESA and TERI workgroup conclude that vulnerability and adaptation to climate change needed to be mainstreamed into sustainable development planning (TERI, 2006).

Focusing on the MDGs, the OECD (2009) notes that there are close linkages between "regular development activities" and adaptation to climate change. Business as usual development may increase adaptive capacity. However, some types of development projects may fail to consider climate change and in turn contribute to maladaptation. "Integrating adaptation to climate change within development activities will thus be essential if governments wish to achieve the targets set in the MDGs, as well as related national poverty eradication efforts and sustainable development" (OECD, 2009). The OECD prescribed a four-step approach to assessing adaptation actions: 1) identify current and future vulnerabilities and climate risks; 2) identify adaptation measures; 3) evaluate and select adaptation options; and 4) implement and mainstream adaptation with stand-alone adaptation policies and the integration of adaptation measures into existing development processes and activities (OECD, 2009).

However, fast forward, in the backdrop of the 2015 Sustainable Development Goals (SDGs) adoption, Bhatasara and Nyamwanza (2018) discovered that sustainability is a missing dimension in CCA in Africa. The researchers argue for a clearer framework of sustainability in adaptation. Citing Eriksen et al. (2015), the researchers noted that minor attention had been devoted to the outcomes of adaptation policies and practices for sustainability. They concluded that a "shift should involve conceptualizing adaptation as an element of broader sustainable development" (Bhatasara & Nyamwanza, 2018).

In an International Union for Conservation of Nature and Natural Resources (IUCN) report, Marshall et al. (2010) advocated that resilience provides a conceptual framework for sustainability in socio-ecological systems. This is natural resource users' resilience to changing natural resource conditions and to new climate driven regulations. In this context, resilience is defined as the ability to anticipate and prepare for change (Marshall et al., 2010). Adaptation efforts and attempts to promote sustainable development share common goals and determinants including access to resources, the equitable distribution of resources access to risk sharing mechanisms and access to decision support mechanisms to cope with uncertainty (Yohe et al., 2007).

Resilience theory focuses on considering the complex, dynamic nature of socio-ecological systems as the approach to dealing with change (Acosta & Espaldon, 2008; Colding et al., 2002; Gallopín, 2006; Walker et al., 2003). Marshall et al. (2010) notes that applying the resilience theory evolved by necessity because prior system models had dependent social systems that collapsed or failed to meet sustainability goals (Ayensu et al., 1999; Jackson et al., 2001; MacKenzie, 2003; Milich & Varady, 1999). These system models for resource management built on stability. The resilience theory emerged as describing the phenomenon of more fluid resource management through monitoring, accommodating external changes and internal feedbacks, and incorporating learning and adaptation (Berkes & Folke, 1998; Ludwig et al., 1997). The resilience theory includes a conceptual model with three system characteristics: 1) the amount of change that a system can absorb and still retain the same structure and function; 2) the degree to which the system is capable of self-organization, and 3) the degree to which the system can build and increase the capacity for learning and adaptation (Carpenter & Gunderson, 2001; Folke, 2002; Holling, 1973).

Klepp and Chavez-Rodriguez (2018) note that concepts of *vulnerability* and *resilience* are indeed linked to adaptation. Resilience is "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions" (IPCC, 2012: 34). Vulnerability is "the degree to which a system is susceptible to, or is unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2012).

There are 4 important international agreements on climate change. First, every country ratified the 1987 Montreal Protocol which required eliminating production of ozone depleting substances such as chlorofluorocarbons. The Kigali Amendment in 2016 added the reduction of hydrofluorocarbons. Second, the 1992 United Nations Framework Convention on Climate Change (UNFCCC) was ratified by 197 countries.

This established the Conference of the Parties (COP) annual forum to discuss concentrations of greenhouse gases. Third, in 2005, the Kyoto Protocol was adopted as a legally binding climate treaty. The goal was to reduce emissions by 5 % below 1990 levels in developed countries. Fourth was the Paris Agreement in 2015 which required all countries to set emissions reduction pledges (Maizland, 2021). There is also a 2020 suite of documents by the International Organization for Standardization (ISO) including ISO 14090, 14,091, ISO/TS 14092 and 14,080. These set forth standards for the Adaptation to climate change providing principles; requirements; general guidelines; guidelines on vulnerability, impacts and risk assessment; requirements and guidance on adaptation planning for local governments and communities; and greenhouse gas management with a framework methodologies and management of climate action (ISO, 2020).

In addition, for two decades, there has been an ongoing global debate between adaptation and development. Schipper et al. (2020) describes the debate in detail and notes that a distinction between the adaptation and development is necessary for two reasons. First, the distinction is needed given the existing structure for funding adaptation and sustainable development project proposals. Second, the distinction is needed to ensure that adaptation is more than just business as usual. One position among debaters is that global development is not adapting to climate change. The opposing position is that global development is adapting to climate change. Schipper et al. (2020) concludes that the reality is a combination of these two perspectives. Nevertheless, development needs to be rethought despite evidence that adaptation will take place through development. Adaptation will inclusive, equitable "transformative development – that is, development that takes everyone into account and places issues of equity and justice in the centre and is founded on sustainability as an ultimate goal" (Schipper et al., 2020).

Another detailed analysis of the debate has been undertaken by Lindgren (2021) who follows the UNFCCC debates and has published and updated findings since 2015. In this arena, the debate is called adaptation versus mitigation. In light of Schipper et al. (2020) advocacy of rethinking sustainable development, such development projects should serve to mitigate. Thus, the debate is still adaptation versus sustainable development. Lindgren (2021) notes that both adaptation and mitigation issues are visible in the UNFCCC negotiations. However, mitigation has been the top priority.

Lindgren (2021) also notes that there are two risks to shifting the climate debate from mitigation to adaptation. First, doing so may divert attention from efforts to mitigate. This argument dates back further than two decades. It dates back to the 1990s. Ayers and Forsyth (2009) note that adaptation was controversial in policy debates as some argued that paying too much attention to adaptation could detract from funding expensive mitigation projects. These researchers noted that Al Gore was not a fan of adaptation in his 1992 book *Earth in Balance*; but later changed his view in an *Economist* magazine interview. He changed his stance because poor countries are vulnerable and need help. Also, since adaptation is more complex and requires taking into consideration social and natural factors, the adaptation approach is more complex and perhaps more prone to failure. Just as Schipper et al. (2020) points out, the debate is centered on which types of projects deserve to be funded - - adaptation projects versus sustainable development projects that serve to mitigate? Burmeister et al. (2019) advocates that in terms of funding proposal development, sustainable development priorities need to be known to get ready for adaptation project financing.

Given that the UNFCCC emphasized the need to develop public policies for CCA, Dupuis and Knoepfel (2013) studied whether certain adaptation framings are less tractable and if so, why. They stated that since barriers to adaptation is undertheorized, there is a need to verify whether patterns of causation between adaptation capacity or if they hold in wealthy nations. They used the 1995 Hisschemoller and Hoppe definition of tractability as the political, societal, and technical capacity of managing and taming a collective problem through proposed policy solutions. They studied India and Switzerland regional level policies and (1) how adaptation framings are translated into formal policy designs; (2) the tractability of adaptation framings by identifying the policy outputs that were produced in relation to each problem and goal formulation, and their problem- solving contribution; and (3) tractability limitations. Dupuis and Knoepfel (2013) found that CCA is more likely to face a deficit in implementation where adaptative capacity is low.

Fünfgeld and Mcevoy (2014) studied Australian government stakeholders involved in local adaptation policy formulation. They found that the dominant frames were avoiding disasters, community resilience and averting organizational risk. There was a lack of a shared view about the meaning and purpose of adaption among the policy making stakeholders. Fünfgeld and Mcevoy (2014) recommend using explicit framing processes to clarify adaptation goals to generate shared ownership of adaptation processes. When there is lack of agreement, low levels of ownership and acceptance of adaptation strategies and plans result.

Further, Romsdahl et al. (2017) found that in the UK, national discourse interacts with the local government framing of climate policy. They argue that local government practitioners used strategic reframing of the term 'climate change' to make progress in developing climate adaptation policies. They reframed to better align with local concerns in problem-solving discourse. This commenced after the UK government was found to be perceived as lacking heroics in climate discourse and climate change policy implementation.

As described above, the adaptation-sustainable development discourse has not been terminated and the dynamics between sustainable development, resilience and adaptation seem to take different shapes in different local policies and therefore debatable. Moreover, adaptation is difficult to trace due to the undefined and untheorized boundary of its activities (Dupuis & Knoepfel, 2013). Based on what previous researchers assumed (Ayers & Forsyth, 2009; Lindgren, 2021; Schipper et al., 2020), the concept of adaptation in this study will be understood a posterior response to the global GHG emissions and climate change impacts, as opposed to mitigation. While mitigation is to reduce the amount of GHG emissions in an anterior manner, adaptation is to mitigate the impact of climate change which occurs due to the accumulated carbon in the atmosphere and/or failed mitigation. More specifically, the study accepts the framing theory to confine the meaning of CCA for research convenience (Fünfgeld & Mcevoy, 2014; Romsdahl et al., 2017). Thus, urban adaptation in this study will be framed to a series of municipal activities to prevent and recover from water-related disasters due to climate change in coastal and non-coastal areas. Here, the term 'resilience' will be crucial in forming the concept of CCA. We define resilience as the ability to absorb the impacts of climate disasters. For the concept of sustainability or sustainable development, the UN's 2030 sustainable development agenda is adopted, encompassing economic, social and environmental dimensions of development, because that is the intended meaning of 'sustainable development' in the IPCC assertion.

