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Climate stress tests as a climate adaptation information tool in Dutch municipalities

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ABSTRACT

Climate information plays a key role in adaptation to climate change, but providing and using it in effective ways is a challenge. Climate information often remains underutilized and even when used, its influence on policy making is far from clear. In the Netherlands, climate stress tests were introduced to inform and stimulate climate adaptation policy on a municipal level. In the stress tests, risks and vulnerabilities were estimated for scenarios of extreme precipitation, heat stress, drought, and flooding. This article examines whether and how this new tool has effectuated mainstreaming of climate adaptation information into municipal policy. Based on interviews with municipal officials and document analysis we show that the stress tests did so along two general pathways. In the 'applied' pathway, the stress tests were used in an instrumental way to influence policy goals and measures. In the 'configuring' pathway, stress tests were primarily used for learning and persuasion, and mostly influenced problem perceptions and actor involvement. In the 'applied' pathway, the accuracy and resolution of the information were key factors; in the 'configuring' pathway, its influence depended on the accessibility of information and the kind of interaction during policy formulation. Which of the pathways predominated depended on how an adaptation problem fitted with existing policy arrangements. The findings show that stress tests are a promising tool for policy mainstreaming and for promoting local climate adaptation. They also highlight the importance of identifying the pathways of information use, in order to increase the impact of climate information.

1. Introduction

While societies have adapted to their climate throughout history, proactive adaptation to climate change is a very recent phenomenon. Growing acceptance that a significant degree of climate change is inevitable, has led public decision-makers to increasingly consider the effects of future climates and options for adaptation (Hewitt et al., 2017; Lourenço et al., 2016; Soares et al., 2018). Climate information –in our understanding the predictions about future climate conditions and potential response options– plays a key role in informing adaptation. The provision of information in forms that are actionable and usable remains a key challenge for researchers and practitioners (Arnott et al., 2020a; Lemos et al., 2018a).

Coastal areas, especially low-lying and urbanized deltas, are vulnerable to climate change (Hallegatte et al., 2013). In the Netherlands, most public efforts towards meeting climate change challenges are concentrated in the so-called Delta Program. Named

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after the historical Delta Plan –which successfully staged a huge, nation-wide coastal protection program after disastrous flooding in 1953 – this program aims to develop long-term policies to protect the Netherlands from the consequences of a changing climate. It consists of a policy formulation track, but also commissions climate research and invests in projects in various climate change affected sectors. One part of the program, the Delta Plan on Spatial Adaptation (*Deltaplan Ruimtelijke Adaptatie;* DPRA) considers the challenges of climate change for spatial planning in a broad sense. The DPRA highlights four adaptation themes: extreme precipitation[1], heat stress, drought, and (urban) flooding due to dyke breaches. It aims to achieve adaptation to these risks through an on-going cycle of 'analysis-ambition-action' when it comes to producing new climate information as well as giving shape to adaptation by practical interventions (Delta Commissioner, 2018).

To start this cycle, all levels of Dutch government (the national government, provinces, regional water authorities and municipalities) have agreed to conduct so-called climate stress tests. Having a background in the financial sector, stress tests are a tool to assess the stability of systems or institutions in the face of external shocks such as an economic downturn (Borio et al., 2014). During the global financial crisis that started in 2007, stress testing increasingly received public attention. Inspired by this instrument, climate researchers have proposed stress testing as a way to assess vulnerability to climate change (Brown and Wilby, 2012; Stern et al., 2013; Swart et al., 2013). By now, climate stress tests have been applied to a range of topics, such as national security (National Research Council, 2013), hydropower (Ray et al., 2018) and water quality management (Tariq et al., 2017).

Within the DPRA, a stress test calls for the analysis of climate change impacts, specified for the four adaptation themes, and for specific geographical areas. Based on a national set of climate scenarios for 2050, the tests map the effects of climate change and the vulnerability of the spatial area, objects, functions and individuals to these effects. For example, by mapping which urban areas will show the highest temperatures during heat waves, municipal officers get insight in where public health risks may occur; scenarios of road flooding during peaks of rainfall help identify future drainage problems. The mandatory stress tests provide such information and hence input for the formulation of sectoral policy. In doing so, they contribute to what has been called the mainstreaming of climate adaptation: the integration of climate adaptation into existing policy sectors (Runhaar et al., 2018).

The Dutch stress tests are a type of climate service, i.e. they provide climate information that is tailored towards meeting users' needs and assisting decision-making (Hewitt et al., 2012; Raaphorst et al., 2020). This type of climate service arose in response to the observation that despite the increasing availability and quality of climate information, use of that information by decision-makers remained limited (Jones et al., 2017; Lemos et al., 2018b, 2012). This observation led information providers and researchers to pay increasing attention to the intended users of climate information, for example by addressing user types (Swart et al., 2017), sectoral differences (Soares et al., 2018), user comprehension (Lorenz et al., 2015) and decision contexts (Simpson et al., 2016). The Dutch climate stress tests have been informed by the lessons from this body of literature and provide an opportunity to study how effectively these have been applied, as well as to extend the line of inquiry.

Seizing this opportunity, our study aims to shed more light on the (non-)use of climate information by analyzing how and to which effect climate information of the stress tests is used. Studies on the use of scientific information in other fields (governance, education, health) show that information can be used in many different ways (see e.g. Amara et al., 2004; Cain, 2015; Estabrooks, 1999; Shulha and Cousins, 1997). Recent studies of climate information use have also addressed this diversity (Arnott et al., 2020a; VanderMolen et al., 2020; Wall et al., 2017). Our study adds to this literature by exploring how the provision of climate information in the form of stress tests has affected the mainstreaming of climate adaptation into municipal policy.

2. Research framework

A new research framework, consisting of three analytical steps, has guided the research. The first step refers to *whether or not* climate information is used in the studied municipalities, and which factors have influenced this. The second step refers to *how* information is used. A third step centers on the impacts of using climate information on *mainstreaming* climate adaptation.

