10-2021

# A Global Assessment of Policy Tools to Support Climate Adaptation

Nicola Ulibarri
*University of California*

Idowu Ajibade
*Portland State University*, iajibade@pdx.edu

Eranga K. Galappaththi
*Department of Fisheries and Oceans Canada, Winnipeg, Manitoba, Canada.*

Elphin T. Joe
*World Resources Institute, New Delh, India.*

Alexandra Lesnikowski
*Concordia University, Montreal, Canada*



## Citation Details

Nicola Ulibarri, Idowu Ajibade, Eranga K. Galappaththi, Elphin Tom Joe, Alexandra Lesnikowski, Katharine J. Mach, Justice Issah Musah-Surugu, Gabriela Nagle Alverio, Alcade C. Segnon, A.R. Siders, Garry Sotnik, Donovan Campbell, Vasiliki I. Chalastani, Kripa Jagannathan, Vhalinavho Khavhagali, Diana Reckien, Yuanyuan Shang, Chandni Singh, Zinta Zommers & The Global Adaptation Mapping Initiative Team (2021): A global assessment of policy tools to support climate adaptation, Climate Policy, DOI: 10.1080/14693062.2021.2002251

Climate Policy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcpo20

# A global assessment of policy tools to support climate adaptation

Nicola Ulibarri, Idowu Ajibade, Eranga K. Galappaththi, Elphin Tom Joe, Alexandra Lesnikowski, Katharine J. Mach, Justice Issah Musah-Surugu, Gabriela Nagle Alverio, Alcade C. Segnon, A.R. Siders, Garry Sotnik, Donovan Campbell, Vasiliki I. Chalastani, Kripa Jagannathan, Vhalinavho Khavhagali, Diana Reckien, Yuanyuan Shang, Chandni Singh, Zinta Zommers & The Global Adaptation Mapping Initiative Team

**To cite this article:** Nicola Ulibarri, Idowu Ajibade, Eranga K. Galappaththi, Elphin Tom Joe, Alexandra Lesnikowski, Katharine J. Mach, Justice Issah Musah-Surugu, Gabriela Nagle Alverio, Alcade C. Segnon, A.R. Siders, Garry Sotnik, Donovan Campbell, Vasiliki I. Chalastani, Kripa Jagannathan, Vhalinavho Khavhagali, Diana Reckien, Yuanyuan Shang, Chandni Singh, Zinta Zommers & The Global Adaptation Mapping Initiative Team (2021): A global assessment of policy tools to support climate adaptation, Climate Policy, DOI: 10.1080/14693062.2021.2002251

**To link to this article:** https://doi.org/10.1080/14693062.2021.2002251



Published online: 18 Nov 2021.

CLIMATE POLICY
https://doi.org/10.1080/14693062.2021.2002251

Taylor & Francis
Taylor & Francis Group

SYNTHESIS ARTICLE

OPEN ACCESS Check for updates

# A global assessment of policy tools to support climate adaptation

Nicola Ulibarri [a], Idowu Ajibade [b], Eranga K. Galappaththi [c], Elphin Tom Joe [d], Alexandra Lesnikowski [e], Katharine J. Mach [f,g], Justice Issah Musah-Surugu [h,i], Gabriela Nagle Alverio [j], Alcade C. Segnon [k,l], A.R. Siders [m], Garry Sotnik [n], Donovan Campbell [o], Vasiliki I. Chalastani [p], Kripa Jagannathan [q], Vhalinavho Khavhagali [r], Diana Reckien [r], Yuanyuan Shang [s], Chandni Singh [t], Zinta Zommers [u] and The Global Adaptation Mapping Initiative Team[a]

[a]Department of Urban Planning & Public Policy, University of California Irvine, Irvine, CA, USA; [b]Portland State University, Portland, OR, USA; [c]Virginia Polytechnic Institute and State University, Blacksburg, VA, USA; [d]World Resources Institute, New Delhi, India; [e]Concordia University, Montreal, Canada; [f]Department of Environmental Science and Policy, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL, USA; [g]Leonard and Jayne Abess Center for Ecosystem Science and Policy, University of Miami, Coral Gables, FL, USA; [h]United Nations University, Bonn, Germany; [i]Department of Public Administration, University of Ghana, Accra, Ghana; [j]Duke University, Durham, NC, USA; [k]CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), ICRISAT, Bamako, Mali; [l]University of Abomey-Calavi, Cotonou, Republic of Benin; [m]University of Delaware, Newark, DE, USA; [n]Stanford University, Stanford, CA, USA; [o]University of the West Indies, Kingston, Jamaica; [p]Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Zografou, Greece; [q]Lawrence Berkeley National Laboratory, Berkeley, CA, USA; [r]University of Twente, Enschede, Netherlands; [s]The Australian National University, Canberra, Australia; [t]Indian Institute for Human Settlements, Bangalore, India; [u]United Nations Office for the Coordination of Humanitarian Affairs, New York, NY, USA

**ABSTRACT**

Governments, businesses, and civil society organizations have diverse policy tools to incentivize adaptation. Policy tools can shape the type and extent of adaptation, and therefore, function either as barriers or enablers for reducing risk and vulnerability. Using data from a systematic review of academic literature on global adaptation responses to climate change ($n = 1549$ peer-reviewed articles), we categorize the types of policy tools used to shape climate adaptation. We apply qualitative and quantitative analyses to assess the contexts where particular tools are used, along with equity implications for groups targeted by the tools, and the tools' relationships with transformational adaptation indicators such as the depth, scope, and speed of adaptation. We find diverse types of tools documented across sectors and geographic regions. We also identify a mismatch between the tools that consider equity and those that yield more transformational adaptations. Direct regulations, plans, and capacity building are associated with higher depth and scope of adaptation (thus transformational adaptation), while economic instruments, information provisioning, and networks are not; the latter tools, however, are more likely to target marginalized groups in their design and implementation. We identify multiple research gaps, including a need to assess instrument mixes rather than single tools and to assess adaptations that result from policy implementation.

**Key policy insights**

- Information-based approaches, networks, and economic instruments are the most frequently documented adaptation policy tools worldwide.
- Direct regulations, plans, and capacity building are associated with higher depth and scope of adaptation, and thus more transformational adaptation.

**ARTICLE HISTORY**
Received 7 May 2021
Accepted 31 October 2021

**KEYWORDS**
Climate change adaptation; policy instruments; systematic review; Global Adaptation Mapping Initiative (GAMI); transformational adaptation; equity

**CONTACT** Nicola Ulibarri ulibarri@uci.edu

- Capacity building, economic instruments, networks, and information provisioning approaches are more likely to target specific marginalized groups and thus equity challenges.
- There are many regions and sectors where certain tools are not widely documented (e.g. regulations and plans in Africa and Asia), representing a key research gap.

## Introduction

Climate change is affecting societies and ecosystems globally. With increasing warming, future climate impacts could be severe, widespread, and potentially irreversible (IPCC, 2021; Sanderson & O'Neill, 2020). Warming of more than 1.5°C is estimated to increase the risk of floods, droughts, and heatwaves by 2050, impacting global food supplies, ecosystem services, human health, and economic growth (Hoegh-Guldberg et al., 2019; IPCC, 2018; Xu et al., 2020), with impacts disproportionately affecting marginalized communities and low-income countries (Levy & Patz, 2015; Moellendorf, 2015). To reduce climate change's impacts, the Paris Agreement converged on the goals of building adaptive capacity and reducing vulnerability to climate change, while paying special attention to equity (i.e. the needs of marginalized populations) (UNFCCC, 2015). Yet adapting to climate change impacts incrementally is insufficient to support capacity-building actions in many regions (af Rosenschöld & Rozema, 2019; Fook, 2017; Kates et al., 2012).

Increasingly, transformational adaptation – defined as actions that lead to the adoption of new behaviours and functionings that take place across a wide spatial or sectoral range and signify a deep systemic change (de Coninck et al., 2018) – is considered necessary for lessening the impacts of climate change and preventing major losses (Ajibade & Adams, 2019; Few et al., 2017; Kates et al., 2012). Conventional definitions of transformational adaptation commonly focus on the depth and extent of change (de Coninck et al., 2018; Termeer et al., 2017). However, such adaptations may entail adopting a future-oriented approach and can include a combination of technological and institutional innovations, changes in power structures and social and economic behaviours, and shifts in individual and system capacities to allow for new development trajectories (Béné et al., 2014; Eakin et al., 2016; Kofinas et al., 2013), making them inherently about social equity as well. Understanding how to incentivize adaptation that is both transformational and equitable can thus help the global community achieve the provisions of the Paris Agreement.

Governments, corporations, and civil society organizations at multiple levels are spearheading climate change adaptation efforts and incentivizing individuals and communities to take action (Berkhout, 2012; Mubaya & Mafongoya, 2017). These organizations use various policy options, tools, instruments, actions, and interventions (henceforth referred to as 'policy tools') to respond to specific impacts of climate change. The types of policy tools used shape both adaptation governance approaches and longer-term reduction of risk and vulnerability (Milhorance et al., 2020; Olazabal & Ruiz De Gopegui, 2021). Numerous typologies exist to capture the range of tools that governments and other actors use to implement adaptation, but generally, these encompass instruments like command and control mandates, economic incentives, information provisioning, and support and capacity building (Clar & Steurer, 2018; Henstra, 2016; Lesnikowski et al., 2019; Milhorance et al., 2020). The optimal mix of tools depends on the risk in question, geographical and institutional contexts, organizational priorities, institutional path dependencies, perceptions about tool appropriateness, and degrees of vulnerability of the affected population (Eliadis et al., 2005). For instance, slow-onset impacts may require different tools than fast-moving extreme events. Likewise, a country's capacity to finance the development of tools or to enforce their implementation may make certain tools more effective at reducing risk.

A number of recent papers have reviewed adaptation policy tools at local, regional, and national scales (e.g. Bhandary et al., 2021; Biesbroek & Delaney, 2020; Henstra, 2016; Hurlbert et al., 2019; Patterson, 2021; Thistlethwaite & Henstra, 2017). However, a global analysis of adaptation policy tools across regions, sectors, and types of tools is pending. The lack of a global overview has three major implications. First, understanding what tools are used and how they influence adaptation can contribute to the planned global stocktake of collective progress towards achieving the Paris Agreement goals (Berrang-Ford et al., 2019; Tompkins et al., 2018), specifically understanding the 'adequacy and effectiveness of … support for adaptation' (UNFCCC, 2015). Second, a global

overview of the types of tools available for incentivizing adaptation, and information on which tools work well for different contexts, can inform organizations' future choice of tools to match their capacity and goals. Third, understanding where different policy tools and mixes are documented in the peer-reviewed literature can highlight key research gaps.

This paper draws on a systematic and comprehensive review of the global climate adaptation literature (2013–2019) to answer the following questions:

(1) What types of adaptation policy tools are documented in the peer-reviewed literature?
(2) How does tool use vary by type of organization, region, sector, and hazard?
(3) How are marginalized groups targeted by adaptation policy tools?
(4) How do policy tools shape transformational adaptation?