The aim of this study is to understand global cities' CCA policies for the sustainable development perspective. Based on the IPCC's theory that urban adaptation helps lead to sustainable development, the study seeks to understand whether and to what extent this theoretical goal is achieved in local policies of cities. With a working hypothesis that urban adaptation is associated with sustainable development in practice, we examine a dataset of urban projects addressing climate change and sustainability challenges. By investigating the cities' reported progress in implementing measures addressing the rising urban problems as well as environmental threats, we seek to provide empirical evidence of the alignment between urban adaptation measures and sustainable development. More specific research questions and aligned research methods are listed in Table 1.

The paper is organized as follows. The next section reviews previous literature on urban adaptation and sustainable development. Section 3 describes methods and data, then Section 4 demonstrates the analytic results and validates the hypothesis. The final section concludes with the

Table 1
Research design.

	Questions	Methods
1	What is/are the cities' main concern in terms of sustainability? Is adaptation a concerned issue of the cities in their sustainability policies?	Term frequency analysis, Topic modeling
2	How frequently is the topic of CCA discussed among the cities?	Topic ranking analysis
3	Is adaptation associated with (sustainable) development in municipal sustainability policies? Which topic/term is closely linked to CCA?	Network analysis, Topic model visualization (LDAvis) and clustering
4	How and how much are the UN's sustainable development goals aligned with the urban adaptation policies?	Case study: systematic literature review

interpretation and implications of the results.

2. Related work

Urban adaptation refers to a series of adaptation plans and actions for adjusting to existing and anticipated climate change effects in cities. Urban adaptation to climate change has been found to produce development co-benefits through safer, healthier, and more comfortable urban housing and environments, especially for low-income livelihoods (Anguelovski & Carmin, 2011; Burch, 2010; Clapp et al., 2010; Hallegatte et al., 2011; IPCC, 2014; Kousky & Schneider, 2003; Roberts, 2008). Conversely, some argue that prioritization of development policies such as poverty reduction, food security, and disaster risk reduction provide the backbone of a successful adaptation strategy (Measham et al., 2011; Moser & Luers, 2008). However, it is also claimed that adaptation can be regarded as a mere 'environmental' domain in the face of the traditional prioritization of economic goals of a national government, local authorities, and communities (Shaw & Theobald, 2011; Solecki, 2012). Further, addressing climate change requires taking a long-term perspective whereas local authorities are easily driven to make short-term decisions for economic growth and competitiveness (Leichenko, 2011; Moser & Luers, 2008; Pelling & Manuel-Navarrete, 2011; Romero-Lankao & Qin, 2011; Viguié & Hallegatte, 2012).

The challenges of information, institutional fragmentation, and lack of resources also lead to a situation where climate agenda is merely added on to the existing policy regime (Kithiia, 2010; Kithiia & Dowling, 2010; Mees & Driessen, 2011; Roberts, 2008; Sánchez-Rodríguez, 2009). However, adaptation can be institutionalized in local policies by different forces of different stakeholders. As defined by Ferrell et al. (2017), "institutionalization relates to legal and societal forces that provide both rewards and punishment to organizations based on stakeholder evaluations of specific conduct … deviations from expected conduct are often considered ethical issues and are therefore a concern to stakeholders (Ferrell et al., 2017: 86)." Thus, the institutionalization of adaptation by local governments, businesses and communities includes laws, culture and industry practices that reward CCA behavior.

Nevertheless, many researchers studied the linkage between urban adaptation and sustainable development. Chu et al., (2017) studied different alignments of adaptation planning with development needs and found out urban adaptation strategies tackle social vulnerability and equity problems. However, the researchers explored only three example cities, Durban, South Africa; Indore, India; and Medellin, Columbia to see how the planning process can work with large urban political-economic forces. Anguelovski et al. (2018) evaluated whether particular adaptation plans result in the promised outcomes of inclusive and far-reaching sustainable development. However, they narrowed the scope of their study of adaptation plans for urban greening alone, seeking to reveal urban interventions for green space created new dynamics of exclusion, polarization, and segregation. With a broader concept of adaptation, Viguié and Hallegatte (2012) conducted a multicriteria analysis to demonstrate the positive interactions between urban climate policies and other development policy goals, but they focused on three urban policies of greenbelt, zoning, and transportation subsidies. In sum, most of the previous research on urban adaptation and development were case studies on selective cities or projects. As a result, the utilization of a small number of cases in trying to understand a broad concept of CCA has so far in research outcomes that indicate different answers to a similar question, and existing urban adaptation research lacks an aggregated scale of research for discussing urban adaptation and development at a national or global level.

While the main problem in (urban) adaptation research is data, the 'messiness of adaptation' is also pointed out as a reason for the difficulty of adaptation tracking (Berrang-Ford et al., 2011, 2014, 2015; Ford et al., 2013, 2015, 2016). Adaptation is conceptually messier than mitigation, which is principally measured by CO_2 emissions, as what is to be counted as 'adaptation' is often debated in the absence of measurable indicators or outcomes (Dupuis & Biesbroek, 2013). Another challenge is the lack of empirical data on urban adaptation. Existing urban data are mostly incoherent, inconsistent, or insufficiently tailored for quantitative research purposes. In this regard, the absence of appropriate data sources for adaptation tracking is claimed to be the major obstacle for understanding adaptation (Ford et al., 2016). To tackle this problem, some research utilized non-numeric data sources which can better represent adaptation practices (Berrang-Ford et al., 2011; Boussalis et al., 2019; Ford et al., 2015; Geneletti & Zardo, 2016; Lesnikowski et al., 2019; Sacchelli, Fabbrizzi, Menghini, 2016a, 2016b), yet they did not necessarily address the question of urban adaptation from a development perspective (Table 2).

3. Methodology

As we went through the literature in the previous chapter, a major problem that many urban adaptation studies have is incurred by the limited scope and availability of urban adaptation data. In order to overcome the issue, several scholars made attempts to utilize the data from media, policy documents, and other grey literature by carrying out the methodologies of content analysis or systematic review (Araos et al., 2016; Berrang-Ford et al., 2011, 2014, 2015; Ford et al., 2015; Geneletti & Zardo, 2016; Handayani et al., 2019; Lesnikowski et al., 2019 and 2020; Palutikof et al., 2019; Sherman et al., 2016).

This study employs text mining techniques and a machine-learning topic model approach to understand urban adaptation practices. The goal is to understand how a broad class of urban governments have or have not connected climate adaptation and sustainable development as they try to improve the circumstances for their citizens. To this end, we have applied the most common topic model algorithm Latent Dirichlet Allocation (LDA) to a collection of 400 best practices of urban projects from the C40 global network. Coupled with multidimensional scaling and visualization techniques, the approach is expected to determine whether urban adaptation is one of the significant policy agenda for sustainable development for these cities.

3.1. Method

3.1.1. LDA topic model

LDA modeling is an unsupervised algorithm that infers the unknown patterns in the semantic structures from an observed body of texts. Based on a Bayesian theorem, this iterative process computes the posterior distribution of the hidden variables (topic distribution) from the observed ones (word distribution). With this model, one can explore the large store of textual or narrative data and discover hidden themes in the documents. The study is conducted with 'LDA' and 'topicmodel' packages in the program R, following the definitions and the assumptions suggested by Blei et al. (2003).

Table 2
Examples of using grey literature.

Author (Year)	Method	Data	Result
Berrang-Ford et al. (2011)	Systematic literature review	A thousand peer-reviewed articles in the Web of Science	Explored the magnitude of adaptation challenges and the current status of adaptation works.
Boussalis et al. (2019)	Topic model (LDA); multilevel logistic regression	Op-eds, articles, blogs, policy reports, speech transcripts, etc.	Updated the literature of conservative think tanks; revealed the link between policy-related topics and counter-claims for climate skepticism
Ford et al. (2015)	Systematic literature review	100 peer-reviewed articles, 27 National Communications, 161 grey literatures	Preliminary insights on how adaptation is taking place at a general level, in 47 countries.
Geneletti & Zardo, 2016	Content analysis	Planning documents of 14 European cities	Investigated Ecosystem-based Adaptation (EbA) measures implemented in the European region.
Lesnikowski et al. (2019)	Topic model (LDA)	Speeches in COP (2010–2016); Canadian city council meeting records	Revealed how adaptation is discussed among the political leaders and decision-makers
Sacchelli, Fabbrizzi, Menghini (2016a, 2016b)	Quantitative literature review; multidimensional scaling	Web of Science (WoS), Scopus and Elsevier databases	Analyzed climate change impacts on wine sector; found the high frequency of 'climate change' and 'sustainable development'

3.1.1.1. Definitions.

a. A word is the basic unit of discrete data, defined to be an item from a vocabulary indexed by {1, …, V}. The v^{th} word in the vocabulary is represented by a V-vector w such that $w^v = 1$ and $w^u = 0$ for $u \neq v$.

b. A document is a sequence of N words denoted by $w = (w_1, w_2, \ldots, w_N)$, where w_n is the n^{th} word in the sequence.

c. A corpus is a collection of M documents denoted by $D = \{w_1, w_2, \ldots, w_M\}$.

3.1.1.2. Model specification. For LDA, the generative process for each document w in a corpus D containing N words, w_i consists of the following three steps:

a. The term distribution β is determined for each topic by $\beta \sim$ Dirichlet (δ).
b. The proportions θ of the topic distribution for the document were determined by $\theta \sim$ Dirichlet(α).
c. For each of the N words w_i

i) Choose a topic $z_i \sim$ Multinomial (θ).

ii) Choose a word w_i from a multinomial probability distribution conditioned on the topic z_i, $p(w_i \mid z_i, \beta)$, where β is the term distribution of topics and contains the probability of a word occurring in a given topic.