2.1. Step 1: Factors influencing (non-)use of climate information

As mentioned above, there is a large body of research that discusses which factors influence the lack of use of climate information (see e.g. Jones et al., 2017; Lemos et al., 2018b), captured in the statement that "despite both the considerable amount of climate change research made available in the past thirty years and evidence that decision-makers […] are actively seeking to increase their climate information uptake, there is a persistent gap between knowledge production and use" (Lemos et al., 2012, p. 789). This gap represents a range of disconnects between information producers (e.g. scientists, knowledge brokers, consultants) and users (e.g. public officials and private companies) at various scales and levels. Researchers have proposed a range of (complementary) solutions to bridge this gap, such as using boundary organizations (Gustafsson and Lidskog, 2018; Kirchhoff et al., 2013b), placing emphasis on co-production (Lemos et al., 2018a; Meadow et al., 2015) and the development of climate services such as information portals (Hewitt et al., 2012; Lourenço et al., 2016; Vaughan et al., 2018). This can address specific information needs and translate abstract climate knowledge into actionable information, suitable for the type of audience to be reached and the scale of the climate issue to be addressed.

Research has identified a wide range of factors influencing the (non-)use of such climate information. These may relate to the

[1] The DPRA theme is actually called waterlogging, which is the saturation of soil with water. While this is one of the impacts included in the theme, it mostly focuses on flooding due to extreme rainfall. Thus, extreme precipitation is used here as a more accurate translation.

characteristics of the knowledge itself (e.g. Dilling and Lemos, 2011; Raaphorst et al., 2020); to information users and their contexts (Flagg and Kirchhoff, 2018; Jones et al., 2017; Page and Dilling, 2020); to information producers and their contexts (Dilling and Lemos, 2011; Ernst et al., 2019); and to the relationship between information producers and users (Jones et al., 2017; Kirchhoff et al., 2013b; Mach et al., 2020).

Our study's scope is limited to two categories of factors: *output factors* related to the produced information, and *process factors* related to the process of information production. While acknowledging that context factors are crucial to climate information use (Flagg and Kirchhoff, 2018; Simpson et al., 2016), we posit that these more direct factors are most actionable to information providers and thus are most relevant for increasing the usability of the stress tests. Within these two categories, a total of eight factors are considered (see Table 1). These factors have been distilled from literature on climate information use, primarily from a set of reviews by Dilling and Lemos (2011); Lemos et al. (2012); based on Kirchhoff, 2010) and Jones et al. (2017). The factors were selected based on their applicability to stress tests at the municipal level; in addition, we aimed to minimize the conceptual overlap resulting from varying terminology in the literature.

2.2. Step 2: Different ways of using climate information

Academic literature is less explicit in answering how climate information can be used. What is meant by 'use' of climate information often remains undefined, and application of structured typologies is rare (for notable exceptions, see Shafer, 2008; Wallet al., 2017; Arnott et al., 2020b; Vandermolen et al., 2020).

Views on information use in policy making depend on views on the process of policy making (for a discussion, see Stone, 2001). To capture this diversity of views, this study uses Nutley et al.'s (2007) typology of four types of research use: instrumental, conceptual, strategic and process use. This typology is primarily based on evaluation studies literature. In this field, similar distinctions have for a long time informed research into the impacts and value of evaluations (see e.g. Leviton and Hughes, 1981; Shulha and Cousins, 1997). As the same issue is now increasingly relevant for climate research, this typology provides a suitable starting point for analysis.

Instrumental use refers to the direct application of specific research findings to a specific policy decision. This is the most straightforward conception of information use; however, research suggests that instrumental use is relatively rare (Nutley et al., 2007).

More commonly found is *conceptual use*. This is a broader category, "comprising the complex and often indirect ways in which research can have an impact on the knowledge, understanding and attitudes of policy makers and practitioners" (Nutley et al., 2007, p. 36). It corresponds to the idea of the enlightenment function of research (Weiss, 1977), which poses that conceptual thinking and use can have significant long-term effects by informing policy makers' world view.

Strategic use is the use of research to persuade others, or to legitimate or challenge policy decisions.[2] What distinguishes strategic use from instrumental and conceptual use is that the views of the user itself are not affected. While strategic use is sometimes considered to be improper, an important use of climate information may well be to demonstrate the relevance of climate adaptation to actors (see e.g. Howarth et al., 2017; Lorenz et al., 2015).

Finally, *process use* refers to the effects of the process of conducting research, irrespective of any use of its results. As defined by Patton (1997) for the field of evaluation studies, process use is the result of learning that occurs during an evaluation process. This learning has been argued to have a wide range of potential effects on individuals' views and behavior in relation to policy development (Amo and Cousins, 2007). In the same vein, actors engaged in climate research can be expected to be influenced by its outcomes, independent of any direct use of its results.

The first three types are commonly used in studies of information use in a range of fields to capture the diverse ways in which information has impacts (Leviton and Hughes, 1981; Nutley et al., 2007; Pelz, 1978; Shulha and Cousins, 1997). Recently this trinity has also been applied to climate information use (VanderMolen et al., 2020). The fourth type, process use, is less commonly studied. However, we would argue that the frequently stressed importance of interaction and co-production for climate information use (Jagannathan et al., 2020; Lemos et al., 2018a; Meadow et al., 2015) indicates that process use merits increased attention.

2.3. Step 3: Mainstreaming climate adaptation

Generation and use of climate information can affect the mainstreaming of climate adaptation. In general, mainstreaming refers to the integration of climate adaptation into existing policies and practices (Runhaar et al., 2018). The mainstreaming of climate adaptation involves the integration of new goals, such as the management of heat stress or other climate risks, into existing policy sectors. It can also mean aggravating existing policy challenges. Limiting vulnerability to extreme precipitation, for example, is not a new goal for Dutch municipal water managers, but climate adaptation requires additional and new types of measures. Conversely, mainstreaming does not stop at the inclusion of goals: its ultimate aim is actual climate proofing (Runhaar et al., 2018).