The paper first briefly reviews policy tool theory and its application in climate change research. It then explores how the adaptation literature documents the use of policy tools to mandate, incentivize, or support climate adaptation responses. It then examines the contexts underlying the tools that are used. Lastly, it explores the relationship between tool type and the broader transformational nature of adaptation, including equity, depth, scope, and speed. It concludes with a discussion of key research and policy needs.

## Policy tools and climate change

Policy tool theory argues that tool choice is a fundamentally political process shaped by a policy problem's framing, the character of the instruments, and the context in which policy processes occur (Howlett, 2018; Linder & Peters, 1989). Tool choices are reflected in distinct policy styles that emerge in different sectors and countries (Hall, 1993; Howlett & Tosun, 2018; Richardson, 1982). Policy tools tend to accumulate over time in increasingly complex policy mixes, rather than undergoing periodic dismantling and re-design (Béland, 2007; Howlett & del Rio, 2015; Rayner et al., 2017). Policy failure, therefore, often lays in poor policy design and fit between tool choice, mix and institutional context.

Climate change scholarship increasingly draws from the policy design literature to explain tool choice and change over time (Schaffrin et al., 2015). The policy mix concept has been applied to examine policy strategies in sustainability transitions research (Kern et al., 2019; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016), particularly in the case of energy transitions (Johnstone et al., 2017; Lindberg et al., 2019; Schmidt & Sewerin, 2019). Policy mixes are also central to climate policy integration analysis (Di Gregorio et al., 2017; Hogl et al., 2016; Kalaba et al., 2014).

While early adaptation research focused on developing unique typologies of adaptation tools to track adaptation efforts across countries and levels of government (e.g. Biagini et al., 2014; Gagnon-Lebrun & Agrawala, 2007; Lesnikowski et al., 2011), recent work has pushed for the adoption of established frameworks from policy design scholarship to examine the political and institutional factors that shape tool choice (Berrang-Ford et al., 2019; Biesbroek et al., 2015; Henstra, 2016; Mees et al., 2014). Policy mix analysis is consequently becoming more prominent in empirical adaptation scholarship (Biesbroek & Delaney, 2020; Hughes, 2020; Hurlbert & Gupta, 2019; Milhorance et al., 2020). Comparative studies of adaptation policy mixes observe that distinct policy approaches are emerging across countries at national and local levels, suggesting the possibility that different adaptation policy styles are emerging in different contexts (Biesbroek et al., 2018; Lesnikowski et al., 2020). These mixes tend to grow more complex over time, reflecting the layering pattern observed in other policy areas (Lesnikowski et al., 2019).

## Methods

### *Data collection*

Our analysis draws on the Global Adaptation Mapping Initiative's (GAMI) database of academic studies documenting adaptation practices. GAMI is a global network of over 120 researchers who sought to analyze

adaptation to climate change through the largest systematic review to date of articles in the peer-reviewed literature (Berrang-Ford, Siders, et al., 2021b). The GAMI database was created through (1) article screening and database constructing; (2) article coding; (3) data reconciliation and synthesis; and (4) expert elicitation of results. Details on the construction and coding of the GAMI database are available in a series of published protocols (Berrang-Ford, Lesnikowski, et al., 2021; Fischer et al., 2021; Lesnikowski et al., 2021). In brief, a search of Scopus, Web of Science, and Google Scholar based on search terms that combined concepts of climate change and adaptation or adaptation-related responses identified nearly 50,000 articles published between 2013 and 2019 (Fischer et al., 2021). These articles were screened through a combination of machine-learning and manual review to include only articles that reported empirical data on adaptation-related responses by human actors to climate change. Ultimately, 1682 articles were included in the final GAMI dataset and were coded by at least two coders (Lesnikowski et al., 2021). The GAMI administrative team conducted a quality-control assessment to re-code any unreliable codes and address conflicting codes. Finally, an expert elicitation protocol was carried out to assess and confirm the validity of the results.

GAMI coders answered 27 questions about each paper. The full codebook is available in Lesnikowski et al. (2021). A subset of these variables is analyzed in this paper, including geographic region, topical sector, actors, equity, transformational nature, and motivating hazard (Table A1). Coding responses for geographic region, topical sector, response type, and hazards were modelled on the structure of IPCC AR6 to enable future comparisons with IPCC analyses and syntheses (e.g. countries were assigned to continents and/or identified as Small Island States based on the IPCC assignment of countries to these regions). 'Actors' reflect common organizational categories, including governments, businesses, and civil society, as well as individuals. 'Equity' asked whether adaptation responses were designed or intended to specifically benefit one or more marginalized groups (e.g. women, migrants, Indigenous peoples). Studies were not coded for, and often lacked information about, whether the adaptation actions achieved their goal of improving equity, so our analysis measures whether equity was noted as an intention rather than an outcome; future work will be needed to assess equity outcomes (Araos et al., 2021).

To further understand the transformational nature of adaptation, we categorize adaptation actions in terms of their depth, scope, and speed (Termeer et al., 2017; see Table A2 for GAMI definitions). Depth refers to the degree to which an adaptation action differs from existing practices or alters fundamental systemic features (Kates et al., 2012). Scope entails the spatial scale of change, the geographic reach, and/or the number of institutions and sectors affected. Speed reflects the rapidity with which a change occurs. A transformational adaptation involves activities that go beyond business-as-usual adaptations, extends over multiple sectors or larger spatial scales, and occurs quickly (Ajibade & Adams, 2019; Termeer et al., 2017).

To identify broad classes of policy tools used to support adaptation, we conducted a deductive, qualitative content analysis of quotes and summaries in the GAMI dataset. We used four predefined tool categories as defined in Taylor et al. (2012)'s review of environmental policy instruments: direct regulation, economic instruments, information-based instruments, and capacity building[1] (Table 1). We added two additional categories that have been documented as particularly important for climate adaptation: plans and networks. Plans, a

**Table 1.** Overview of policy tool types used in this paper.

| Category | Definition | Examples from GAMI dataset |
|---|---|---|
| Direct regulation | Law or policy mandating or restricting actions | National water policy (Alam, 2015), zoning ordinance (Bowden et al., 2019) |
| Plan | Strategy or plan (voluntary or mandated) | Hazard mitigation plan (Boyer et al., 2017), climate action plan (Noblet & Brisson, 2017) |
| Economic instrument | Use of taxes, subsidies, insurance, or other financial mechanisms | Flood insurance (Thistlethwaite, 2017), agricultural subsidy (Burnham & Ma, 2017) |
| Information-based instrument | Activities to raise awareness or promote particular actions through provisioning of information | Early warning system (Kaján, 2014), training on water conservation techniques (Yaffa, 2013) |
| Capacity building | Activities to help individuals be more effective at adaptation | Providing seeds for farmers (Stoilova et al., 2019), constructing irrigation infrastructure (Zhang et al., 2016) |
| Network | Community networks or inter-organizational collaborations to develop or implement adaptation responses | Water user association (Villamayor-Tomas & García-López, 2017), regional adaptation collaborative (Khan et al., 2018) |

form of procedural authoritative instrument (Howlett, 2000), are widely used to identify and direct climate adaptation strategies at local and national levels (UNEP et al., 2021). The GAMI database includes studies that provided evidence of plans being implemented (not planning activities alone), so our analysis captures organizations whose plans are implemented or whose adaptation actions are guided by a plan, rather than planning as an adaptive action itself (Fischer et al., 2021). Networks refer to groups of individuals or organizations that work collectively to plan or implement adaptation strategies; these can be seen as a form of co-regulation or self-regulation (Taylor et al., 2012).

The full GAMI dataset of 1682 papers was scrutinized to eliminate papers where the adaptation response was suggested but had not been documented in practice, as well as papers that lacked sufficient descriptions of adaptation responses to determine whether policy tools were used. This process resulted in the exclusion of 133 papers and a final dataset of 1549 papers. These 1549 papers were coded for the six tool categories in Table 1. Two team members coded 120 of these papers to check for intercoder reliability (which was 78%). Papers with conflicting tool codes were reconciled by the lead author.

### *Data analysis*

The GAMI database, as well as our additional coding, resulted in a variety of categorical variables describing where and how adaptation tools are used (Table 1 and Table A1). We first cross-tabulated each tool type with the sector, region, actor type, and climate hazard variables to assess the context in which each tool type was used. A similar descriptive analysis was performed to understand what types of disadvantaged groups were targeted by each tool type.

To formalize the conditions under which particular tools are used, we conducted a series of logistic regressions, with tool use (a binary variable indicating the presence of each tool type) as the dependent variable and sector, region, actor type, and climate risk type as independent variables. To analyze the transformational nature of adaptation, we used ordered multinomial logistic regressions to model how the inclusion of each tool type affected the probability that an adaptation was low, medium, or high in depth, scope, or speed. Regression analysis was conducted using *R*'s *MASS* package (Ripley et al., 2021).

The cross-cutting analysis of policy tools was complemented by a case-study exploration of each type of policy tool. In papers providing extended documentation of the application and outcomes of the different types of policy tools, several case studies were identified in which each tool type was used alone or in combination with other policy tools. This comparative analysis focused on ways the policy tools influenced adaptation and factors that enabled or constrained their implementation and impacts.

## Results

### *Overview of policy tools in the adaptation literature*

Of the 1549 papers in our dataset, 657 (42%) described one or more policy tools. Of these, 211 described information provisioning, 182 described networks, 171 described economic instruments, 136 described plans, 135 described direct regulations, and 88 described capacity building. Each category contained diverse examples of these tools (Table 1); they were implemented by diverse organization types and at local, regional, and national scales. The remaining 58% of papers discussed autonomous adaptations[2] that occurred without an associated policy tool.

Of papers that described a policy tool, the majority ($n = 454$, 69%) focused on only one type. One hundred forty six papers (22%) described two tool types, 51 (8%) described three, and 6 (1%) described four tool types. This implies either that many adaptations are supported by a single tool type or that researchers tend to focus on single tools or tool types and, therefore, only describe those in their analysis. Additionally, correlations between tool types are negative, suggesting that no specific tools tend to be documented in tandem with statistically significant frequency (Figure A1).