3.1.1.3. Assumptions. The LDA assumes "all the documents in the collection share the same set of topics but each document exhibits those topics in different proportions (Blei et al., 2003)."

a. Bag of words: analyses focus on individual words ignoring structures (e.g. word position, ordering) and semantic relationships (e.g. synonym, hypernym).
b. Prior parameters: For fitting the model, the number of topics needs to be fixed a priori.

Based on the second assumption (b), the model begins with the selection of K, the number of topics. Finding an optimal value for K is critical to fit the model (Airoldi et al., 2010; AlSumait et al., 2009; Lynam, 2016; Panichella et al., 2013). If the K value is too small, the corpus is divided into a few general semantic topics while the bigger K allows a high degree of detail from the model output. It is the trade-off between granularity and interpretability that affects the decision of K-means. The process of choosing K is presented in the next section, Results and Validation (Fig. 1).

3.1.2. Multidimensional scaling and cluster analysis

Visualization helps the interpretation of results. Effective visualization offers a tool for analysts to make inferences about the data through the lens of a model abstraction (Chuang, Manning, et al., 2012; Chuang, Ramage, et al., 2012; Fortuna et al., 2005). Particularly due to the wide adoption of big data in different fields of study, there is a general agreement that visualization can support and enhance the interpretability of results (Gardner et al., 2010; Chaney & Blei, 2021; Chuang, Manning, et al., 2012; Gretarsson et al., 2011; Sievert & Shirley, 2014). In this study, we visualize LDA results by using a multidimensional scaling method to extend the analysis of topic modeling and illustrate the results of the analysis for increased interpretability.

For the multidimensional scaling and cluster analysis, we use a web-based tool LDAvis, available with "LDAvis" package in R. This tool provides an interactive visualization of topics upon the configuration set by a researcher. On one side of the displayed layout, a spatial map of the topics depicts inter-topic differences computed from the Jensen-Shannon divergence between topics. With this map, the study can do a cluster analysis and tell if one topic is related to another and how closely they are related. On the other side of the layout, a bar graph provides the frequency of terms over the topics as well as the term frequency over the corpus. The method supports an intuitive understanding of the topics and words.

3.1.3. Data

As noted previously, the data used for this study are obtained from the C40 network, a global organization of 96 megacities (as of 2019) that are committed to addressing climate change. The study leverages the data from the collection of Cities100, a shared initiative by the C40 and Sustainia to present innovative urban projects for a resilient and low-

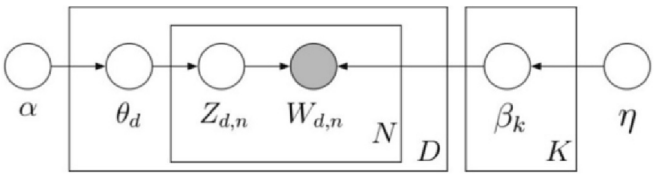


Fig. 1. LDA Topic Model
Source: Blei et al. (2003).

carbon sustainable future. The publication of Cities100 first began in 2015, and four sets of publications covering the year 2015–2017 and 2019 are available as of today. Each project description is 1–2 pages long, summing up a total of 160–230 pages for an entire document. We use these documents because they are the selected successful cases of urban sustainability projects. The data may not encompass all the developing and developed cities around the world due to the limited coverage of the C40 network, but it will still be valid and useful for seeking key trends and themes of global cities' actions toward resilient and sustainable development. Table 3 summarizes the description of the data.

3.1.3.1. Preprocessing the data. The collected set of textual documents is to be pre-processed for statistical analysis because the extracted linguistic data are too raw to run the model. A standardized procedure of preprocessing includes tokenization, lowercase conversion, stopwords and non-words removal, and stemming. For this procedure, we use the 'quanteda' package in R.

3.1.3.2. N-gram transformation. After disposing of all the meaningless elements and unnecessary terms in the corpus, we identify n-grams to transform them into single units of analysis and then make them vectorized for analysis. In Natural Language Processing (NLP), an n-gram is a continuous sequence of *N* words and examining n-grams captures the structure and the context of the dataset.

The first worthwhile case is the proper nouns indicating a particular region. In our texts, due to the characteristics of the source of data, a number of city and country names appear, many of which are comprised of two or more words. For example, three individual terms "new", "york" and "city" represent de-facto one term called "New York City". Therefore, these location names are recognized as a single unit of analysis.

The next case is technical terms and other proper nouns. Many of them, such as climate change, urban heat islands, metric ton, and sea-level rise, are subject to the n-gram transformation. At this stage, it is helpful to search out bigrams and trigrams with high frequency by using the *tokens_ngrams()* function of the 'quanteda' library. Because multiple layers of n-gram transformation can occur at the same time, we need to avoid the collapse and compound of having too many n-grams. For example, "reduc_co2_emiss_reduct" is the result of combining multiple bigrams "reduc_co2", "co2_emiss", and "emiss_reduct", thus asking a researcher's decision call on what n-grams should remain to be combined while others not.

To further examine the relationship between terms, the network analysis method also demonstrates the connection between the tokens, giving hints to make n-grams (see Fig. 2). In sum, a researcher must identify n-grams with the assistance of both frequency charts and a network analysis to distinguish stronger linkages between bigrams and trigrams. In the end, it is the researcher's judgment call to separate eligible n-grams for transformation from simply highly correlated words. The decision must reflect his or her own research objectives.

Consequently, 121 bigrams and 10 trigrams are identified for n-gram transformation. The following Table 4 contains our list of selected n-grams that were transformed.

3.1.3.3. Removing sparse terms. Lastly, terms with high sparsity are eliminated to prevent them from distorting the analysis. At the end of the data preprocessing procedure, we obtain a large bag of 5105 unique terms (174,112 words in total) from 400 documents, stored in the document-term matrix (DTM). A term having many "zeros" in its column in the DTM is called "sparse term", meaning the term occurs in few documents. Since text analysis is fundamentally based on the frequency of terms, terms with high sparsity shall be identified as outliers. By removing the terms which individually have a sparsity of 97 % or higher, by a rule of thumb, we obtain a matrix of 926 unique terms (Non-sparse entries: 41,383 / Sparse entries: 329,017) consequently, with a decreased 89 % for total sparsity.

Table 3
Description of data.

Year(s)	2015, 2016, 2017, and 2019
Number of documents	400
Number of cities	140
Number of countries	50
Regional distribution	North America (29 %), East Asia & Pacific (21 %), Europe & Central Asia (19 %), Latin America & Caribbean (15 %), Sub-Saharan Africa (11 %), South Asia (4 %), and Middle East & North Africa (1 %)
Economic distribution	High-income (62 %), Upper-middle-income (28 %), Lower-middle-income (6 %), and Low-income (4 %)

Note: Categorized by World Bank list of economies (June, 2020)

4. Results and validation

This section presents the results from applying the methodology described in the previous section and validates the results through a close reading of the original literature.

4.1. LDA topic model

4.1.1. Determining K

For determining the number of topics, K, researchers have explored several quantitative and qualitative methods, of which frequently discussed and used are perplexity, cross-validation, and topic coherence (Boussalis & Coan, 2016; Griffiths & Steyvers, 2004; Grün & Hornik, 2011; Lesnikowski et al., 2019; Lynam, 2016; Roberts et al., 2014; Taddy, 2011; Teh et al., 2006; Wallach, Mimno, et al., 2009; Wallach, Murray, et al., 2009). However, on the dataset of this study, none of the above-mentioned methods produced a valid result for finding K. As shown in Fig. 3(a), all three approaches do not reach a limit of sequences or a flat area in convergence or divergence graph(s), which would otherwise be a clue for optimal K. Extending the testing range of K, i.e., exceeding 100, may provide the clue, but in that case, it will fail to meet the capability of human interpretation as criticized (Chang et al., 2009; Krasnov & Sen, 2019). Alternatively, we used an R command *FindTopicsNumber()* of an 'ldatuning' library to achieve the grounds for deriving an optimal K value. Fig. 3(b) indicates the K value set to be 17 by comparing four given metrics –Griffiths2004, CaoJuan2009, Arun2010 and Deveaud2014.

4.1.2. Discovery of topics

With K determined as 17, latent topics are discovered by computing the iterative LDA model with Gibbs sampling. As a result, the fitted LDA model produces a list of terms that are most relevant to each of the 17 topics with high frequency, the terms that in turn represent a distinctive theme of each topic (see Table 5).

