Deliverable D4.2

Conceptual framework for unpacking the causal mechanisms between climate change, climate service information, and socio-economic behaviour

July 2023

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037293

Innovating Climate services through Integrating Scientific and local Knowledge

Deliverable Title:	Preliminary report on causal mechanisms between climate change, climate service information, and socio-economic behaviour
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Contributing Authors(s):	[Insert Contributing authors]
Date	[Insert Date]
Suggested citation:	
Availability:	☒ PU: This report is public [Please select] ☐ CO: Confidential, only for members of the consortium (including the Commission Services)

Document Revisions:

Author	Revision	Date
Lotte Muller, Riccardo Biella, Nikoletta Ropero Szymanska, Lucia De Stefano, Nuria Hernandez-Mora Zapata, Giuliano Di Baldassarre, Maurizio Mazzoleni	First draft	16-06-2023
Micha Werner	Revised draft	25-06-2023
Lotte Muller, Riccardo Biella, Nikoletta Ropero Szymanska, Lucia De Stefano, Nuria Hernandez-Mora Zapata, Sumiran Rastogi, Giuliano Di Baldassarre, Maurizio Mazzoleni	Final version	24-07-2023

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Executive Summary

Climate Services (CS) are useful tools to reduce the impact of natural hazards, such as droughts. While the benefits of CS have been widely explored, it is still unclear how their introduction can lead to feedbacks between human adaptation and climate-related events, and potentially generate unexpected dynamics, including the emergence of undesired risks or unintended consequences.

This report highlights the importance of understanding, representing, and quantifying the feedback between CS and human adaptation in the LLs. Individuals change their perceptions and behaviours over time based on the availability of CS and the information provided. These changes depend on individual and/or social norms, attitudes, risk preferences, and heuristics that are often neglected in climate-related modelling.

In this report, we provide new insights about the interplay between climate and human systems mediated by the way in which societies respond to the availability of CS. First, we establish a conceptual framework for exploring the feedbacks between CS, human behaviour, and climate-related events. Then, we apply the framework and co-develop, together with local stakeholders, a number of system archetypes for the different living labs (LL) of the I-CISK project. This allows inferring complex system behaviours, such as the consequences of unequal access to CS.

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1 Introduction

Climate Services (CS) are useful tools to reduce the impact of natural hazards, such as droughts. While the benefits of CS have been widely explored, it is still unclear how their introduction can lead to feedbacks between human adaptation and climate-related events, and generate unexpected dynamics, including the emergence of undesired risks and unintended consequences.

In this context, there has been a number of studies assessing the influence of human behaviour on the implementation of different adaptation actions (Haer et al., 2017; Mazzoleni et al., 2021). However, a systematic review to explore how users respond to CS has not been performed. Existing literature is scattered, and unconnected.

There is a multitude of general behavioural theories from psychology and economics that have been developed and implemented over last years. These theories differ widely in how they assume that individuals perceive risk, and consequently make decisions based on risks and the complexity thereof (Figure 1A). An example of a rational behavioural theory is expected utility theory, where an agent chooses between risky options by comparing expected utility values. I-CISK could make use of the richness of existing behavioural theories to better represent feedback mechanisms than is currently the case and use them within modelling frameworks. However, how these theories are integrated also depends on modelling methods.

Schlüter et al. (2017) developed a framework for mapping and comparing behavioural theories in the modelling of social-ecological systems. This framework considers social-ecological system prompts and how people process information. However, it does not connect to resulting behavioural actions. Schlüter et al. (2017) is alsonot tailored to CS and adaptation/mitigation behaviour. Wens et al. (2019) describe a framework to extend traditional risk modelling to include two-way feedbacks between adaptation and drought exposure, vulnerability and hazard. Van Valkengoed and Steg (2019) report a meta-analysis of factors of adaptive behaviour, neglecting the connection to CS and how people respond to this. Meijer et al. (2021) conducted a review analysis to assess what methods, theories and concepts have been used for the quantification of human responses to changes in water availability. This is not tailored to CS, but to an event and with a focus on how behaviour is quantified, which does not always align with actual behavioural responses.

Modelling the interactions between the physical and the social systems is a difficult task riddled with uncertainties, complexity, and unexpected dynamics. Over the years many approaches have been developed in order to model the complexity of the human-water system. Some of these approaches inductively try to generate a conceptual model starting from the observations of the state of the system, such as in the case of participatory system dynamic modelling. Others, like system archetypes, try to deductively infer specific system behaviours onto specific system models (Elsawah et al., 2017). System archetypes conceptualize different emergent behaviour of the system and specific challenges and dynamics across temporal or spatial scale. Figure 1B shows an example in which two competitors are competing over limited resources while climate change impacts them by shrinking the total resource pool. Both competitors carry out adaptation measures. In recent years, new approaches such as agent-based modelling tried to model the system based on abductive reasoning (Schlüter et al., 2017). This was done by mixing generalized theories of human-behaviour and bottom up modelling (Schlüter et al., 2017). Despite the latest modelling advances, lack in models representing the CS-human dynamics remains.

This report aims to identify the feedback mechanisms between climate change, CS data, socio-economic behaviour, and adaptation measures that can generate dynamics preventing or facilitating resilient pathways in the living labs (LL) of the I-CISK project. This work is expected to pave the way for the implementation of a modelling framework within the different LLs in order to formalize human responses to climate change and CS information by also building upon results from WP1 and WP2.

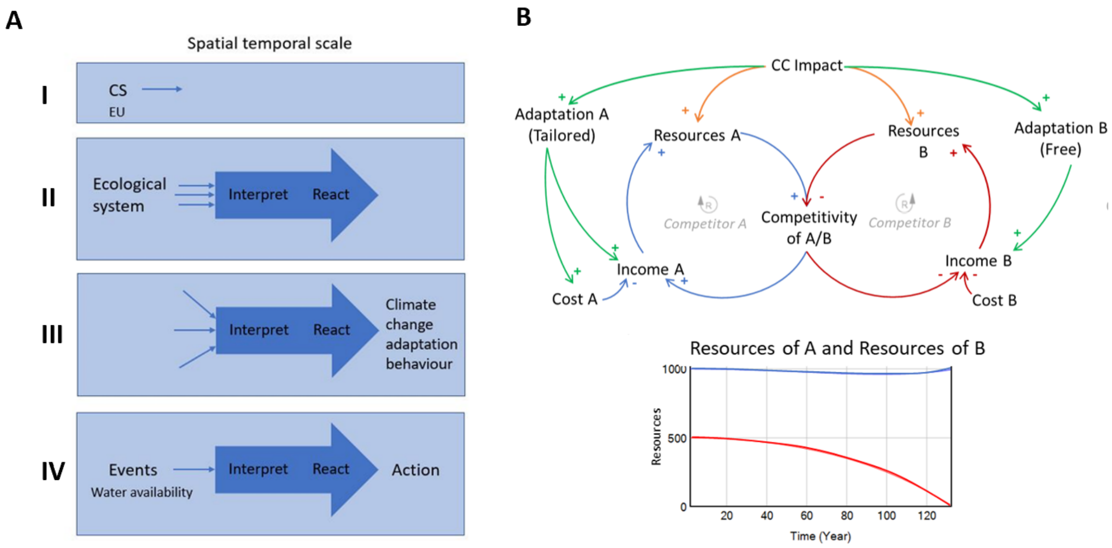


Figure 1: A. Representation of the link between CS, decision making, and actions; B. System dynamic model quantifying the interplays between competitors over limited resources while climate change impacts them by shrinking the total resource pool.

