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Urban Informatics and Future Cities

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Editors
S. C. M. Geertman
Faculty of Geosciences
Utrecht University
Utrecht, The Netherlands

Christopher Pettit
City Futures Research Centre
University of New South Wales
Sydney, NSW, Australia

Robert Goodspeed
Taubman College of Architecture
and Urban Planning
University of Michigan
Ann Arbor, MI, USA

Aija Staffans
Department of Built Environment
Aalto University
Helsinki, Finland

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Chapter 24
Planning Support Systems for Long-Term Climate Resilience: A Critical Review

Supriya Krishnan, Nazli Yonca Aydin, and Tina Comes

Abstract As climate change is becoming a reality, there is an increasing demand to improve urban resilience. Planning Support Systems (PSS) enable climate-informed planning. However, previous research confirms difficulties in the uptake of PSS due to their resource-intensive nature and lack of awareness of their usefulness. This chapter aims to make a headway in understanding research priorities and gaps that need to be addressed for PSS to address climate resilience in the long run. To this end, we review the emerging body of knowledge in academia and practice, by conducting a text-mining analysis of academic (n = 36,405) and non-academic (practice) (n = 86) literature on urban planning and climate resilience. We extract trends on climate pressures, infrastructure drivers, and planning responses. A key finding from academic literature is that long-term planning continues to be limited to a few fixed scenarios and places a strong focus on single sector strategies. Practice documents continue to be designed to inform high-level policies, but not spatial plans that require integrated thinking. Our analysis concludes with a research agenda for improving PSS to (1) identify and integrate the full range of variables in the long-term; (2) support selection of appropriate planning responses across multiple infrastructure systems; and (3) improve flexibility in planning by a deeper understanding of temporal aspects such as planning timeframes.

Keywords Urban resilience · Planning support systems · Uncertainty · Urban knowledge systems · Long-term planning · Urban climate adaptation · Machine learning · Literature review · Topic modeling · Academic publishing

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S. Krishnan (✉) · N. Y. Aydin · T. Comes
Resilience Lab, Delft University of Technology, Delft, Netherlands
e-mail: s.krishnan@tudelft.nl

N. Y. Aydin
e-mail: n.y.aydin@tudelft.nl

T. Comes
e-mail: t.comes@tudelft.nl

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24.1 Introduction

Cities are making concentrated efforts to improve their climate resilience. Significant work is being undertaken on resilience frameworks, bioclimatic urban design, nature-based solutions, blue-green masterplans, multifunctional urban spaces, and sector-specific strategies. To improve long-term resilience, urban planning must adapt to rapidly changing constraints and be flexible to continuously integrate evolving insights (Campbell 2006). However, changing demands on cities means that planning is increasingly characterized by uncertainty and complexity that aren't solvable by using conventional methods (Batty 2007). In the context of climate change, long-term planning must consider a scope of 30–100 years which is especially complex since cities must constantly manage unforeseen events that require both incremental and structural changes in the planning process (Balducci 2011). Cities currently develop largely'fixed' masterplans for 5–20 years which focus on immediate development needs. Thinking beyond 20–30 years is a procedural and financial challenge despite availability of climate projections. This why climate projects are often isolated as small or medium-scale initiatives that are not integrated with larger development goals hindering long-term resilience. Hence, the motivation among planners to adopt a long-term planning perspective and use a PSS that enables it has been missing (Berkes 2007).

Long-term planning requires the identification of changing insights and connecting them with decision-making windows within urban planning timeframes. Planning Support Systems (PSS), such as large-scale urban models and visual tools, provide applications to navigate this complexity, deliberate on issues collaboratively (Lieske et al. 2015) and capture the behaviour of urban systems under changing conditions (Batty 2007; Brail and Klosterman 2001; Geertman et al. 2013). However, compared to the advances in the domain, the uptake of PSS in planning has been low due to their resource-intensive nature and inability to acknowledge the constraints of its end-users (Russo et al. 2018; Vonk et al. 2005). Moreover, in the planning process, there is a lack of balance in combining the objectivity (formalism) of large-scale PSS models with the experience and intuitive knowledge of urban planners that guides decisions (Lee Jr 1973; Pelzer et al. 2014).

In this study, we make a headway in understanding research priorities and gaps that must be addressed for PSS to address climate resilience in the long run. To this end, we review the emerging body of knowledge in academia and practice, by conducting a text mining analysis of literature on urban planning and climate resilience. The results are analyzed to identify similarities and variations in consideration of climate and environmental pressures, infrastructure sectors, planning approaches, and understanding of resilience. We precede this with an examination of the merits and demerits of existing PSS applications in climate and resilience to assess overall trends and what areas require work. As compared to previous work, we present a comprehensive overview of the knowledge landscape in academia and practice to highlight how both areas can work collaboratively to improve PSS. We conclude with a research agenda for designing an improved PSS that is useful in accounting for long-term resilience goals.

24.2 Background

Planning has traditionally promoted the creation of fixed plans for the 'here and now' which prioritizes development needs in a 5–20 year timeframe (City of Amsterdam 2012; Greater London Authority 2016; Surat Urban Development Authority 2017). Investments made in this single planning cycle create path dependencies that have far-reaching impacts on infrastructure, land-use and overall urban growth. The dichotomy is that most practitioners would consider a 20–30 year timeframe to be significantly long since rapid unanticipated changes could change the direction of development. However, a timeframe of 5–20 years also provides little incentive for planners to bring in the integration and flexibility required for long-term climate resilience (Roy 2009). Hence, there is a dilemma as well as a gap in methods that can assist planners in accounting for long-term changes and incorporating them within the standard planning cycle.

Due to a large number of stakeholders in the planning process, planners also seek a 'negotiated certainty', which divides the urban problem into different manageable modules or sectors (De Roo and Hillier 2016). Hence, the role of PSS is automatically steered towards sector-specific tools and tools on 'communication and collaboration' as opposed to decoding complexities of planning itself (Pelzer et al. 2014).

The tendency for sector-specific PSS applications also comes from the need to present successful proofs-of-concept. For instance, for blue-green infrastructure, there is the *Adaptation Support Tool (AST)* (Voskamp and Van de Ven 2015), SUSTAIN (Lai et al. 2007) and EPA's National Stormwater Calculator (*EPA. National stormwater calculator* 2012). For transport, there is *Infrastructure Planning Support System (IPSS)* which is used to assess the long-term success of roads by analyzing costs and benefits for climate adaptation. However, it does not account for local knowledge of inundation that causes disruptions (Schweikert et al. 2014). For energy, there is E-GIS which is used for site selection for low carbon urban energy systems (Yeo et al. 2013) and (Aydin et al. 2013) which presents a method for site selection for renewable energy systems. The single sector focus does not lend well to an integrated planning approach that must account for path-dependencies with other sectors.

PSS are also designed to work with a few fixed scenarios. For instance, the Dhaka Metropolitan Development Planning Support System (DMDPSS), demonstrates the benefits of using land-use planning and scenario modeling to manage climate issues, both useful for long-term thinking. However, it constructs two fixed development scenarios and does not discuss the roadblocks in using multiple scenarios (Roy 2009). To manage uncertainties, (Deal et al. 2017) advocates for a PSS with a higher degree of contextual awareness ('sentience') that allows planners to adjust variables and constraints based on a context. There is a gap in systematically identifying and interpreting evolving variables and constraints for planning (Porter and Davoudi 2012; Wilson and Piper 2010).

However, urban planning, especially long-term planning, is characterized as a 'deep uncertainty' problem, which cannot necessarily be solved by identifying an exhaustive range of variables that impact planning. There is no definite method to.evaluate the plan outcomes (Walker et al. 2003). Uncertainties may originate from climate stresses (sea level rise, precipitation, temperature) and shocks (storms, flash floods, heatwaves) and may be compounded due to interactions with socioeconomic, environmental and political variables (Dessai and van der Sluijs 2007) as well as the scale of the urban form itself (Gunderson 2007).