Much of the literature on mainstreaming has focused on outcomes, arguing for example that its effectiveness should be measured in terms of outputs and outcomes (Runhaar et al., 2018). An exception are Candel and Biesbroek (2016), who argue that a processual view is needed to better understand mainstreaming. Given the fact that Dutch municipalities have only recently started to mainstream climate adaptation, its ultimate effectiveness has yet to materialize. Thus, the processual approach of Candel and Biesbroek seems most promising for studying the effects of information use.

[2] Some typologies use similar but slightly more narrow concepts, like justification and symbolic use (see e.g. Vandermolen et al., 2020).

Table 1
Factors affecting climate information use.

Factor	Description	Sources
Output factors		
Relevance	The perceived relevance of information to a policy sector or decision.	Jones et al. (2017); Lemos et al. (2012); Raaphorst et al. (2020); Vaughan and Dessai (2014)
Credibility	The perceived credibility of information, based on its scientific adequacy and actors' beliefs.	Dilling and Lemos (2011); Jones et al. (2017); Lemos et al. (2012)
Accessibility	The ease of access to information, as well as its understandability.	Jones et al. (2017); Lorenz et al. (2015); Raaphorst et al. (2020); Vaughan and Dessai (2014)
Accuracy	The degree of certainty of information.	Lemos et al. (2012); Vaughan and Dessai (2014)
Spatial resolution	The spatial level of detail of information.	Archie et al. (2014); Dilling and Lemos (2011); Jones et al. (2017)
Process factors		
Degree of interaction	The degree of interaction between information users and producers during the production process.	Dilling and Lemos (2011); Lemos et al. (2012, 2019)
Responsiveness	The responsiveness of information producers to users' needs and wishes.	Dilling and Lemos (2011); Jones et al. (2017); Kirchhoff et al. (2013a)
Legitimacy	The perception that the process of information production has been unbiased and fair.	Dilling and Lemos (2011); Lemos et al. (2012)

Candel and Biesbroek (2016) argue that integration of policy domains consists of four dimensions. The *policy frame* describes "whether a cross-cutting problem is recognized as such and, if so, to what extent it is thought to be requiring a holistic governance approach" (p. 218). *Subsystem involvement* describes the range of actors and (lower-level) institutions involved in the governance of the problem and the density of their interactions. The dimension of *policy goals* refers to explicit concern with the problem, captured by the range of policies in which goals are included and the coherence of policy goals. Finally, *policy instruments* describe the degree to which the problem is addressed by procedural instruments to coordinate policies and the consistency of both procedural and substantive instruments that are employed.

While these dimensions interact, they do not necessarily develop over time in a concerted manner. Depending on circumstances, change in some dimensions may well precede change in others or happen without those other dimensions changing at all. Candel and Biesbroek (2016) hypothesize that change in the dimensions related to policy regimes (policy frame and subsystem involvement) is likely to precede, and lead to, change in the dimensions related to concrete sets of policies (policy goals and instruments).

2.4. Research framework

Fig. 1 graphically presents the research framework as discussed in the previous section. In this framework, two sets of factors are employed to analyze whether climate information is used or not. If it is used, this can happen in four ways as proposed by Nutley et al. (2007). Through these types of use, research can affect mainstreaming in (some of) the four dimensions as proposed by Candel and Biesbroek (2016).

Two points deserve further elaboration. First, the model makes no a priori assumptions about the relationships between specific use factors, types of use or mainstreaming dimensions. While some might intuitively seem more related than others, we did not find sufficient support in existing literature to formulate specific hypotheses at this point; therefore, we investigated these relationships inductively. Second, the relationship between climate information use and mainstreaming is two-way. Mainstreaming is affected by information use, but mainstreaming efforts also set the conditions that make information go (un)used, for example by affecting its relevance to actors. This is particularly relevant given the iterative nature of (Dutch) climate adaptation, as this cycle of 'analysis-ambition-action' is meant to lay the foundation for future cycles.

3. Methods

The effects of the stress tests on the mainstreaming of climate adaptation were studied in ten Dutch municipalities between March and June 2019. The municipalities were identified through the network of Platform Climate Proof Together (*Platform Samen Klimaatbestendig*); an organization created as part of the DPRA to facilitate knowledge-sharing on climate adaptation. It provided a good entry point to identify municipalities which had recently completed their climate stress tests. Of those ten municipalities, five commissioned individual stress test and six were (also) involved in collective stress tests. This resulted in nine stress test reports (see Table 2 for details).

Given the small sample size, the municipalities were purposively selected on two characteristics. First, they were selected to provide a varied and for municipalities in the Netherlands fairly characteristic sample on population size, including both smaller and larger municipalities. Smaller municipalities have been found to be constrained in their capacity to develop climate policy (Hoppe et al., 2016). They are less aware of climate risks than larger municipalities (Rauken et al., 2015), but at the same time potentially more capable of rapidly implementing policy change (Van den Berg and Coenen, 2012). Larger municipalities have more professional capacity and financial resources to conduct research on climate change effects and formulate responses. Second, municipalities were selected to provide variation on the timing of their stress tests. Recently completed stress tests would enable municipal officials to