2 Conceptual framework including the links between climate services, human behaviour, and decision-making

In this section, we first propose the main framework and then describe how it can be applied in the different LL. Within I-CISK, this framework will be also based on the socio-economic behaviours identified in WP2. The expected outcome of this task is a framework to characterize the competing hypotheses on the feedbacks between climate and adaptation actions in the different LL defined in WP1. To develop a conceptual framework including the links between CS, human behaviour, and climate risk, it is crucial to consider each individually to isolate key features or characteristics which will be included in the framework. With an understanding of each of the ingredients, they can be linked to create a conceptual framework of CS, human behaviour, and climate risk.

2.1 Conceptualising Climate Services

It is important to highlight key characteristics of CS in their current form in order to create a framework that captures the dynamics generated by feedbacks between climate change, CS, socioeconomic behaviour, and adaptation measures. According to Bessembinder et al. (2019), the common elements of CS are that these:

I. involve provision of climate information for some form of decision making, including policy-making, be it to support adaptation, mitigation, or disaster risk management;

II. are driven by the needs of users, including decision-makers, indicated by terminology such as useful, of value, customised, tailored, co-developed or co-produced; and

III. involve dissemination or guidance for the use of science-based climate information. Such information can include climate data or knowledge based on climate data.

CS can differ in terms of sectors, themes, regions, purposes, time horizons, data sources, level of processing of climate data, background knowledge and type of CS providers (Bessembinder et al., (2019).

2.2 Conceptualising Human Behaviour

As mentioned, there are multitudes of general behavioural theories from psychology and economics, which could be included in the modelling of feedback mechanisms. A conceptual framework would benefit from ensuring sufficient scope and detail to be able to include a variety of customisable theories. For instance, theories differ widely in their assumptions on how individuals perceive risk and make decisions based on risks. An example is the *Expected Utility theory*, where an individual chooses between risky options by comparing expected utility values. Boundedly rational theories include relaxing assumptions from rational behavioural theories, for instance, by allowing the likelihoods used to calculate expected utility to be subjective (*Subjective Expected Utility theory*). Yet, this type of behavioural theory remains very restrictive, as it does not allow for cognitive heuristics (Tversky and Kahneman, 1992). *Prospect theory*, for example, posits that people value losses differently to gains.

Alternative theories focusing on how individuals behave under stressful situations have originated from psychology and other social sciences. For instance, the *Theory of Planned Behaviour*, where behavioural decisions are influenced by the individual's attitude, subjective social norms and perceived control over the situation (Ajzen, 2011). Another frequently cited theory is *Protection Motivation Theory*, where agents intentions to adapt depend on threats and coping appraisals (Rogers, 1975). Behavioural theories also vary in scope, for example, the Consumat approach incorporates various aspects of boundedly rational theories, while influenced by social network (Jager et al., 2000).

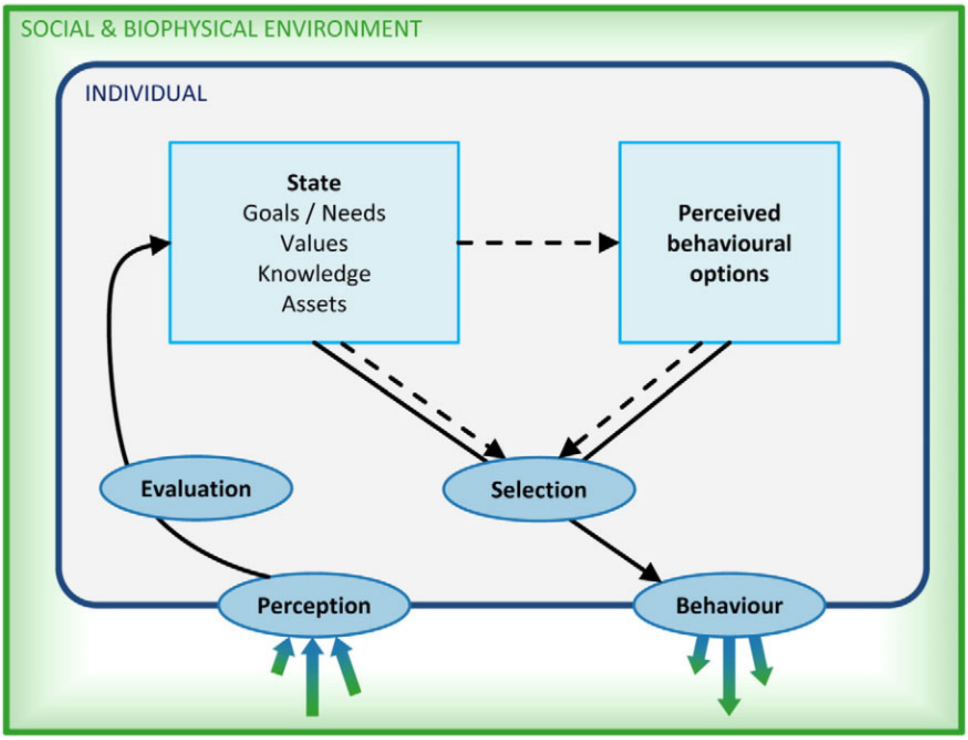


Figure 2: MoHub Framework developed by Schlüter et al. (2017)

To capture the scope and variety of behavioural theories, the key dimensions in which these theories differ in social-ecological systems has been identified by Schlüter et al. (2017). Schlüter et al. (2017) developed a framework for mapping and comparing behavioural theories in models of social-ecological systems, shown in Figure 2. In this framework, Schlüter et al. (2017) highlights structural elements, namely an individual's needs/goals, knowledge, assets and values, which describe an individual's current state, but also the perceived behavioural options available to them. This is an important distinction as these variables also differ across theories, for example *Expected Utility theory* assumes all behavioural options are known to the individual, however, this is not the case for *Theory of Planned Behaviour*).

Schlüter et al. (2017) connects these structural elements to processes. First an individual perceives their social and biophysical surroundings, captured in process element *Perception*. How individuals perceive their surroundings differs per case, and hence is operationalised in theories differently, for example, *Theory of Planned Behaviour* places great emphasis here on perceiving the behaviour of other individuals, whereas *Prospect Theory* highlights that individuals consider the probabilities of events occurring.

According to Schlüter et al. (2017), once an individual has perceived their social and biophysical surroundings, the next important process undertaken is *Evaluation*. This entails determining the significance, worth or condition of the social and bio-physical environment just perceived. In theories with *Bounded Rationality*, individuals have cognitive limitations, but through the element of Evaluation it can be specified how they learn from their surroundings.

Once the surroundings have been perceived and evaluated, individuals consider their best course of action by making a *Selection* based on their *State* (needs/goals, knowledge, assets and values) alongside their *Perceived behavioural options.* In the co-creation of climates services (CS) the importance of local knowledge and its complementary role to science-based knowledge is increasingly recognised. We elaborate on the potential implications of knowledge within this framework. For example, local knowledge can provide important insights into adaptive strategies to be developed over long time-horizons (Agrawal, 2008). Moreover, local knowledge can help the interpreting of climate data in a more meaningful way to local communities (Orlove et al., 2010). Without the appropriate knowledge, we may not identify the most suitable goals and we may not be able to efficiently or effectively use the best assets. Hence, the emphasis on knowledge in the context of CS is to ensure that actions are informed, relevant, and effective.

Descriptions of local knowledge differ across disciplines, with different terminology used across disciplines (for e.g., traditional or traditional ecological knowledge, indigenous knowledge, tacit knowledge etc.). Notwithstanding, all definitions allude to a knowledge that is derived from practical experience, encapsulates culturally derived values, is deeply rooted in the local context, and is accumulated over a period of time. Failing, Gregory, and Harstone (2007) in their review posit that local knowledge tends to be more experience-based and rooted in a place, without devolving into generalisable rules and is more holistically expressed. Based on this, local knowledge here is defined as an overarching concept that encapsulates different types of knowledges, derived either through traditional or cultural norms, personal observations, lived or occupational experiences. It provides an insight into the 'way of life' of individuals and communities, shedding light on how they perceive their surroundings, solve problems and validate new information (Van den Homberg et al. 2022).