Building a robust plan towards uncertainties requires bringing flexibility into the planning process and understanding inherent flexibility in urban systems (Jabareen 2013; Kwakkel et al. 2016). For instance, road networks, occupation patterns, ecosystems, etc., have their own lifecycles and adaptation rhythms which help determine actions to adapt, retrofit or renew. A systematic understanding of these temporal aspects becomes central in determining planning actions for changing conditions, identify trade-offs and lock-ins to promote resilience. Urban resilience practice hasn't yet presented methods to account for temporal scale resilience trade-offs (Chelleri et al. 2015). Model-based decision support tools like Dynamic Adaptive Policy Pathways (DAPP), that have proven useful for setting long-term policies and short-term actions. But they do not capture the spatial complexity required to inform masterplans (Haasnoot et al. 2019). Methods such as the *Urban layers approach* (Roggema et al. 2012) are enabling the classification of urban systems based on their lifecycles and properties. However, these are at an early stage and PSS can make a valuable contribution in mainstreaming these spatial and temporal aspects into planning. Based on the above review, PSS applications for long-term resilience must potentially fulfill three key requirements (Fig. 24.1):

1. Manage complexity (Geertman 2017): PSS must support planners to identify multiple variables from climate, socio-economics, environment, etc. that

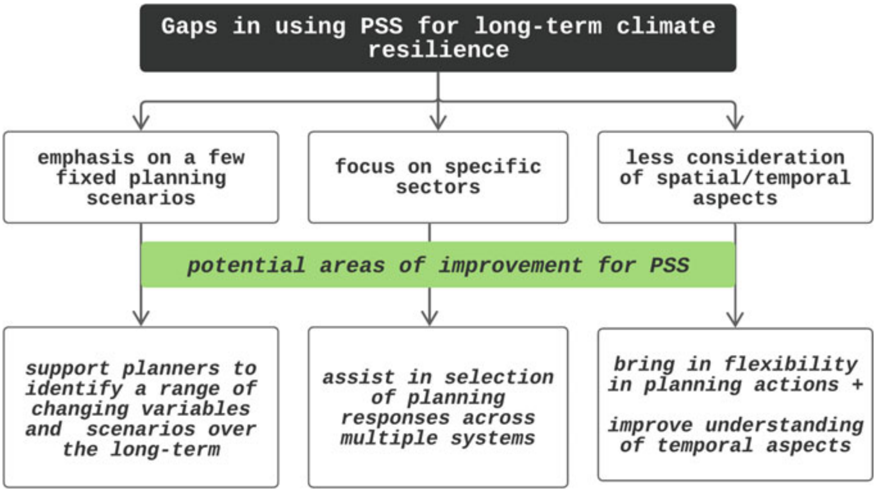

Fig. 24.1 Gaps in using PSS for long-term climate resilience and potential areas for improvement

are constantly changing and select them in a manner that is feasible for implementation.

2. Support selection of planning responses: PSS can assist planners in selecting combinations of planning responses across multiple sectors to scale up resilience goals.
3. Bring in flexibility: Long-term planning calls for a deeper understanding of the temporal aspect of the planning. PSS can help systematically understand planning timeframes as well as lifecycles of components within a plan to work on long-term climate goals within relatively short-term masterplans (Jepson Jr 2011).

24.3 Methodology

The study aims to suggest improvements for PSS to become useful for long-term urban planning for resilience. The methodology comprises two main components (Fig. 24.2): (1) Derive an understanding of emerging themes and trends in the literature on urban planning and climate resilience by conducting a systematic text mining analysis of academic and non-academic (practice) documents; (2) Draw comparisons between the two areas to establish research priorities and conceptual gaps in the implementation of resilience goals. Understanding variations are interesting because we can find areas of synergy and dissonance and how those can be addressed to push boundaries in research and practice. It allows us to reflect on how PSS can play a bigger role in bridging process and knowledge gaps on urban climate resilience.

The PSS domain encompasses a large number of urban components, sectors, and planning approaches. Understanding its knowledge landscape requires a common

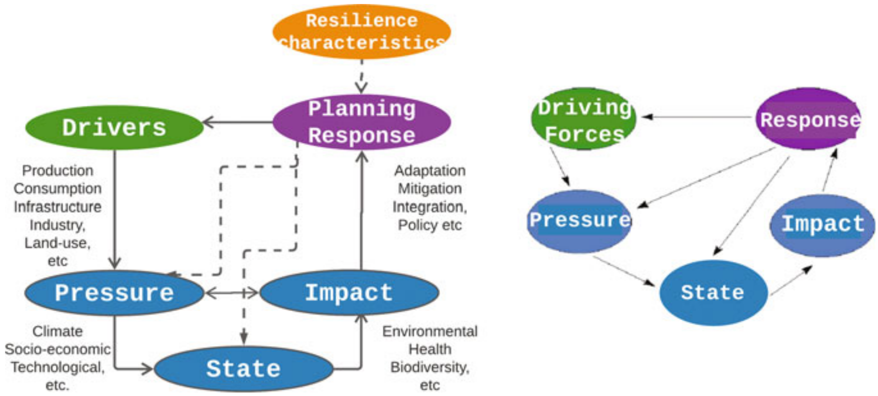

Fig. 24.2 Deriving a common language to analyze academic and practice literature using the DPSIR Framework (right). DPSIR helps in categorising results of text-mining analysis into knowledge categories (streams) representing urban infrastructure systems, external pressures, and causal links between them (Tscherning et al. 2012)

Fig. 24.3 The total corpus of academic and non-academic (practice) literature along with the four knowledge streams used for the analysis identified in Fig. 24.2

language to assess these components and identify links between them. In order to do this, we rely on a widely accepted framework used by planners known as the DPSIR framework which stands for *('Drivers-Pressures-State-Impact-Response').* The DPSIR is a constantly evolving framework that is used to represent the origin and consequences of environmental problems using nodes and causal links (Niemeijer and de Groot 2008). It has been useful in conveying simplified information to a broad range of stakeholders and has been applied for assessment of coastal areas, biodiversity, etc., by the European Environment Agency (EEA), Organisation for Economic Co-operation and Development (OECD), and Dutch National Institute for Public Health and the Environment (RIVM) (OECD and Development 1993).

DPSIR has evolved from three main information categories: *Driving Forces* (economic and infrastructure sectors, human activities), *Impacts* (On ecosystems, human health and functions) and *Responses* (plans, prioritisation, target setting, indicators) which are adapted based on the area of the study. Two additional categories added later are *Pressures* and *State* that are closely related to *Impacts*. For instance, urbanization leads to deforestation leads to air pollution leads to health Impacts. The cause and consequence can be multiple or be interrelated to each other. For this study, we combine these three under one stream. Studies on DPSIR present indicative lists of terms that can be included under each category (Tscherning et al. 2012). We acknowledge the complexity of the real world and that it cannot be classified into simple categories. However, for the purposes of this study, we set out the following knowledge streams for analysis (Fig. 24.3):

1. **Stream 1: Pressures, State and Impacts** (climate triggers, environmental impacts, air quality).
2. **Stream 2: Driving forces** (production, consumption, infrastructure).
3. **Stream 3: Planning Responses and Approaches** (actions, policies, tools).
4. **Stream 4: Resilience characteristics** (self-organization, diversity, flexibility, redundancy). We introduce a fourth stream to explicitly focus on resilience terminology in literature. This is related to Stream 3 but has been analyzed separately (Berkes et al. 2008; Godschalk 2003; Holling 2001).

24.4 Data Collection

This section describes methods of data collection adopted for academic and non-academic literature.

24.4.1 Academic Literature

We developed a search strategy using the following three groups of words: (a) urban planning, (b) climate, and (c) frameworks, and support systems. For each group, we enlisted an exhaustive set of synonyms, similar terms and combined them into a final'search string' (see Table 24.1) which we ran on the online database Scopus (Elsevier 2004). The resulting corpus included publications ranging from urban planning strategies, support systems for climate adaptation to climate frameworks covering risks and uncertainties published between 1900 and 2021. We filtered these to include four publishing avenues: peer-reviewed journals, conference proceedings, book chapters, and reviews. We excluded unrelated domains such as infectious diseases, manufacturing, nanoscience, archaeology, and computational biology. This amounted to a corpus of 37,745 publications (Fig. 24.4).

24.4.2 Non-academic Literature

The urgency among cities to plan for climate change has led to a steadily increasing number of publications by governments, businesses, multilateral development banks, United Nations agencies, etc., on building resilience in general and in specific regions and sectors. These are in the form of guidelines, action plans, strategies, and frameworks which are closely connected to how PSS can be utilized. For a comprehensive overview, it was essential to include this grey literature in our analysis as they constitute a rich and complex source of information. However, there is no rigorous search method for grey literature or a comprehensive database for publications on urban resilience. Moreover, there is no mandated structure or format for such documents, hence the level of detail shows a vast variation. To make our search manageable but intuitive, we adapted the search method developed by (Godin et al. 2015). Our search plan consisted of a combination of terms similar to that used for academic literature. However, these had to be adapted into multiple shorter combinations of words as databases often had different filters and nomenclature for documents. For instance, we used *policy brief urban resilience, urban climate framework, resilience knowledge network, urban climate adaptation* and *center for resilience*. In order to minimize the risk of omitting important documents, we incorporated three strategies:

1. **Databases**: We searched prominent databases that publish in the domain of urban resilience and climate adaptation. This included the Open Knowledge

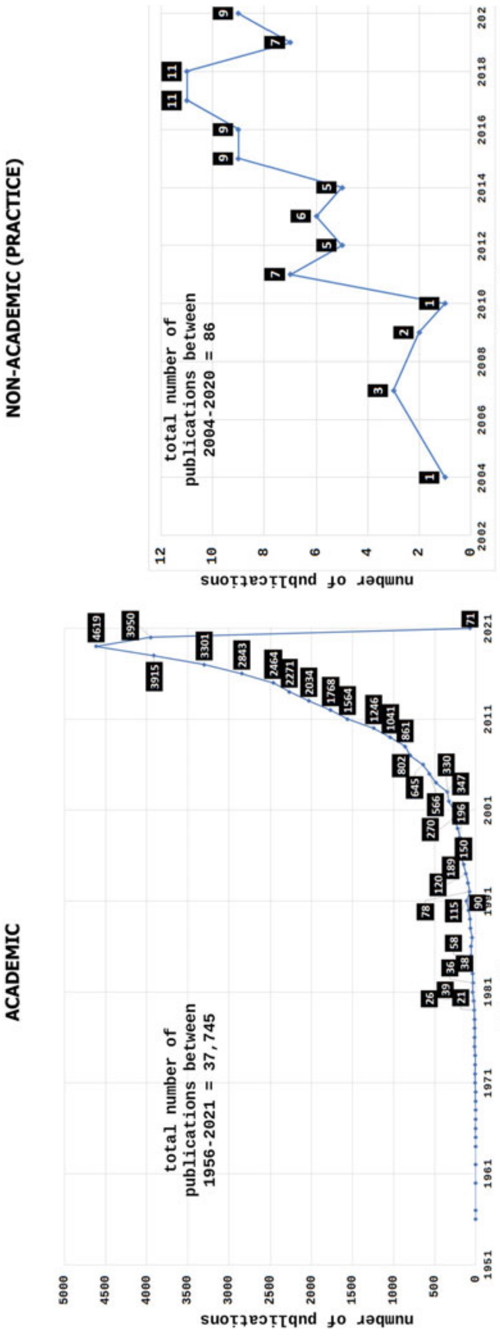

Fig. 24.4 Total number of academic (1990–2021, n = 37,745) and non-academic (2004–2020, n = 86) publications extracted

