Framing environmental transitions.
How policy actors perceive social-ecological interdependencies?

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Abstract

Environmental transitions face the challenge of incentivizing change and governing complexity. Changing perceptions is critical to address these challenges. Perceptions shape policy and directly determine the potential and pathway of environmental transitions. While often addressing risk perception, economists rarely study perceptions in regard of policy process and change. Social-Ecological System components interdependencies drive dynamics and potential for sustainability. We elicit the perceptions of these interdependencies, offering a comprehensive understanding of the mechanisms at stake by measuring three dimensions of perceptions: likelihood, intensity and polarization. Then, we investigate the mechanisms determining the perceptions, and the association of interdependencies perception with policy preferences. Empirically, water uses serve as a case for investigation. We develop an original measurement of perception using a survey that puts the emphasis on the perceived interdependencies between water uses, while most of the literature measures the importance attributed to each water use. We focus on the 19 principal water uses in the Geneva region, i.e., a system of 342 relations. Results show important variations in the perception of use-use relations among actors and uses. This variation depends on individuals characteristics, and nature of uses. Perceptions associate with preferences for participation and policy instruments, like precautionary principle.

Keywords: Transition, Perception, Policy, Natural resource, Social-ecological system.
JEL Codes: D70, D91, H83, Q25, Q57, Q58.

1 Introduction

Environmental transitions face the challenges of incentivizing change and governing complexity.[1] Perceptions of social-ecological systems (SES) functioning are pivotal to tackle the two challenges. Firstly, individuals use their perceptions to interpret the world and make choices, i.e., perceptions affect preferences and behaviors (Kahneman, 2003; North, 2005). Secondly, shared perceptions affect the likelihood of a topic being recognized as a salient issue, i.e., to move higher in the policy agenda (Baumgartner et al., 2009; Vatn, 2005b; **?**). Thirdly, SES are complex systems and complexity primarily refers to the plethora of, often dialogical, interdependencies between natural resource's environmental functions and anthropic uses, e.g., use conflicts and non-linear impacts (Ostrom, 2009). The way those interdependencies are perceived shapes the framing of policy solutions, and arguably the scope of possible futures. Perceptions are pivotal in shaping policy and determining the set of feasible pathways for environmental and social transitions (Arrow et al., 2004; North, 2005).

Understanding how actors could adapt or would react to contextual change, like new policy instrument implementation or environmental conditions evolution, motivates most of the research on perceptions (Douenne and Fabre, 2020; Frondel et al., 2017; Mathias et al., 2020; Wheeler et al., 2021). Therefore, the lens of reaction to risks and opportunities is predominant in the literature, conducting empirical design to investigate actors perceptions of a given component in a social-ecological system. However, it is now established that SES sustainability depends extensively on how SES components interrelate (Di Baldassarre et al., 2019; Duit et al., 2010; Gunderson and Holling, 2002). Norgaard stressed it with the co-evolution principle (Kallis and Norgaard, 2010; Norgaard, 1994), which is foundational to many approaches in economics interested in sustainability (Ostrom, 2009; Spash, 2017). We contribute to filling this gap at the crossroad of perception and co-evolution.

In this research, we investigate the determinants and effects on policy preferences of the perception of SES components interdependencies. Because of the need to understand the processes of environmental transition and embrace the complexity of institutional change, we distinguish the three characteristics of perceptions: occurrence, intensity, and polarization. Eliciting the variations, determinants, and effects on policy preferences of perception characteristics contributes to finding the levers and barriers to environmental transitions and measuring cognitive co-evolutionary mechanisms. We define perception as actors' reaction to stimuli (Kahneman, 2003). Based on environmental science literature (Di Baldassarre et al., 2019; Duit et al., 2010; Gunderson and Holling, 2002), we assume that, within a SES, all components interlink to each other but at different de-

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grees (stimuli). The analysis measures to which extent actors are aware of these interlinkages (perception), why and how it associates with SES and actors characteristics, and with policy preferences. Studying SES interdependencies contribute to advance knowledge on the potential and determinants of transformative policies that accounts for complementarities and conflicts between anthropic and environmental needs.