The *Selection* process is specified by Schlüter et al. (2017) in their framework to emphasise that individuals may optimise differently (or not optimise at all). For example, a *Rational* individual may optimise to find the absolute 'best' behavioural response, whereas a *bounded rational* individual may use satisficing heuristics. This entails choosing a 'good enough' behavioural response as it recognises that individuals do not have unlimited cognitive resources.

Once an individual has made a *Selection*, it is translated into a *Behaviour* or a behavioural response. It is important to note that the framework by Schlüter et al. (2017) does not exclude the option that the selected response is to not respond, or that the selected response is in the end infeasible, hence also resulting in no response. This is an important distinction as literature has shown that receiving a CS does not necessitate a visible response, it is possible that the CS is not deemed trustworthy, hence is intentionally not acted upon (Changnon, 2002; Dilley, 2000).

A strength of this framework is that it highlights in which ways several theories can be used together, adjusted and customised to suit many contexts. This is valuable when considering case studies in the I-CISK LL contexts, as behaviour will likely vary.

2.3 Conceptualising Climate Risks

The disaster risk framework for climate risk reflects the interactions between hydroclimatic systems, and vulnerabilities of exposed people, economies and ecosystems (Beckage et al. 2018; McGlade et al. 2019). Research and applications in climate impacts, vulnerability, and risk have been evolving for decades, with the IPCC closely tracking these developments. Initially, the focus was on understanding the physical effects on biophysical systems through exposure and sensitivity interactions. *Vulnerability* reflects a complicated indicator about how different social groups can prevent, cope with and recover from climate-related events. This includes physical, social, economic, and environmental factors closely tied to the level of development (World Health Organization, 2021). For example, if individuals do not understand flood warnings, they will not be able to respond quickly and effectively, meaning they are more vulnerable to floods. As concerns about the impacts on social systems grew, and the realization that these systems have the ability to adapt intentionally and resourcefully, the concept of social vulnerability gained attention. This help assessing which regions, countries, or sectors may be susceptible to climate change.

Over time, the evidence and consequences of climate impacts have become more apparent, highlighting the importance of socio-economic effects. As a result, the focus has shifted from vulnerability to risk, considering risk as a function of exposure, current and future hazards, and vulnerability (Figure 2.a). Risk is often quantified by the likelihood of physical and social impacts. The term *Hazard* refers to natural (e.g. earthquakes, floods, droughts etc…), biological (e.g. disease outbreaks), technological (e.g. chemical and radiological agent release), and societal (conflicts, migration) ways in which a population could be impacted negatively (World Health Organization, 2021). If these hazards are to affect a population, they must be sufficiently exposed, which is reflected in the term *Exposure* (World Health Organization, 2021). For instance, the level of exposure to floods is high, if there is a large population living unprotected in the floodplain. Incorporating vulnerability into risk assessment and transitioning to a risk-focused approach in research and practice aims to make it easier for decision-makers to act.

Since the move from vulnerability to risk assessments, there has been a growing focus on Climate Risk Assessments (CRAs) across various scales, sectors, regions, and communities (Ara Begum et al., 2022). The risk-centred framing is now deeply ingrained in the IPCC's 6th assessment cycle (AR6), building on the earlier SREX "Risk Propeller Framework" (IPCC, 2012) by incorporating adaptation (and sometimes mitigation) responses into the "risk equation" (Figure 2.b)

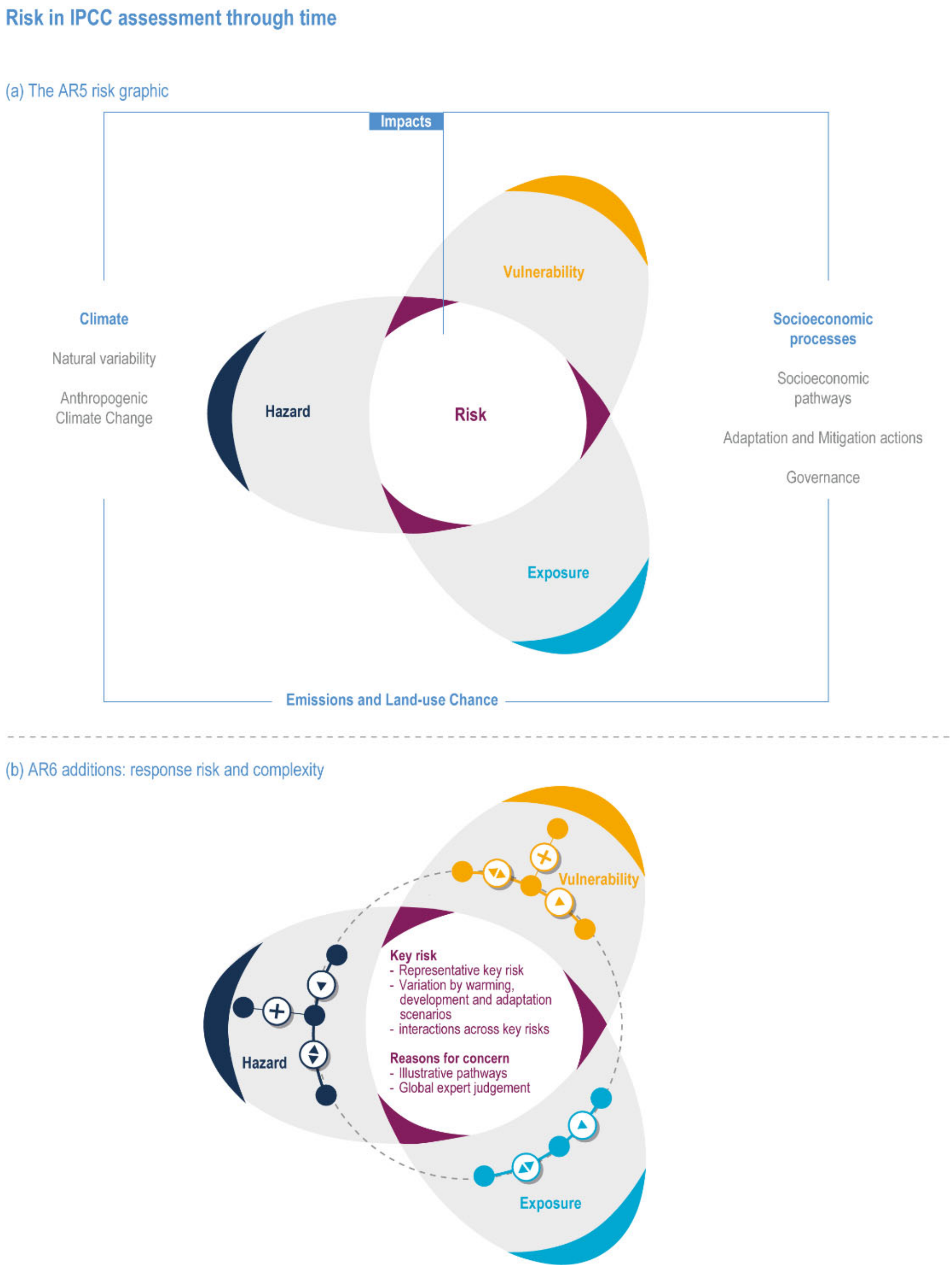


Figure 3. Original IPCC 'risk propeller' (a) and current version including the role of responses in modulating the determinants of risk (Ara Begum et al., 2022).