For Topic 1 labeled "waste management", terms indicate the issues around the process of collecting, recycling, and composting wastes. Topic 2 "financing" is explained by terms like investment, fund, capital, cost, finance, and market. While Topic 3 explicitly discusses educational projects for schools around the subject of sustainability and environmental issues, Topic 4 labeled "sustainable development" deals with different development projects for green growth and sustainable development. Topic 5 refers to the transportation system for improving mobility, and Topic 6 discusses cities' plans and strategies for achieving climate goals. Topic 7 addresses the theme of "community support", for example, supporting low-income families and vulnerable communities with housing or job training. Topic 8 and Topic 9 are labeled "renewable energy" and "partnership", respectively. And, Topic 10 contains terms

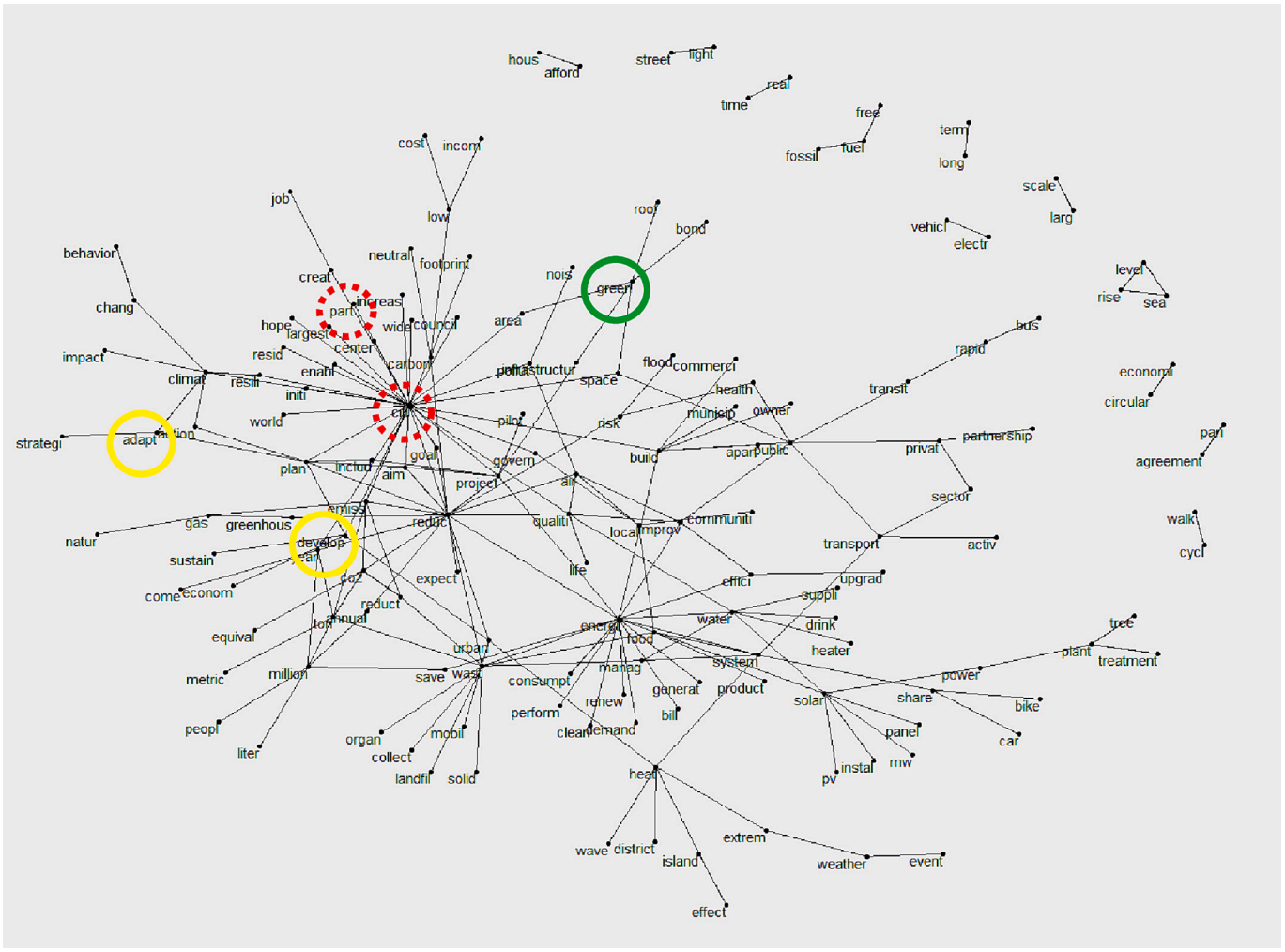


Fig. 2. Network of Bigrams

Note: The term "green" (green circle) is connected to the words "area", "bond", "infrastructur*" "roof" and "space," implying the varied meaning of "green" in different domains. Meanwhile, even a highly connected link between "citi" and "part" (red circles) has no substantial meaning in this study. The word "develop*" appears to be indirectly connected to the word "adapt*" (yellow circles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

like "flood", "resili*", "climat_chang*", "adapt*", and "sea_level_ris*", telling the issue of building resilience and protection against increased flooding risks due to potential sea-level rise, stormwater, and other extreme events. The topic seems to be of our interest and thus labeled as "adaptation". Topic 11, 12 and 13 are addressing energy-efficient buildings, air quality schemes, and securing green areas. Topic 14 is delineated by terms related to water, and Topic 15 is "engagement" as it has terms like participation, engagement, and campaign. Topic 16 addresses a smart data system and finally Topic 17 refers to the issue of carbon emissions.

To further examine the interested topics, Topic 4 and Topic 10, a couple of examples for each topic are selected and studied with the data analytics tool. For Topic 4, two documents are selected as exemplary cases, the case of Qingdao (text275) and the case of Guangzhou (text146), and for Topic 10, the case of New York City (text119) and the case of Qingdao (text353) are chosen. These four cases are selected based on the location and the size of the cities as well as the topic proportion. All the areas are characterized by their large population and the coastal position, three of which are the major cities of China and the other is of the US. Below are the 50 keywords extracted from each two groups of sample cases. Compared with Table 5, visualized terms for Topic 4 in Fig. 4(a) seem to allude the contents of selected two cases of China has a slightly different focus on the theme of green growth and sustainable development. Still, the most important keywords for this topic are all present, such as "growth", "develop*", and "green". On the other hand, terms for Topic 10 shown in Fig. 4(b) appear relevant to the labeled topic of adaptation in Table 5.

When closely looking to the original documents, the identified topics by LDA are validated with higher degree. Cases of Qingdao and Guangzhou are dealing with the green growth plan for decoupling carbon emissions from economic development. Both plans include industrial planning, transportation, low-carbon buildings, and technologies for energy efficiency, employment opportunities, improved air and water qualities and well-being of citizens. These plans do not decisively touch upon reorganizing the urban landscape ("area", "district", "space" or "park" in Table 5) but do deal with the green growth initiative which encourages curbing carbon emissions while maintaining development, as described by "Qingdao has established a close connection between its economic development target and mitigation target over the short, medium, and long term (C40)" for instance. Cases of New York City and Qingdao for Topic 10 are, meanwhile, similarly taking adaptation instruments. While NYC conducts a series of studies to assess future flood risks, Qingdao has built a scientific model to quantify large-scale risks such as coastal flooding, storm surges, and typhoons. Both cities in coastal position attempt to assess climate change risks for urban resilience.

Table 4
Selected N-grams in Cities100 (2015– 2019).

	Examples
Technical and Scientific Terms	"action plan", "adapt plan", "adapt strategi", "afford hous", "air pollut", "air qualiti", "apart build", "behavior chang", "bike share", "build energi", "build owner", "bus rapid transit", "cap trade scheme", "car free day", "car share", "carbon emiss", "carbon footprint", "carbon neutral", "circular economi", "citi aim", "citi center", "citi council", "citi goal", "citi govern", "citi plan", "citi resid", "citi wide","clean energi", "climat action", "climat adapt", "climat chang", "climat resili", "co2 emiss", "co2 equival", "commerci build", "creat job", "district cool system", "district heat", "drink water", "econom develop", "effici improv", "effici upgrad", "electr vehicl", "energi bill", "energi consumpt", "energi demand", "energi effici", "energi generat","energi perform", "energi project", "energi save", "energi system", "energi water", "extrem heat", "extrem weather", "flood risk", "food product", "food wast", "fossil fuel", "green area", "green bond", "green infrastructur", "green roof", "green space", "greenhous gas", "health risk", "heat system", "heat wave", "larg scale", "largest citi", "local communiti", "local food", "local govern", "long term", "low carbon", "low cost", "low incom", "manag system", "metric ton", "million liter", "million peopl", "million year", "municip build","nation park", "natur gas", "nois pollut", "organ wast", "pari agreement", "pilot project", "plant tree", "power plant", "privat sector", "public build", "public health", "public privat", "public space", "public transit", "public transport", "qualiti life", "rainwater harvest system", "rapid transit", "real time", "renew energi", "sea level rise", "set back line", "solar energi", "solar panel", "solar power", "solar pv", "solar water heater", "solid wast", "street light", "sustain develop", "ton wast day", "ton wast", "ton year", "transport sector", "transport system", "treatment plant", "tree plant", "urban develop", "urban heat island", "wast collect", "wast energi", "wast landfil", "wast manag", "wast reduct","water manag", "water qualiti", "water suppli", "weather event"

In conclusion, CCA was discovered as one of the 17 meaningful topics in our urban documents by the method of topic modeling. The relevant terms delineating the topic of adaptation (Topic 10) connote the nature of adaptation to climate change, mainly regarding upfront measures against urgent climate threats (See Table 5 and Fig. 4(b)).

4.1.3. Topic ranking

Based on the term frequency measure, we also computed how frequently the topics occur (See Table 6 for the result). Over the entire corpus, the topic of climate action (Topic 6) turned out to have the highest frequency, followed by the topics of transport (Topic 5), building (Topic 11), adaptation (Topic 10) and renewable energy (Topic 8). However, the difference between the topic frequency scores is not large. The highest frequency score is 6.75 %, indicating that the top-ranked topic of climate action accounts for less than 7 % of the entire data, while the lowest frequency score is 5.18 % for the topic of data system (Topic 16). Besides, when the score is measured by the number of documents where the topic is predominant, the topic of waste management (Topic 1) takes the first place and the same topics (Topic 5, 10, 8 and 11 – ordered by the rank) are named as top 5 frequent topics. Out of 400 documents, 50 documents primarily discuss the topic of waste management. In other words, 12.5 % of the cases put a focus on the waste management issue whereas the topic of climate action and all the other topics are widely encompassed across all the documents. In the case of the adaptation topic, it is 38 documents (9.5 %) where the adaption agenda is most discussed.