Literature documenting adaptation in different regions and sectors varies in its focus on policy tools (Figure 1). For reference, Table A3 reports the total number of papers in the dataset by region and sector. In this summary,

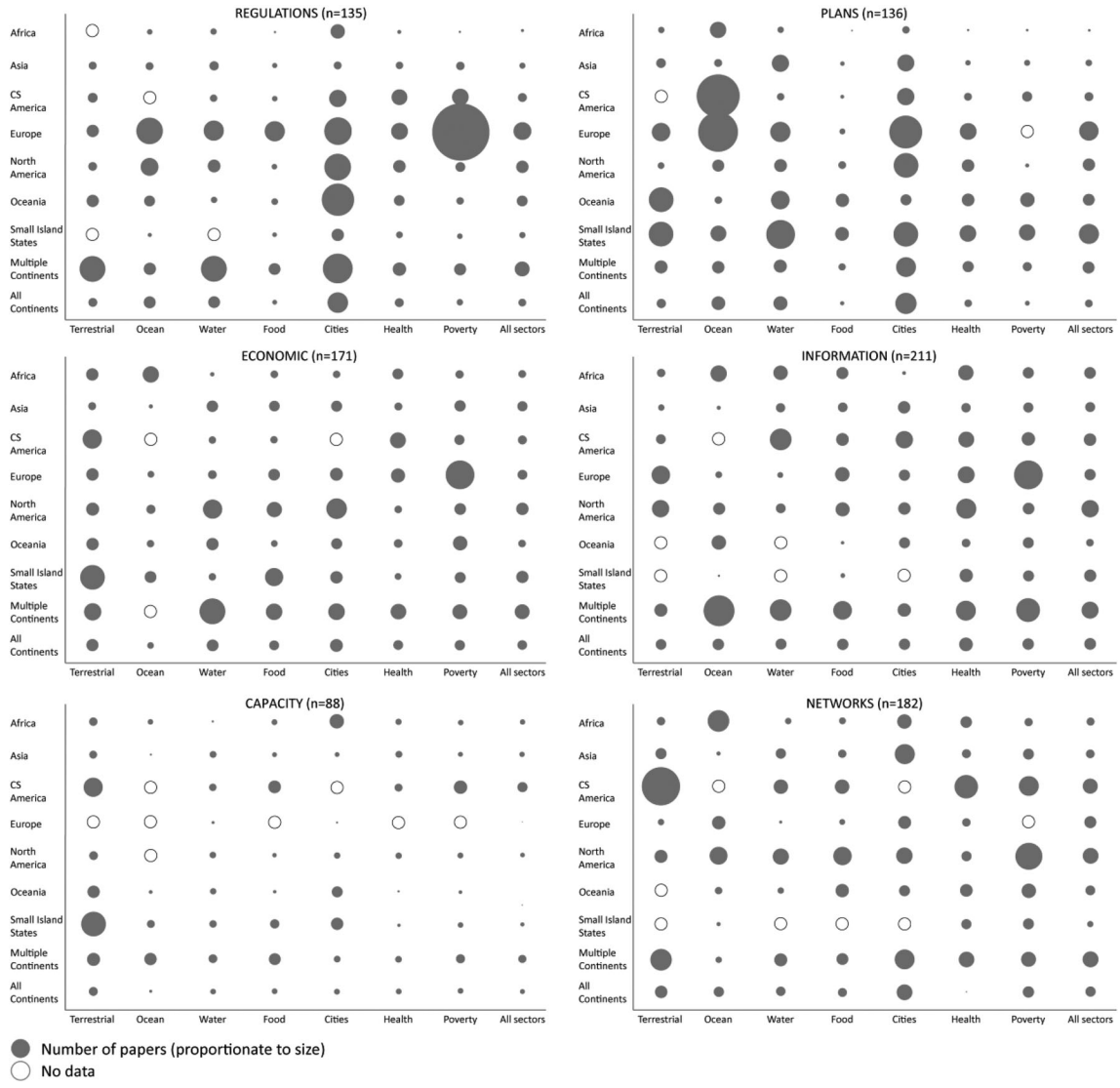


**Figure 1.** Frequency of tool description by region and sector. Circles depict the percentage of papers in a region/sector combination that describe each tool. (Poverty: *Poverty livelihoods & sustainable development*; Health: *Health, well-being & communities*; Cities: *Cities settlements & key infrastructure*; Food: *Food fibre & other ecosystem products*; Water: *Water & sanitation*; Ocean: *Ocean & coastal ecosystems*; Terrestrial: *Terrestrial & freshwater ecosystems*).

we ignore region/sector combinations with fewer than five papers overall. For instance, while 67% of *Poverty, livelihoods & sustainable development* ('Poverty') papers in Europe describe direct regulations, there are only three papers total, so it is unclear whether this frequency is representative of adaptation tools in practice.

- Direct regulations feature in 24% of papers describing adaptations for the sector *Cities, settlements & key infrastructure* ('Cities'), and are common in Europe (21%) and papers describing multiple continents (18%).
- Plans are most common in the *Cities* sector (25% of papers) as well as across sectors in Europe (23%) and Small Island States (23%); they are also particularly common in the *Ocean & coastal ecosystems* sector in Europe (46%).
- Economic instruments are not a predominant tool in any region or sector, appearing in less than 15% of papers in any region or sector; however, they are more common in *Terrestrial & aquatic ecosystems*

('Terrestrial') papers from Central and South America (22%) and Small Island States (29%), as well as *Water & sanitation* ('Water') papers describing multiple continents (30%).
- Information-based approaches are most frequent in North America (20%) and Multiple Continents papers (20%), and they are used across continents in the *Health, wellbeing & communities* ('Health') sector (16%).
- Networks appear frequently in the *Cities* sector (18%), in North America (18%), and in papers describing multiple continents (18%), and they are particularly common in Central & South American adaptations in the *Terrestrial* (44%) and *Health* sectors (27%), as well as in the *Poverty* sector in North America (31%).
- General capacity building approaches are the least commonly described of any tool (<12% in any region or sector), but they do appear regularly in the *Terrestrial* sector in Central & South America (22%) and in Small Island States (29%).
- Despite being the most common regions in the dataset overall, papers in Africa and Asia did not describe specific policy tools as frequently as other regions; however, economic instruments, information provisioning, and networks were the three most common types in both regions. Only 4% of papers in Africa and 8% in Asia described either direct regulations or plans.

### *Factors associated with tool use*

To understand the contexts where tools are most frequently used, Table 2 shows the odds ratios (ORs) for logistic regressions predicting when particular tools are documented by region, sector, actor type, and hazard. The OR can be interpreted as the difference in likelihood of having a tool documented when a particular characteristic is present versus absent; for instance, in the Regulation model, an OR of 2.48 on *Cities* says that a paper describing adaptation in the *Cities* sector is 2.48 times more likely to describe a direct regulation than one not in the *Cities* sector. An OR greater than one means that variable increases the likelihood of a tool being described, and an OR less than one decreases the likelihood that the tool is described (holding all other variables constant).

Autonomous adaptations are negatively associated with all six tool types, with papers describing an autonomous adaptation being significantly less likely to describe a policy tool. This suggests either that autonomous adaptations are truly 'autonomous', in that they are taken by individual actors acting independently, or that researchers are unlikely to explore both policy tools and autonomous adaptations in the same manuscript. The latter indicates that papers describing tools are unlikely to describe the individual level adaptations that may result from the tool's application, and that papers on autonomous adaptations are unlikely to explore external policies that may have influenced individual decisions.

Different tools are used in different contexts. In the articles we assessed, direct regulations are described more frequently than average in the *Cities* and *Poverty* sectors, and they are less likely to accompany an adaptation in Africa. Direct regulations are strongly associated with national and local governments, as well as corporations; they are less likely to be used in adaptations with large scale civil society organizations present. No specific hazard is associated with the use of direct regulations.

Plans or strategies are most frequently used in *Cities*, but surprisingly they are statistically less likely to be described in academic studies documenting *Health* sector adaptations.[3] Adaptations addressing extreme heat are significantly more likely to be described as using plans. Plans are less frequently described in Africa. Plans are described in tandem with international organizations and national and local governments, and they are unlikely to appear when individuals are involved.

Economic instruments are significantly associated with the *Food, fibre, and other ecosystem products* ('Food') sector, and they are often described in tandem with international organizations and national governments. Economic instruments (especially insurance) are frequently used to respond to flooding. No region is significantly more or less likely to use economic instruments.

Information-based approaches are often described in tandem with local level civil society organizations and are used to respond to precipitation variability and a loss of Arctic sea ice. Holding actors and hazards

**Table 2.** Odds ratios (ORs) predicted by logistic regression models of factors associated with tool use.

| | Regulation | Plan | Economic | Information | Capacity | Network |
|---|---|---|---|---|---|---|
| (Intercept) | 0.06*** | 0.21*** | 0.06*** | 0.19*** | 0.02*** | 0.13*** |
| *Sector* | | | | | | |
| Cities | 2.48** | 1.87* | 1.26 | 0.74 | 1.89 | 1.50 |
| Food | 1.01 | 0.91 | 1.75* | 1.34 | 2.03* | 1.30 |
| Health | 1.01 | 0.62* | 1.05 | 1.07 | 1.14 | 0.78 |
| Ocean | 1.00 | 1.07 | 0.51 | 1.00 | 0.31 | 0.65 |
| Poverty | 1.66* | 0.91 | 1.39 | 0.93 | 1.38 | 1.08 |
| Terrestrial | 0.97 | 0.95 | 1.18 | 0.61 | 2.27* | 1.15 |
| Water | 0.89 | 1.65 | 0.89 | 0.80 | 0.73 | 0.59* |
| *Region* | | | | | | |
| Africa | 0.46** | 0.43** | 0.92 | 1.42 | 1.83 | 0.78 |
| Asia | 1.11 | 1.11 | 1.14 | 1.12 | 1.68 | 0.92 |
| Oceania | 1.53 | 1.43 | 0.97 | 1.17 | 1.12 | 1.49 |
| Central/South America | 1.29 | 0.86 | 0.98 | 0.80 | 1.89 | 0.95 |
| Europe | 1.21 | 1.13 | 1.15 | 1.09 | 0.22* | 0.94 |
| North America | 0.78 | 0.93 | 1.48 | 1.58 | 1.25 | 1.05 |
| Small Island States | 0.56 | 1.39 | 0.80 | 0.82 | 0.43 | 0.44 |
| *Actor* | | | | | | |
| International | 1.40 | 2.42** | 2.06** | 0.66 | 2.73** | 1.36 |
| National Government | 2.67*** | 2.07** | 2.86*** | 1.29 | 1.56 | 0.83 |
| Subnational Government | 1.02 | 0.76 | 0.78 | 1.38 | 0.76 | 0.96 |
| Local Government | 2.36*** | 1.98** | 0.82 | 0.76 | 1.19 | 1.47 |
| Corporation | 1.96* | 0.54 | 1.02 | 0.71 | 0.68 | 1.14 |
| Small/Med Enterprise | 0.99 | 0.72 | 1.29 | 1.14 | 1.17 | 1.11 |
| National Civil Society | 0.51* | 0.92 | 0.67 | 1.27 | 1.40 | 1.98** |
| Local Civil Society | 0.87 | 0.93 | 0.94 | 2.27*** | 1.10 | 2.73*** |
| Individual | 0.89 | 0.56* | 1.31 | 1.23 | 1.72 | 0.93 |
| *Hazard* | | | | | | |
| Sea level rise | 0.71 | 1.19 | 1.32 | 0.67 | 0.81 | 0.79 |
| Flooding | 0.82 | 0.71 | 1.47* | 1.18 | 1.08 | 1.26 |
| Heat | 1.40 | 1.68* | 0.99 | 0.96 | 1.01 | 0.97 |
| Precipitation variability | 0.95 | 0.79 | 1.11 | 1.57* | 0.82 | 0.82 |
| Drought | 1.25 | 1.16 | 1.29 | 1.05 | 1.09 | 1.21 |
| Ocean temperature | 2.22 | 2.07 | 0.20 | 0.68 | 3.65 | 1.73 |
| Arctic Ice | 1.36 | 0.22 | 0.48 | 3.96** | 1.31 | 1.57 |
| General Climate | 1.27 | 1.21 | 0.85 | 0.89 | 0.85 | 1.29 |
| Autonomous adaptation | 0.20*** | 0.13*** | 0.28*** | 0.15*** | 0.24*** | 0.27*** |
| *AIC* | *750* | *702* | *1011* | *1107* | *637* | *1012* |

Significance codes: ***$p < 0.001$; **$p < 0.01$; * $p < 0.05$; $n = 1549$. AIC = Aikake's Information Criteria, a common measure of model goodness-of-fit.

constant, they are not significantly associated with any specific sectors or regions (contrasting the visual trends in Figure 1).