The water sector in Geneva region is the SES under scrutiny. We define 19 different water uses as system components, corresponding to 342 possible relations among water uses. A survey of water policy actors measures the perceptions of the SES interdependencies. Three dimensions of perceptions are distinguished to disentangle the complexity of perception and governance in SES: 1) perceiving a relation, 2) the perceived intensity of the relation, and 3) the polarization of perceptions. Aggregating responses enables drawing the actors' mental map of SES interdependencies in the Geneva region water sector. We estimate the association of the three perception characteristics with actors and uses attributes to find perceptions determinants. Estimates of perceptions intensity association with policy preference for participation in collaborative governance, on the one hand, and with policy preference for policy instruments, on the other hand, enable deriving how policy perceptions could affect environmental transition implementation.

The remainder of the paper organizes as follows. Section 2 discusses the existing literature and the conceptual framework that underpins the empirical analysis. Section 3 presents the data and the empirical framework. Section 4 displays results on the variations of perceptions (4.1), their determinants (4.2), and their association with policy preferences (4.3). Section 5 discusses the results and concludes.

2 Literature review

We address environmental transition by combining three complementary fields in environmental governance: 1/ connectivity in social-ecological systems to address resource use interdependencies, 2/ perceptions in transitions to study the drivers of perceptions, and 3/ perceptions in the policy process to delineate patterns of relationships between perceptions and policy preferences.

2.1 Measuring perceived connectivity: social-ecological systems and co-evolutionary processes

Research on sustainability and transition is fundamentally about how humankind and nature interact and for what results. Human and Nature interactions form complex systems, in terms of interactions number and properties, that reveal difficult to be observed in a comprehending framework. The SES approach eases knowledge cumulation through replicating comparative analyses of complex systems and has gained importance since the 2000ies. The perspective being integrative, contributions come from environmental (Gunderson and Holling, 2002; Redman et al., 2004) and social (Hinkel et al., 2015; Ostrom, 2009) scientists. Environmental scientists emphasize that dynamic environmental models offer biased results if social phenomena are excluded, as humans and their behaviors are primary triggers of environmental changes and their non-linear patterns. For instance, hydrology of floods has been recently revitalized by endogeneizing human dynamics (Di Baldassarre et al., 2019; Nohrstedt et al., 2021). Social scientists stressed that collective action dilemmas related to natural resources and environment require singular theoretical and empirical specifications, even if commonalities with other social dilemmas exist. This statement is at the core of the field of ecological economics for instance (Costanza, 2020; Spash, 2017).

Research argues that connectivity among SES components is instrumental in shaping SES evolution (Bolognesi et al., 2018; Folke et al., 2007; Gunderson and Holling, 2002; Ingold et al., 2019). In practice, studying SES means accounting for complexity in three directions (Balland et al., 2022; Heikkila, 2017; Ostrom, 2010):

1. the inflated number of interactions among components of different natures (e.g., consumers, policy-makers, laws, habitats, and animals),
2. the multilevel embeddedness of the interactions from the local to the global (e.g., a floodplain, a large watershed, a farm, and international regulations are interconnected),
3. the multiple dimensions at stake (e.g., institutions, ecology, climate, decision-making).

Given the central place granted to environment-social interactions (connectivity), the SES perspective embraces Ecological Economics ontology (Costanza, 2020) and, consequently, gains recognition in the field. Schlüter et al. (2017) explore how to integrate six of the most developed behavioral theories in social-ecological modeling, eliciting how perceptions, evaluation, selection, and behavior, as processes, affect the state of an SES. They emphasize that perceptions are pivotal and affect outcomes depending on how limited they are, how they legitimize or not behaviors, the identification of probability of events and of dominant behavior they permit. Bolognesi and Nahrath (2020) show that ecological interdependencies generate unexpected institutional incoherencies. They indirectly limit governance efficiency and lead to institutional complexity traps. The central concept of co-evolution encompasses such complex interactions. A co-evolutionary dynamics imply multiple interactions between values, knowledge, organization, environment, and technologies (Kallis and Norgaard, 2010). In other words, complexity in SES results from and feeds co-evolutionary mechanisms.

Despite the importance of social-ecological interactions, co-evolutionary mechanisms have received little empirical attention in studying environmental transition. This gray area is particularly noticeable in the analysis of perceptions, while the latter is pivotal in explaining decision-making processes and systemic change (Kahneman, 2011). Because interactions make the SES complexity, we hypothesize that actors have limited perceptions of interdependencies within the SES (H1). We expect:

- (H1.1) significant variations in the perceptions of the interdependencies between resource uses, both in terms of the scope, i.e., number of perceived interdependencies,
- (H1.2) and of the intensity of interactions.