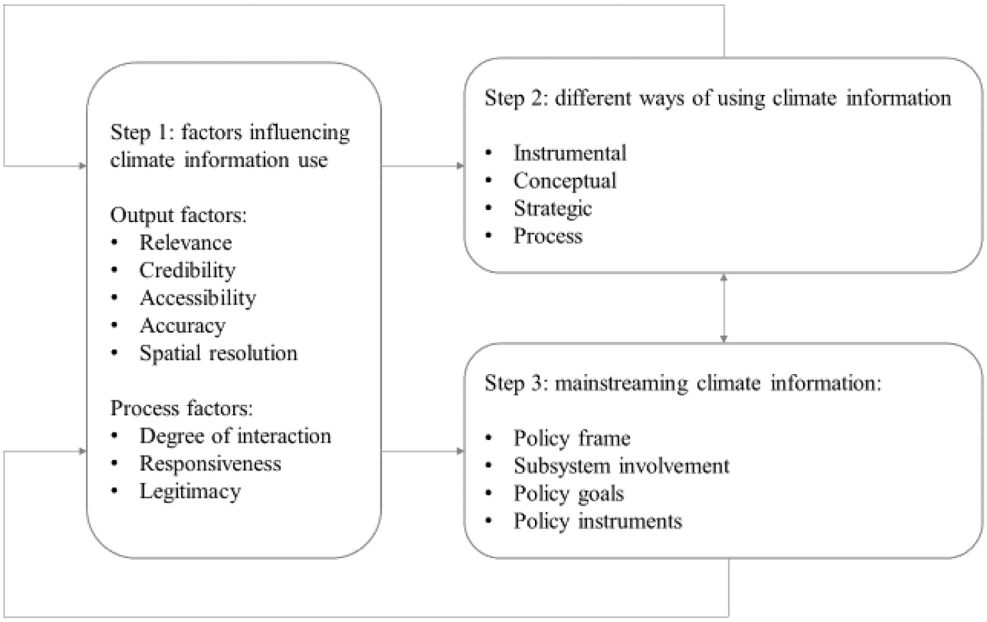

Fig. 1. Research framework: from climate information use to mainstreaming climate information.

Table 2
Characteristics of the studied municipalities.

Municipality	Inhabitants	Year [d]	Officials interviewed [e]
Almere	200.000	2015 & 2016	• Water management • Water policy
Bernheze	30.000	2016 [a]	• Water management & policy
Ede	110.000	2018[b]	• Water policy • Water management • Soil & spatial policy • Landscape architecture • Project management
Enschede	160.000	2014	• Water policy • Water design
Goeree-Overflakkee	50.000	2018	• Water management & policy
Neder-Betuwe	25.000	2018	• Water management & policy • Road management
Nieuwegein	60.000	2015 & 2018[c]	• Climate adaptation & water policy • Water management
Rhenen	20.000	2018[b]	• Water policy
Utrecht	350.000	2018[c]	• Water policy • Climate adaptation policy • Green zoning policy • Healthy living environment
Zeist	65.000	2018[c]	• Water management & policy

a) *Bernheze commissioned a collective (regionally oriented) stress test*
b) *Ede and Rhenen commissioned a collective stress test*
c) *Nieuwegein conducted an individual stress test in 2015, and commissioned a collective one with Utrecht and Zeist in 2018.*
d) *This resulted into nine individual stress tests reports.*
e) *This list reflects the variety of policy sectors involved in climate adaptation. Not all departments were engaged in climate adaptation to the same extent. Especially in smaller municipalities, frequent interaction and collaboration between department staff takes place.*

recall in more detail how a test was developed and used. The longer-term effects of a stress test on mainstreaming could be reflected on by incorporating municipalities where some time has passed since the completion of a text.

The development and general impact of the stress tests were studied through twenty-one semi-structured interviews with municipal department officials (Table 2). When possible, officials of multiple departments were interviewed to reflect the diversity of sectors affected by climate change as well as to triangulate findings. Few discrepancies and contradictions were found between the interviews

within each municipality, suggesting the interviewees to be reliable informants. The interviews were transcribed and coded using ATLAS.ti and studied along with relevant policy documents. This included the stress test reports, sectoral plans and adaptation strategies, which provided additional information about the degree of mainstreaming. This resulted in a coherent narrative of the mainstreaming process in each municipality.

4. Results

This section discusses the use and effects of the stress tests. In the first part of this section, we present the main empirical findings and characterize the stress test information and use in the investigated municipalities. The use of the produced climate information varies significantly for each of the adaptation themes[3] (extreme precipitation, heat stress, drought). For this reason, after analyzing the general stress test procedures, specific findings are organized by themes. Next, we analyze the links between the information use factors, the different types of information use and the impacts on mainstreaming.

4.1. The stress tests in Dutch municipalities

4.1.1. General procedure of formulating the stress tests

For seven of the studied municipalities, the main reason for commissioning stress test was to anticipate the future DPRA obligation to do so. Five municipalities had specific reasons to commission an individual test, including the need to update sectoral policy plans, to formulate response to recent extreme weather events, or concerns about how to climate proof urban development plans. Six municipalities commissioned collective tests with neighboring municipalities, because of geographical interdependencies (e.g. management of water bodies) or to save costs.

The stress tests were executed by a wide range of technical and management consultancy firms. Except for one, these companies did not specialize in climate adaptation but were active in the domains of water management, engineering or the environment. Usually, the stress tests consisted of three activities: collecting existing information, additional data collection by digital modeling and/or measurements, and a workshop to present and discuss the results. One municipality left out the second activity, one left out the workshop and five others included multiple workshops. The results of the stress tests were presented in reports, and often in online climate atlases.[4]

Interviewees mostly felt that the process of developing the stress tests could be characterized as interactive and engaging with a variety of primarily internal stakeholders. While the stress tests were commissioned by municipal water departments, with limited prior input from other departments, workshops were considered a valuable means to explain, discuss and validate the results of the tests with professionals from various backgrounds. The clearest determinant of the responsiveness of consultants to specific user needs was whether a municipality commissioned the stress test individually or as part of a collective. The five municipalities commissioning it individually generally felt their aims or circumstances were different from their neighbors, and that a more customized test would be more valuable. The collective, regionally oriented stress tests provided more abstract narratives.

Legitimacy rarely was an issue before or during the development of the stress tests but surfaced after publishing the results. Especially when respondents felt they lacked the expertise to judge results, their trust in the process and its outcomes became an important determinant of their willingness to use the stress tests. The two stress tests commissioned by Nieuwegein (individually in 2015 and collectively together with Utrecht and Zeist in 2018) had dissimilar results for heat stress. As the municipality found it difficult to compare the results, their trust in one of the consultants as well as its university partner was the reason to value one set of heat maps over the other one.