Capacity building is used more frequently in the *Food* and *Terrestrial* sectors. It is unlikely to be used in European adaptation and is most often accompanied by international organizations.

Networks are unlikely to appear in adaptations in the *Water* sector and are strongly associated with both national and local scale civil society organizations. They do not appear more or less frequently for specific regions or hazards.

## *Relationship with equity*

Figure 2 displays how often each tool was intended to target specific marginalized groups. Overall, capacity building was the tool that most often targeted marginalized groups (75% of papers documenting capacity building), followed by economic instruments (64%), networks (63%), and information-based approaches (60%). Direct regulations (47%) and plans (38%) were less likely to target marginalized groups. Low-income groups were the equity category targeted most frequently by every kind of tool, while migrants and people with disabilities were targeted the least. Across marginalized groups, information-based approaches were the most frequently used tool, apart from ethnic minorities (most commonly targeted by networks), migrants

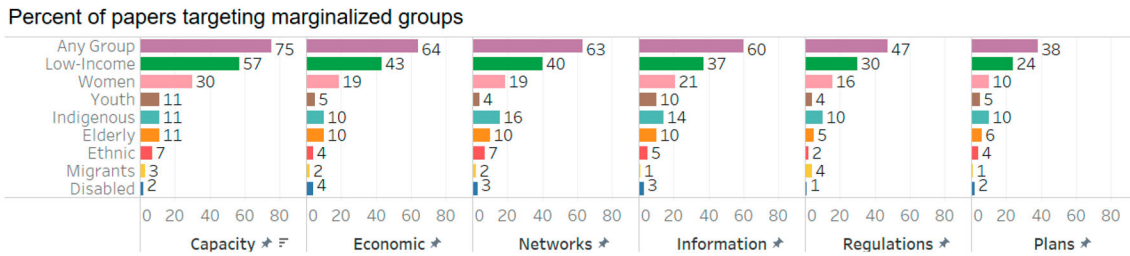


**Figure 2.** Tools by the targeted marginalized group.

(most commonly targeted by regulations), and people with disabilities (most commonly targeted by economic instruments).

Although we cannot make definitive claims about why certain tools were utilized to target certain groups, we obtained a richer qualitative understanding of how tools promote equity from the studies examined. For instance, in Baja California Sur, Mexico, Finkbeiner (2015) highlights the critical role that networks, in the form of fishing cooperatives, play in climate adaptation for small-scale fishers. Caretta (2014) describes economic instruments (specifically microcredit schemes) that target women's groups; combined with training about agricultural adaptations, the credit enhances women's adaptive capacity to climate change. In northern Mali, local strategies based on livelihood diversification, specifically targeting seasonal migrants, provide mechanisms to cope with climate change, while sub-national and national plans are needed to elevate coping to adaptation (Brockhaus et al., 2013). In Mexico, after Hurricane Dean, government regulations on forest harvesting allowed for low-income subsistence farmers to adapt to the damage of the hurricane by shifting to charcoal harvesting (Schramski & Keys, 2013). Capacity building is exhibited in the roll-out of extension services targeted at low-income farmers, which significantly increased their adoption of conservation farming practices, thereby making them more resilient to climate change and protecting their livelihoods (Arslan et al., 2014).

## *Tools and transformative potential of adaptation*

A core question underlying tool use is whether certain policy tools lead to more transformational adaptation. Importantly, adaptation responses demonstrating high depth, scope, or speed are rare. Only 25 studies (2%) were high depth, 72 (5%) high scope, and 119 (8%) high speed, and no studies were high in all three transformation categories. Nevertheless, some policy tools are associated with more transformational adaptations. Three hundred thirty nine studies (22%) reported medium depth adaptations and 417 (27%) reported medium scope adaptations.

Table 3 displays results from ordered logistic regressions predicting the depth, scope, or speed of adaptation. The coefficients are the ORs of being low versus medium or medium versus high depth, scope, or speed when a given tool is present. For example, an adaptation associated with a direct regulation is 2.24 times more likely to be in a higher depth category than one not using a direct regulation. Adaptations

**Table 3.** Ordered logistic regression predicting depth, scope, and speed of adaptation by tool use.

| | Depth | Scope | Speed |
|---|---|---|---|
| Direct regulation | 2.24*** | 2.66*** | 0.99 |
| Plan | 2.04*** | 2.65*** | 0.94 |
| Economic instrument | 1.19 | 1.57** | 1.22 |
| Information provisioning | 0.96 | 1.27 | 0.85 |
| Capacity building | 2.23*** | 2.11*** | 1.12 |
| Network | 1.80*** | 1.38 | 0.81 |
| Intercept Low/Med | 1.33 | 0.96 | 0.72 |
| Intercept Med/High | 4.36 | 3.30 | 1.69 |
| *AIC* | *1750* | *2168* | *1363* |
| *n* | *1279* | *1424* | *801* |

Significance codes: ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

supported by direct regulations, plans, capacity building, and networks are significantly more likely to be higher in depth (i.e. resulting in a more substantial transformation of behaviour or practice). Adaptations supported by regulations, plans, economic instruments, and capacity building are more likely to be higher scope (i.e. impacting a larger region or number of sectors). None of the tool types were significantly associated with slower or faster adaptations.

To understand how and why different tools have differential relationships with the extent of adaptation, we draw on case studies from specific papers in the database.

National level regulations are shown to catalyze local planning and infrastructure changes with mixed success. Flyen et al. (2018) discuss how three Norwegian municipalities incorporated climate change into their local planning after an amendment to the Norwegian Planning and Building Act. In one municipality, the revisions catalyzed political and administrative support for climate-adapted storm water management through legally binding provisions in local plan documents. In another municipality, planning agencies had several directions for climate adaptation, but these were fragmented and difficult to exercise holistically. Li et al. (2013) analyze several policies developed for local communities in China to help adapt to climate change. A regulation to enhance the use rights of small rural water infrastructure and farmlands led to investments in water infrastructure and application of water saving technology.

Papers documenting how plans shape on-the-ground adaptations are scarce in the dataset. Beaudoin and Gosselin (2016) analyzed the implementation of the health component of Québec, Canada's Climate Change Action Plan for 2006–2012. Implementation included pilot projects using city greening and suggested that significant gains in coolness can only be achieved with large projects. Koski and Siulagi (2016) analyzed climate action plans in large United States cities to assess whether they included adaptation. They found that 33% of plans had no adaptation planning, while 21% integrated adaptation throughout the plan. Cities that framed climate change effects in the language of hazards were more likely to incorporate adaptation approaches in their climate action plans.

Economic instruments are often used to incentivize behaviour that builds individual and community resilience. Pasaribu and Sudiyanto (2016) found that rice farmers responded positively to a pilot insurance scheme introduced by the Indonesian government, although they also identified many constraints for wider implementation. Caretta (2014) analyzed the impact of two microfinance schemes in Kenya to improve women's capacity to adapt to climate change. The study found that all women increased their income, while also expanding and diversifying their small business or agricultural production. The microfinance scheme's success depended on factors including learning new farming and retail practices and experience sharing with other members.

Information provisioning has mixed effects on adaptation practices. Allaire (2016) conducted an experiment to test the effect of information provision on flood management actions taken by households in Bangkok, Thailand. The treatment group received details on home retrofits and home insurance, and were told about the insurance purchasing practices of their peers. These interventions had no effect on home retrofits but increased insurance purchase by about 5%. Haworth et al. (2018) analyzed 27 ICT initiatives for communicating climate and agricultural information to smallholder farmers. Most programmes were top-down initiatives from non-profits, government, and companies. One exception, Digital Green, identified local 'champions' to create videos on farm practices that were then viewed by the community. As a result, sustainable livelihood practices increased in the community. Haworth et al. (2018) identify several traits that tend to determine the initiative's success, including affordability, accessibility, and local relevance of the information provided.

Capacity building tools generally incentivized individuals to adopt more adaptive strategies, but not all tools effectively mitigated climate impacts. Examples included governmental and non-governmental organization's interventions to increase access to improve seed and irrigation technology for farmers in Afghanistan, an intervention that significantly reduced flood risks and improved economic and financial opportunities for farmers (Jawid & Khadjavi, 2019). In Bangladesh, the government offered resources to residents to build cyclone resilient housing. However, only 6% of reconstructed houses could withstand cyclones, indicating a need for increased institutional and infrastructural support (Islam et al., 2018). In China, government support for construction of private tubewells in villages improved adaptation to drought; while this enhanced irrigation for farmers, there were concerns about groundwater tables and its redistribution around villages and households (Zhang et al., 2016).

Networks were important for enabling higher depth adaptations, but often focused at very local scales. Dapilah et al. (2020) evaluate how social networks supported livelihood diversification and climate change resilience in rural Ghana. The networks provided material and non-material resources necessary for diversification. However, social networks could simultaneously reinforce exclusion or lead to the marginalization of some groups, limiting the resilience of the whole community. Murtinho (2016) showed that in response to water scarcity, Water Users Associations in Andean Colombia helped build community capacity for micro-watershed management (land purchases, reforestation, and establishing fences to protect water sources).

## Discussion

This paper reviewed the climate adaptation literature's depiction of adaptation policy tools. Our findings suggest that most of the adaptation literature focuses on single tools rather than the dynamics of tool mixes. Of papers that documented any tool, nearly 70% focused on only one tool type. This runs counter to the policy design literature, which demonstrates that major problems are rarely addressed through single policy tools. Policy responses – including in climate adaptation – tend to see the accumulation of multiple tools over time (Del Rio & Howlett, 2013; Lesnikowski et al., 2019). This empirical gap is concerning: it presents a partial view on how adaptation is being implemented in different contexts, and leaves open questions about how tool interactions shape adaptation and risk reduction. Individual policy tools interact within policy mixes in unique ways and can produce unintended consequences that either support or undermine progress towards policy goals. A focus on single instruments may miss these interactions and raises the possibility that outcomes ascribed to individual tools (whether negative or positive) may actually be outcomes of tool interactions or other tools within a mix.

Additionally, very few of the 30% of papers that described multiple tools documented relationships between these tools. Many discussed different tools used in different locations or contexts (e.g. one city that adopted a plan and another that developed a new zoning code). Others did not describe the relationship between tools in enough detail to draw conclusions about their influence on equity or transformational adaptation. Studying the dynamics between policy tools is an important research gap.

We also find that papers that focus on autonomous adaptations rarely describe policy tools that may have prompted or supported those adaptations, and that papers describing policy tools often do not depict individual-level adaptations that may result. For a full understanding of how adaptation is progressing, documenting both policy triggers and resulting adaptations is important.