2.2 Perceptions and environmental transitions

Perceptions are pivotal to understanding choices and coordination because they shape the cognitive interface of individuals with the world (Kahneman, 2011; North, 2005). They are at the intersection of contextual and individual levels. In the decision-making processes, they affect the evaluation of a situation and the selection of behavioral options (North, 2005; Schlüter et al., 2017). Regarding context, culture affects perceptions and institutional design in return (Alesina and Giuliano, 2015; Aoki, 2011). For instance, the cultural difference between Maghribi (collectivist) and Genoese (individualistic) traders in the 11th and 12th shaped the institutional change and development of these two societies. At other spatial and temporal scales, research gives evidence of the effects of culture on institutions or economic outcomes, e.g., on firms organization (Aoki, 2001), on growth (Gorodnichenko and Roland, 2016), or financial sector performance (LaPorta et al., 2008).

Regarding environmental outcomes, McNeill (2001) stressed how religions and economic philosophy affect our perceptions of the environment and explain its current state. Cahen-Fourot (2020) puts forward that the characteristics of capitalisms associate with the social relations to the environment. He also emphasizes how complex this association is. Indeed, there are feedback effects: institutional design affects culture and perceptions (Alesina and Giuliano, 2015; Hodgson, 2006). In sum, perceptions of social-ecological interdependencies are an important trigger for transformative social-ecological transitions at many levels of the governance architecture (Bolognesi et al., 2018; Geels, 2010; Vatn, 2005a).

Perceptions are measurable at the individual level. Mostly, scholars focus on risks perception because it is assumed that actors will tend to change their behaviors in order to limit their risk exposure (Dohmen et al., 2011). For instance, Swiss local governments' perception of flood risk intensity is significantly associated with policy instruments adoption (Glaus et al., 2020). Counterintuitively, the authors did not find association between flood exposure and policy instruments adoption. Perception and physical exposure have different effects, stressing how pivotal perception is in decision-making. Nohrstedt et al. (2021) give support to the Glaus et al's important null-result. Carrying-out a cross-country comparison of policy changes after natural hazard events, they conclude that there is significant institutional inertia. This inertia prevents social-ecological transition and advocates for implementing specific measures dedicated to change individuals perceptions. More generally, Mathias et al. (2020) demonstrate that there is a perception threshold to achieve better social-ecological outcomes. They show that individuals characteristics and social interactions affect the likelihood to reach this threshold. Their proposed theoretical model establishes that opinion dynamics are a significant driver of ecosystem dynamics. However, perceptions are not stable over time, causing non-linearities in SES dynamics. Wheeler et al. (2021) give evidence of a feedback effect between Australian farmers' perception of climate change and the likelihood of including pro-climate measures in their production decisions. They found, as a feedback effect, production decisions affect the farmers' perception of climate change risk (i.e., pro-climate measures adoption reduces climate risk perception). It reminds that perceptions are a cognitive media intricated among components of complex systems (Aoki, 2011). In this vein, Cottet et al. (2013) give empirical evidence that visual aesthetics and trophic criteria affect individuals perceptions of wetland healthiness. Furthermore, they found that people declaring ecological knowledge has a slightly different perception than others.

Literature puts at the forefront the effects of individuals characteristics on perceptions. We thus hypothesize expertise, education and sensitivity to the environment are significant drivers of the perception of social-ecological interdependencies (H2). This general hypothesis is derived into five testable expectations. The three first ones relate to knowledge (H2.1):

- (H2.1.a) Higher knowledge in environment-related disciplines results in different perception likelihood and intensity of social-ecological interactions *vis-a-vis* of other individuals.
- (H2.1.b) The level of education is positively associated with perception likelihood and negatively with perception polarization.
- (H2.1.c) The more sensitive to environment is an individual, the higher its likelihood of perceiving the different SES interdependencies.

We also hypothesize that the current context of awareness on environmental issues affect SES perception (H2.2). Therefore, we expect:

- (H2.2.a) The youngest have higher perception likelihood and intensity of SES relations.
- (H2.2.b) The implication of environmental uses in an SES interaction increases perception likelihood and the intensity.
- (H2.2.c) Affiliation to a political or professional organization increases perception intensity and polarization.

2.3 Perceptions and policy preferences

Perceptions associate with policy preferences. They determine salient issues and policy attention contributing to set policy agenda. Institutional and policy change results from structural inertia and punctuated attention (North, 2005; Roland, 2004). Studying the allocation of budgets in

American politics, Baumgartner and Jones (2009) demonstrate that policy-making is punctuated and the punctuation is driven by policy attention. Perceptions of policy issue salience affect policy attention, therefore Glaus et al. (2020) found that perception of flood risks associate with policy change.