The process of the stress test was often seen as an opportunity to stimulate dialogue about the results as well as the wider adaptation challenges and the associated responsibilities of various municipal departments. This process use was considered especially useful to engage otherwise uninvolved officials. In Goeree-Overflakkee for example, the stress test took the shape of an expert dialogue based on existing information, as the primary need at their stage was felt to be interdepartmental discussion and awareness rather than new information. Data collection was also sometimes seen as an opportunity to raise public awareness, which was then a reason to prefer it over modeling.

4.1.2. Extreme precipitation

All stress tests studied extreme precipitation. This was not a new topic for Dutch municipalities as one of their key responsibilities is to reduce impacts of extreme precipitation. Precipitation maps generally consisted of the modeled local water level and its expected effects on infrastructure and buildings coupled with certain rainfall events. Sometimes these models were based on projections, at other times they reflected specific past rainfall events.

The results were considered to be relevant especially for water managers, although two of them commented that the studied events were exceptional cases. Precipitation maps were considered easily understandable and credible. It was relatively easy to identify mismatches between the modeled results and practical experiences with urban flooding due to extreme precipitation. As one official

[3] The fourth theme, urban flooding due to dyke breaches, was studied in only five out of ten municipalities. Also during interviews, urban flooding due to dyke breaches was found less relevant. This provided insufficient data to elaborate on the theme.

[4] For some examples (in Dutch), see the regional climate atlas of the municipalities of Ede and Rhenen (https://klimaatvalleienveluwe.nl/atlas/) and the municipality of Almere (https://almere.klimaatatlas.net/)

commented: "especially for water, if it is located in places of which we as municipality say it cannot be located, the trust [in the stress test results] disappears quickly." For this official, this was a reason not to use the results of this particular stress test. Both the accuracy and the resolution of the stress tests were considered important.

With the single exception mentioned above, instrumental use of the results for extreme precipitation was prevalent. Results were used to identify problem areas and determine how much water would need to be infiltrated, drained or stored within a certain time span. Conceptual use was less common. While some water managers were surprised by the severity of the results for extreme precipitation, this usually confirmed existing views. The modeled extreme precipitation events confirmed problem areas known from prior studies as well as practical experience. The results were also used strategically to increase awareness and raise (financial) support for measures to reduce vulnerability. In this regard, their extremity was an advantage; as one official commented about the precipitation maps, "the more blue spots [i.e., flooding zones], the better."

The stress tests affected the policy frame concerning extreme precipitation somewhat, but not fundamentally. The results did show that reducing vulnerability usually required measures involving other spatial disciplines such as road management and urban green management. Dealing with extreme precipitation remained a 'water topic' though: the involvement of other departments increased, but the formal responsibility remained with the water department. The stress tests resulted in new water management policies and instruments. Preparedness for severe precipitation events was advocated by linking water measures to other domains. For example, insights in the effects of extreme precipitation were incorporated in existing spatial plans, informed building construction, were integrated in agreements with social housing organizations, and initiated subsidy programs for citizens. Thus, extreme precipitation was mainstreamed effectively into municipal policy without many fundamental changes. As an official described it: "adaptation to future climate change primarily involves doing the math, running a few tests based on the climate atlas and then seeing how large the sewage pipe has to be."

4.1.3. Heat stress

Nine out of ten municipalities touched upon heat stress. Unlike extreme precipitation, heat stress was a relatively new phenomenon. Municipalities lacked expertise to address this and sectoral responsibilities were unclear. Stress test maps for heat stress were developed and provided all kinds of information, including maximum temperature during hot days, the expected annual number of tropical nights (20 °C or higher) by 2050, and living places of vulnerable elderly people.

The relevance of these maps was far from straightforward. While municipal interviewees saw the theme as important, they frequently commented that it was unclear at what threshold heat becomes problematic, which indicators were important (e.g. absolute temperature, temperature relative to the cooler countryside, or apparent temperature), and when action was needed. Having these studies conducted was rated positively. Credibility of the results was not perceived as problematic. The accuracy and resolution of the information were lower than for extreme precipitation, but this was not considered a problem: formulating detailed policies was not yet feasible, or because the results were in line with common sense. As one official commented: "I will not wait until the method to map heat has completely crystallized, because you probably end up with the same picture: the downtown is very hot and needs greenery."

Officials were more likely to use the results for heat stress conceptually and strategically than instrumentally. The results were useful to demonstrate the salience of heat stress, and how it was affected by the design of neighborhoods, for instance via the amount of urban green. Maps were found helpful to visualize this. Instrumental use was considered very difficult, mainly because heat stress was complex due to the variety of potentially relevant indicators and lack of clear thresholds. In Nieuwegein, the stress test showed that relatively green and shaded neighborhoods have peak temperatures of (only) 3 to 5 °C higher than rural areas. This was taken up as a goal for the entire city. While this goal was not robust enough to be translated into spatial planning norms, in the words of an official: "it is a statement; better than nothing." In neighboring Utrecht, a similar norm of 3 °C was tried for spatial planning, but it was dropped as it was considered too arbitrary.

Mainstreaming of heat stress primarily happened in the dimensions of policy frame and subsystem involvement and less in policy goals and instruments. Regarding the first, heat stress was redefined from a non-existent problem into one potentially involving sectors ranging from spatial planning to public health. Actual involvement lagged behind, but also increased. Water managers often had difficulty involving public health care departments and governmental responsibilities often remained ill-defined, but involvement increased among spatial planners. Formulating policy goals for heat stress was perceived to be a bigger challenge, as illustrated in the previous paragraph. The lack of clear goals in turn limited its inclusion in policy instruments: while potential measures were known, there were no standards for when to apply them. As a result, measures against heat stress were limited to no-regret measures that also served other purposes. As a water manager who struggled with the theme explained: "I figured, when we take measures in public space against flooding [due to extreme precipitation], I want us to bring back more green in urban areas. And of course, that is also positive for reducing heat stress."