4.2. Visualization of multidimensional scaling

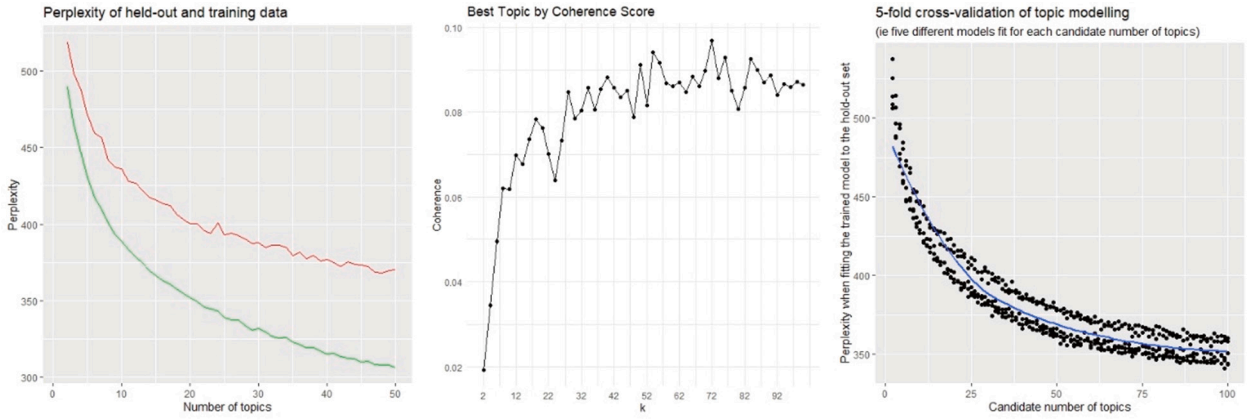
A multidimensional scaling approach on the topic model outcome reveals significant findings on the qualitative data with the assistance of a visualization tool. Fig. 5 is an output of applying an LDAvis to the fitted model. On the left panel, there are seventeen light-blue circles spread on the Intertopic Distance Map which denote seventeen topics revealed from the LDA. The size of these circles is proportional to the prevalence of each topic within the corpus. The distance between the circles displays how similar or distant the topics are to each other. On this map in Fig. 5, most topics are gathered in the second quadrant, showing a moderate connection among the topics. It seems many urban projects around the different topics are more or less related or similar to each other.

Assuming there is a line crossing zero ('0') to the upper-right direction in the middle of the chart, there are three other clusters or cases on the lower-right side of the line. One cluster is shown as two overlapping circles in the first quadrant, a close relevance between Topic 11 (Building) and Topic 17 (Emissions). In this case, "emis*" and "reduc*" are the words with the most overlap between these topics. This implies an overlap between the cities' efforts to construct and maintain sustainable and energy-efficient buildings and the agenda of reducing carbon emissions. Another cluster is in the fourth quadrant between Topic 1 (Waste Management), Topic 3 (Education), and Topic 15 (Engagement). This cluster suggests a similarity between the three topics. The topic of waste management (Topic 1), which has the biggest circle on the map, is adjacent to the topic of engagement (Topic 15) and has a lot in common with the topic of education (Topic 3). Therefore, having food wastes collected and recycled or processed seems to be closely related to the programs for educating students and citizens with knowledge about sustainability and the environment. These programs are likely to be carried out collaboratively and complementarily. The last type is an isolated class. Topic 7 (Community Support) is located alone on the y-axis and Topic 8 (Renewable Energy) is also separate on the x-axis between the clusters. Implementing programs for supporting homeless residents and low-income households and promoting more renewable energy sources both appear to be independent domains on average.

Looking closely at the topic of adaptation (Topic 10), we find that the concerned topic circle has an intersection with the topic of green space (Topic 13). Given that vegetation is one of the typical and effective adaptation measures to control the surface water in urban areas, it is a reasonable outcome that Topic 10 and Topic 13 are related. More importantly, Topic 10 is in a cluster with the topics of sustainable development (Topic 4), transportation (Topic 5), partnership (Topic 9), green space (Topic 13) and data system (Topic 16). Of particular note is the short distance between Topic 10 and Topic 4, which demonstrates a close relationship between the cities' action for CCA and their agenda of green growth and sustainable development. On the other hand, the topic of adaptation (Topic 10) seems to be averagely far from the issues of carbon emissions (Topic 17), energy-efficient buildings (Topic 11), and renewable energy (Topic 8).

Another feature of the LDAvis output is the display of the relevant terms on the right plane of its layout. For the topic selected (Topic 10 on this paper), the graph shows the 30 most frequent terms for the topic of adaptation in two ways. The blue bar represents the frequency of a term in the whole corpus while the red bar does the topic-specific frequency of a term. Many of the terms having no or little blue bars appear to be highly important for this topic alone. For Topic 10, these exclusive terms are "flood", "resili*", "risk", "adapt*", "coastal", "assess*", "damage*", "storm", "sea_level_rise" and "rain". In other words, they are the elements that explain nothing but the topic of adaptation in 400 documents from 140 cities. The fact that most of the terms lying on a higher list of terms in the bar chart are topic-specific terms is important because this demonstrates the exclusiveness of the topic. By the order of terms enlisted, the term "flood" is found to be the most representing term for the theme of CCA, and other terms like resilience ("resili*") and "risk" also highly contribute to the writing about the topic. This is the same result that was derived from the previous finding in the wordcloud (Fig. 4).

(a) Using Perplexity, Coherence Score, and Cross Validation methods



(b) Using R command *FindTopicNumber()*

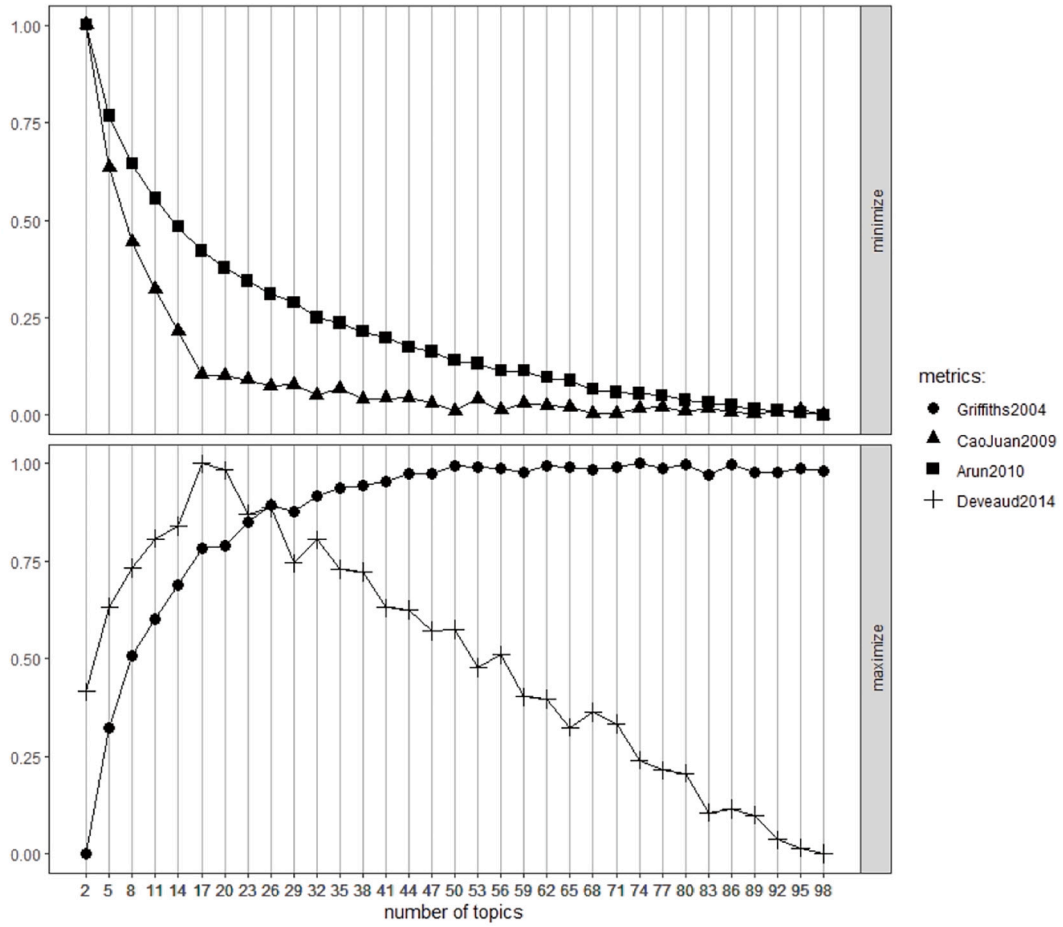


Fig. 3. Optimal K selection
(a) Using Perplexity, Coherence Score, and Cross Validation methods
(b) Using R command *FindTopicNumber()*
Note: Any of three plots in (a) do not see a limit of sequences in each given range. The results do not change in extended ranges. In plot (b), the optimal K value is 17 based on CaoJuan2009 and Deveaud2014. Griffiths2004 and Arun2010 metrics are not informative in this study.

4.3. Validation – discussion of topic 10

For validation purposes, we selected a handful number of the documents focusing on adaptation (Topic 10) and examined the source documents under the framework of 5W1H questions – Who/Where, When, Why, What, and How (also called "Kipling Method").