Considering that policy change and policy preferences relate to the regulation design, we stand on Aghion et al. (2010) and North (2005) to explicit how perception should affect policy preferences. Preference for regulation and intervention is positively related to externalities, notably because distrust leads to increased demand for regulation (Aghion et al., 2010). Empirical evidence in the case of water pollution confirms the mechanism (Pinotti, 2012). This put at the forefront the role of bounded rationality and value. Actors choose partly in regard of how they interpret the world and if they identify behaviors that are misaligned with their own beliefs. In that case, they may consider other people as opportunistic individuals, and then the demand for safeguard mechanisms to prevent negative effects from future adaptive or transaction costs increases (Bolognesi and Nahrath, 2020; North, 2005).

Perception of SES interdependencies should affect policy preferences in terms of preferences for the scope of participation in collaborative governance and the design of policy instruments to implement (H3). Complementary, we suppose the perception effect will be stronger as the perception of relation intensity strengthens and concerns environmental uses as actors perceive threats from negative externalities.

Regarding participation, Emerson et al. (2012) propose a diagnosis model for collaborative governance emphasizing the role of shared motivation (i.e., trust and legitimacy) and capacity for joint action (e.g. leadership, knowledge, resource, institutional arrangements). It posits government to be a key player in the collaborative governance of salient issues. The recent empirical literature suggests that the more complex the issue, the more extensive the participation (Bell et al., 2022). It is due to the legitimacy attributed to actors (Hui and Smith, 2022). In complex systems, such as SES, support for private actors is more likely. Trust and legitimacy are the explanation of the expectation. Private actors are perceived as the ones who hold experience and know the issue, while stakeholder groups may intervene in the participatory process to defend their self-interest mainly. State intervention should also be favored because considered to be legitimate in dealing with significant negative externalities. We expect that:

- (H3.1) preference for wider participation in collaborative governance is higher with environmental use than in the entire SES
- (H3.2) the more intense the perceived impact, the higher the preference for state intervention

A similar rationale support our expectations about policy instrument preferences. We consider higher demand for regulation corresponds to higher preference for policy stringency, limiting room for opportunistic behavior. In this regard, precautionary principle posits as one of the more stringent policy instrument (Hayden and Mahin, 2022). We expect that:

- (H3.3) the more intense the perception, the more actors favor stringent policy instruments
- (H3.4) perception of high impacts involving environmental uses associates with a preference for precautionary principle

3 Method

3.1 Data

3.1.1 Water uses: definitions and categories

The SES under scrutiny is water in the Geneva Canton. In particular, the focus is on the perceived interdependencies among water uses by decision-makers and key stakeholders. Past literature on water resources and governance has proved the relevance of the water sector to advance environmental governance understanding (Buchs et al., 2020; Cox et al., 2016; Lubell, 2013; Ostrom, 1990). For instance, water SES mix a natural resource, of varying quality and quantity, with uses of very diverse nature, e.g. cultural, environmental or economic, and with significant technical infrastructures behind or not. In the Geneva Canton, water is abundant and available from diverse and interconnected sources (Lake Geneva, the Rhône and Arve rivers, and two large groundwater systems) (Bréthaut and Pflieger, 2020). Water management has a long history in Swiss development and occupies a central position in the political agenda (Varone et al., 2013). These environmental and socio-political conditions ease the measurement of interdependencies and perceptions.

We focus on water uses because they intersect environmental and social dimensions (Pinto et al., 2022). We follow Calianno et al. (2017) defining water use as an "act of mobilization of water functions to achieve desired effect" (p. 8, authors translation). Water uses interdependencies reflect the systemic and co-evolutionary processes related to the water resource. Consequently, we have organized two focus groups on the water governance challenges with stakeholders of the water policy to identify the most significant water uses in Geneva Canton. We also rely on previous efforts in delineating water uses (Reynard et al., 2000; **?**). The nineteen selected uses delimit the scope of the SES (Table 1). The list contains human uses, i.e., final water consumption or use enabling human activities, and environmental uses, i.e., the satisfaction of ecological and hydrological functions. The list is consistent with existing studies on multiple water uses and is likely to be relevant in most water-related SES, especially in developed countries. To our knowledge, few lists of water uses exist, referring to the proposed one could significantly contribute to streamline water research, enhance comparability and accumulate knowledge.