Repository of World Bank Group (World Bank Group nd), Rockefeller Foundation (Arup 2015), Asian Development Bank Institute (ADB nd), Urban Resilience Hub - UN Habitat (UN nd), Climate Adaptation Knowledge Portal (Kingdom of Netherlands nd), PreventionWeb—UNDRR (UNDRR nd), EU Science Hub (European Commission n.d.), 4TU Resilience Engineering (4TU RE nd), IIHS Knowledge Gateway (IIHS nd), etc.

2. **Targeted websites**: We made a list of resources and agencies that publish practitioner-focused documents and guidelines for the implementation of urban resilience. This is a hand-searching method based on the existing knowledge of the authors and recommendations from colleagues in the domain. Websites included those of ICLEI—Local Governments for Sustainability (ICLEI nd), Asian Cities Climate Change Resilience Network (ACCRN nd), Global Center On Adaptation (GCA nd), The Energy and Resource Institute (TERI nd), World Resources Institute (WRI nd), etc.
3. **Customized Google search**: We searched for documents on Google search engine using multiple combinations of search terms. As this is a very vast resource, we decided after initial search runs to only review the first 30 to 40 links per search term to keep our work feasible and ensure consistency. Here, we relied on the relevancy ranking of Google and screened the title and short text underneath to decide if it is relevant for further review.

As an emerging research area, a vast body of literature needed to be screened. In addition to the thematic focus, we set inclusion and exclusion criteria to make the analysis feasible (see Table 24.2). The final corpus had 86 documents covering 6 continents including 31 global/general documents, 41 location-specific documents, 11 sector-specific documents, and 3 special projects. A comprehensive list of resources and search terms may be accessed on this link: https://github.com/supadupa09/cupum2021_KAC (see Fig. 24.4, Table 24.3 in Appendix A).

Table 24.1 The search string used to build academic corpus on Scopus (Elsevier 2004). In addition, some simpler groups of words were used including: *"urban resilience", "urban plan(ning)*" AND climate, [(climate OR resilience) W/15 "urban informatics"], [(climate OR resilience) AND "planning support system"]*

	Urban	Plan	Climate
Concepts: Combine with AND	Urban* OR city OR cities OR spatial	Climate OR risk* OR hazard* OR resilien* OR uncertain* OR "climate change" OR future OR long-term OR vulnerab* OR "climate adapt*"	Strateg* OR vision OR framework OR "land use" OR method* OR scenario* OR variable* OR adapt* OR tools OR models

Table 24.2 Inclusion and exclusion criteria used for selecting of non-academic (practice) documents for analysis, adapted from (Godin et al. 2015)

Inclusion criteria	Exclusion criteria
• English	• Books, Webpages
• Open Access Action-oriented document written by governments including policy briefs, planning. guidelines, action plans, frameworks, etc	• Documents focusing on specific aspects such as financing, governance, community resilience, social protection etc
• Documents written with an urban focus targeting practitioners	• Broad conceptual frameworks or very short flyer-style documents
• Overall resilience and climate adaptation planning at a city, regional, country scale	• Specific case study or summary of case studies
	• Focus on a single type of risk like heat, flood, etc

24.5 Analysis

The earliest academic publication extracted was for 1956, but the volume of publications rose significantly from 1990 which we consider as the starting point for the analysis. Our tool to analyze the corpora was LiTCoF (Literature Topic Co-occurrence and Frequency), a collection of open-source Python libraries used for text mining analysis of large and unstructured bodies of text (Dayeen et al. 2020). We chose LiTCoF for the following abilities:

1. **Topic Modelling (TM)**: To retrieve main topics that emerge from literature.
2. **Term Frequency (TF)**: To extract frequently occurring terms.
3. **Term Evolution (TE)**: Analyze the evolution of selected terms over a number of years. Here, **Relative Frequency (RF)** is used to quantify the importance of a term in the corpus. LiTCoF adjusts the frequency of occurrence based on the length of the document.

LiTCoF requires data on *Titles, Abstracts, and Year of Publication* in a*.csv* format for analysis. Due to the non-standard format of non-academic literature, we extracted the detailed executive summary/ introduction instead of *Abstracts*. LiTCoF provides inbuilt packages to reformat, process the data, and define a list of overused or unrelated words we can exclude from the analysis. This required running LiTCoF on the corpus iteratively to calibrate the dataset for final analysis. Details on the preprocessing along with full datasets may be accessed at https://github.com/supadupa09/cupum2021_KAC.

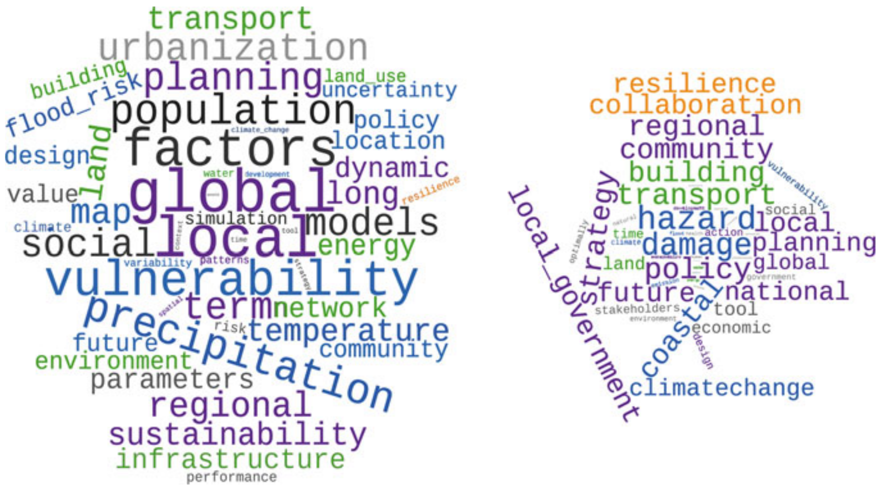

Fig. 24.5 Word clouds depicting results of Topic Modelling (TM); highlighting emerging terms in academic (left) and non-academic corpora

24.6 Results

24.6.1 Topic Modelling (TM)

We used Topic Modelling (TM) to extract 50 and 40 topics from academic and non-academic literature respectively. The number of topics selected was based on a low perplexity score (a measurement of good model performance in LiTCoF) (Fig. 24.5). TM is a useful indicator of themes and trends that represent the corpus. For instance, academia sees a dominance of *vulnerability, flood risk, precipitation, uncertainty, models, land-use, regional (scale), and sustainability*. Non-academic corpus sees terms on *adaptation, disaster-risk, community, local government, stakeholders, health, environment, and transport*.

24.6.2 Term Frequency (TF)

In both corpora, the top 100 most frequently occurring terms include the following:

- **Stream 1: Climate (and related) Pressures, State and Impacts:** *Flood risk, climate change, temperature, precipitation, health, pollution, emission, traffic, damage.*
- **Stream 2: Driving Forces:** *Agriculture, transport, energy, water, health, ecological.*

- **Stream 3: Planning Responses and Approaches:** *Adaptation, resilience, policy, integrated, sustainability, long-term.*
- Miscellaneous: *Evaluation, indicators, parameters, assessment, simulations, performance, stakeholders, decisions, coordination.* There are not many terms on **Resilience characteristics**.