4.1.4. Drought

Stress tests for seven municipalities included drought. While the Netherlands can be characterized as a water-rich country, water availability during summer can be low due to reduced inflow from rivers (e.g. Rhine, Meuse) and lack of precipitation. Occurrence of drought depends on geography, and its impacts range from actual water scarcity (mainly in higher, sandy areas) to land subsidence and difficulties with river navigation. Drought related risks are taken more seriously and the very dry summer of 2018 underscored this. However, the responsibilities of municipalities were ambiguous; while they had a duty to provide water and preserve subsurface water tables, this also was the responsibility of homeowners and regional water authorities. Moreover, municipal water managers argued they could do little to mitigate droughts.

Drought maps showed changes in the average lowest water table, land subsidence in peatlands and the vulnerability of building

foundations to land subsidence. Respondents generally found these maps relevant, but knowledge gaps regarding for example the type of foundations beneath buildings made the impacts of drought difficult to estimate. A further complication was that while dry periods were predicted to increase in frequency and intensity, climate scenarios varied in their predictions for the overall amount of precipitation. This made it difficult, for example, to select tree and plant species that would be suited to future climate conditions. Nonetheless, officials generally found the predictions credible, especially given their experiences during the previous summer. In one municipality, an interviewee observed that "one of the sceptics was the urban green manager and, well, last year he had to invest 50,000 euros to water the plants in the dry period… so he is convinced."

All in all, the stress tests saw little instrumental use for drought. On the one hand water managers lacked options to mitigate drought, while on the other hand the knowledge gaps hindered measures by others to reduce sensitivity. Conceptual use was more frequent, as the stress tests led diverse actors to consider how the increasing frequency of droughts would affect them in the future. In this way, the stress tests most strongly contributed to a change in policy frame and subsystem involvement, while integration into policy goals and instruments was rare. While an increasing number of actors perceived droughts as relevant for them, their vulnerability and potential measures often remained unclear. Water managers did implement no-regret measures like increasing water storage and infiltration capacity, but respondents mostly felt there was no real municipal policy against drought.

4.2. Information use and mainstreaming

The findings described above provide a variegated picture of climate information use, with clear differences across climate adaptation themes. This subsection reflects on the four ways in which climate information has been used and has informed mainstreaming, discussing for each the factors contributing to it and its impact on mainstreaming.

4.2.1. Instrumental use

Instrumental use of the stress test involved its direct application in decision making. As the previous section showed, this happened most commonly for extreme precipitation. For this theme, the stress tests were often used to identify or reconfirm problem areas and design measures. Instrumental use for the other themes was less prominent though not absent, as the examples in 4.1.3 show. As one official explained the difference: "Water is very easy to quantify. You can assign someone to drain a specific amount of water in a specific time frame, but for heat that is very difficult."

Instrumental use was clearly affected by the relevance, accuracy and spatial resolution of the stress tests. The clarity of the relevance was one of the reasons why officials felt the results for extreme precipitation were more suitable for instrumental use than the results for heat stress. As 4.1.3 discusses, the host of potentially relevant indicators and the lack of thresholds at which risks become unacceptable complicated instrumental use of heat stress information. Appropriate accuracy and resolution were important to develop effective and efficient policy. When the results for extreme precipitation were considered ill-suited for instrumental use, this was due to either inaccuracies or the extremity. As a water designer in Enschede explained, "they are useful for awareness and not for taking measures … Because those are situations in which half the city is flooded." Credibility, responsiveness, degree of interaction and legitimacy were also perceived to be beneficial, but less strongly so. The accessibility of the results was less relevant for instrumental use, as actors for whom instrumental use was relevant, in general had sufficient expertise to understand complex results.

Instrumental use directly affected the mainstreaming dimensions of policy goals and policy instruments. Policy frame and subsystem involvement were affected less clearly. These dimensions influenced the degree of instrumental use, as higher levels of agreement on problems, roles and responsibilities facilitated the instrumental use of the stress tests.

4.2.2. Conceptual use

Conceptual use, emphasizing learning from the tests, was common for the newer themes but less common for extreme precipitation. As 4.1.3 discusses, for heat stress, respondents found the stress tests valuable for demonstrating its relevance as a policy topic and the influence of various urban planning factors on it. As shown in 4.1.2 the results for extreme precipitation yielded comparatively fewer new insights. While they did sometimes show new vulnerabilities, water managers mostly felt their existing views were confirmed.

Officials perceived conceptual use to be strongly influenced by relevance, accessibility, credibility and the degree of interaction. Officials needed to first understand the general relevance of results, to be motivated to study them in more detail. Accessibility was important as conceptual use often took place for topics that were new. In Goeree-Overflakkee and Rhenen, this was the reason to prioritize understandable results over accurate but complex ones. Maps were seen as an understandable and helpful format. Credibility and confidence in the recommendations of stress tests were important. The degree of interaction, especially in the form of workshops, facilitated learning by officials from various disciplinary backgrounds. Responsiveness and legitimacy, while also appreciated, were less clearly relevant. Finally, the accuracy and spatial resolution of the results were generally not important. Some forms of conceptual use required detailed information, such as when the stress test in Almere showed the risk of a series of tunnels flooding, effectively cutting the city in half. For most conceptual use though, general results were sufficient.

Conceptual use primarily affected mainstreaming through the policy frame and subsystem involvement. It helped demonstrate the relevance of climate adaptation, both to the municipality as a whole and to specific subsystems, thereby stimulating involvement. Nonetheless, conceptual use had little impact on the integration of climate adaptation into policy goals and instruments. Higher awareness of heat stress, through conceptual use, resulted in links with already planned spatial projects, e.g. through multi-functional measures like urban green. But with regard to climate adaptation policy more generally, most respondents felt that no clear policy strategy emerged from the stress test information.