1/Habitat	2/ Biodiversity	3/ Hydrological cycle
4/Sediments	6/ Industrial	7/ Drinking water
8/Irrigation	9/ Discharge	10/ Refreshment
11/Leisure	12/ Bathing	13/ Fishing
14/Drainage	14/ Hydroelectricity	15/ Commercial navigation
16/ Nautism	17/Hydrothermal power	18/Fire
19/ Protection against water-related damages		

Table 1: The nineteen studied water uses

3.1.2 Perceptions of a social-ecological system: a survey on the perceptions of water uses interdependencies

Perceptions are multidimensional and difficult to observe directly. Lab experiments favor causal inference but fall short in simulating complex mechanisms (Kahneman, 2003). Surveys reveal complementary and appropriate as they enable accurate identification of complex relationships, replications and comparisons over individuals and cases (Cottet et al., 2013; Douenne and Fabre, 2020; Glaus et al., 2020; Mathias et al., 2020; Nohrstedt et al., 2021; Wheeler et al., 2021). An alternative is carrying out an in-depth case study with focus groups or embedded research, which has the virtue of offering fine-grained characterization but the pitfalls of limiting replicability and comparability (Pacheco-Vega, 2020; Scolobig et al., 2012). In this research, we are interested in the perception of complexity within a SES. We focus on connectivity (use impacts) instead of components (uses), which is in line with how ecologists characterize social-ecological systems (Gunderson and Holling, 2002; Holling, 1973; Redman et al., 2004). Given our aim and considering the three methodological options, we administer an exhaustive survey of the key stakeholders to enable replication and offer a unique richness of the SES perceptions measurement (342 relations).

We question the key stakeholders of the SES on their perceptions of the impact of each use on the eighteen others . Stakeholders are affiliated to different organizations (Table 2). To ensure measuring perception, we ask people to respond intuitively, underlining we are interested in their judgment not in the search for a correct/false response (Kahneman, 2003). This approach reveals original as it assesses connectivity instead of components to reveal the systemic perception of the SES.

Groups	sent	responses	
		partial	complete
Municipalities	58	44	14
Environmental offices	107	38	24
Professional associations	58	10	5
Public organizations	12	14	4
Water company	30	18	12
Total	265	104	59
Response rate		39.24%	22.26%

Table 2: Survey respondents

Information is retrieved by a series of 342 questions asking "According to you, what is the magnitude of the influence of the [use x] on the [use y]?" From responses, we derive the variable *Perception*, which is a dummy variable coding 1 if the stakeholder responds a value, and 0 if not. We code the variable *Intensity* as a categorical variable reporting the magnitude of the impact perceived by the respondent on a 5-point Likert scale (1 being the lowest impact and 5 the highest impact). We measure the variable *Polarization* as the difference between the *Intensity* and the average *Intensity* of the relations.

3.1.3 Individuals attributes

Following bounded and situated rationality principles, we consider that individuals perceive their environment according to their own values, beliefs, information, knowledge, and computational capacities (Kahneman, 2003; North, 2005; Simon, 2000; Vatn, 2005b). We account for these attributes by asking individuals about their expertise in economics, law, geography, political sciences, ecology & biology, hydrology, engineering, or chemistry (5-point Likert scale for each discipline). We then allocate and aggregate the disciplines into two fields of expertise: social and environment. We also collect information on age (from less than 20 to upper than 65 by a 10-years range), degree of education (five categories from high-school to PhD degree), frequency of involvement in water topics (four categories: daily, weekly, monthly, yearly), affiliation to an organization with water-related activity (three types of organizations: political, professional, and others).

3.1.4 Policy preferences

We consider that the policy design depends on the perception of a policy problem (Jones and Baumgartner, 2005; Kim et al., 2022; Ostrom, 2005). We focus on policy participation and instruments, two pillar-features of any policy design (Howlett, 2019; Vatn, 2005a). We approach policy design through actors' policy preferences to clean our measurement of perception from effects related to politics and policy implementation. Actors were asked: 1) who should participate in water policy-making and 2) what policy instruments should be implemented. Responses are the degree of agreement with each proposition on a 5-points Likert scale.

Regarding participation, we ask: "According to you, what importance should be attributed to the following actors in water policy implementation?" The enumerated actors are municipalities, regional authorities, national administrations, firms with a concession on their water uses (labeled PPP for Public-Private Partnership), private sector, associations, and citizens.