Figures 24.6, 24.7 and 24.8 illustrate comparative trends of terms in academic and non-academic literature. In **Stream 1**, both corpora place an emphasis on *climate, climate change, flood risks, population, and vulnerabilities* but practice places emphasis on *disaster risk, sea level rise and heat stress.* In **Stream 2**, both corpora include terms on major infrastructure systems and economic drivers. However,'practice' illustrates more nuanced systems like *food, green infrastructure, river and waste management*. **Stream 3** indicates a separation of trends where practice places a high emphasis on *local action, community engagement, strategies and adaptation* and academia emphasises broader concepts such as *uncertainty, sustainability, spatial development, models, and the future.*

24.7 Term Evolution (TE)

Term Evolution (TE) is an indicator of changing priorities in research and practice and may help deduce new directions for study. We examine the Relative Frequency (RF) of terms over the time period of analysis for the four knowledge streams identified in Sect. 1.2 (see Fig. 24.9). We enlist terms under each stream based on results from Topic Modelling (TM) (Sec. 1.4.1) and Term Frequency (TE) (Sect. 1.4.2), as well as literature on DPSIR framework and urban resilience. The results are discussed below:

1. **Stream 1: Climate (and related) Pressures, States and Impacts** (Fig. 24.10)

    - **Academic literature**: Occurrences of *climate and climate change* have risen steadily over 31 years. 1991 and 1999 saw a surge of publications with keywords on urban climate, housing, climate variability, water resources, etc. *Flood risk* has emerged as a consistently strong theme in literature which may be a direct outcome of the number of cities that are suffering losses from flooding (Hallegatte et al. 2013). *Temperature and precipitation* see a moderate RF, whereas *heat and drought* which are emerging as high-impact risks have a low RF. This is backed by literature that cites a lack of sufficient studies and comparable data on heat (Mora et al. 2017). *Health and population* occur consistently, so do *migration and politics*. Environmental variables such as *pollution and emissions (carbon, greenhouse gas)* find significant mentions. *Technological* disruptions due to electric vehicles, autonomous driving, smart highways, etc., seem to be rising but not significantly.
    - **Non-academic literature**: Climate variables are dominated by hydrometeorological stresses from *precipitation, sea-level rise, storm surges,*

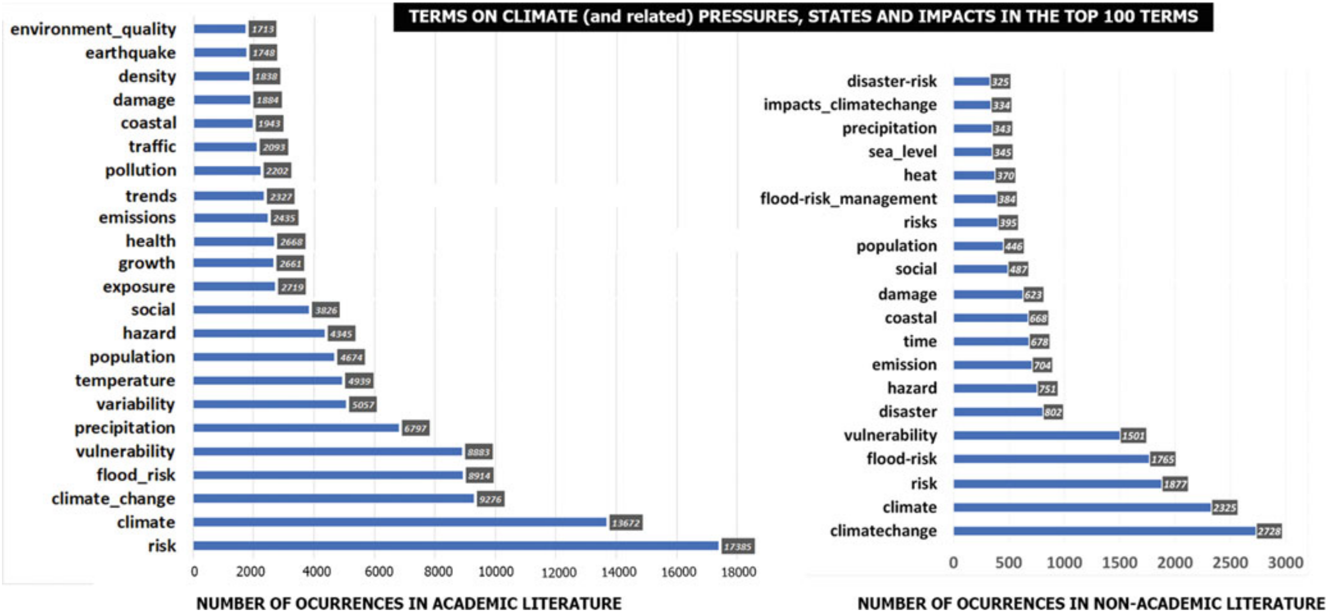

Fig. 24.6 The most frequently occurring terms related to **Climate Pressures, State and Impacts** in academic (bottom) and non-academic literature (extracted from the top 100 terms)

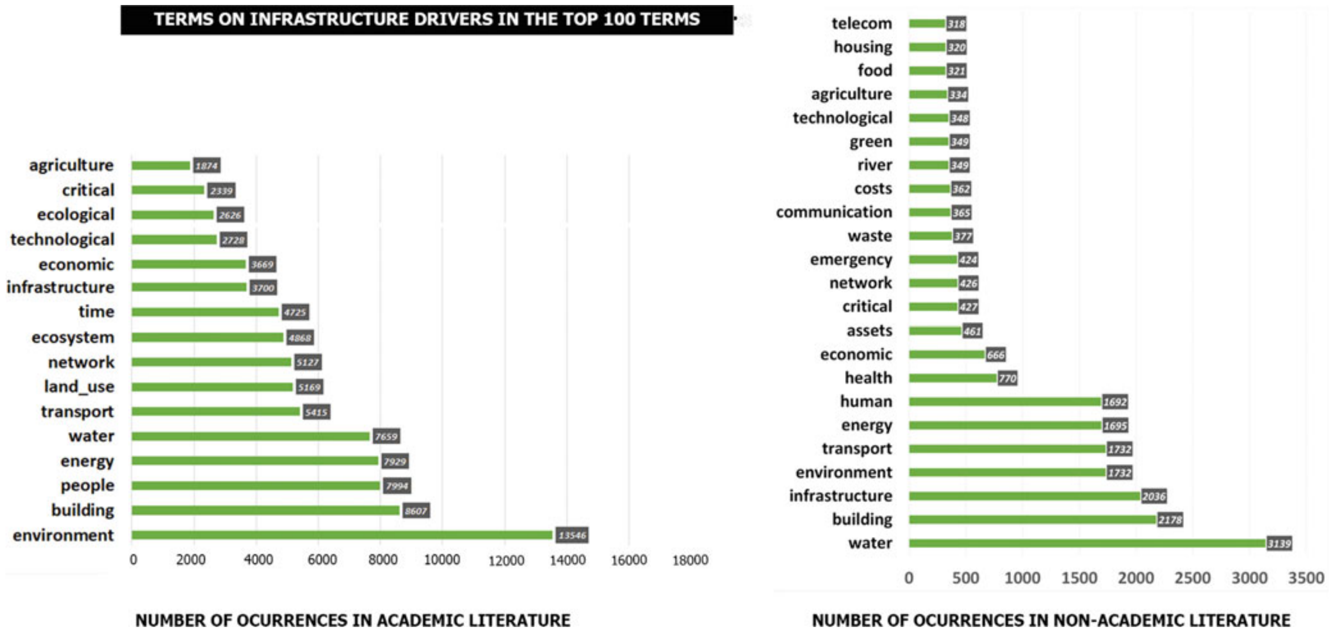

Fig. 24.7 The most frequently occurring terms on **Infrastructure Drivers** in academic (bottom) and non-academic literature (extracted from the top 100 terms)

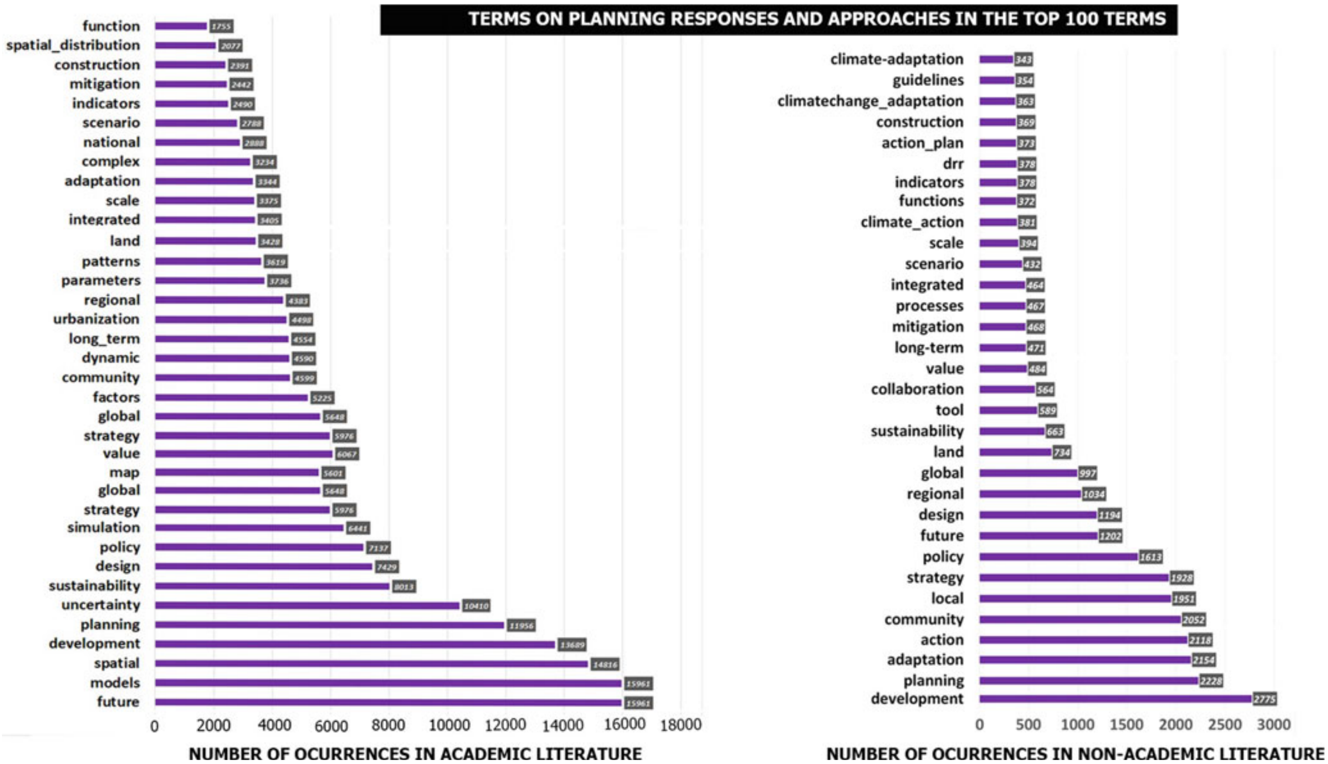

Fig. 24.8 The most frequently occurring terms on **Planning Responses and Approaches** in academic (bottom) and non-academic literature (extracted from the top 100 terms)