4.2.3. Strategic use

Officials often used the stress tests strategically to create awareness and a sense of urgency, and sometimes to influence specific decisions and the allocation of budgets. Strategic use to create awareness was very common and took the form of presentations, information events and dialogue with colleagues, citizens and municipal politicians. These bordered on conceptual use: while one goal was to raise awareness (by stimulating conceptual use by others), another goal was to learn more about the relevance of climate adaptation for other policy makers and stakeholders. Strategic use to influence specific decisions was less frequent, but also happened. Officials used and sometimes commissioned the stress tests to justify decisions they were already convinced of, such as taking measures to reduce vulnerability to precipitation and reserving time to promote climate adaptation. In one case, the results were used to push for strict norms for new urban development, even when the plans for this development were not analyzed in the stress test itself.

Interviewees perceived the relevance, accessibility and credibility of information to be most important for its strategic use. In Ede an additional analysis was done to enhance the relevance of the stress test for specific officials. This analysis estimated the costs of climate change for the municipality, since "those who do not like maps might like euros." Especially when used to raise awareness, officials felt information needed to be clear and trustworthy. Legitimacy, while less often brought up by respondents, was also important to strategic use. The accuracy and spatial resolution of the results and degree of interaction and responsiveness of the process had less influence.

Strategic use for raising awareness affected the mainstreaming process by changing the policy frame and subsystem involvement. Respondents often considered convincing others of the importance of climate adaptation to be their most important challenge. When stress tests were strategically used to influence decisions, in the ways described here, this also affected policy goals and instruments in some/several/most reported cases.

4.2.4. Process use

In addition to these uses of the results of the stress tests, use of their process was very common. Most officials involved in the commissioning of the stress tests saw them as an opportunity not just to gain knowledge, but also to involve others and stimulate dialogue. In all municipalities but one, workshops were organized to discuss results with various government officials. These were seen as valuable opportunity for involving people who would usually be more difficult to engage. As discussed, in Goeree-Overflakkee this was even the primary aim of the stress test, which took the shape of an expert dialogue. In two municipalities the process of data collection was also used as an opportunity to raise awareness, especially among citizens.

Process use is somewhat different from the other types as it is not actual use of the information provided by the stress tests. As such, several output factors – credibility, accuracy and spatial resolution – were not particularly relevant to it. Factors that were important were relevance, accessibility and the degree of interaction. Interviewees felt the national obligation to conduct a stress test provided initial relevance for actors unfamiliar with climate adaptation. They also acknowledged accessibility as a necessary condition to involve a diverse audience, while interaction was crucial for stimulating learning and future involvement. Less influential but still beneficial were responsiveness and legitimacy, the latter of which was in part also provided by the national obligation to conduct a stress test.

Process use of the stress tests mainly affected the policy frame and subsystem involvement. Interviewees emphasized the opportunities the tests provided to collectively discuss the implications of climate change and adaptation for the municipality and to engage a broad range of officials, especially those who would normally not be involved. In Goeree-Overflakkee, an official explains that "Especially because we approached the stress test with a broad group from the municipality, it has created awareness with the other officials that climate really will be a topic affecting us in the coming years." Stress tests were sometimes also used to discuss policy goals and instruments. In Neder-Betuwe for example, the stress test included two workshops for the spatial departments to discuss ambitions and potential measures. Given the novelty of climate adaptation for most officials though, this was usually not considered practical.

5. Synthesis: Pathways towards mainstreaming

Generalizing from these findings, we can identify two distinct pathways through which climate information influences mainstreaming of climate change adaptation. Tables 3 and 4 provide a comprehensive though simplified overview of the findings discussed in the previous section.

Table 3 shows that the perceived importance of the information use factors differs for the various uses of climate information. While

Table 3
The relevance of the information use factors for the different types of information use.

	Instrumental use	Conceptual use	Strategic Use	Process use
Relevance	++	++	++	++
Credibility	+	++	++	–
Accessibility	–	++	++	++
Accuracy	++	–	–	–
Spatial resolution	++	–	–	–
Degree of interaction	–	++	–	++
Responsiveness	+	+	–	+
Legitimacy	+	+	+	+

++ very relevant; + relevant, but less (clearly) so; - not relevant.

Table 4
The relevance of the different types of information use for the four dimensions of mainstreaming.

	Policy frame	Subsystem involvement	Policy goals	Policy instruments
Instrumental use	–	–	++	++
Conceptual use	++	++	–	–
Strategic use	++	++	+	+
Process use	++	++	–	–

++ very relevant; + relevant, but less (clearly) so; - not relevant.

relevance was important to each of these uses and credibility to almost all, a clear difference can be seen between instrumental use on the one hand and conceptual, strategic and process use on the other. Accuracy and spatial resolution were important for many forms of instrumental use but mattered much less for the other uses. For these, accessibility and the degree of interaction were critical, which for instrumental use were less relevant. Responsiveness and legitimacy were found to be generally beneficial, but of less clear importance than the other factors.

Table 4 summarizes how the different types of use affected the various dimensions of mainstreaming. Instrumental use had a strong impact on the integration of climate adaptation into policy goals and instruments. It did less to promote changes in the policy frame and subsystem involvement, which were affected more by conceptual, strategic and process use. While these types of use also had the potential to impact policy goals and instruments, their effect on these dimensions was much weaker than that of instrumental use.

Thus, two pathways for the use of climate change information emerge. In the *applied pathway*, as we call it, instrumental use depending on accurate, high-resolution information affected policy goals and instruments. In the *configuring pathway*, conceptual, strategic and process use, depending on accessibility and interaction, combined to change the policy frame and subsystem involvement. Relevance and credibility were important to both pathways.