2.4 Connecting Climate Services, Human, and Climate Risk

CS have been considered in frameworks describing socio-economic behaviour and the climate in a limited, applied capacity (Shafiee-Jood et al. 2021; Quiroga at al. 2011; Lines et al. 2018). Their addition in this framework would enable unpacking of causal mechanisms explaining the emergence of different feedbacks. The behavioural framework defined by Schlüter et al. (2017) captures the depth and scope of human behaviour, however, does not capture the effect of specific environmental contexts, as it does not specify the social and biophysical environment. By explicitly stating the social and biophysical environment, the framework can be built upon and adjusted to better describe, compare and communicate alternative theories of behaviour *responses to CS*.

Merging frameworks of CS, human behaviour and climate risks has resulted in the following conceptual framework:

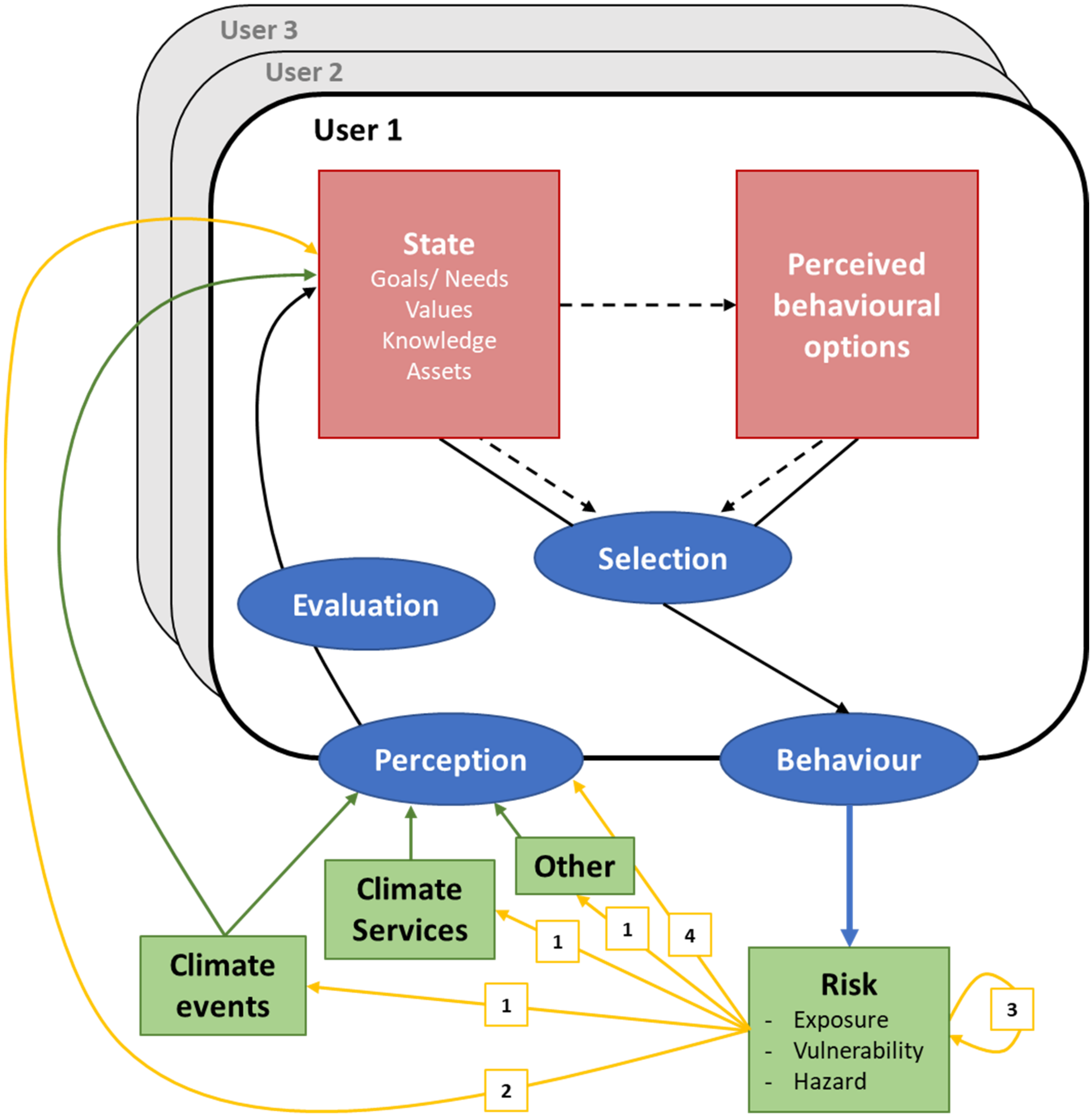


Figure 4: Conceptual framework developed in ICISK to represent the interplays between CS, human, actions, implementation of adaptation actions, and climate risk. Components in User 1 box are inspired by the MoHub framework developed by Schlüter et al. (2017). Solid arrows represents the flows of information, the dashed arrows show the influence of one element on another, while the yellow arrows represent adaptation feedback across time. Element Risk has been inspired by IPCC (2012), and the yellow feedback lines by Wens et al. (2019).

In this conceptual framework, we have connected *CS* to the element of individual perception pf different users, alongside the perception of C*limate Events* and *Other*. Climate events refers to, for example, rising temperatures due to climate change. These are not always perceived by individuals; however, literature has shown

that CS can aid in improving the perception of climate events, for example, droughts (Guido et al., 2013; Demnitz et al. 2020) and climate change (Nkuba et al. 2022). The element called *Other* is a category which enables the inclusion of influential stakeholders e.g. government policy. Once these highlighted elements are perceived by the individual, they follow the same process as defined by Schlüter et al. (2017).
In particular, we can see how perception influence the state (i.e. values , goals, needs, and assets) though the user evaluation, which in turn influence the perceived options. Knowledge plays an important role in shaping perceived behaviour and may be based on prior local and/or scientific knowledge of a certain climate risk. For example, a user with higher climate risk awareness due to a more profound local knowledge may perceive risk in a different way and react differently (Mondino et al., 2020). Opposite results can be observed when no prior local knowledge is in place and behaviour changes are driven mainly by collective actions from other users (Alonso Vicario et al., 2020). In this respect, user perception of a certain climate risk can influence its corresponding state. As a result, in the framework it is assumed that the state of a user can influence the perceived behavioural options by either limiting an initial broader range of perceived options (e.g., due to limited available assets) or by allowing the user to select from additional options because, for example, of new knowledge. It is also assumed that the perceived behavioural options can change over time as the result of learning, forgetting or other changes.

To emphasise the possibility for heterogeneous behaviour, other users (grey boxes labelled 'User 2' /'User 3') have been included. This element serves as a reminder that there are other CS users who may experience the same inputs, but may perceive and consequently evaluate, select and respond differently. These users can come from different sectors (including also civil society) and can have heterogeneous characteristics also within the same sector. Users can also be defined depending on specific case-study/application context. Once a CS user has acted (or actively chosen not to act) through the *Behaviour* element in the conceptual framework, we emphasise that this affects *Risk*. When Risk proceeds to impact other elements in response to the behavioural change, reflected in the yellow arrows in *Figure 4*, a feedback begins.