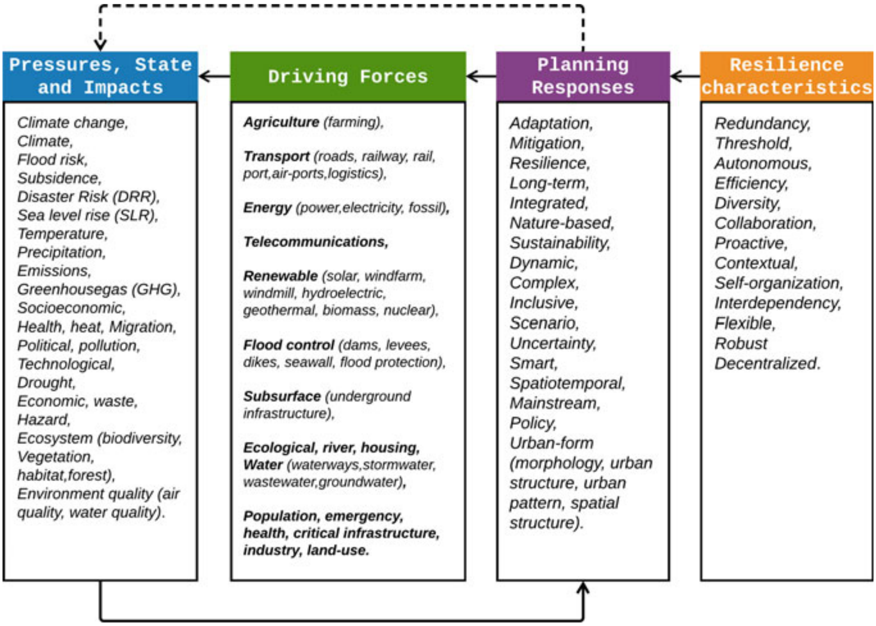

Fig. 24.9 Terms enlisted under the four knowledge streams derived from the DPSIR framework (see 1.2). We will use LiTCoF to analyse the evolution of these terms between the years 1990–2021. These terms are shortlisted based on results of *Term Frequency (TF), Topic Modeling (TM)* as well as literature on DPSIR framework and urban resilience)

inland/coastal flooding and subsidence. Heat stress is discussed but continues to be underrepresented. California is one of the few regions that presents a dedicated strategy for heatwaves (California 2018). Geophysical risks from *landslides and volcanoes* find mentions. There is a relatively higher representation of *socioeconomic* aspects of development including *health (stress, disease, mortality), population, politics,* and *environmental aspects* (*emissions, waste and pollution*). As implementation-oriented documents, climate variables are represented using extreme scenarios like 'identification of 15 worst events that should never happen' (Japan 2018) or as a set of guiding national scenarios (Netherlands 2016).

2. **Stream 2: Driving Forces** (Fig. 24.11)

- **Academic literature**: *Water* emerges as the strongest sector with a steep increase after 2010 concerning publications on water supply, rainwater harvesting, stormwater, wastewater, watershed management, etc. *Energy and ecological systems* see a steady upward swing. The year 1998 saw a jump in *energy* with one of the first papers on decisions in energy planning (Beccali et al. 1998) followed by highly cited publications on consumption, water-energy-food nexus, energy transition, global energy management and

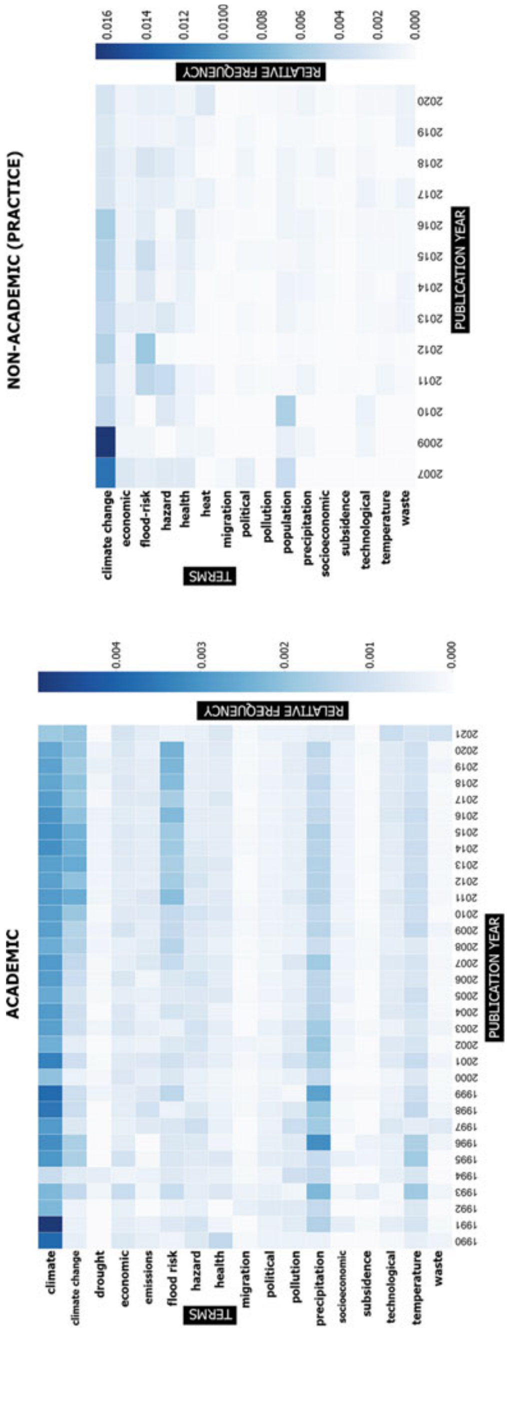

Fig. 24.10 Stream 1: Evolution of Terms (TE) related to **Climate Pressures, State and Impacts** between 1990–2021 (academic, bottom) and 2007–2020 (non-academic)

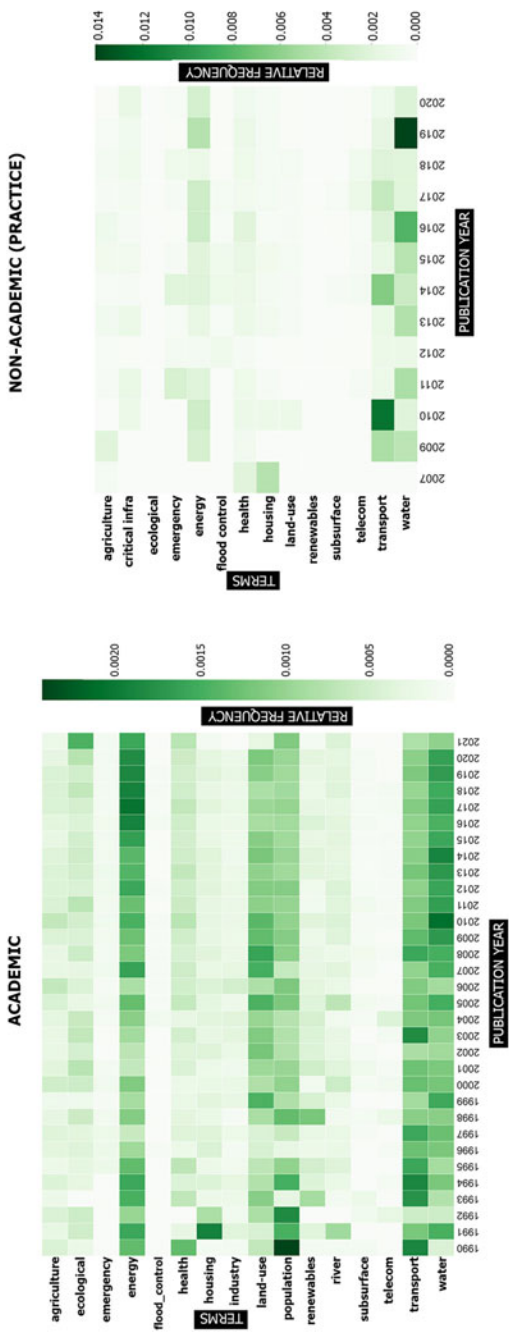

Fig. 24.11 Stream 2: Evolution of Terms (TE) related to **Driving Forces** between 1990–2021 (academic, bottom) and 2007–2020 (non-academic)

energy-climate policy. However, RF of *transport and agriculture* are seeing a downward trend. The unusually low RF for *transport* could be attributed to a dedicated transport domain that conducts research independent of urban planning. *Renewable* (energy), *flood control* infrastructure and *blue green infrastructure* see a low RF, possibly because they see intensive research in specific regions of the world. *Subsurface* infrastructure, which plays a critical role in determining infrastructure layouts, renewal, sustainability measures and even energy transition has a very low RF.