Our logistic regression results (Table 2) indicate that tool use is most significantly associated with differences in actor types, with regulations, plans, and economic tools (unsurprisingly) associated with governments, and informational and network-based tools associated with civil society. The significant associations between regulations and corporations and national civil society, and between plans and individuals, likely reflects the targeting of these tools, rather than their implementation.[4] These relationships suggest that tool choice reflects differences in authority over more coercive instruments like regulations, plans, or taxes, as well as the different actors' financial capacity to create market- or subsidy-based adaptation interventions.

Trends by region and sector were less pronounced, apart from direct regulations and plans being predominant in cities. Moreover, some specific relationships appear counterintuitive; for instance, women's networks and Water User Associations are considered a primary tool in water and sanitation (e.g. Murtinho, 2016; Villamayor-Tomas & García-López, 2017), yet networks are described less frequently in the water sector within the GAMI database than in other sectors. This may relate to the limits of keyword-based literature searches and to challenges with defining adaptation: if many studies on water and sanitation policies do not use climate adaptation language, they would not show up in a review of the adaptation literature despite potentially having climate resilience implications (see Nalau et al., 2021). Similar search biases may affect other sectors as well.

Policy instrument choice theory may help us to understand the relationship between tool choice and the transformational potential of adaptation efforts, and more specifically why economic instruments, information-based instruments, and networks are not consistently associated with depth or scope of adaptation. Economic tools like market-based instruments or subsidies tend to be adopted where government capacity is high, when the problem being addressed is complex, and when many actors are being targeted. Tools

like national flood insurance programmes or crop insurance programmes would fall into this category; they address many actors with diverse circumstances (Howlett, 2005). Our results indicate that economic instruments are associated with a wider scope but shallower depth of change and with international actors and national governments. This suggests that economic instruments are being adopted at higher levels of governance and reach many people, but may not provoke a deeper level of behavioural or cultural change. This same theory suggests that information provisioning is prevalent where capacity is high but policies target a smaller number of actors (Howlett, 2005). This may result in adaptation outcomes that are shallower and narrower in scope. We find information-based tools are significantly associated with local civil society organizations but no other types of actors, suggesting that these types of tools tend to be smaller in extent. Finally, the policy implementation styles model predicts that networks are prevalent where capacity is low, but actors are aiming to affect many people or other targets. Our results appear inconsistent with this expected relationship, as networks are associated with great depth of change but not a wider scope. This relationship may be influenced, however, by our finding that networks are associated with national and local civil society organizations, but no other types of actors. Adaptation activities implemented by civil society may tend to be more targeted than those of government actors, and so achieve a greater depth of change but to a limited scale. Notably, no policy tools appear to be associated with speed of change. This is consistent with scholarship that argues transformational change is a long, and sometimes discontinuous, process (Termeer et al., 2017).

The relationship with equity also points to considerations for incorporating equity into transformational adaptation. Whereas policy tools are being applied to support and target some groups such as low-income communities and women, there are also marginalized groups insufficiently considered in documented adaptation policy tools, especially migrants and individuals with disabilities (see also Araos et al., 2021). This study is limited to adaptation tools documented in the academic literature, and it is possible that non-documented adaptation tools are focusing on a wider range of disadvantaged groups. However, the lack of academic documentation demonstrates a gap in the research and most likely signals areas for improved knowledge and practice. In particular, research and practice will need to consider which policy tools or mix of tools enable adaptation by marginalized groups and underserved communities. Further, understanding how different combinations of tools can best serve groups with multiple marginalized identities is essential, as climate impacts frequently are amplified where intersectional vulnerabilities and government disinvestment magnify outcomes. In this study, tools with greater transformational potential, particularly regulations and plans, were found to be less likely to consider equity, as compared to tool types less associated with high depth and scope of adaptation (i.e. networks, economic instruments, and information provisioning). This pattern highlights the potential for certain types of potentially transformational adaptation to perpetuate or exacerbate existing inequities in societies (Blythe et al., 2018; Pelling et al., 2015).

## Conclusion

This paper presented an overview of how policy tools are depicted in the global adaptation literature. We found that information-based approaches, networks, and economic instruments are the most frequently documented adaptation policy tools worldwide. Each tool type was associated with particular actors, geographies, sectors, and contexts, with (for instance) regulations and plans prominent in cities and economic instruments common in food-related adaptations. Direct regulations, plans, and capacity building are associated with more transformational adaptation, while capacity building, economic instruments, networks, and information provisioning approaches are more likely to target specific marginalized groups. These findings underscore a key policy need: developing policy tools that both support transformational adaptation and protect the needs of marginalized groups. Our work suggests that capacity building tools already do this, and that direct regulations and plans could if they added more attention to supporting equity.

As a limit of the GAMI systematic review and this subsequent evaluation, published articles are the unit of analysis. The relationships identified are, therefore, those that exist in the peer-reviewed literature. Any biases that exist in what is studied are present in our work. The literature in some cases may robustly reflect relationships between specific policy tool types and factors affecting their adoption. In other cases, however, there are likely limits in the degree to which prevalence of tool types and their documented outcomes in the literature

represent overall prevalence and outcomes. For example, economic instruments and general capacity building approaches were documented relatively infrequently across sectors, and it remains uncertain whether their prevalence in the systematic review dataset is a function of their actual prevalence or of tool types most commonly studied. Similarly, papers focusing on Africa and Asia described policy tools less frequently. The relative importance of actual prevalence versus research-topic bias is another important question for future research, as geographic biases in adaptation literature have been well-documented (Hendrix, 2017; Nalau & Verrall, 2021).

Addressing such limits, future research could productively explore mixes of tool types, their evolution through time, and their impact on adaptation responses. Such research could involve process-tracing and explanatory work on how and why policy tools are changing (Lesnikowski et al., 2020), as well as evaluative assessment of how tool interactions influence risk and vulnerability reduction and outcomes. Additionally, future research should document the relationship between autonomous adaptation and policy tools, explore why capacity building can be transformational, and study policy tool use in under-documented contexts (e.g. Africa and Asia and in food sector adaptations). Finally, further exploring the interaction between equity and transformational adaptation will help identify policy tools that support both goals.

## Notes

1. While many 'capacity building' activities entail provisioning of financial support or education, these were coded as economic instruments and information-based instruments, respectively. The 'capacity building' category captures capacity building activities that were not explicitly financial or educational.
2. Autonomous adaptations are risk management strategies undertaken by individuals or organizations, without planning, coordination, or external interventions (Fankhauser et al., 1999).
3. The health sector often has a strong government focus. Adaptations in the health sector may not be catalogued as such in the academic literature or there may be a lack of research in the health sector (Scheelbeek et al., 2021).
4. The GAMI dataset is not explicit about the specific roles each actor played.

## Acknowledgements

Thank you to Angel Castro, Ariel Daniels, Nervana Fadle, Ivan Fonseca, Janette Hernandez, Joshua Nacino, Nathan Potter, Alyssa Schaff, and Cassandra Vo for assistance coding for policy tools.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This work was supported by the National Science Foundation (CNH2-L-RUI-ROA award 2010014) (I. A.); Portland State University Vision 2025 (I. A.); Social Sciences and Humanities Research Council of Canada (A. L.); Fonds de recherche de Québec- Société et Culture (A. L.); China Scholarship Council (Y. S.); Australian National University Climate Change Institute Supplementary Scholarship (Y. S.).

## ORCID

*Nicola Ulibarri* http://orcid.org/0000-0001-6238-9056
*Idowu Ajibade* http://orcid.org/0000-0002-9767-0435
*Eranga K. Galappaththi* http://orcid.org/0000-0002-3926-2206
*Elphin Tom Joe* http://orcid.org/0000-0003-1468-6413
*Alexandra Lesnikowski* http://orcid.org/0000-0003-4576-2765
*Katharine J. Mach* http://orcid.org/0000-0002-5591-8148
*Justice Issah Musah-Surugu* http://orcid.org/0000-0002-3058-169X
*Gabriela Nagle Alverio* http://orcid.org/0000-0001-7050-3381
*Alcade C. Segnon* http://orcid.org/0000-0001-9751-120X
*A.R. Siders* http://orcid.org/0000-0001-6788-8313
*Garry Sotnik* http://orcid.org/0000-0002-2422-1110

*Donovan Campbell* http://orcid.org/0000-0003-4511-838X
*Vasiliki I. Chalastani* http://orcid.org/0000-0002-1404-0682
*Kripa Jagannathan* http://orcid.org/0000-0003-4584-8358
*Vhalinavho Khavhagali* http://orcid.org/0000-0002-9553-7710
*Diana Reckien* http://orcid.org/0000-0002-1145-9509
*Yuanyuan Shang* http://orcid.org/0000-0002-8405-1352
*Chandni Singh* http://orcid.org/0000-0001-6842-6735
*Zinta Zommers* http://orcid.org/0000-0003-4755-6279

## References

af Rosenschöld, J. M., & Rozema, J. G. (2019). Moving from incremental to transformational change in climate adaptation policy? An institutionalist perspective. In E. C.H. Keskitalo & B. L. Preston (Eds.), *Research handbook on climate change adaptation policy* (pp. 91–107). Edward Elgar Publishing.

Ajibade, I., & Adams, E. A. (2019). Planning principles and assessment of transformational adaptation: Towards a refined ethical approach. *Climate and Development*, *11*(10), 850–862. https://doi.org/10.1080/17565529.2019.1580557

Alam, K. (2015). Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. *Agricultural Water Management*, *148*, 196–206. https://doi.org/10.1016/j.agwat.2014.10.011

Allaire, M. C. (2016). Using practical and social information to influence flood adaptation behavior. *Water Resources Research*, *52*(8), 6078–6093. https://doi.org/10.1002/2015WR018258

Araos, M., Jagannathan, K., Shukla, R., Ajibade, I., Coughlan de Perez, E., Davis, K., Ford, J. D., Galappaththi, E. K., Grady, C., Hudson, A. J., Joe, E. T., Kirchhoff, C. J., Lesnikowski, A., Nagle Alverio, G., Nielsen, M., Orlove, B., Pentz, B., Reckien, D., Siders, A.R., … Turek-Hankins, L. L. (2021). Equity in human adaptation-related responses: A systematic global review. *One Earth*, *4*(10), 1454–1467. https://doi.org/10.1016/j.oneear.2021.09.001

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., & Cattaneo, A. (2014). Adoption and intensity of adoption of conservation farming practices in Zambia. *Agriculture, Ecosystems & Environment*, *187*, 72–86. https://doi.org/10.1016/j.agee.2013.08.017

Beaudoin, M., & Gosselin, P. (2016). An effective public health program to reduce urban heat islands in Québec, Canada. *Revista Panamericana de Salud Publica = Pan American Journal of Public Health*, *40*(3), 160–166.