Regarding policy instruments, we ask: "According to you, what importance should be attributed to the following policy instruments?" The list of instruments includes subsidies, taxes, market-based instruments, information on water uses, information on the water resource, ban, and precautionary principle. The table 3 presents the summary statistics of our outcome variables.

	Mean	SD	Min	Max	N
Perception					
Perception	0.52	0.50	0.00	1.00	25270.00
Intensity	2.84	1.51	1.00	5.00	13069.00
Polarization	-0.00	1.21	-3.52	3.72	13069.00
Participation					
Municipalities	4.08	1.08	2.00	5.00	21660.00
Regional gov.	4.69	0.72	2.00	5.00	21299.00
National gov.	4.37	0.99	1.00	5.00	21299.00
PPP	4.08	1.03	1.00	5.00	19133.00
Private	3.25	1.13	1.00	5.00	19133.00
Associations	3.51	1.06	1.00	5.00	19133.00
Citizens	3.50	1.21	1.00	5.00	19494.00
Instruments					
Subsidies	3.81	1.07	1.00	5.00	19494.00
Taxes	3.33	1.14	1.00	5.00	19494.00
Market	2.51	1.23	1.00	5.00	18411.00
Information on use	4.27	0.81	2.00	5.00	20216.00
Information on resource	4.39	0.84	1.00	5.00	20216.00
Ban	3.43	1.16	1.00	5.00	19494.00
Precautionary principle	4.04	0.97	2.00	5.00	19855.00

Table 3: Summary statistics of outcome variables

3.2 Empirical framework

3.2.1 Determinants of the perceptions of water uses interdependencies

To analyze what affects actors perception probability, intensity and polarization, we estimate the three following models:

$$Perception_{i,j,r} = \alpha + \beta_1.expertise_r + \beta_2.individuals_r + \beta_3.uses_{i,j} + controls_{i,j,r} + \epsilon \qquad (1)$$

$$Intensity_{i,j,r} = \alpha + \beta_1.expertise_r + \beta_2.individuals_r + \beta_3.uses_{i,j} + controls_{i,j,r} + \epsilon \quad (2)$$

$$Polarization_{i,j,r} = \alpha + \beta_1.expertise_r + \beta_2.individuals_r + \beta_3.uses_{i,j} + controls_{i,j,r} + \epsilon \quad (3)$$

where the perceived relation by the respondent r is determined by the use i affecting the use j. Expertise is the score obtained in social and environmental disciplines variables. Individuals comprehend individuals attributes variables, i.e., the respondent's age, educational level, frequency of relation to water and organizational affiliation. We inform the uses with two dummy variables tagging if the affecting or affected use is an environmental use (i.e., biodiversity, hydrological cycle, and habitat protection). We use the probit method to estimate the likelihood of perceiving a relation, ordered logistic method to estimate determinants of perception intensity, and OLS method to estimate determinants of actors' perception polarization. Ordered logistic estimates enable to consider that increase in the intensity perceived is non equivalent among categories, e.g., a change from 1 to 2 might represent a lower change in intensity than between 4 and 5. The robust standard error is clustered at the respondent level to avoid bias due to heteroscedasticity.

3.2.2 Relations between policy preferences and interdependencies perceptions

To observe the association of policy preferences with the perceptions of water uses interdependencies, we estimate:

$$\begin{aligned} Participation_{i,j,r} = \alpha &+ \beta_1.intensity_{i,j,r} + \beta_2.env_i + \beta_3.env_i \times intensity_{i,j,r} \\ &+ \beta_4.env_j + \beta_5.env_j \times intensity_{i,j,r} + \beta_6.env_i \times env_j \\ &+ \beta_7.env_i \times env_j \times intensity_{i,j,r} + controls_{i,j,r} + \epsilon \end{aligned} \quad (4)$$

$$\begin{aligned} Instrument_{i,j,r} = \alpha &+ \beta_1.intensity_{i,j,r} + \beta_2.env_i + \beta_3.env_i \times intensity_{i,j,r} \\ &+ \beta_4.env_j + \beta_5.env_j \times intensity_{i,j,r} + \beta_6.env_i \times env_j \\ &+ \beta_7.env_i \times env_j \times intensity_{i,j,r} + controls_{i,j,r} + \epsilon \end{aligned} \quad (5)$$

in each model i specifies the source use and j the receptor use. r relates to the respondent. We include the determinants of impact intensity perception from equation (2) to estimate the association of policy preferences with impact intensity perceptions under similar conditions of perception. It allows us to identify accurately the supposed policy-related cognitive effects. We fit the models using ordinal probit estimates and robust standard error clustered at the respondents level to avoid heteroscedasticity biases. Ordered probit estimates enable to consider that increase in preference is non equivalent among categories, e.g., a change from 1 to 2 might represent a lower change in preference than between 4 and 5.