In this conceptual framework, we have integrated the feedback avenues identified by Wens et al. 2019. Wens et al. identify three feedback types; a bi-directional influence between adaptation and risk (yellow line, number 2), influence of adaptation on risk across temporal scales (yellow line, number 3), and influence of risk on individual decision making (yellow line, number 4). A bi-directional influence between adaptation and risk has been integrated by allowing the *Risk* element to directly affect an individual's *State* element. An individual may have less assets, limiting their behavioural responses, which affects *Risk* once more. Influence of adaptation on risk across temporal scales is indicated through the self-loop from element *Risk*, back to *Risk*. For example, this allows for the possibility that the behavioural response of one individual, may affect their own exposure, but also the exposure of others across time. The influence of risk on individual decision making is included through the arrow from element *Risk* to *Perception*. This is an important feedback type as it not only reflects and individuals perceive the changing risk over time, but also that this changing risk is not perceived the same by all individuals. In the conceptual framework developed (Figure 4), we also highlight new avenues for feedbacks that have not been discussed by Wens et al. 2019, shown by the yellow line numbered 0. Here we show that Risk also affects the characteristics of the *Climate Event*, *CS*, and workings of other influential stakeholders (*Other*). In this conceptual framework, we recognise that no user starts with a 'blank slate', meaning that there is knowledge prior to the implementation of any CS interventions in a given context. Individuals have been involved in livelihood activities, interacting with their local environment and implementing coping or adaptation strategies. These practices, experience and understanding of the local reality together inform the local knowledge. With this in mind, it is difficult to specify the start or origin of the feedback. For instance, knowledge plays an important role in shaping the perception. It is also important to emphasize that knowledge as defined in the State element is not static, as it is continuously updated based on the experiences of the individual. Finally, local knowledge is also crucial in understanding how individuals perceive their surrounding and recognise problems, validate new information and evaluate the risk management and adaptation options.

3 System archetypes for representing CS-Human dynamics

System archetypes, which were originally proposed in Senge's book The Fifth Discipline (1990), are simple models that capture specific emergent system behaviours through series of paired feedback loops (Mirchi et al., 2012; Wolstenholme, 2003). Although system archetypes were developed independently from system dynamics, their similarities have led them to become one of the most commonly used conceptual tools for this type of modelling (Elsawah et al., 2017). Due to their simplicity, archetypes serve as a convenient starting point for conceptualizing complex systems (Elsawah et al., 2017). Their intuitiveness and simplicity also make them an ideal tool for participatory modelling, as the dynamics reproduced by archetypes help to bridge the gap between users and modellers as they are generally recognizable to the general public (Elsawah et al., 2017). Examples of such dynamics are; “the tragedy of the commons”, ”limits to growth”, “success of the successful”, and “fixes that backfire” (Mirchi et al., 2012; Moallemi et al., 2022). The complex behaviours of system archetypes arises from the presence of reinforcing and balancing feedback loops (Mirchi et al., 2012). A reinforcing feedback can explain why the effects of an action might spiral out of control in the long-term, while in a balancing feedback different processes or actions try to bring conditions into equilibrium (Forrester, 1994; Sterman, 2001). An example of the use of system archetypes to conceptualize complex behaviours is Moallemi et al. (2022), where archetypes are utilized to highlight challenges arising from complex emergent behaviours in the context of Sustainable Development Goals (SDGs), examining synergies and trade-offs. Similarly, Biella et al. (2022) present a conceptual model based on the success of the successful archetype, demonstrating how the competition between two users with limited resources under climate change can lead to a scenario where the initially more successful competitor gains progressively greater advantages.

In I-CISK, system archetypes were used to initiate the conceptualization process that will lead to the modelling of the complex interactions between CS and adaptation. To this end, the team of WP4 designed a survey intended for LL leaders and their collaborators. The purpose of this survey was to identify dynamics within the LLs that could be associated with specific system archetypes. The survey questions were formulated based on an extensive literature review that focused on the challenges encountered in the development and utilization of CS. A total of 16 responses were collected from participants representing all LLs, and were subsequently analysed by the WP4 team. Based on the analysis of these results, the most relevant archetypes were identified. This has led to the identification of generalized dynamics that were commonly observed across multiple LLs and could be reconducted to those highlighted in the existing literature on CS. The LL leaders were then invited to assess the findings of the survey. At the time of writing, this evaluation process is still ongoing.

4 Application of the conceptual frameworks for the different Living Labs

A set of empirical explanatory models have been defined for selected LLs, and will be used as one of the main inputs for Task4.2 which aims at assessing the long-term climate-human feedbacks and their influence at different spatial scales.

4.1 Application of the CS-Behaviour-Risk conceptual framework

In the previous section, we describe the developed conceptual framework for CS, human behaviour and climate risk, however, this has been a theoretical discussion. In this section, we aim to demonstrate the applicability through preliminary case study demonstrations of the conceptual framework. It is important to note that the observations discussed in this section are based on interactions with the I-CISK LL stakeholders directly, and is subject to change as the project progresses and as we develop a deeper understanding of the workings of the LL. We have selected two preliminary case studies to highlight different aspects of how the conceptual framework works. First, we apply the framework to the LL in Spain to demonstrate how this works with CS users from a specific sector, namely agriculture. Second, we apply the framework to the CS user Rijnland water authority (*Hoogheemraadschap van Rijnland*) in the LL in the Netherlands to demonstrate that the conceptual framework can be applied to CS at a different scale. These demonstrations are intended as a starting point for I-CISK Task 4.2

4.1.1 Spain LL CS User: Farmers

Here we demonstrate that the conceptual framework shown in *Figure 4* can be applied to livestock/feed farmers. Other relevant CS users in this context are other livestock/feed farmers who may have different (combinations of) livestock, reflected in the framework as *User 1/User 2.* These other livestock/feed farmers are relevant as there is much communication between farmers and they interact/overlap in the use of the same agroforestry extensive grazing system.

Table 1. Spain LL farmer preliminary application to the developed conceptual framework.

Framework Element	**Preliminary observations from LL Spain**
Perception	They rely on their own perception of precipitation/water level as well as using their social network extensively to share information.
Evaluation	There are 15-day weather forecasts available, but farmers do not fully trust forecasts and predictions (beyond 24-48 hours), so these are not considered with a great weight. They place more value in their own experience of the environment
State	Goals/ Needs: - Conservation of the genetic lineage of the livestock (family heirloom) - Conservation of the family farm and tradition - Conservation of the traditional landscape and of helm oaks. Values: - The lineage of their livestock is considered a farmer's heritage.

	Knowledge: - Past experiences - Traditional knowledge - Livestock market prices Assets: - Stocking rate - Water availability - Pasture and acorns availability/production (rainfall and temperature dependant) - Size and number of farms –larger sized farms or the availability (through ownership or rental) of different farms allows for the movement of the cattle among fields when pasture is scarce due to drought. - Financial assets – which facilitates or (lack of) hinders purchase of additional feed.
Perceived behavioural options	- Management of the stocking rate - Buy/build water storage infrastructure - Buy additional feed - Purchase water (tank trucks) - Adapt barns and shelters to manage heat waves - Rotate pasture use - Rent additional pastures/ access to dehesa[1] fields in times of "montanera" (acorn production) - Block streams to retain water
Selection	Satisficing[2] selection methods are present; options are evaluated until a behaviour is found that is expected to satisfy. They also try to use as many options as possible to limit damage during droughts, however, the behavioural options taken also depends on the drought duration.

The selected behaviour will be chosen to minimise the Drought Risk component. Selecting behaviour to reduce drought Risk might also feed back into what type of information the CS relay. Current CS available to farmers in the region are 15-day forecasts, drought indicator reports and meteorological information which can be accessed online. Other farmer influences (represented in the form of the *Other* component) in this case could be policies like the EU Common Agricultural Policy (CAP), which supports farmers by buying up stock during times of drought. The water authority can also influence farmersby means of, for example, groundwater policies and changes in water allocation from water supply reservoirs.