4.3.1. Selection of key adaptation documents

The distribution of documents, based on the probability of Topic 10, is positively skewed with a long tail. No document is 100 % devoted to this topic, but all documents have at least 0.958 % of their discussion contributed to the adaptation agenda. Averagely, around 6 % of the urban project documents are likely to address the topic of adaptation, and yet, most of the documents are irrelevant for our detailed analysis

Table 5
Topic model result (K = 17).

	Topic	List of Terms
1	waste management	wast recycl food landfil collect reduc process resourc compost plant food_wast ton organ facil product generat site wast_manag produc increas
2	financing	invest year fund citi public green million capit pari financ cost initi annual signific billion financi make region market hope
3	education	project includ reduc school addit sustain environment result share educ innov impact issu learn high social student particip scale key
4	sustainable development	develop park resid sustain neighborhood construct district area green improv activ opportun focus space growth hous social econom plan creat
5	transportation	transport car mobil citi cycl increas public_transport bike traffic transit bicycl km street system activ road improv commut travel walk
6	climate action	plan citi strategi climat includ goal action aim achiev ensur climat_chang target emiss climat_action reduct sector base carbon_neutral futur set
7	community support	communiti program resid engag home support provid benefit social increas famili job access train offer peopl low_incom month improv vulner
8	renewable energy	energi electr power instal renew_energi solar renew generat suppli municip sourc mw fossil_fuel price local wind provid technolog develop coal
9	partnership	citi work local busi municip effort collabor govern approach partnership part integr result solut relat creat lead led partner opportun
10	adaptation	flood resili climat_chang risk protect increas develop impact adapt infrastructur vulner coastal event citi effect assess plan damag mitig storm
11	building	build energi program retrofit energi_effici save reduc improv reduct emiss effici upgrad million properti requir owner cost hous annual energi_consumpt
12	air pollution	citi year london polici carbon scheme low_carbon emiss reduct grow air_qualiti air_pollut carbon_emiss level million target standard industri pollut high
13	green space	citi urban improv area natur garden increas green local health tree green_space creat restor land part m2 green_infrastructur ecosystem urban_heat_island
14	water management	water citi reduc prevent manag system provid year region secur ensur resourc save due sourc demand rainwat river cost combin
15	engagement	citizen initi public creat aim reduc encourag particip campaign involv engag servic free challeng provid promot inform chang reach sustain
16	data system	citi system heat enabl data tool reduc smart inform cool resid center monitor cost network map base launch track mak
17	emissions	emiss reduc co2_emiss co2 ton vehicl electr expect save greenhous_gas fuel oper buse compani reduct million fleet drive ev replac

Note: The topics list is attained from the LDA result run by Gibbs sampling method with K = 17 (seed = 202).

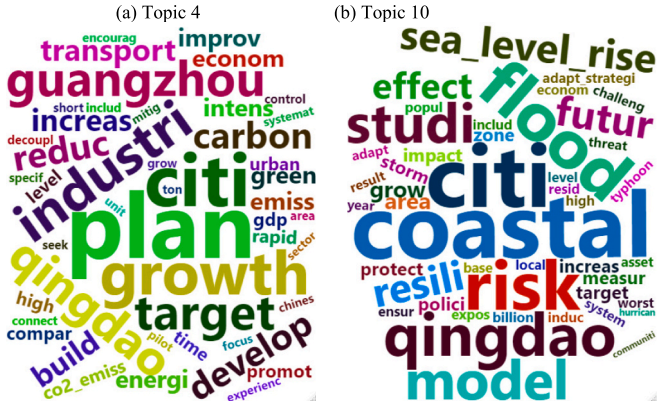


Fig. 4. Wordclouds of sample documents ($N = 50$).

Table 6
Topic ranking.

Corpus-wide Topic Frequency				In-Document Topic Frequency		
Score	Topic Label	Topic	Rank	Topic	Topic Label	Score
6.75 %	climate action	Topic 6	1	Topic 1	waste management	50
6.58 %	transport	Topic 5	2	Topic 5	transport	42
6.48 %	building	Topic 11	3	Topic 10	adaptation	38
6.33 %	adaptation	Topic 10	4	Topic 8	renewable energy	37
6.30 %	renewable energy	Topic 8	5	Topic 11	building	35
6.18 %	emissions	Topic 17	6	Topic 6	climate action	32
5.99 %	waste management	Topic 1	7	Topic 4	sustainable development	28
5.95 %	air pollution	Topic 12	8	Topic 13	green space	25
5.83 %	green space	Topic 13	9	Topic 17	emissions	25
5.81 %	sustainable development	Topic 4	10	Topic 12	air pollution	18
5.62 %	community support	Topic 7	11	Topic 14	water management	16
5.54 %	partnership	Topic 9	12	Topic 16	data system	15
5.48 %	engagement	Topic 15	13	Topic 2	financing	11
5.46 %	financing	Topic 2	14	Topic 15	engagement	10
5.30 %	water management	Topic 14	15	Topic 7	community support	8
5.22 %	education	Topic 3	16	Topic 3	education	5
5.18 %	data system	Topic 16	17	Topic 9	partnership	5
100.00 %			Total			400

for Topic 10. The study initially cut off the top 30 documents addressing Topic 10, expecting that the selected data is meaningful enough to further investigate the issue of adaptation. These data are the observations in the tail of the right-skewed distribution, with at least 17.68 % for topic probability. Nevertheless, having a relatively high probability of the topic discussed does not always mean the prevalence of a topic within the document. For instance, the city of Columbus describes the topic of adaptation at nearly 20 % of its document (text30), but the foremost agenda of the document turned out to be Topic 14 (Water Management), which explains almost 32 % of the document, not Topic 10.

Because the purpose of this part of the analysis is to assess the accuracy of the model through manual reading, only a meaningful number of documents are to be winnowed for further investigation. Among the 30 cases, the top 8 cases appear to address the topic of adaptation as their main agenda, with more than 35 % of the texts committed to the theme. Apparently, there is a noticeable gap between the eighth document and the ninth in terms of the proportion of Topic 10 discussed, between 36 % and 32 %. When comparing the in-document probability of Topic 10 with that of the secondary topic, it becomes more obvious that these eight cases are distinct from the rest. As a consequence, 8 out of 400 documents – text119 (New York City), text353 (Qingdao), text22 (Cape Town), text126 (Belo Horizonte), text122 (Eugene), text255 (San Francisco), text24 (Vancouver), and text252 (New York City) – are designated as key adaptation documents. The detailed information for the process of classifying eight key adaptation documents is available in Table 7.

In these key documents, the topics of sustainable development (Topic 4), community support (Topic 7), and partnership (Topic 9) appear to be