- **Non-academic literature**: Like academia,'practice' continues to see a high RF for *water* and *transport* sectors. In line with planning practice's tendency to formulate'response-based measures', we see high occurrences of *emergency preparedness, disaster risk management and community engagement*. *Housing* is mentioned in publications with a focus on affordable, low-income, and sustainable housing. *Agriculture, housing and telecommunications* also find mentions in several documents. Contrary to academia, *energy* has a medium RF which could be attributed to independent initiatives in this sector that aren't
- integrated in planning documents. *Land use* regulations which play a key role in scaling up resilience and adaptation measures have a low RF (Cities 2017; Japan International Cooperation Agency 2018; UNDRR 2017).

> **Box 1**: Main takeaways from analysis of Stream 1 and Stream 2. We deduce that future PSS applications could account for:
>
> a. Impacts from emerging risks such as heatwaves, extreme rainfall, sub- sidence etc.
> b. Consider the potential of subsurface (underground) infrastructure to inform other long-term planning decisions.
> c. Find ways to spatially account for interdependencies between sectors like identifying complementary sectors.
> d. Consider the potential of technological disruptions.
> e. Bring in focus on spatial planning and land-use to enable scaling up resilience measures.

3. **Stream 3: Planning Responses and Approaches** (Fig. 24.12) This stream investigates scientific concepts and practical processes on planning for climate. Non-academic literature served as a starting point to shortlist terms being used by cities (Dessai and van der Sluijs 2007; Jabareen 2013)

- **Academic literature**: Occurrences of *sustainability* and *resilience* have risen gradually from 1990 and sharply after 2010. 2013 was the year the Rockefeller Foundation institutionalized the 100 Resilient Cities Framework which may explain a high interest in the urban resilience domain since then (Arup 2015). *Adaptation* has a rising RF as compared to *mitigation* which

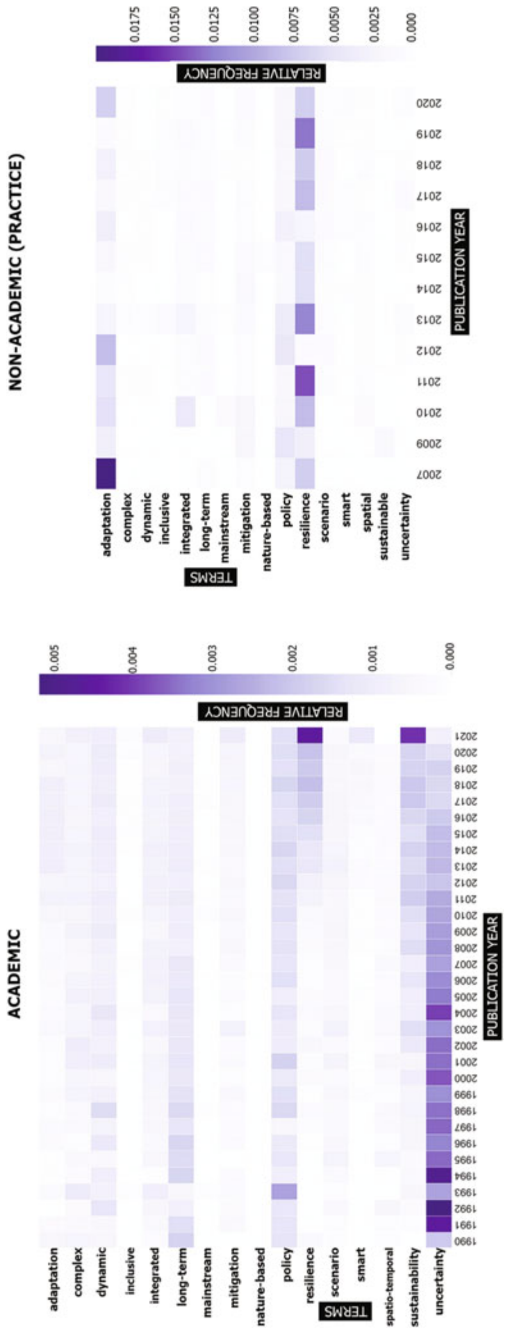

Fig. 24.12 Stream 3: Evolution of Terms (TE) related to **Planning Responses and Approaches** between 1990–2021 (academic, bottom) and 2004–2020 (non-academic)

could be explained by increased scientific and practical interest by cities on climate adaptation. *Mitigation* is mentioned concerning hazards, disaster risks, greenhouse gas emissions, public transport, etc. The small corpus of 71 documents for the year 2021 already sees 31 and 20 publications with keywords on sustainability and resilience respectively including research on shifting from sustainability to resilience, critical infrastructure and water stress.

Concepts such as *complex, integrated, dynamic, long-term* see a varying but consistently medium RF whereas *smart* sees a rise around 2016. *Circular economy, scenarios and nature-based solutions*, which are recurrent in non-academic documents finds low mentions in academia. *Spatio-temporal* did not make it to the list due to its low RF, though we see selected publications on air pollution, heat islands, temperature and environmental modelling. However, the study of spatio-temporal dynamics for urban resilience sees limited work.

- **Non-academic literature**: There is a strong trend towards *resilience and adaptation* but a rather low RF for *uncertainty* and dealing with changing constraints. *Long-term* planning is recognized through *long-term adaptation and resilience* actions. Low to medium RF is observed for *integrated, sustainable, inclusive* development and for the term *smart*, which is used in the context of smart spatial combinations in planning (Brazil 2016) and climate-smart agriculture (Kenya and Resources 2016; Netherlands 2016). Spatial and temporal aspects are insufficiently addressed with most documents providing policies and checklists with no concrete timelines. Exceptions to this are the *Bangladesh Delta Plan* (Bangladesh 2018), *Netherlands Adaptation Strategy* (Netherlands 2016) and *Thames 2100* (UK 2012) that set out detailed scenarios and short-term, medium-term and long-term phasing plans.

4. **Stream 4: Resilience Characteristics** (Fig. 24.13) We introduced this additional stream of knowledge to observe how resilience characteristics are represented in the literature on urban planning.

- **Academic literature**: Of the 36,405 abstracts, 922 documents are indexed by keyword *resilience*, and, only 174 mention *urban resilience*, with the first mention in 2005. With regards to resilience properties, *robust and efficiency* see the strongest presence. *Robustness* was initially used for control systems in the 1990s, followed by modeling economic effects in the 2000s and finally sectoral applications in water, climate assessment, information technology starting 2003. Application of robustness principles in urban growth was first seen in 2010 (Paulsen et al. 2010) followed by long-range transportation plans, road network robustness (Santos et al. 2010), flood risk analysis, and spatial climate scenarios (van Vliet et al. 2012). *Efficiency* is predominantly used for energy with limited mentions for water-use, economics and transport.

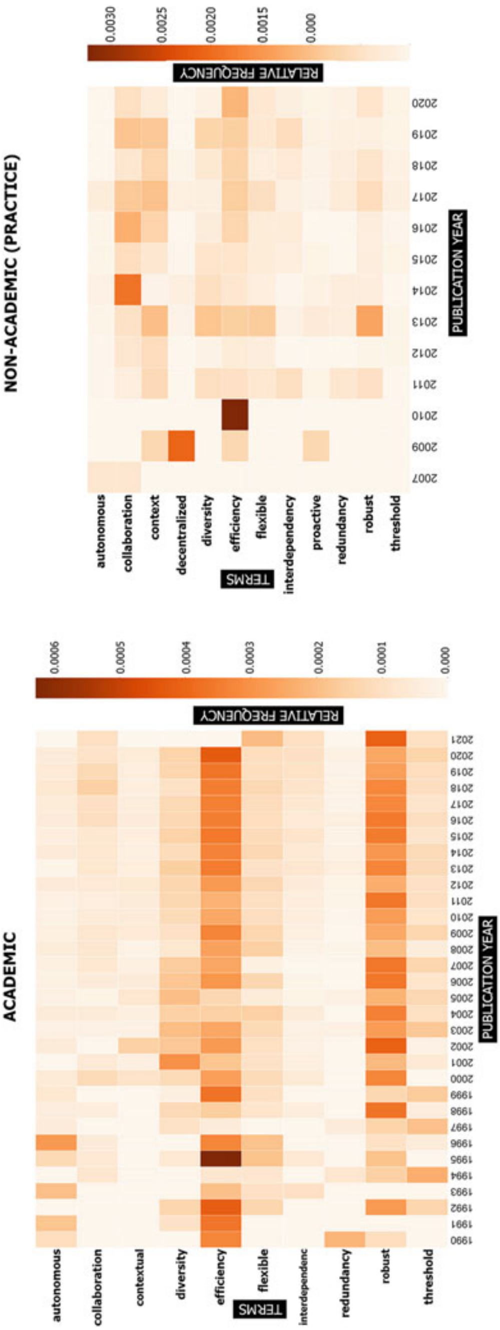

Fig. 24.13 Stream 4: Evolution of Terms (TE) related to **Resilience Characteristics** between 1990 and 2021 (academic, bottom) and 2004–2020 (non-academic)

Terms showing dispersed mentions are *diversity*, in relation to biodiversity, culture and more recently spatial and functional diversity. *Flexible* is used for transport (Gifford 1994), architecture, long-term decisions, adaptive management and infrastructure (Huang et al. 2010) with emphasis on water (Zhou and Hu 2009). Recently, flexibility is being investigated in planning through *flexible city* (Venco 2016) and flexible planning processes for climate (Szpilko 2020). *Interdependency* became an area of investigation starting 2013 with rising awareness of cascading effect in disasters including infrastructure interdependencies during earthquakes, floods and risk assessments of critical infrastructure (Comes and Van de Walle 2014; Fotouhi et al. 2017).