[1] Dehesa: Type of agroforestry system that is found mainly in southwestern Spain and Portugal characterized by open woodland pasture where holm oak and/or cork oak trees are grown alongside grasses and other vegetation. Dehesas primarily focus on the production of non-timber forest products such as wild game, mushrooms, honey, cork, and firewood. Dehesas can be private or communal property

[2] A decision-making strategy or cognitive heuristic that entails searching through the available alternatives until an acceptability threshold is met.

4.1.2 Rijnland LL CS User: Rijnland water authority

Here we demonstrate that the conceptual framework shown in *Figure 4* can be applied also to organisations such as the water authority Rijnland (*Hoogheemraadschap van Rijnland*). Other Users (depicted as *User 1* and *User 2* in the conceptual framework) can be considered relevant neighbouring water authorities in terms of water provision (e.g. Delftland, Schieland en de Krimpenerwaard and Stichtse Rijnlanden, Ministry of Infrastructure and Water Management, Rijkswaterstaat). It is important to note that there is also the possibility to make distinctions or specific spatiotemporal applications; here there have been distinctions made between the temporal scale of *Perceived Behavioural Options* as for Rijnland water authority there are occasions when a choice need to be made between short term and long-term solutions.

Table 2. Rijnland water authority preliminary application to the developed conceptual framework.

Framework Element	**Preliminary observations from LL Rijnland**
Perception	Explicitly monitor water level and salinity. This means they also have ‘perfect’ memory through the use of historical data. However, their perception is limited to specific measuring locations of salinity/water level, meaning their perception is bounded. They perceive the other water authority actions, but not always the stakeholders actions. They do not know the amount of water that is withdrawn from the river.
Evaluation	Rijnland makes use of historical data, and makes detailed records for the purposes of analysis for effectiveness, but also for transparency (e.g. demonstrate impartial decision making)
State	Goals/ Needs: - Provision of sufficient water allocated in the most appropriate way (minimise long term damages, while remaining impartial). Values: - Allocate water according to the *Verdringingsreeks* (sets priority of allocation to different uses to minimise long term damages). - Treat all stakeholders within each category fairly. Knowledge: - Past experiences of water allocation during droughts. - Expert knowledge of the water system. Assets: - Limited time to take physically implement adaptation actions - Decision-support systems - Expert knowledge - Limited financial resources - Limited water management infrastructure (e.g. water pumping stations) During severe national droughts, limited mandate to make decisions.

Perceived Behavioural Options	During drought: - Close sluice gates to retain water. - Implement measures to retain water level (e.g. turn on specific water pumps). - Negotiate for more water from neighbouring water authorities. - Advise stakeholders (e.g. farmers) to reducing water usage. - Demonstrate water needs to national committee to allocate scarce water (*Landelijke Coordinatiecommissie Waterverdeling*). - Checking dyke stability/safety. - Install emergency equipment (e.g pump equipment) Not during drought/ long term: - Build better water infrastructure. - Invest in better measuring systems. - Make binding agreements for water allocations. - Run better modelling scenarios.
Selection	If selection is about modelled situations: Enact strategies which have been optimised by modelling scenarios prior to drought. If selection is about not modelled situations: Boundedly rational by optimising using *Verdringingsreeks* in the face of limited knowledge and more importantly time. These decisions are made based on expert knowledge and results are recorded in detail.

Behavioursthat Rijnland enacts have been carefully selected via several modelling exercises and optimisation processes to manage all the components shown of *Risk*. Main goals are to allocate water in such a way that minimal damage occurs. This has been operationalised into a displacement series (*Verdringingsreeks*), shown in Table 2

Table 3. The Displacement Series (Verdringingsreeks). This is a set of rules whereby the water authorities prioritise the order with which stakeholders are allocated fresh water. Category 1receives water first, category 4 last. Within category 1 and 2 there is also a hierarchy (bullet 1 has a higher priority than 2). Within category 3 and 4 there is no hierarchy, meaning this is up to the discretion of the water authority to allocate.

Category 1: Safety and prevention of irreversible damage	Category 2: Utilities	Category 3: Small-scale high-quality use	Category 4: Other interests (economic consideration, also for nature)
1. Stability of flood defences 2. Soil subsidence and compaction 3. Nature (irreversible damages, overwise cat. 4)	1. Drinking water supply (to guarantee supply, otherwise cat 4.) 2. Energy supply (when there is a danger to supply, otherwise cat. 4)	• Temporary irrigation capital intensive crops • Process water	• Shipping • Agriculture • Nature (only if no • irreversible damage occurs) • Industry • Water recreation • Fishing

Resulting *Behaviour* tends to be a variant of the perceived behavioural options. The behaviours and measures enacted by Rijnland water authority during droughts tends to only be recognized by stakeholders involved, although their choices are made public via their website and the summer drought monitor (*Zomermonitor*) that Rijnland water authority develop (Hoogheemraadschap van Rijnland, 2022). For example, if there is no water shortage (drinking water companies remain unaffected by the drought), then the general public tends to be unaware that there are water supply problems. This is in contrast to the drought management measures implemented in for example drought management planning in Spain, where public communication is one of the first measures taken.

Actions taken by Rijnland affect the risks they are trying to manage, and in turn affect *Climate Events* (e.g. consecutive floods after drought periods), the *CS* they are using (adding more measuring stations for more detailed data), and the *Other* framework element in this case represents various affected stakeholders (in the ICISK LL we explore impacts on tourism and the agriculture sector).

One of the challenges for Rijnland is anticipating unknown risks, as they cannot be modelled and optimised for etc… In these situations, they perceive those situations through the lens of an experiment. This entails making small adjustments and recording the results such that after the drought these adjustments can be thoroughly analysed to assess their effectiveness.

4.2 Application of the System Archetypes

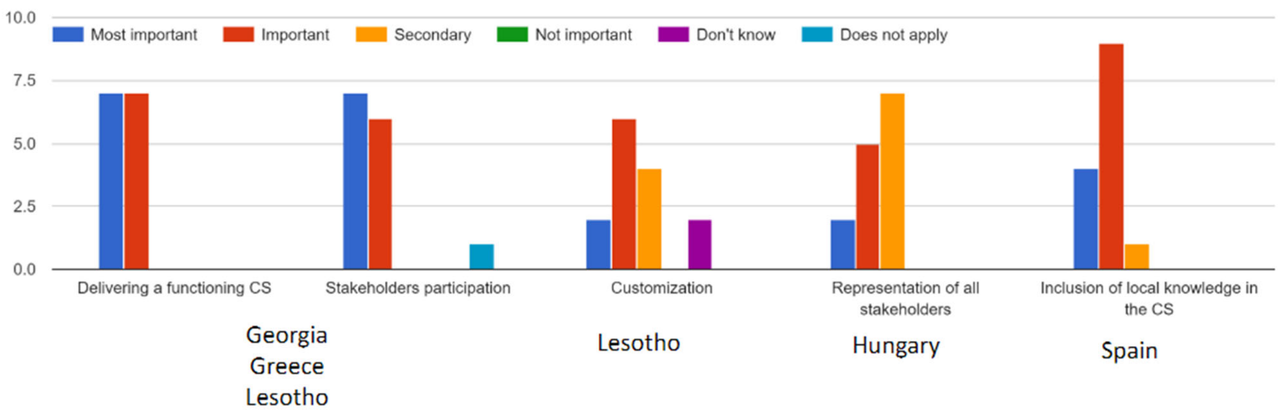
A survey was developed to support the conceptualization of system archetypes for the various LLs. The survey was structured on the questions classes "what are the goals" (questions 1-3), "what is the focus" (questions 4-6), and "who benefits" (questions 7-9):