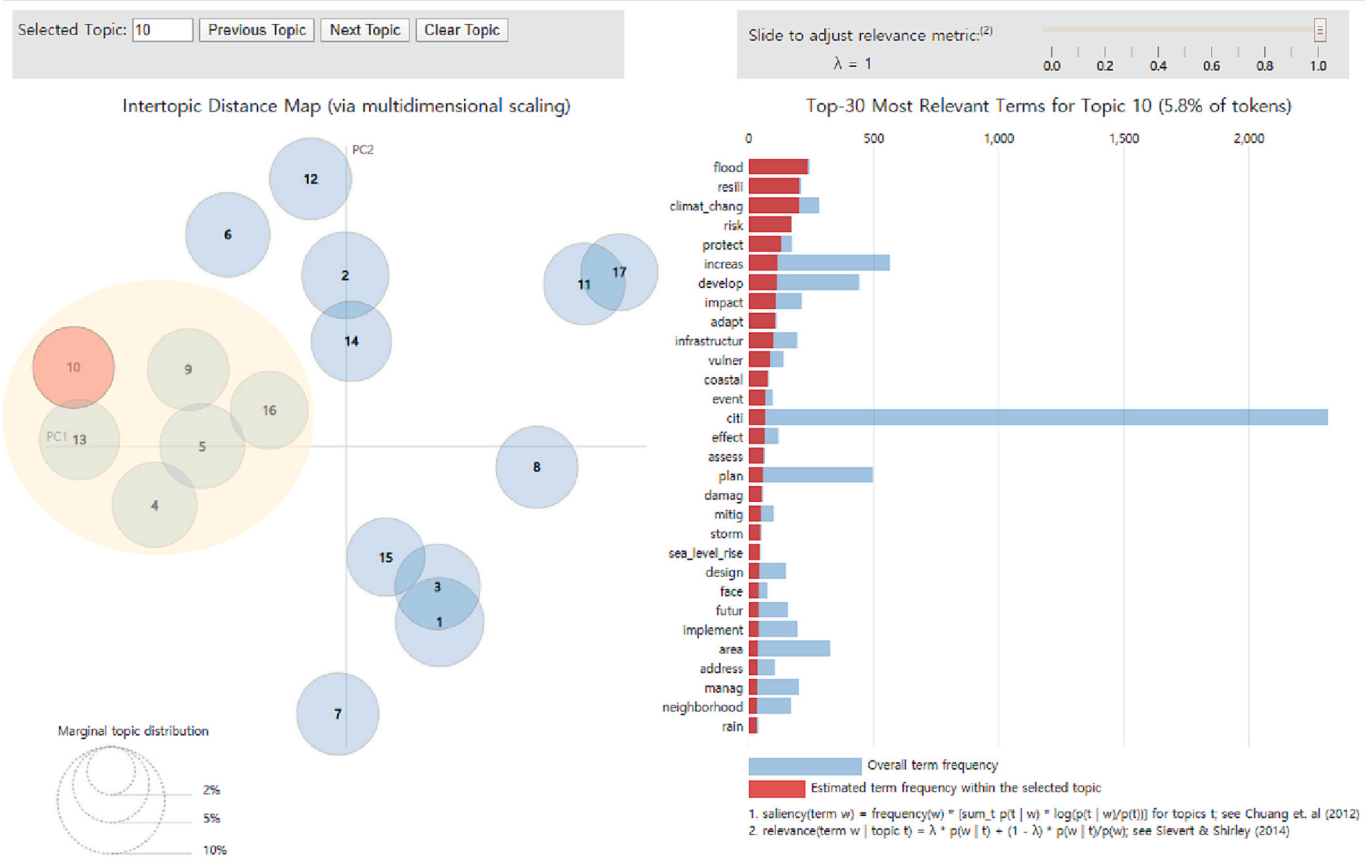


Fig. 5. Layout of LDAvis (Topic 10 selected)
Note: The left panel is a distance map of the topics, and the right panel is a bar graph of individual terms for topic 10 as selected in the left plane. Blue bars and red bars on the chart represent corpus-wide term frequency and topic-specific term frequency, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the most frequent secondary topics, notwithstanding their exceedingly low and thus negligible share in the documents. Interestingly, the appearance of these three topics along with the topic of adaptation is not unfamiliar as they also appeared in a close relationship with adaptation on the distance map of the LDAvis output.

4.3.2. *Review of adaptation documents*

The study made an investigation on individual adaptation documents, with the following questions: a) On what purpose or from what background did they introduce an adaptation strategy?; b) What did they expect from the plans?; and c) Did they acknowledge the link between adaptation and sustainable development before or after carrying out the plans? By manually reading the selected literature, it is expected to see if cities intended to achieve socially and economically sustainable development, not limited to the environmental resilience at the planning stage of adaptation strategies. Additionally, we investigated which of the 17 Sustainable Development Goals of the UN (See Fig. 6) are embedded in each document and hence validate the link between their adaptation action and the sustainable development agenda. The summary of the review is available in Table 8.

As a result of reviewing the individual documents, the study discovered several findings. First, all eight projects were introduced from the background of increased threats of climate change, such as sea-level rise, coastal storms, flooding, and heatwaves. Considering that each city government is a player of the projects, and each project is to build a resilient urban environment against disasters, SDG 11 (Sustainable Cities and Communities) is a goal commonly applied to all cases. Second, while four out of eight documents deal with the project of assessing the vulnerability or risks, the other half suggests conducting studies on land use, planning and designing resilient cities, and implementing a comprehensive plan with technologies. Next, all the documents clearly state economic and social benefits as well as environmental benefits as expected results from taking adaptation action. Although how taking adaptation measures is viewed in each city – i.e. whether they are considered as an active means for the long-term sustainable growth and well-being or merely as a tool for minimizing climate-related risks and damage – appears different, the overall understanding throughout the documents is that adaptation action has paved or is expected to pave the road to sustainable development.

New York City (text119) conducts resilience studies to bring economic and financial benefits to the city though resilient development of the urban areas. By providing information for resilient land use planning, the city expects to see "the future growth and development of these 10 neighborhoods", "businesses to better manage flood risk through resilience investments, protecting 271,000 jobs and encouraging the development of new businesses" and "property owners to take retrofitting measures and reduce their insurance premiums." These expected benefits are aligned with the SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure) and SDG 11.

Also in Qingdao's case (text353), the city aims to come up with an adaptation strategy which not only counts environmental threat of growing typhoons and coastal flooding, but includes socio-economic factors to "better integrate science and policy for outcomes that are environmentally, economically, and socially desirable." However, as written in the document, "By effectively identifying and planning adaptation measures with the city's model, risk of future economic damage from coastal flooding can be minimized," the city doesn't seem to propose its adaptation plan as a pursuit of long-term sustainable

Table 7
Top 30 Cities and Documents around Topic 10.

No	Document	City	Topic	Proportion	2nd Topic	Proportion
1	text119	NEW YORK CITY_6	X10	0.47085	X7	0.097516
2	text353	QINGDAO_3	X10	0.44735	X4	0.097696
3	text22	CAPE TOWN_1	X10	0.40882	X9	0.07246
4	text126	BELO HORIZONTE	X10	0.38741	X9	0.087847
5	text122	EUGENE_1	X10	0.38571	X6	0.074303
6	text255	SAN FRANCISCO_4	X10	0.37129	X7	0.082299
7	text24	VANCOUVER_1	X10	0.3691	X4	0.058294
8	text252	NEW YORK CITY_11	X10	0.35893	X3	0.071504
9	text124	BOSTON_3	X10	0.31993	X9	0.110439
10	text134	NEW YORK CITY_7	X10	0.31575	X3	0.120352
11	text127	TORONTO_3	X10	0.31551	X6	0.138475
12	text21	MELBOURNE_1	X10	0.31041	X9	0.121224
13	text125	DUBAI_1	X10	0.30331	X16	0.280987
14	text29	WASHINGTON, D.C._1	X10	0.30278	X14	0.112299
15	text76	SAN FRANCISCO_1	X10	0.29436	X7	0.16988
16	text346	BOSTON_5	X10	0.27479	X13	0.139076
17	text27	MEXICO CITY	X10	0.25307	X9	0.119739
18	text28	SYDNEY	X10	0.24594	X13	0.125333
19	text243	GIBSONS	X10	0.2316	X13	0.144643
20	text26	NEW ORLEANS	X10	0.22902	X14	0.146013
21	text271	NEW ORLEANS_3	X10	0.21514	X6	0.093598
22	text258	SURREY	X10	0.21324	X13	0.218444
23	text250	NEW ORLEANS_2	X10	0.20498	X7	0.126381
24	text257	STUTTGART	X10	0.20172	X13	0.17142
25	text368	NEW YORK CITY _4	X10	0.19864	X7	0.168965
26	text249	MIAMI BEACH	X10	0.19761	X14	0.150735
27	text30	COLUMBUS	X10	0.19549	X14	0.318899
28	text251	NEW YORK CITY AND COPENHAGEN	X10	0.1815	X3	0.186851
29	text260	WASHINGTON, D.C._7	X10	0.17847	X6	0.140175
30	text369	SALVADOR_3	X10	0.17684	X7	0.30106

Note: The first "proportion" column indicates the probability of Topic 10 discussed within the document. The two right-most columns present the information of the most frequent topic, except for Topic 10, in the document.

Fig. 6. UN Sustainable Development Goals
Source: UN (https://www.un.org/).

growth of the city. Instead, the adaptation measures are suggested as a passive method for sustainable development by reducing disaster risks and damage in this document (SDG 11). In the way that the municipal government and the local university together develop a coastal risk model to establish a science-based adaptation strategy, SDG 17 (Partnerships for the Goals) is also met.

In the meantime, Eugene (text122) and San Francisco (text255) aligned climate change to the public health issue (SDG 3: Good Health and Well-Being). The expected benefits mentioned in the documents include alleviating adverse health effects caused by climate change such as "extreme heat, flood inundation increasing molds, worsening air quality" and wildfire causing respiratory illnesses. Like in the previous case of Qingdao, these benefits can be seen as the following outcomes from mitigating the risks of climate change. However, it is worth taking a look at both documents that also suggest enhancing the adaptive capacity of the cities (SDG 11). For instance, Eugene's climate and hazards vulnerability assessment evaluates 12 essential sectors based on their adaptive capacity and indicates which sectors are the least adaptive

Table 8
Review of Key Adaptation Documents.

Text	Who / Where	When	Why	What	How	Expectations / Benefits	SDGs
119	New York City	2016	Coastal storms (Hurricane Sandy)	Resilience Study	Land use, zoning changes, mapping tool	Protect the 71,500 buildings; protect 271,000 jobs; influence the future growth and development	SDG 8 SDG 9 SDG 11
353	Qingdao	2019	Sea level rise and typhoons	Coastal Risk System Model	Partnership with local university, risk mapping	Protect $600 billion of assets expected to be exposed to coastal flooding by 2070; propose an adaptation strategy for the city; reduce risks by 80 %	SDG 11 SDG 17
22	Cape Town	2015	Uncontrolled coastal development	Coastal Setback Line	Risk-averse planning and regulation	Protect more than 240 km coastline and $5.9 million worth of ecosystem services; improve city resilience and social justice	SDG 8 SDG 10 SDG 11 SDG 14
126	Belo Horizonte	2016	Unevenly distributed climate impacts	Vulnerability Assessment	4 Hotspots identified by vulnerability index for landslides, floods, heat waves, and dengue fever	Enable evidence-based adaptation and resilience projects; improve efficiency of public spending	SDG 10 SDG 11
122	Eugene, Springfield Oregon	2016	Severe rains, earthquakes, flooding, wildfires, etc.	Climate & Hazards Vulnerability Assessment	Evaluating adaptive capacity of 12 essential community sectors	Develop strategies to reduce risks; secure alternative water sources; create updates to floodplain maps.	SDG 3 SDG 11
255	San Francisco	2017	Health risks related to extreme heat days, sea-level rise, storms, and droughts	Climate and Health Adaptation Framework	Comprehensive approach connecting climate change with public health, sensor network, green space, 70+ interventions	Prepare citizens for the consequences of a changing climate; reduce health disparities and climate health impacts; provide real-time monitoring of air quality and weather-related warnings; support vulnerable communities.	SDG 3 SDG 11
24	Vancouver	2015	Coastal flooding and no insurance mechanisms	CCA Strategy; Coastal Flood Risk Assessment	Building bylaws, information-based risk assessment, prioritizing vulnerable populations	Protect 11.8 km2 of land; reduce 4500-truck debris wastes; avoid damage to 800 buildings and displacement of 14,000 residents;	SDG 9 SDG 10 SDG 11
252	New York City	2017	Sea level rise, storm surges, heat waves, extreme heat, intense rain	Climate Resiliency Design Guidelines	Informing constructors of resilient facilities design	Limit urban flooding from extreme precipitation; become increasingly resilient and a more enjoyable place to live	SDG 9 SDG 11 SDG 17

sectors or the most funding needed. In San Francisco's document, the adaptation framework aims "to develop an outreach plan that builds capacity" and to "improve social cohesion" through its various measures.