- **Non-academic literature**: 20 out of 30 documents specify a definition of resilience with the most popular being the definition presented by Arup and Rockefeller Foundation (Arup 2015). World Bank's *CityStrength Diagnostic framework* sets out qualities of resilient systems (Bank 2018) whereas the resilience of spatial development is explained in *Netherlands Climate Adaptation Strategy*. *ASEAN Guidebook* provides a resilience checklist (Japan International Cooperation Agency 2018; Netherlands 2016). A high RF is observed for *collaborations, diversity and efficiency*. A medium to high RF is seen for *flexibility* (plans, processes, water use, management), *redundancy* and *interdependency* (infrastructure, cascading failures). *Robust* is used for applications including spatial structures, energy, telecommunication, flood protection and land-use.

Box 2: Main takeaways from analysis of Stream 3 and Stream 4. From Streams 3 and 4, we deduce that future PSS applications could account for:

1. Spatial planning characteristics to build resilience such as diversity, flex
2. ibility, self-organization, etc.
2. Combining adaptation and mitigation measures.
3. Temporal aspects of planning such as urban planning timeframes, infrastructure lifecycles. Consider and clarify the concept of'short-term' and'long-term' and the granularity of decisions required for each time span.

24.8 Conclusions and Discussions

In this study, we set out to develop a research agenda to improve PSS for long-term climate resilience. We presented an overview of applications of PSS in the climate adaptation and resilience space where we identified three important issues that hinder long-term resilience thinking including: (a) Emphasis on a few fixed planning scenarios; (b) Focus on individual sectors, and; (c) Less consideration of spatial and temporal aspects in planning. Based on these, we suggested three potential areas of improvement for PSS (Fig. 24.1). We also observe that cities make urban plans for timeframes of 5–20 years which has proven insufficient to account for long-term climate projections as most investments made in that period will last much longer and suffer intense impacts from climate. With advances in long-term climate projections, mapping, monitoring, the fast pace of technology plans that are made for 20 years are fast becoming outdated even before they are published. There is a clear dichotomy between how practitioners and researchers perceive'short-term' and'long-term' timeframes for planning. Recalibrating what constitutes as'long-term' can assist in better scoping resilience objectives, which can improve understanding of temporal aspects of planning.

In order to further investigate the knowledge landscape of urban planning and climate resilience, we conducted a text-mining analysis of 36,405 academic and 86 non-academic publications in this domain (see Sect. 1.3.2). We analyzed and classified the results along four knowledge streams: **S1:** Pressures, State and Impacts; **S2:** Driving forces; **S3:** Planning Responses; and **S4:** Resilience Characteristics. In the following sections, we will discuss two aspects: (1) the findings derived from text-mining analysis; and (2) the procedural challenges in conducting this study.

24.9 Findings Derived from Text-Mining Analysis

The results of the text-mining analysis reinforce two of the three issues with PSS that we identified including the heavy focus specific sectors and the low consideration of spatial and temporal dimensions (Fig. 24.1). The drivers of climate risks are covered well in both academia and practice, especially *flood risks* and *environmental aspects.* Almost all non-academic documents address climate risks though the level of detail varies from outlining all possible variations of risks to using'risk' as an umbrella term. As compared to academia,'practice' seems to place a higher emphasis on *socio-economic aspects, health & disease, migration, poverty,* etc.(Fig. 24.6).

The infrastructure sectors highlighted in the non-academic corpus are also a representation of sectors that attract heavy investments or those that stimulate bottom-up initiatives such as *water and energy*. The role of digital infrastructure, *telecommunications* and *critical infrastructure* that have visible widespread impacts are discussed, although *interdependencies* between infrastructure sectors are not addressed sufficiently. Though some work is available, a significant gap in both areas is the potential of subsurface (underground) infrastructure that can guide long-term resilient urban form (Krishnan et al. 2019; Norrman et al. 2016).

Spatial aspects find a place in the top five most recurrent terms in academia concerning land-use and building regulations. But, non-academic guidelines continue to be written to inform theoretical policies, not spatial actions. Though the benefits of long-term planning are recognized, terms on implications of policies in space or mainstreaming risks in planning do not find mentions. Non-academic literature places a heavy focus on climate adaptation and disaster risk while mitigation measures are limited to the reduction of greenhouse gas and carbon emissions. Resilience building requires combining both measures to capitalize on their co-benefits, which requires further investigation in academia. Non-academic documents do discuss spatial impacts for small-scale projects such as flood-prone urban spaces, rainwater harvesting on rooftops, etc. Academia can play a major role in developing methodologies to bring in a spatial perspective and guide the development of a PSS that enables scaling up measures. This can snowball into more research on spatial diversity specially to address flexibility and diversity of functions for planning resilience.

24.10 Procedural Challenges in Conducting This Study

While the study set out to be a comparative analysis between academic and non-academic literature, a fair comparison was not possible due to the stark imbalance in the number of publications (Fig. 24.4). Despite a focused search plan, the number of relevant non-academic (practitioner-focused) documents remained low. This points to the lack of comprehensive databases on urban planning and climate. Moreover, as many such documents are being written for the first time by governments and independent agencies, the format and nomenclature vary vastly. A document that is tasked with communicating implementation strategies for climate resilience can go by the names of *resilience frameworks, climate action plans, adaptation strategy* or take the names of the programmes that fund them such as the*'citystrength framework'* (Bank 2018) and*'making cities resilient'* (UNDRR 2017). While an'urban masterplan' has an associated recall value and definition of what it is expected to contain, a'resilience guideline' continues to be open to interpretation. This made the search and analysis challenging.

24.11 Future Directions

As discussed in Sect. 1.2, urban planners currently lack the incentive to think long-term (Roy 2009). A PSS can play a critical role in bringing in a concrete long-term perspective for climate resilience. The takeaways from the text mining analysis present specific insights on how to materialize the suggested improvements in a PSS (Fig. 24.14). Firstly, a PSS should support planners to identify and integrate constantly changing variables such that they can anticipate and prepare for emerging risks. Secondly, for long-term decision-making, a PSS should assist planners in selecting appropriate planning responses across multiple infrastructure sectors. A key sector that a PSS should target is underground (subsurface) infrastructure that forms the literal backbone of city utilities and has a huge role to play in sustainable transitions. Thirdly, a PSS can play a role in improving understanding of infrastructure dependencies. Based on the context, it can help identify complementary urban systems, that can be clubbed together for decision-making and to reduce negative

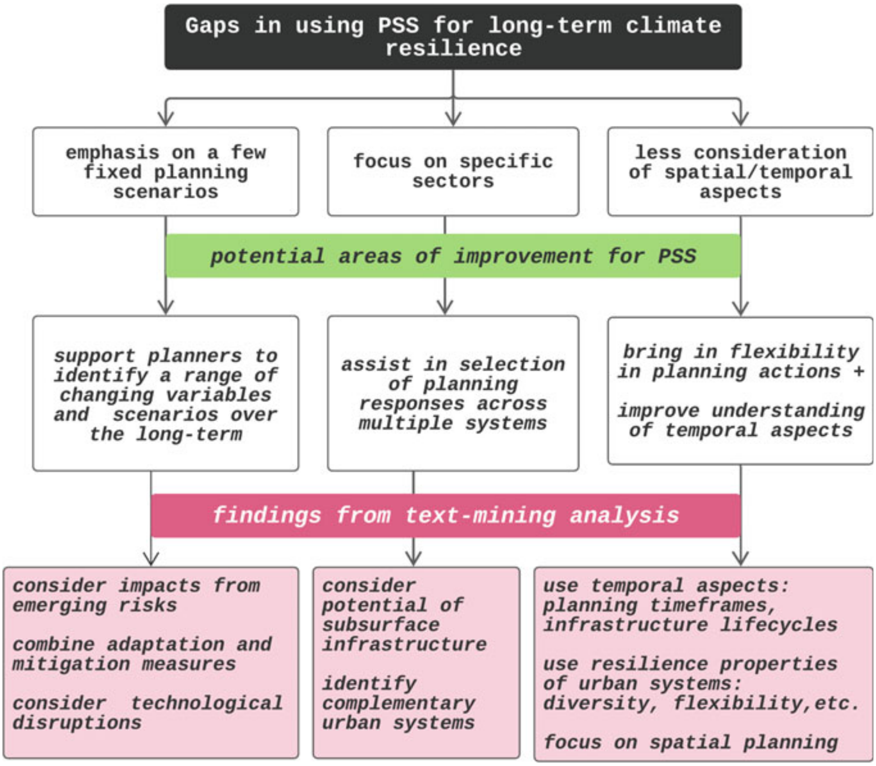

Fig. 24.14 Conceptual framework indicating three potential areas for improving PSS applications for long-term climate resilience building upon Fig. 24.1. It also indicates detailed findings from text mining analysis as direct inputs to each area (see Boxes 1 and 2)

dependencies. Lastly, it becomes important to draw upon the resilience properties of urban systems such as functional diversity, flexible functions, emergence etc., that can directly inform planning responses for the long-term (See Box 2). These are related to the lifecycles of infrastructure systems and thus can improve our understanding of temporal dimensions of planning.