1. What are the main goals of the climate services connected to I-CISK and how relevant are they for the project?

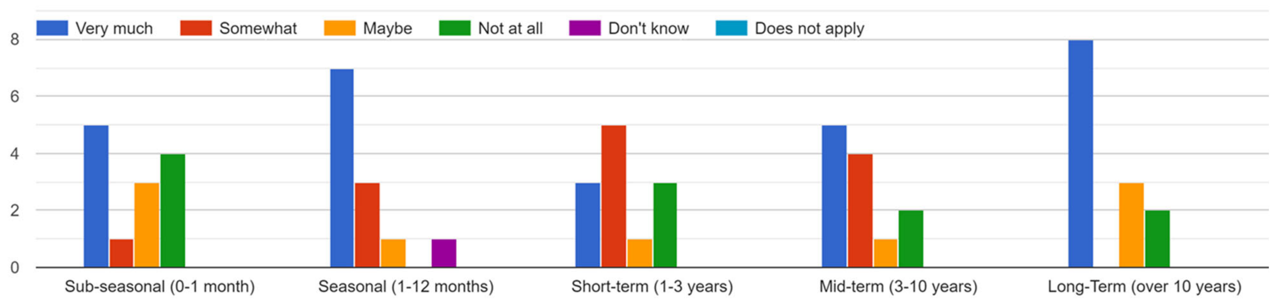
2. How likely are they to reach the said goals?
3. Have the goals remained the same since the beginning of the process?
4. Do the climate services developed through I-CISK address challenges at the following time scales?
5. Do the climate services developed through I-CISK address the root causes of the problems identified in the LL or do they focus on immediate challenges?
6. Are the climate services developed through I-CISK aimed at fostering transformation in the following sectors?
7. Can the climate services delivered through I-CISK benefit a certain group at the expenses of another?
8. Can the climate services developed through I-CISK be used to reduce an existing situation of socio/economic inequity in the LL?
9. What are the main limitations to the uptake, use, and success of the climate services connected to I-CISK in the LL?

The results of the survey involving 16 I-CISK LL leaders from the all 7 LLs are briefly reported below. It is important to note that this analysis is still preliminary.

1. What are the main goals of the climate services connected to I-CISK and how relevant are they?



4. Do the climate services developed through I-CISK address challenges at the following time scales?



7. Can the climate services delivered through I-CISK benefit a certain group at the expenses of another?

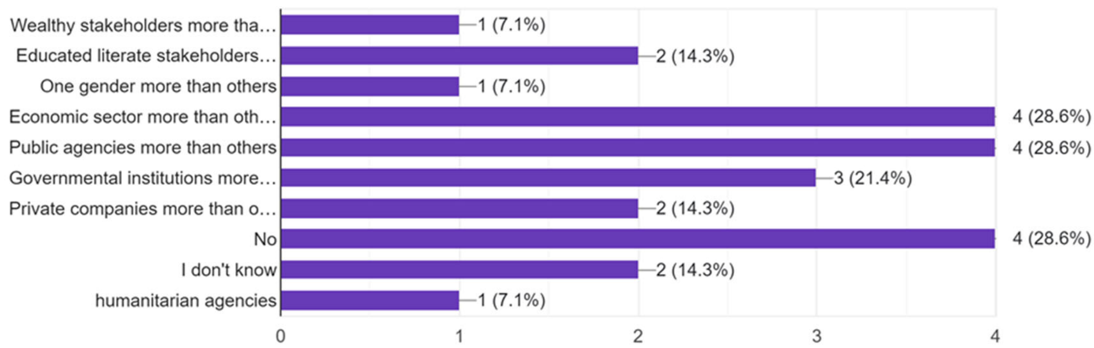


Figure 5. Part of the results from the survey. Upper panel refers to question 1, middle panel to question 4, while lower panel to question 7. The values in the bar charts represent the number of responses received.

Based on the results of the survey, different possible uses of system archetypes were identified. In particular, three main ones were explored more in depth as they are relevant for most LLs. *Drifting goals, band-aid solutions* and *success to the successful*.

4.2.1 Drifting goals (a.k.a eroding goals)

In this archetype, goals are progressively lowered in order to reach them. However, this comes at the expense of the overall outcome.

In the case of I-CISK, it emerged how the pressure to deliver a functioning CS within the timeframe of the project is regarded as the most important objective. However, the prioritization of this objective comes at the expense of other objectives such as customization, stakeholder representation, and inclusion of local knowledge. Nonetheless, literature shows how these have a positive impact on the usability of the service, meaning that the prioritization of delivering a CS might come at the expenses of its usability. This was observed in several LLs, yet it is still in the evaluation phase. The archetype exemplifying this dynamic is characterized by two paired balancing loops (Figure 6).

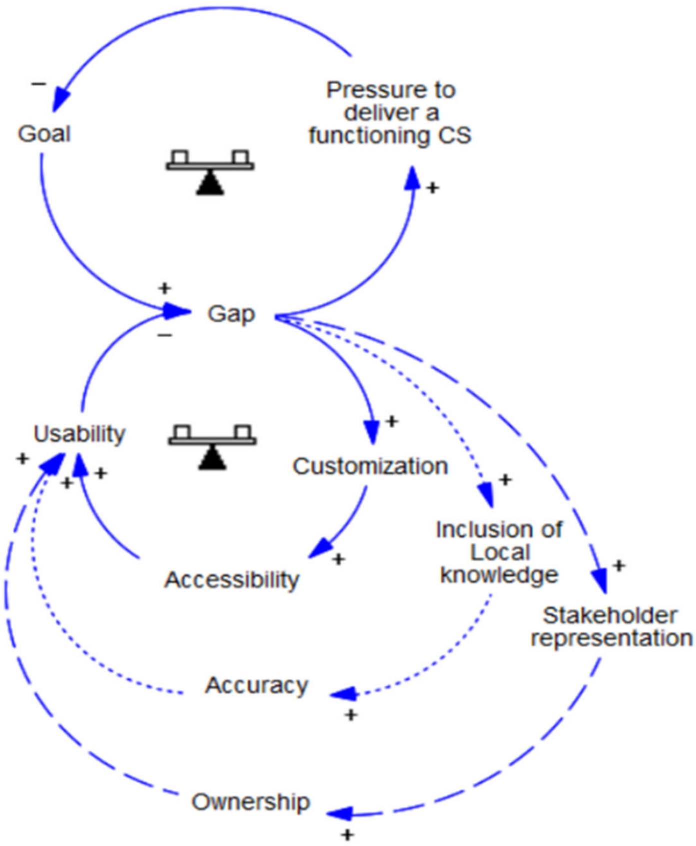


Figure 6. Eroding goals, adapted for I-CISK LLs

For the Lesotho LL while the user of the CSs is the Disaster Management Authority (DMA), the ultimate benefits should be for the farmers and while the main limitation to the use by the DMA is the communication between agencies, the farmers' main challenge is the lack of adaptive capacity even when provided with information. Nevertheless, the representation of farmers is limited. This could lead to a situation where the CSs are tailored to for use by the DMA, yet this only have limited effects on the overall usability of the climate information. For the Georgia and Italy LLs, the pressure to deliver a functioning CS could lead a downplay the importance of customization, local knowledge and co-creation, leading to a less usable CS overall.

4.2.2 Band-aid solutions (a.k.a. Shifting the burden)

A problem symptom is addressed by a short-term and a fundamental solution. The short-term solution produces immediate results at the expense of the more fundamental one.

CS have the potential to both preserve unsustainable systems or facilitate transformation. For instance, when short-term focused they may enhance the resilience of sustainable agricultural practices but could backfire and lead to increased damage on the long-term. Conversely, CS can also provide the essential long-term perspective needed to initiate and guide systemic transformations. This example shows how different CS can compete with one another and in some case lead to maladaptive outcomes.