3.2.3 Controls

Two types of controls ensure identification reliability. First, we control for the respondent professional affiliation to free estimates from noise related to group phenomena as people perceptions also depends on their social network. Second, considering the complexity of the survey, we include a continuous variable "question number" to avoid any "fatigue effect" of the survey structure to be included in our estimates. This variable allows to control for the effort required to respond the all survey, i.e., last questions are less likely to be responded which inflates non-perceptions. Variation of responses along this variable shows the "fatigue effect" is not that important in comparison to uses salience (see Appendix A).

4 Results

4.1 Perception of uses interdependencies

Figure 1 reports the number of responses signaling the perception of an impact of the the x-axis water uses on the y-axis water uses, i.e., a matrix view of the outcome variable *Perception*. On average each relation is perceived by 34 respondents with a maximum of 55 and a minimum of 26. It indicates that each single of the 342 possible relations is perceived and that some are more perceptible than others. These variations pinpoint the necessity to focus on connectivity and the systemic role of social and environmental sub-systems (Bolognesi et al., 2018; Ingold et al., 2019; Ostrom, 2009).

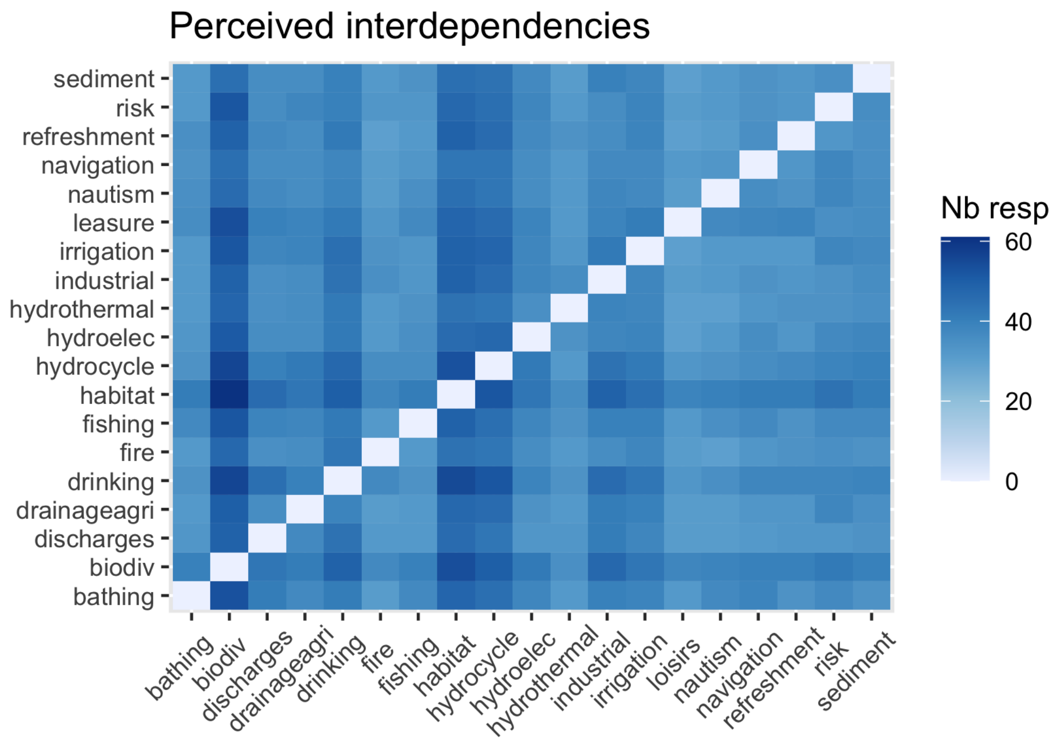


Figure 1: Water uses interdependencies perceptions
Note: Each square is the number of responses with a value to the "According to you, what is magnitude of the influence of the [use x] on the [use y]?". The darker the color, the higher the number of responses.