While the information use factors affected the success of each pathway, which of the two predominated depended primarily on the fit between adaptation problems and the policy sectors into which they were mainstreamed. In the case of extreme precipitation little configuring of existing policy arrangements was necessary and the applied pathway dominated. Heat stress and drought fit less well into existing policy arrangements and as a result instrumental use would have been difficult even with more accurate and detailed information. As explained by an official describing the difference between extreme precipitation and the other themes, this makes sense: "The Municipal Sewage Plan has been around since 1993 … climate adaptation, climate change, climate renewal, this new terminology has been used for just two years. So it is little wonder it is not taken into account, as people are unfamiliar with it." Thus, for heat stress and drought the configuring pathway predominated, as officials attempted to make sense of the problems, their responsibilities and directions for solutions.

6. Discussion

Our study has shown that two distinct pathways can be identified through which use of climate stress tests influenced mainstreaming of climate adaptation into municipal policies in the Netherlands. In interpreting these findings, it is important to keep in mind that the studied municipalities were front-runners. There are various reasons why these municipalities operated very proactively (ahead of formal regulations) to develop stress test, ranging from previous exposure to extreme weather (increasing the urgency to act) to personal ambitions of municipal officials for climate change adaptation. This affected how municipal officials set up, received and used the stress tests.

The results provide lessons about stress tests as a tool for climate adaptation and about the general provision of climate information. In the portfolio of climate change adaptation instruments stress tests are a relatively new tool (Räsänen et al., 2017). Our analysis and the experiences of Dutch municipalities show that stress tests are a promising instrument. Efforts to translate climate scenarios to policy-relevant indicators like water levels and temperature changes largely succeeded in making climate information relevant and accessible to existing policy sectors. The provision of tailored climate parameters at relevant scales is important for increasing use by local authorities (Archie et al., 2014; Hackenbruch et al., 2017). This requires combining climate projections with non-climate information (Goosen et al., 2013; Räsänen et al., 2017). Stress tests managed to do so, although it was sometimes unclear how to tailor climate information for specific policy sectors.

The starting point of this study was the observation that the diversity of the types and impacts of information use has received limited attention in academic literature on climate information. In line with a recent study by Vandermolen et al. (2020), this study finds that non-instrumental types of use are prevalent in climate adaptation. It also provides a first attempt to link these types of use to the factors that are relevant to them, and to the ultimate impacts. While the studied factors were important to the success of the different types of use, which types occurred depended primarily on the fit between an adaptation problem and the existing policy arrangement. This suggests the typology can play a role in conceptually connecting users' context-dependent needs (e.g., to raise awareness) to their information demands (e.g., for credible and accessible information). This mirrors recent work by Dewulf et al. (2020) on different logics of decision-making, which each have different implications for climate information use.

The inclusion of process use proved important for understanding the impact of the stress tests. Compared to literature on the co-production of climate information, the stress tests were not all that interactive (Klenk et al., 2015; Meadow et al., 2015). Nonetheless, officials were positive about the degree of interaction and perceived process use to be an important contributor to the value of the stress tests. Arguably, process use will be more prominent in purposefully interactive processes of information production. Process use also

provides a perspective to identify the wider benefits of co-production, apart from the improvement of the produced information. This can aid in the evaluation and deliberate design of co-production processes (cf. Lemos et al., 2018a; Meadow et al., 2015; Vincent et al., 2018; see also Jagannathan et al., 2020; Mach et al., 2020), as well as providing opportunities to learn from research in other fields (such as Amo and Cousins, 2007; Preskill et al., 2003)

More generally, the findings highlight the role of other than instrumental use as a means to increase the use of climate information. As Vandermolen et al. (2020) put it, "Conceptual and justification [strategic] uses of information can meaningfully translate climate science into action" (p.185). In literature on information use, this observation is captured in stage models, in which conceptual uses of information are likely to precede and build towards instrumental uses (Nutley et al., 2007). In literature on policy integration, Candel and Biesbroek (2016) similarly argue that shifts in policy frame and subsystem involvement are often a precondition for shifts in policy goals and instruments. Likewise, the interviewed officials regarded the formulation of stress tests for creating a network of shared understanding as an important step towards eventual instrumental use. Thus, the suggestion here is that leveraging the 'configuring' pathway is crucial for creating the conditions necessary for effective use of the 'applied' pathway.

7. Conclusion

While climate information is crucial for climate adaptation, its effective provision and uptake is a continuous challenge. This study set out to investigate how the provision of climate information in the form of stress tests to Dutch municipalities affected the mainstreaming of climate adaptation into municipal policy. We studied the experiences of ten municipalities, who commissioned nine stress tests. Climate change information was collected for a number of themes, of which extreme precipitation, heat stress and drought management were of central interest. The results of our study show that two distinct pathways can be identified through which use of the stress tests influenced mainstreaming of climate adaptation into municipal policies. In the 'applied' pathway, instrumental use of climate information (depending on accuracy and spatial resolution) directly affected policy goals and instruments. In the 'configuring' pathway, conceptual, strategic and process use (depending on the accessibility of information and interaction during the research process) affected the policy frame and the involvement of stakeholders and lower-level institutions in the municipal organization. Both pathways depended on credible and relevant information. Which of the two predominated depended on the degree to which an adaptation problem fitted within existing policy arrangements.

This study has examined climate stress tests, as a new tool used by Dutch municipalities to gather climate information, and has reflected on its impact on policy development. It found these stress tests to be a promising tool for the promotion of local climate adaptation. Its use so far is diverse, with conceptual, strategic and process use complementing instrumental use. These non-instrumental uses played a key role in changing problem perceptions and actor involvement, and more generally making sense of climate change within existing policy arrangements. As argued, this 'configuring pathway' was crucial for increasing instrumental usability and ultimately enabling effective policy.

These findings highlight the importance of the 'configuring' pathway for effective use of climate information. The Dutch stress tests contributed to this through their relatively high degrees of relevance, accessibility and interaction. Additionally, process use of the stress tests by policy makers was importance to this pathway. Increasing our understanding of the pathways may help to address current challenges to the use of climate information for successful climate adaptation.

Declaration of Competing Interest

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

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