In the context of the Spanish LL, it has been observed that milk production has emerged as a lucrative source of livelihood. Although milk production currently offers economic advantages, it also requires significant resources, particularly in terms of water usage and also in terms of groundwater pollution from manure. Conversely, the traditional agro-ecological landscape known as the "dehesa" presents a more resilient option in the long term. Furthermore, while milk production is more susceptible to the impacts of climate change, it could potentially benefit from CS to shore its assets. Paradoxically, this could exacerbate the challenges in preserving the dehesa system, due to decreasing water quality (used as drinking water for other cattle) and as the incentives to transition to milk production increase. Long-term CS can instead serve as guide for climate change adaptation and be instrumental in avoiding maladaptive outcomes. This example shows the tensions that can arise between different CS as these favour different adaptive outcomes. Figure 7 illustrates the case of the Spanish LL.

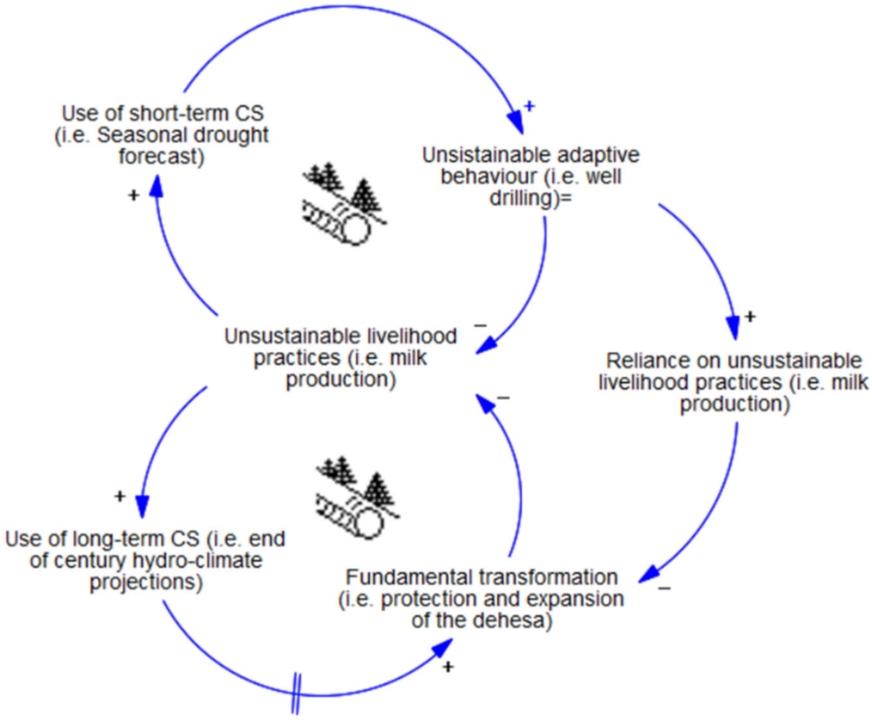


Figure 7. Band aid solutions adapted for the Spanish LL

4.2.3 Success to the successful

In situations where, multiple actors are competing for limited resources, the most successful competitors tend to receive a disproportionately larger share of the resources, with negative consequences on the other actors involved.

The impact of CS on inequality can vary depending on the accessibility and representation of interests. To mitigate the potential for inequality, it is essential to engage in co-creation processes that ensure the representation of all stakeholders' interests. This inclusive approach helps reduce the risk of creating or perpetuating disparities in accessing and benefiting from CS. In the case of I-CISK, based on preliminary assessments, could be observed in the Rijnland LL, where the stakeholders involved in the development of CS to date have been mostly representatives of the agricultural sector, while the recreationist sectors have been largely unrepresented. Within the I-CISK project, the recreationists have been explicitly included in discussions and the co-creation of CS, as such improving their representation within water management. This can prevent in the long term to the creation of services thatonly benefit the agricultural sector, who otherwise could progressively reduce the access to the shared resources for the recreationists (Figure 8).

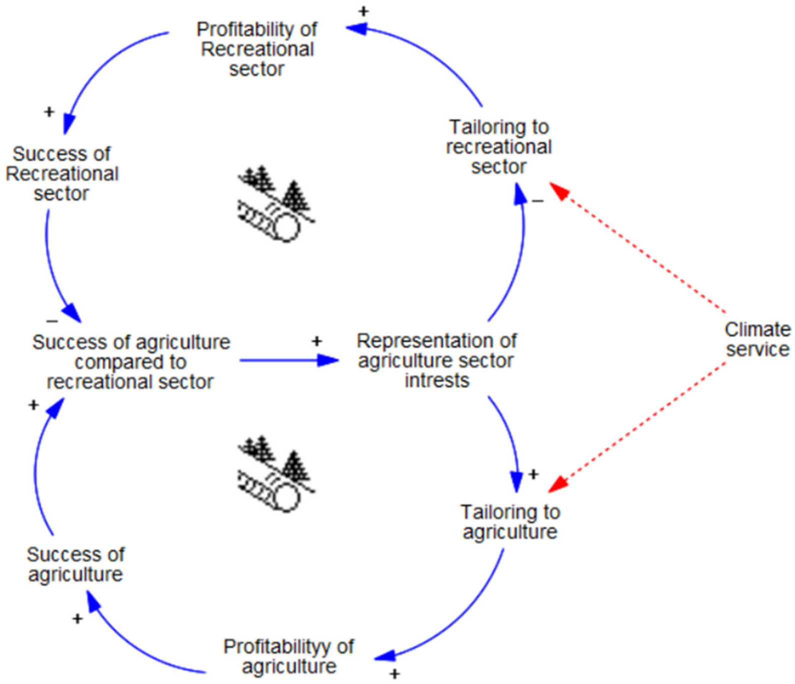


Figure 8. Success to the successful, adapted for the Dutch LL

5 Conclusions

This report provides new insights from the I-CISK project about the interactions between climate and human systems mediated by the way in which societies respond to the availability of CS. We established a conceptual framework including the links between climate services, human behaviour, and decision-making is established. Then, we applied the framework and co-developed system archetypes for the different LL together with local stakeholder.

This report highlights the importance of understanding, representing, and quantifying the feedback between CS and human adaptation in the LLs. Individuals change their perceptions and behaviours over time based on the availability of CS and the provided information. These changes depend on individual and/or social norms, attitudes, risk preferences, and heuristics that are often neglected in climate-related modelling. The frameworks developed in I-CISK are expected to help capture feedbacks between CS, human behaviour, and the environment based on a better understanding of how people respond to CS. Using system archetypes allowed inferring complex system behaviours, e.g., unequal CS access consequences. Similar archetypes were identified based on a survey conducted on the I-CISK LLs.

The conceptual framework and empirical explanatory models developed will pave the way for the more complex models that will be developed in the different LLs for assessing the emerging patterns and quantify long-term effects of different adaptation actions and socio-economic behaviours with the final goal of reaching a resilient future based on CS information.

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I-CISK

HUMAN CENTRED CLIMATE SERVICES

Colophon:

This report has been prepared by the H2020 Research Project "Innovating Climate services through Integrating Scientific and local Knowledge (I-CISK)". This research project is a part of the European Union's Horizon 2020 Framework Programme call, "Building a low-carbon, climate resilient future: Research and innovation in support of the European Green Deal (H2020-LC-GD-2020)", and has been developed in response to the call topic "Developing end-user products and services for all stakeholders and citizens supporting climate adaptation and mitigation (LC-GD-9-2-2020)". This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037293.

This four-year project started November 1st 2021 and is coordinated by IHE Delft Institute for Water Education. For additional information, please contact: Micha Werner (m.werner@un-ihe.org) or visit the project website at www.icisk.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037293