On the other hand, Belo Horizonte (text126)'s climate policy begins with realizing the problem of "climate change related impacts not distributed equally across the city." In order to reduce this "vulnerability inequality" and achieve socially and economically equitable development in local areas, the city completed vulnerability assessment as an adaptation measure. The aim for this project is therefore clearly stated as "improv[ing] the resilience of vulnerable areas and social groups while improving the efficiency of public spending" and "provid[ing] decision makers with evidence for developing public and private investment in low-income areas disproportionately affected by climate change impacts," which is in line with SDG 10 (Reduced Inequalities) and SDG 11.

Similar to this, the problem of reckless development along the coastline is a starting point for the City of Cape Town (text22) to embark on the project of coastal setback line, which is to ensure development "that does not encroach on the coastal environment." Viewing the coast as "a treasured asset" (SDG 14: Life Below Water), the city enforces legislative measures for resilient coastal planning. The objective of implementing regulatory mechanisms and policies is to encourage sustainable economic growth and enhance social justice, articulated as "the socio-economic potential of the coast can be enhanced through economic development strategies, supported by the Coastal Set back Line, which will benefit previously disadvantaged communities and help redress entrenched social injustices caused by apartheid" (SDG 8 & SDG 10). From this quote, another notable finding is that the city attempts to connect the adaptation plans with its development plans, not isolating them in the environmental sphere.

Vancouver (text24) also considers the increasing risk of climate change disasters not just an environmental problem. The city states "coastal flooding cause[s] serious economic implications for the city" as its background understanding to adopt its comprehensive CCA strategy (SDG 9). By changing the legislation for buildings, the city aims to protect its 11.8 km^2 of land and 14,000 residents, reduce flooding-caused wastes and decrease disaster response costs, thereby "benefit [ing] the community regardless of the degree of sea level rise" (SDG 11) and "prioritizing vulnerable populations" at the same time (SDG 10).

Another document of New York City (text252) deals with the integration of CCA into city planning and infrastructure design strategies. The city provides guidelines for construction companies and designers to make facilities resilient and protect the city from coastal storms, meeting SDG 9, SDG 11 and SDG 17. An interesting difference of New York City from the others is how the concept of adaptation is viewed. In this document, the adaptation plans enable the city "not only [to become] increasingly resilient but also a more enjoyable place to live for millions of New Yorkers." From this quote, the philosophy of New York City

toward adaptation can be glanced that it further allows the city more pleasant.

In summary, our key adaptation documents address the sustainable development agenda. The cities attempt to integrate the idea of building resiliency and sustainability of socio-economic-environmental urban systems into the framework for CCA. The efforts include establishing new rules and legislative systems for resilient constructions, assessing the vulnerability across the region and the communities, adopting digital technologies and geographic tools to better identify the state and distribute useful information as well as increasing green spaces. They touch upon not only environmental sustainability, but social justice, economic benefits, and systematic improvements of urban facilities and others. Although these eight documents are only 2 % of the whole dataset, they themselves demonstrate the urban planning for adaptation have recognized the connection between adaptation and sustainable development.

5. Discussion

This study begins with questions on one of the Intergovernmental Panel on Climate Change (IPCC) assertions in its Fifth Assessment Report (AR5). The report affirms that "urban adaptation provides opportunities for … resilience and sustainable development," which is "highly agreed" but backed by "limited evidence". The research is therefore designed to provide evidence on the municipal practices of climate action. As a result, the analysis of 400 urban projects in this study demonstrates an alignment between adaptation and development in practice, supporting the argument made in the IPCC Report. Below are the key lessons described.

First, the topic of adaptation is identified among the 17 topics that 100 sustainable cities have taken actions for. Using the data analytics method including Latent Dirichlet Allocation (LDA), the study discovers that the cities have dealt with the agenda of CCA as one of the key themes of their projects for sustainability. This analysis result provides an answer to our fundamental question of whether adaptation and sustainable development are aligned in urban practices.

Second, the study finds the topic of climate action is not discussed as a single dominant agenda within individual documents but is widely involved throughout the data. Meanwhile, the topic of waste management is the most popular topic across the cities if measured by the per-document topic prevalence. In summary, it turns out that the topic of adaptation is not pursued by the major cities as a single-most crucial agenda, but this also implies the adaptation topic is more aligned with other issues than the topic of waste management is.

Further, the LDA model reveals the adaptation topic refers to resilience and protection against increasing flood risks and other climate change impacts such as storms in the given data. The study shows that the topic of adaptation is described by the terms including "resili(ence)" and "develop(ment)" in addition to "flood", "climate change", "risk", and "protect". It appears that the matter of resilience and development is also critically recognized when cities address the adaptation agenda.

Another important clue behind the association between adaptation and development is the short distance between Topic 4 and Topic 10 when plotting the 17 topics on the distance map by using the multidimensional scaling (MDS) method. Consequently, the study identifies the adaptation topic is close to the green growth and sustainable development agenda while being distant from the topics of carbon emissions and energy. This indicates adaptation measures are permeated in the cities' plans in close connection with the development agenda whereas they are least aligned with the mitigation measures in urban planning.

Also, an interesting finding from the MDS is the association of the topic of green space with the topic of adaptation. Having a city equipped with more green spaces and infrastructures benefits the community in various ways including health improvements, reducing urban heat islands effect, and increasing biodiversity. It appears to be one measure implemented for adapting the cities to the changing climate, and the measure seems to pave the way for achieving sustainable development within the communities while protecting at the same time.

Lastly, the study conducts a close review of a handful of documents demonstrating the high connection to adaptation to validate the accuracy of the model in order to see how CCA is associated with sustainable development in cities. Out of 400 cases, only 30 cases are found to be dealing with the adaptation topic at a meaningful level. Additionally, 8 documents among them are classified as key adaptation documents in which the topic is more explicitly addressed. In these key adaptation documents, sustainable development issues are present either as a background of planning and/or as an expected or realized outcome of the project.

6. Conclusion

In the most recent IPCC report (AR6) which has become available after this study, the alignment between climate change adaptation, resilience and sustainable development is addressed as a concept of 'Climate Resilient Development (CRD)' (IPCC, 2022: 132, Fig. 1.2). The CRD, an updated concept from Climate-Resilient Pathways (CRP) in IPCC 2014 report (AR5), is suggested as a framework to connect the dots between adaptation, vulnerability, resilience and other key elements to meet the goals of the Paris Agreement and the Sustainable Development Goals. Meanwhile, in cities, it still appears that "the shift… to action in ways that identify and advance synergies and co-benefits of mitigation, adaptation and SDGs has occurred slowly and unevenly (*high confidence*)" (IPCC, 2022: 910).

This paper attempts to find an answer to the question of whether and how CCA and sustainable development are identified and interconnected in urban practices. By applying multiple text mining and data analytics methods on 400 project documents of cities, the study discovers that: first, CCA is mainly discussed as one of the 17 major topics in urban sustainability policies even though the majority of cities have yet to address adaptation as the top 30 cases do (out of 400 cases, 38 cases have CCA as their key agenda). By and large, the adaptation topic matters to the cities toward the goal of sustainability, but it was only meager differences of the frequency scores between the topics indicating there was not an outstandingly discussed issue. Second, the terms 'resilience', 'vulnerability' and 'develop(ment)' appeared as the relevant terms for the topic of adaptation as a result of topic modeling. Since 'sustainable' or 'sustainability' was not included, it is hard to tell the 'develop' here indicates the sustainable development that we are concerned, but the further study of clustering revealed that the topic of green growth and sustainable development is close to the topic of adaptation. Also, as defined earlier in this paper, CCA in practice turns out to bear the meaning of climate risk management for resilience, while keeping distance from the topic of climate mitigation. Lastly, a further review on the selected adaptation cases presented how UN's SDGs are addressed in the adaptation policy documents.

In conclusion, the study provides an example of research to demonstrate how the current actions of local governments can be studied to find the connection between CCA and sustainable development. This paper overcomes the obstacle of data unavailability by treating the grey literature that represents the practices of municipalities with the text mining technique and the machine learning model for data analysis. By incorporating the grey literature as a major data source for statistical analysis, the study also proves the value of topic model analysis over conventional statistical analysis in urban studies. However, using the documents from the C40 network, a US-based organization of globally active cities, the study contains a limitation of not including potential hidden champions of urban sustainable development. Hence, having this research as a beginning step, follow-up research can be developed to explore not only well-known cities' successful cases of urban adaptation but the sustainability projects of cities in less developed countries.

CRediT authorship contribution statement

Saebom Jin: Data curation, Writing-Original draft preparation, Investigation, Revising **Gerald Stokes**: Supervision, Writing-Reviewing. **Clovia Hamilton**: Revising.

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Declaration of competing interest

None.

Data availability

Data will be made available on request.

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