Béland, D. (2007). Ideas and institutional change in social security: Conversion, layering, and policy drift. *Social Science Quarterly*, *88* (1), 20–38. https://doi.org/10.1111/j.1540-6237.2007.00444.x

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Resilience, poverty and development. *Journal of International Development*, *26*(5), 598–623. https://doi.org/10.1002/jid.2992

Berkhout, F. (2012). Adaptation to climate change by organizations. *Wiley Interdisciplinary Reviews: Climate Change*, *3*(1), 91–106. https://doi.org/10.1002/wcc.154

Berrang-Ford, L., Biesbroek, R., Ford, J. D., Lesnikowski, A., Tanabe, A., Wang, F. M., Chen, C., Hsu, A., Hellmann, J. J., Pringle, P., Grecequet, M., Amado, J.-C., Huq, S., Lwasa, S., & Jody Heymann, S. (2019). Tracking global climate change adaptation among governments. *Nature Climate Change*, *9*(6), 440–449. https://doi.org/10.1038/s41558-019-0490-0

Berrang-Ford, L., Lesnikowski, A., Paige Fischer, A., Siders, A. R., Mach, K. J., Thomas, A., Callaghan, M., Haddaway, N., Kerr, R. B., Biesbroek, R., Bowen, K., Deryng, D., Elliott, S., Ford, J. D., Garschagen, M., Gilmore, E., Harper, S., Hassnoot, M., Lissner, T., & Van Aalst, M. (2021a). *The Global Adaptation Mapping Initiative (GAMI): Part 1 – Introduction and overview of methods*. https://doi.org/10.21203/rs.3.pex-1240/v1

Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M., Haddaway, N., Mach, K., Araos, M., Shah, M. A. R., Wannewitz, M., Doshi, D., Leiter, T., Matavel, C., Musah-Surugu, J. I., Wong-Parodi, G., Antwi-Agyei, P., Ajibade, I., Chauhan, N., Kakenmaster, W., … Abu, T. Z. (2021b). A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change*, *11*, 989–1000. https://doi.org/10.1038/s41558-021-01170-y.

Bhandary, R. R., Gallagher, K. S., & Zhang, F. (2021). Climate finance policy in practice: A review of the evidence. *Climate Policy*, *21*(4), 529–545. https://doi.org/10.1080/14693062.2020.1871313

Biagini, B., Bierbaum, R., Stults, M., Dobardzic, S., & McNeeley, S. M. (2014). A typology of adaptation actions: A global look at climate adaptation actions financed through the global environment facility. *Global Environmental Change*, *25*, 97–108. https://doi.org/10.1016/j.gloenvcha.2014.01.003

Biesbroek, R., & Delaney, A. (2020). Mapping the evidence of climate change adaptation policy instruments in Europe. *Environmental Research Letters*, *15*(8), 083005. https://doi.org/10.1088/1748-9326/ab8fd1

Biesbroek, R., Dupuis, J., Jordan, A., Wellstead, A., Howlett, M., Cairney, P., Rayner, J., & Davidson, D. (2015). Opening up the black box of adaptation decision-making. *Nature Climate Change*, *5*(6), 493–494. https://doi.org/10.1038/nclimate2615

Biesbroek, R., Lesnikowski, A., Ford, J. D., Berrang-Ford, L., & Vink, M. (2018). Do administrative traditions matter for climate change adaptation policy? A comparative analysis of 32 high-income countries. *The Review of Policy Research*, *35*(6), 881–906. https://doi.org/10.1111/ropr.12309

Blythe, J., Silver, J., Evans, L., Armitage, D., Bennett, N. J., Moore, M.-L., Morrison, T. H., & Brown, K. (2018). The dark side of transformation: Latent risks in contemporary sustainability discourse. *Antipode*, *50*(5), 1206–1223. https://doi.org/10.1111/anti.12405

Bowden, V., Nyberg, D., & Wright, C. (2019). Planning for the past: Local temporality and the construction of denial in climate change adaptation. *Global Environmental Change: Human and Policy Dimensions*, *57*, 101939. https://doi.org/10.1016/j.gloenvcha.2019.101939

Boyer, M. A., Meinzer, M., & Bilich, A. (2017). The climate adaptation imperative: Local choices targeting global problems? *Local Environment*, *22*(1), 67–85. https://doi.org/10.1080/13549839.2016.1160372

Brockhaus, M., Djoudi, H., & Locatelli, B. (2013). Envisioning the future and learning from the past: Adapting to a changing environment in northern Mali. *Environmental Science & Policy*, *25*, 94–106. https://doi.org/10.1016/j.envsci.2012.08.008

Burnham, M., & Ma, Z. (2017). Climate change adaptation: Factors influencing Chinese smallholder farmers' perceived self-efficacy and adaptation intent. *Regional Environmental Change*, *17*(1), 171–186. https://doi.org/10.1007/s10113-016-0975-6

Caretta, M. A. (2014). "Credit plus" microcredit schemes: A key to women's adaptive capacity. *Climate and Development*, *6*(2), 179–184. https://doi.org/10.1080/17565529.2014.886990

Clar, C., & Steurer, R. (2018). Why popular support tools on climate change adaptation have difficulties in reaching local policymakers: Qualitative insights from the UK and Germany. *Environmental Policy and Governance*, *28*(3), 172–182. https://doi.org/10.1002/eet.1802

Dapilah, F., Nielsen, JØ, & Friis, C. (2020). The role of social networks in building adaptive capacity and resilience to climate change: A case study from northern Ghana. *Climate and Development*, *12*(1), 42–56. https://doi.org/10.1080/17565529.2019.1596063

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L., & Sugiyama, T. (2018). Strengthening and implementing the global response. In IPCC (Ed.), *Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 313–433). IPCC.

Del Rio, P., & Howlett, M. P. (2013). *Beyond the "Tinbergen Rule" in policy design: Matching tools and goals in policy portfolios*. Lee Kuan Yew School of Public Policy Research Paper, 13-01. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2247238

Di Gregorio, M., Nurrochmat, D. R., Paavola, J., Sari, I. M., Fatorelli, L., Pramova, E., Locatelli, B., Brockhaus, M., & Kusumadewi, S. D. (2017). Climate policy integration in the land use sector: Mitigation, adaptation and sustainable development linkages. *Environmental Science & Policy*, *67*, 35–43. https://doi.org/10.1016/j.envsci.2016.11.004

Eakin, H., York, A., Aggarwal, R., Waters, S., Welch, J., Rubiños, C., Smith-Heisters, S., Bausch, C., & Anderies, J. M. (2016). Cognitive and institutional influences on farmers' adaptive capacity: Insights into barriers and opportunities for transformative change in central Arizona. *Regional Environmental Change*, *16*(3), 801–814. https://doi.org/10.1007/s10113-015-0789-y

Eliadis, P. F., Hill, M. M., & Howlett, M. (2005). *Designing government: From instruments to governance*. McGill-Queen's University Press.

Fankhauser, S., Smith, J. B., & Tol, R. S. J. (1999). Weathering climate change: Some simple rules to guide adaptation decisions. *Ecological Economics: The Journal of the International Society for Ecological Economics*, *30*(1), 67–78. https://doi.org/10.1016/S0921-8009(98)00117-7

Few, R., Morchain, D., Spear, D., Mensah, A., & Bendapudi, R. (2017). Transformation, adaptation and development: Relating concepts to practice. *Palgrave Communications*, *3*(1), 1–9. https://doi.org/10.1057/s41599-017-0001-8

Finkbeiner, E. M. (2015). The role of diversification in dynamic small-scale fisheries: Lessons from Baja California Sur, Mexico. *Global Environmental Change: Human and Policy Dimensions*, *32*, 139–152. https://doi.org/10.1016/j.gloenvcha.2015.03.009

Fischer, A. P., Callaghan, M., Berrang-Ford, L., Nielsen, M., Sotnik, G., Canosa, I. V., Haddaway, N., Biesbroek, R., Harper, S., Minx, J., Perez, E. C., Reckien, D., & Van Aalst, M. (2021). The global adaptation mapping initiative (GAMI): Part 2 – Screening protocol. *Research Square*. https://doi.org/10.21203/rs.3.pex-1241/v1

Flyen, C., Hauge, ÅL, Almås, A.-J., & Godbolt, ÅL. (2018). Municipal collaborative planning boosting climate resilience in the built environment. *International Journal of Disaster Resilience in the Built Environment*, *9*(1), 58–69. https://doi.org/10.1108/IJDRBE-10-2016-0042

Fook, T. C. T. (2017). Transformational processes for community-focused adaptation and social change: A synthesis. *Climate and Development*, *9*(1), 5–21. https://doi.org/10.1080/17565529.2015.1086294

Gagnon-Lebrun, F., & Agrawala, S. (2007). Implementing adaptation in developed countries: An analysis of progress and trends. *Climate Policy*, *7*(5), 392–408. https://doi.org/10.1080/14693062.2007.9685664

Hall, P. A. (1993). Policy paradigms, social learning, and the state: The case of economic policymaking in Britain. *Comparative Politics*, *25*(3), 275. https://doi.org/10.2307/422246

Haworth, B., Biggs, E., Duncan, J., Wales, N., Boruff, B., & Bruce, E. (2018). Geographic information and communication technologies for supporting smallholder agriculture and climate resilience. *Climate*, *6*(4), 97. https://doi.org/10.3390/cli6040097

Hendrix, C. S. (2017). The streetlight effect in climate change research on Africa. *Global Environmental Change: Human and Policy Dimensions*, *43*, 137–147. https://doi.org/10.1016/j.gloenvcha.2017.01.009

Henstra, D. (2016). The tools of climate adaptation policy: Analysing instruments and instrument selection. *Climate Policy*, *16*(4), 496–521. https://doi.org/10.1080/14693062.2015.1015946

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Guillén Bolaños, T., Bindi, M., Brown, S., Camilloni, I. A., Diedhiou, A., Djalante, R., Ebi, K., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Hope, C. W., Payne, A. J., Pörtner, H.-O., Seneviratne, S. I., Thomas, A., … Zhou, G. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science*, *365*(6460), 6459. https://doi.org/10.1126/science.aaw6974

Hogl, K., Kleinschmit, D., & Rayner, J. (2016). Achieving policy integration across fragmented policy domains: Forests, agriculture, climate and energy. *Environment and Planning C: Government and Policy*, *34*(3), 399–414. https://doi.org/10.1177/0263774X16644815

Howlett, M. (2000). Managing the "hollow state": procedural policy instruments and modern governance. *Canadian Public Administration: Administration Publique Du Canada*, *43*(4), 412–431. https://doi.org/10.1111/j.1754-7121.2000.tb01152.x

Howlett, M. (2005). What is a policy instrument? Tools, mixes, and implementation styles. In P. F. Eliadis, M. M. Hill, & M. Howlett (Eds.), *Designing government* (pp. 31–50). McGill-Queen's University Press Montreal.

Howlett, M. (2018). The criteria for effective policy design: Character and context in policy instrument choice. *Journal of Asian Public Policy*, *11*(3), 245–266. https://doi.org/10.1080/17516234.2017.1412284

Howlett, M., & del Rio, P. (2015). The parameters of policy portfolios: Verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning. C, Government & Policy*, *33*(5), 1233–1245. https://doi.org/10.1177/0263774X15610059

Howlett, M., & Tosun, J. (2018). *Policy styles and policy-making*. Routledge.

Hughes, S. (2020). Principles, drivers, and policy tools for just climate change adaptation in legacy cities. *Environmental Science & Policy*, *111*, 35–41. https://doi.org/10.1016/j.envsci.2020.05.007

Hurlbert, M. A., & Gupta, J. (2019). An institutional analysis method for identifying policy instruments facilitating the adaptive governance of drought. *Environmental Science & Policy*, *93*, 221–231. https://doi.org/10.1016/j.envsci.2018.09.017

Hurlbert, M. A., Gupta, J., & Verrest, H. (2019). A comparison of drought instruments and livelihood capitals: Combining livelihood and institutional analyses to study drought policy instruments. *Climate and Development*, *11*(10), 863–872. https://doi.org/10.1080/17565529.2019.1585318

IPCC. (2018). *Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. https://www.ipcc.ch/sr15/download/

IPCC. (2021). *Climate change 2021: The physical science basis*.