Through this study, we acknowledge that analysis of terminology is not a direct indicator of the extent of inclusion or impacts in the domain. However, it allows us to scope the priorities of the domain and present a starting point to steer further research. In further work, LiTCoF should be used to analyze more detailed streams of knowledge and a larger corpus of non-academic literature. Finally, we should augment this desk analysis by interviewing planning practitioners to reflect on the processes and knowledge gaps in building long-term resilience. Our ultimate goal through this study is to push the boundaries of urban planning to move from a'static' towards an'uncertainty-oriented' approach for building resilience.

Appendix

Corpus of Non-academic (Practice) Documents

Table 24.3 All documents accessed as on January 16, 2021

S. no	Year	Publication	Author
		Global Frameworks	
1	2020	Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience	World Bank Group
2	2020	Integrating Climate Adaptation toolkit	C40 Cities
3	2019	Resilient Cities, Thriving Cities	ICLEI
4	2018	CityStrength Diagnostic	World Bank Group
5	2018	Guidebook for urban resilience	ASEAN
6	2018	100 Resilient Cities Handbook	Rockefeller Foundation
7	2018	The EU Strategy on adaptation to climate change	Europe Commission
8	2018	From Planning To Action: Mainstreaming Climate Change Adaptation Into Development	World Resources Institute
9	2018	CityRAP tool - City resilience: Action planning tool	UN Habitat
10	2017	How to Make Cities More Resilient	UNDRR
11	2017	Climate Action Planning Framework	C40 Cities
12	2017	Building a climate resilient city	IISD
13	2016	World Bank Group Climate Change Action Plan	World Bank Group
14	2016	Urban Responses to Climate Change Framework for Decision-making and Supporting Indicators	RAND Corporation
15	2016	Climate Resilient and Disaster Safe Development	NIUA
16	2015	Guiding Principles for City Climate Action Planning	ICLEI
17	2015	Integrating Climate Change into City Development Strategies	Cities Alliance
18	2014	Urban Climate Change Resilience	Asian Development Bank
19	2014	Planning For Climate Change: A Strategic, Values-Based Approach For Urban Planners	UN Habitat

(continued)

Table 24.3 (continued)

S. no	Year	Publication	Author
		Global Frameworks	
20	2014	Building urban climate change resilience: a toolkit for local governments	ICLEI ACCCRN
21	2013	City Resilience Index	Arup
22	2013	Building Resilience: Integrating Climate and Disaster Risk into Development	World Bank Group
23	2013	Building Urban Resilience Principles, Tools, and Practice	World Bank Group
24	2013	A Framework of Urban Resilience Planning - UNDP- IIHS Working Paper on Integrated Planning for Development	UNDP-IIHS
25	2012	Guidelines for National Adaptation Plans	UNFCC
26	2011	Guide to Climate Change Adaptation in Cities	World Bank Group
27	2011	Catalyzing urban climate resilience	ACCRN
28	2010	Climate Resilient and Sustainable Urban Development	DFID, IEP
29	2009	Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters	World Bank Group
30	2007	Adapting to Climate Change in Urban Areas	IIED
31	2007	Climate change adaptation by design: a guide for sustainable communities	TCPS London
		City/Country-specific	
1	2004	Adaptation Policy Frameworks for Climate Change: De-veloping Strategies, Policies and Measures	UNDP
2	2007	Preparing for Climate Change: Guidebook for Local, Regional, and State Governments	ICLEI
3	2009	Understanding and Responding to Climate Change in Developing Asia	ADB Knowledge Institute
4	2011	Building the Netherlands Climate Proof: Urban Areas	Deltares, UNESCO-IHE
5	2011	Managing risks and increasing resilience: The Mayor's climate change adaptation strategy	Mayor's Office London

(continued)

Table 24.3 (continued)

S. no	Year	Publication	Author
		Global Frameworks	
6	2011	Catalyzing urban climate resilience: Applying resilience concepts to planning practice in the ACCCRN program	Institute for Social andEnvironmental Transition
7	2012	Climate Change in Asia and the Pacific: How Can Countries Adapt?	Asian Development Bank
8	2012	A workbook on planning for urban resilience in the face of disasters: Adapting experiences from Vietnam's cities to other cities	World Bank Group
9	2012	Baltimore Climate Action Plan	City of Baltimore TERI
10	2013	Climate Proofing Guwahati, Assam	Government of Japan
11	2014	Fundamental Plan for National Resilience	Indonesia-National
12	2014	National Action Plan for Climate Change Adaptation Indonesia	DevelopmentPlanning DevelopmentPlanning Agency (BAPPENAS)
13	2015	National Climate Resilience and Adaptation Strategy	Australian Government
14	2015	Portland Climate Action Plan	Portland
15	2015	King County Strategic Climate Action Plan	King County
16	2015	Coastal urban climate resilience planning in Quy Nhon, Vietnam	IIED, Rockefeller, ACCRN
17	2016	Brazil National Adaptation Plan to Climate Change	Ministry of Environment, Brazil
18	2016	Singapore's Climate Action Plan	National Climate Change Secretariat, Singapore
19	2016	Adapting with ambition	Ministry of Infrastructure and Water, Netherlands
20	2016	Kenya National Adaptation Plan	Ministry of Environment, Kenya
21	2017	Rotterdam Resilience Strategy	City of Rotterdam
22	2017	Coastal hazards and climate change	MinistryforEnvironment, New Zealand
23	2017	Enhancing Urban Resilience: Accra	World Bank Group
24	2017	Making Fiji Climate Resilient	GFDRR. ACP-EU Natural Disaster Risk Reduction Program
25	2017	Developing city resilience strategies: lessons from the ICLEI–ACCCRN process	ICLEI–ACCCRN

(continued)

Table 24.3 (continued)

S. no	Year	Publication	Author
		Global Frameworks	
26	2017	Piitsburgh Climate Action Plan	City of Pittsburgh
27	2018	Bangladesh Delta Plan	BangladeshPlanning Commission
28	2018	Planning and Investing for a Resilient California	Governor's Office
29	2018	Building Urban Resilience with Nature - A practitioner's guide to action	100RC, Earth Economics
30	2018	Climate Change Adaptation Strategy: Vancouver	City of Vancouver
31	2019	Chennai Resilience StrategyChennai Resilience Strategy	GIZ Climate Smart Cities
32	2019	Durban Climate Action	GIZ Climate Smart Cities
33	2019	Plan Pune Resilience	GIZ Climate Smart Cities
34	2019	Strategy Climate Ready	City of Boston
35	2020	Boston	City of Amsterdam
36	2020	Action Plan for the Amsterdam Climate Proof	TERI, India
37	2020	Guiding Framework for India's Long-Term Strategy: Adaptation	TERI, NIUA
38	2020	Mainstreaming Urban Resilience: Lessons from Indian cities	New York City's Mayors Office
39	2020	Climate Resiliency Design	Chicago Climate Task Force
40	2020	Guidelines Chicago Climate Action Plan	SWECO
41	2020	Climate Action | Planning for Climate Adaptation Southern California Climate Adaptation Planning Guide	Governmentof S. California
		Sector-specific	
1	2011	Keeping the country running	Cabinet Office, UK
2	2011	Adapting to Climate Change: Strengthening the Climate Resilience of Water Sector Infrastructure in Khulna, Bangladesh	ADB Knowledge Institute
3	2013	Increasing Climate Change Resilience of Urban Water Infrastructure	Asian Development Bank
4	2015	Building Climate Change Resilience for Electricity Infrastructure	Power Grid Corporation of India
5	2016	Delta Programme 2019	Ministry of Infrastructure and Water, Netherlands
6	2016	Toward Climate-Resilient Hydropower in South Asia	World Bank Group

(continued)

Table 24.3 (continued)

S. no	Year	Publication	Author
		Global Frameworks	
7	2017	Vulnerability Assessment and Adaptation Framework	Federal Highway Administration, USA
8	2017	Building a Climate-Resilient City: Electricity and information and communication technology infrastructure	Prairie Climate Center
9	2018	EC-RRG resilience guidelines for providers of critical national-telecommunications infrastructure	Cabinet Office, UK
10	2019	Urban Water Resilience approach	Rockefeller Foundation
11	2019	Climate change and critical infrastructure – storms	EU Science Hub
		Special Projects	
1	2015	Rebuild by Design	Rockefeller Foundation, others
2	2015	Towards an EU research and innovation policy agenda for nature-based solutions	European Commission
3	2012	Thames Estuary 2100	UK Environment Agency

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