Islam, M. Z., Kolade, O., & Kibreab, G. (2018). Post-disaster housing reconstruction: The impact of resourcing in post-cyclones side and Aila in Bangladesh. *Journal of International Development*, *30*(6), 934–960. https://doi.org/10.1002/jid.3367.

Jawid, A., & Khadjavi, M. (2019). Adaptation to climate change in Afghanistan: Evidence on the impact of external interventions. *Economic Analysis and Policy*, *64*, 64–82. https://doi.org/10.1016/j.eap.2019.07.010

Johnstone, P., Stirling, A., & Sovacool, B. (2017). Policy mixes for incumbency: Exploring the destructive recreation of renewable energy, shale gas "fracking," and nuclear power in the United Kingdom. *Energy Research & Social Science*, *33*, 147–162. https://doi.org/10.1016/j.erss.2017.09.005

Kaján, E. (2014). Arctic tourism and sustainable adaptation: Community perspectives to vulnerability and climate change. *Scandinavian Journal of Hospitality and Tourism*, *14*(1), 60–79. https://doi.org/10.1080/15022250.2014.886097

Kalaba, F. K., Quinn, C. H., & Dougill, A. J. (2014). Policy coherence and interplay between Zambia's forest, energy, agricultural and climate change policies and multilateral environmental agreements. *International Environmental Agreements: Politics, Law and Economics*, *14*(2), 181–198. https://doi.org/10.1007/s10784-013-9236-z

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(19), 7156–7161. https://doi.org/10.1073/pnas.1115521109

Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, *48*(10), 103832. https://doi.org/10.1016/j.respol.2019.103832

Khan, A., Charles, A., & Armitage, D. (2018). Place-based or sector-based adaptation? A case study of municipal and fishery policy integration. *Climate Policy*, *18*(1), 14–23. https://doi.org/10.1080/14693062.2016.1228520

Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy*, *45*(1), 205–217. https://doi.org/10.1016/j.respol.2015.09.008

Kofinas, G., Clark, D., & Hovelsrud, G. K. (2013). Adaptive and transformative capacity. In *Arctic resilience: Interim report 2013* (pp. 71–93). Stockholm Environment Institute and the Stockholm Resilience Centre.

Koski, C., & Siulagi, A. (2016). Environmental harm or natural hazard? Problem identification and adaptation in U.S. municipal climate action plans. *The Review of Policy Research*, *33*(3), 270–290. https://doi.org/10.1111/ropr.12173

Lesnikowski, A., Berrang-Ford, L., Siders, A. R., Haddaway, N., Biesbroek, R., Harper, S., Minx, J., de Perez, E. C., Reckien, D., Mark, N., Singh, C., Thomas, A., Totin, E., Trisos, C., & Van Bavel, B. (2021). *The global adaptation mapping initiative (GAMI): Part 3 – Coding protocol*. https://doi.org/10.21203/rs.3.pex-1242/v1

Lesnikowski, A., Biesbroek, R., Ford, J. D., & Berrang-Ford, L. (2020). Policy implementation styles and local governments: The case of climate change adaptation. *Environmental Politics*, *30*(5), 753–790. https://doi.org/10.1080/09644016.2020.1814045

Lesnikowski, A., Ford, J. D., Berrang-Ford, L., Paterson, J. A., Barrera, M., & Heymann, S. J. (2011). Adapting to health impacts of climate change: A study of UNFCCC Annex I parties. *Environmental Research Letters*, *6*(4), 044009. https://doi.org/10.1088/1748-9326/6/4/044009

Lesnikowski, A., Ford, J. D., Biesbroek, R., & Berrang-Ford, L. (2019). A policy mixes approach to conceptualizing and measuring climate change adaptation policy. *Climatic Change*, *156*(4), 447–469. https://doi.org/10.1007/s10584-019-02533-3

Levy, B. S., & Patz, J. A. (2015). Climate change, human rights, and social justice. *Annals of Global Health*, *81*(3), 310–322. https://doi.org/10.1016/j.aogh.2015.08.008

Li, H., Gupta, J., & Van Dijk, M. P. (2013). China's drought strategies in rural areas along the Lancang River. *Water Policy*, *15*(1), 1–18. https://doi.org/10.2166/wp.2012.050

Lindberg, M. B., Markard, J., & Andersen, A. D. (2019). Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. *Research Policy*, *48*(10), 103668. https://doi.org/10.1016/j.respol.2018.09.003

Linder, S. H., & Peters, B. G. (1989). Instruments of government: Perceptions and contexts. *Journal of Public Policy*, *9*(1), 35–58. https://doi.org/10.1017/S0143814X00007960

Mees, H. L. P., Dijk, J., van Soest, D., Driessen, P. P. J., van Rijswick, M. H. F. M. W., & Runhaar, H. (2014). A method for the deliberate and deliberative selection of policy instrument mixes for climate change adaptation. *Ecology and Society*, *19*(2). https://doi.org/10.5751/es-06639-190258

Milhorance, C., Sabourin, E., Le Coq, J.-F., & Mendes, P. (2020). Unpacking the policy mix of adaptation to climate change in Brazil's semiarid region: Enabling instruments and coordination mechanisms. *Climate Policy*, *20*(5), 593–608. https://doi.org/10.1080/14693062.2020.1753640

Moellendorf, D. (2015). Climate change justice. *Philosophy Compass*, *10*(3), 173–186. https://doi.org/10.1111/phc3.12201

Mubaya, C. P., & Mafongoya, P. (2017). The role of institutions in managing local level climate change adaptation in semi-arid Zimbabwe. *Climate Risk Management*, *16*, 93–105. https://doi.org/10.1016/j.crm.2017.03.003

Murtinho, F. (2016). What facilitates adaptation? An analysis of community-based adaptation to environmental change in the Andes. *International Journal of the Commons*, *10*(1), 119–141. https://doi.org/10.18352/ijc.585

Nalau, J., Torabi, E., Edwards, N., Howes, M., & Morgan, E. (2021). A critical exploration of adaptation heuristics. *Climate Risk Management*, *32*, 100292. https://doi.org/10.1016/j.crm.2021.100292

Nalau, J., & Verrall, B. (2021). Mapping the evolution and current trends in climate change adaptation science. *Climate Risk Management*, *32*, 100290. https://doi.org/10.1016/j.crm.2021.100290

Noblet, M., & Brisson, G. (2017). Adaptation to climate change in Quebec's coastal zone: A difficult transformation of public action. *International Journal of Climate Change Strategies and Management*, *9*(3), 282–298. https://doi.org/10.1108/IJCCSM-04-2016-0047

Olazabal, M., & Ruiz De Gopegui, M. (2021). Adaptation planning in large cities is unlikely to be effective. *Landscape and Urban Planning*, *206*, 103974. https://doi.org/10.1016/j.landurbplan.2020.103974

Pasaribu, S. M., & Sudiyanto, A. (2016). Agricultural risk management: Lesson learned from the application of rice crop insurance in Indonesia. In S. Kaneko, & M. Kawanishi (Eds.), *Climate change policies and challenges in Indonesia* (pp. 305–322). Springer.

Patterson, J. J. (2021). More than planning: Diversity and drivers of institutional adaptation under climate change in 96 major cities. *Global Environmental Change: Human and Policy Dimensions*, *68*, 102279. https://doi.org/10.1016/j.gloenvcha.2021.102279

Pelling, M., O'Brien, K., & Matyas, D. (2015). Adaptation and transformation. *Climatic Change*, *133*(1), 113–127. https://doi.org/10.1007/s10584-014-1303-0

Rayner, J., Howlett, M., & Wellstead, A. (2017). Policy mixes and their alignment over time: Patching and stretching in the oil sands reclamation regime in Alberta, Canada. *Environmental Policy and Governance*, *27*(5), 472–483. https://doi.org/10.1002/eet.1773

Richardson, J. (1982). *Policy styles in Western Europe*. George Allen & Unwin Ltd.

Ripley, B., Venables, B., Bates, D. M., Hornik, K., Gebhardt, A., & Firth, D. (2021). *Package 'MASS'* (Version 7.3-53.1) [Computer software]. https://cran.r-project.org/web/packages/igraph/igraph.pdf

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Sanderson, B. M., & O'Neill, B. C. (2020). Assessing the costs of historical inaction on climate change. *Scientific Reports*, *10*(1), 9173. https://doi.org/10.1038/s41598-020-66275-4

Schaffrin, A., Sewerin, S., & Seubert, S. (2015). Toward a comparative measure of climate policy output. *Policy Studies Journal*, *43*(2), 257–282. https://doi.org/10.1111/psj.12095

Scheelbeek, P. F. D., Dangour, A. D., Jarmul, S., Turner, G., Sietsma, A. J., Minx, J. C., Callaghan, M., Ajibade, I., Austin, S. E., Biesbroek, R., Bowen, K. J., Chen, T., Davis, K., Ensor, T., Ford, J. D., Galappaththi, E. K., Joe, E. T., Musah-Surugu, I. J., Alverio, G. N., … Berrang-Ford, L. (2021). The effects on public health of climate change adaptation responses: A systematic review of evidence from low- and middle-income countries. *Environmental Research Letters*, *16*(7), 073001. https://doi.org/10.1088/1748-9326/ac092c

Schmidt, T. S., & Sewerin, S. (2019). Measuring the temporal dynamics of policy mixes – An empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Research Policy*, *48*(10), 103557. https://doi.org/10.1016/j.respol.2018.03.012

Schramski, S., & Keys, E. (2013). Smallholder response to Hurricane Dean: Creating new human ecologies through charcoal production. *Natural Hazards Review*, *14*(4), 211–219. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000100

Stoilova, T., van Zonneveld, M., Roothaert, R., & Schreinemachers, P. (2019). Connecting genebanks to farmers in East Africa through the distribution of vegetable seed kits. *Plant Genetic Resources: Characterization and Utilization*, *17*(3), 306–309. https://doi.org/10.1017/S1479262119000017

Taylor, C., Pollard, S., Rocks, S., & Angus, A. (2012). Selecting policy instruments for better environmental regulation: A critique and future research agenda. *Environmental Policy and Governance*, *22*(4), 268–292. https://doi.org/10.1002/eet.1584

Termeer, C. J. A. M., Dewulf, A., & Biesbroek, G. R. (2017). Transformational change: Governance interventions for climate change adaptation from a continuous change perspective. *Journal of Environmental Planning and Management*, *60*(4), 558–576. https://doi.org/10.1080/09640568.2016.1168288

Thistlethwaite, J. (2017). The emergence of flood insurance in Canada: Navigating institutional uncertainty. *Risk Analysis: An Official Publication of the Society for Risk Analysis*, *37*(4), 744–755. https://doi.org/10.1111/risa.12659

Thistlethwaite, J., & Henstra, D. (2017). Municipal flood risk sharing in Canada: A policy instrument analysis. *Canadian Water Resources Journal/Revue Canadienne Des Ressources Hydriques*, *42*(4), 349–363. https://doi.org/10.1080/07011784.2017.1364144

Tompkins, E. L., Vincent, K., Nicholls, R. J., & Suckall, N. (2018). Documenting the state of adaptation for the global stocktake of the Paris agreement. *WIRES Climate Change*, *9*(5), e545. https://doi.org/10.1002/wcc.545

UNEP, UNEP DTU Partnership, & World Adaptation Science Programme. (2021). *Adaptation gap report* 2020. UN Environment Programme. https://www.unep.org/resources/adaptation-gap-report-2020

UNFCCC. (2015). *The Paris agreement*. 21st Conference of the Parties, Paris: United Nations. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Villamayor-Tomas, S., & García-López, G. (2017). The influence of community-based resource management institutions on adaptation capacity: A large-n study of farmer responses to climate and global market disturbances. *Global Environmental Change*, *47*, 153–166. https://doi.org/10.1016/j.gloenvcha.2017.10.002

Xu, C., Kohler, T. A., Lenton, T. M., Svenning, J.-C., & Scheffer, M. (2020). Future of the human climate niche. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(21), 11350–11355. https://doi.org/10.1073/pnas.1910114117

Yaffa, S. (2013). Coping measures not enough to avoid loss and damage from drought in the North Bank Region of The Gambia. *International Journal of Global Warming*, *5*(4), 467–482. https://doi.org/10.1504/IJGW.2013.057286

Zhang, L., Wang, J., Zhang, G., & Huang, Q. (2016). Impact of the methods of groundwater access on irrigation and crop yield in the North China Plain. *China Agricultural Economic Review*, *8*(4), 613–633. https://doi.org/10.1108/CAER-12-2015-0177

## Appendix

**Table A1.** Variables from the GAMI dataset.

| Variable | Options | Description |
|---|---|---|
| Geography | • Africa<br>• Asia<br>• Australasia<br>• Central & South America<br>• North America<br>• Europe<br>• Small Island States | Countries assigned to geographic regions in accordance with the IPCC assessment reports; Papers may be associated with multiple regions if they described adaptations in multiple locations |
| Sector | • Terrestrial & freshwater ecosystems<br>• Ocean & coastal ecosystems<br>• Water and sanitation<br>• Food, fibre, and other ecosystem products<br>• Cities, settlements, and key infrastructure<br>• Health, well-being, and communities<br>• Poverty, livelihoods, and sustainable development | Coders selected all that apply; each had a further description in the coding book to provide examples for coders. |
| Actors | • International or multinational governance institutions<br>• Government (national)<br>• Government (sub-national)<br>• Government (local)<br>• Private sector (corporations)<br>• Private sector (small enterprises)<br>• Civil society (national, multinational, international)<br>• Civil society (sub-national or local)<br>• Individuals or households | Coders selected all that apply. |
| Equity (Targeting) | • Women<br>• Youth<br>• Elderly<br>• Low-income<br>• Disability<br>• Migrants<br>• Indigenous<br>• Ethnic minorities<br>• Other<br>• None | Coders asked whether adaptation responses were designed or specifically intended to affect any of these groups (or select none). |

(*Continued*)

**Table A1.** Continued.

| Variable | Options | Description |
|---|---|---|
| Hazards | • Sea level rise<br>• Extreme precipitation and inland flooding<br>• Increased frequency and intensity of extreme heat<br>• Precipitation variability<br>• Drought<br>• Rising ocean temperature and ocean acidification<br>• Loss of Arctic sea ice<br>• General climate impacts<br>• Other<br>• No information or not assessed | Hazards listed based on major threats identified in IPCC assessment reports. Coders asked to identify the threat(s) to which the adaptation description in the paper was responding/was intended to address. |

More information available in GAMI Protocol 3 (Lesnikowski et al., 2021).

**Table A2.** Transformation potential coding.

| Depth | Depth relates to the degree to which change reflects something new, novel, and different from existing norms or practices. |
|---|---|
| High | High depth (in-depth) change is more transformational: it might involve radically changing practices by altering frames, values, logics, and assumptions underlying the system. This might involve deep structural reform, complete change in mindset, radical shifts in perceptions or values, and changing institutional or behavioural norms. Adaptation actions are increasingly radical (depth of change), including altering of values, re-framing of problems, and dramatic changes in practices. |
| Medium | Medium (moderate) depth describes incremental changes: a shift away from existing practices, norms, or structures, but only to a limited degree. Perspectives, values, and practices are changing to involve novel or more radical approaches (depth of change). Changes in risk perception may be medium depth. |
| Low | Low (limited) depth follows business-as-usual practices, with no real difference in underlying values, assumptions, or norms. This includes practices that are largely expansions of existing practices. Adaptations largely are incremental by expanding existing practices, with limited evidence of novel change beyond business-as-usual practices (depth of change). |
| Scope | Scope refers to the scale of change – geographic or institutional. |
| High | High (broad, large) scope refers to large-scale and system-wide changes that involve an entire organization, a country or large region, and large populations. Broad scope efforts may be multi-dimensional, multi-component, and/or multi-level. Development of networks, inter-organizational coordination are more likely to lead to changes of broad scope. Adaptation is implemented at or very near its full potential across multiple dimensions. Adaptations are widespread and substantial, including most of the possible sectors, levels of governance, actors (e.g. nationally implemented legislation or policy), or reflect widespread changes in behaviour (scope of change). For example, this may include numerous cities or national-level changes, or institution-wide change. It may also address shifts in underlying norms and behaviours across entire populations. |
| Medium | Medium scope could describe multiple communities or households acting without coordination, a single sector taking action, or a small regional action. Adaptation is expanding and increasingly coordinated. There are growing efforts that exceed business-as-usual practices and challenge the fundamental attributes of the social-ecological system. There is some expansion and/or mainstreaming of change (scope of change) to include a wider region, or involvement of coordinated, multi-dimensional, multi-level adaptation. |
| Low | Low (small) scope might refer to local initiatives, activities taken by individuals or households. Adaptation is largely localized. There are primarily disjointed adaptation initiatives, with limited evidence of coordination or mainstreaming across sectors, jurisdictions, or levels of governance (scope of change). This could be a single city or government department. |
| Speed | Speed of change refers to the dimension of time within which changes are happening. |
| High | High (fast) speed adaptation actions are either (a) those described as being fast for their type of action (e.g. building a bridge in a year might still be considered fast) or (b) those that can take place and see results within 1–3 years. |
| Medium | Medium (moderate) speed adaptations are those that occur or see results over 3–5 years. Adaptations are increasingly exceeding business-as-usual behavioural or institutional change to reflect accelerated adaptive responses (speed of change). |
| Low | Low (slow) speed adaptations are those that take 5 years or more to be executed or to see results. Adaptations are largely slow, consistent with existing behavioural or institutional change, and limited evidence of accelerated adaptive response (speed of change). Change is evident, but not rapid. |

**Table A3.** Total papers in dataset by region and sector.

| | Terrestrial | Ocean | Water | Food | Cities | Health | Poverty | All sectors |
|---|---|---|---|---|---|---|---|---|
| Africa | 42 | 16 | 42 | 375 | 24 | 113 | 321 | 492 |
| Asia | 55 | 44 | 76 | 376 | 56 | 167 | 252 | 524 |
| Central & South America | 9 | 4 | 12 | 48 | 10 | 11 | 26 | 69 |
| Europe | 14 | 13 | 30 | 30 | 47 | 31 | 3 | 116 |

(*Continued*)

**Table A3.** Continued.

| | Terrestrial | Ocean | Water | Food | Cities | Health | Poverty | All sectors |
|---|---|---|---|---|---|---|---|---|
| North America | 40 | 29 | 27 | 80 | 42 | 69 | 45 | 175 |
| Oceania | 7 | 24 | 14 | 26 | 8 | 41 | 24 | 81 |
| Small Island States | 7 | 22 | 12 | 19 | 7 | 26 | 16 | 43 |
| Multiple Continents | 20 | 14 | 20 | 37 | 26 | 39 | 29 | 87 |
| All Continents | 187 | 145 | 222 | 972 | 215 | 472 | 700 | 1549 |

Note: A single paper may be listed in multiple sectors. Small Island States papers are double counted with other regions. Poverty: *Poverty livelihoods & sustainable development*; Health: *Health, well-being & communities*; Cities: *Cities settlements & key infrastructure*; Food: *Food fibre & other ecosystem products*; Water: *Water & sanitation*; Ocean: *Ocean & coastal ecosystems*; Terrestrial: *Terrestrial & freshwater ecosystems*.

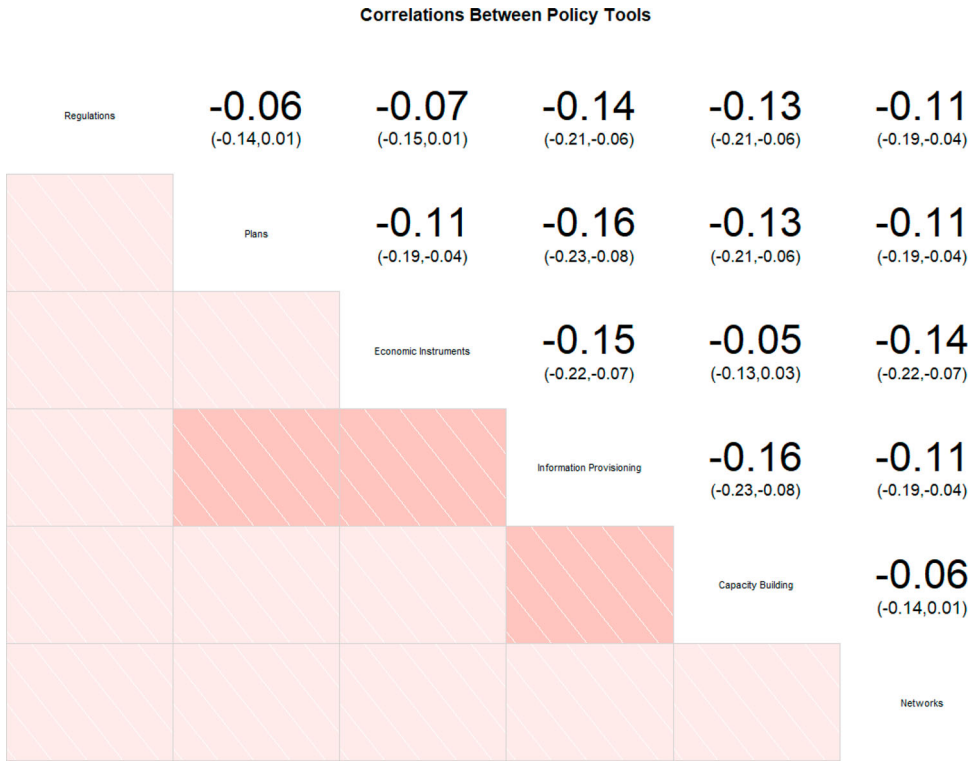


**Figure A1.** Phi correlations between presence or absence of tool types. Analysis uses the subset of papers that described at least one tool type, to remove spurious (0,0) data points.