The perception of the SES relations varies significantly across actors and depending on the interdependencies under focus (H1.1). Some relations are much more perceivable than others while they all play a functional role in system dynamics. Relations involving environmental uses as a source (i.e., biodiversity, habitat and hydrological cycle) as well as, to a lesser extent, the traditional water uses drinking water, industrial use and irrigation are the most frequently perceived uses (Figure 2). Regarding affected uses, relations impacting on habitat and biodiversity are the most perceived ones. Drinking water, hydrological cycle and leisure uses form a second cluster. The range in the degree of perception (i.e., frequencies of responses for a given use) is way wider when considering the source of the relation. With direct implication for environmental policy-making, environmental uses are more clearly perceived when sourcing a relation than when being affected by a use.

The under-perception of how anthropic water uses affect water resource is of paramount importance. It suggests that perceived SES is narrower than its physical perimeter of interdependencies, and actrors tend to be blind to some externalities. It may affect negatively the effectiveness and coherence of the governance design. Moreover, few respondents perceive the entire system limiting the cognitive ability of framing an integrating policy. In our sample, half of the respondents perceives less than 59.64% of the existing relations.

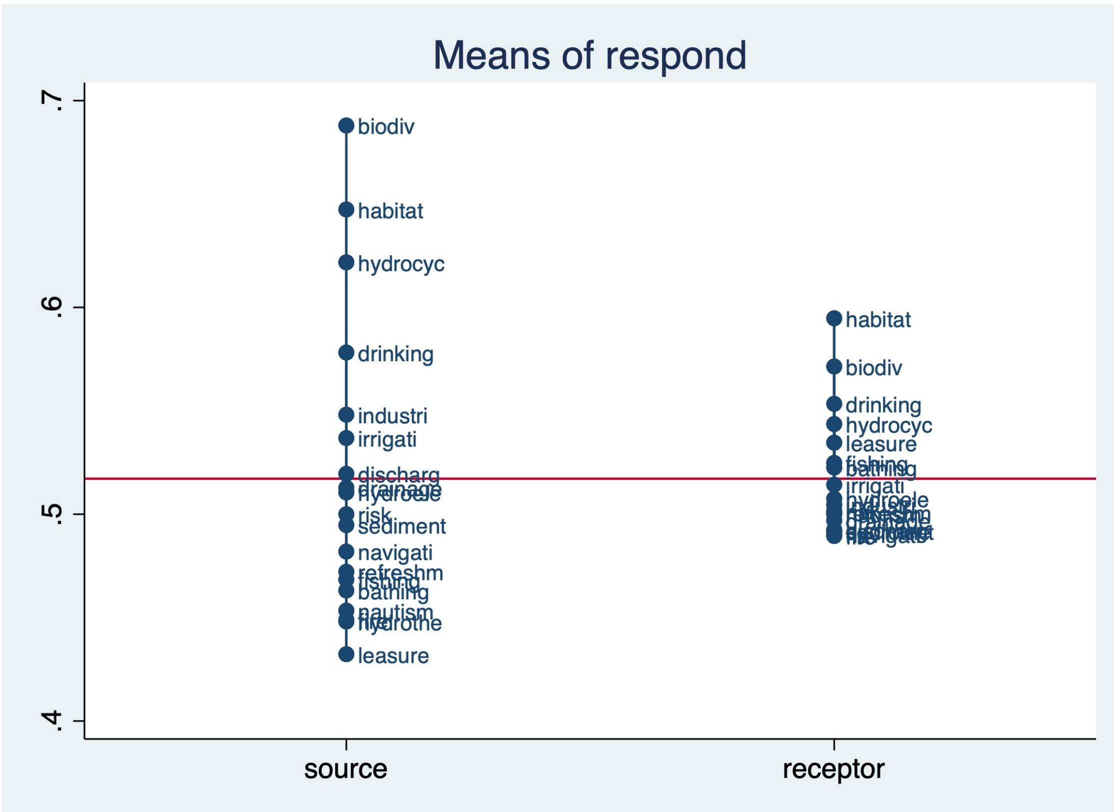


Figure 2: Probability of perception by uses as source and receptor of impacts
Note: relations are observed with the labeled uses as affecting (left, source of the relation) and affected uses (right, receptor of the relation).

The high variation in the number of perceived relations show two major traits of the Geneva water governance that are likely to occur in other SES or policy regime. First, it confirms that deep siloization and specialization of the water policy have occurred (Bolognesi and Nahrath, 2020; Kissling-Näf and Kuks, 2004; Trein and Maggetti, 2020). Even if some respondents have a comprehensive perception of the SES many have not. It contributes to reduce coordination effectiveness and increase collaboration costs (Bolognesi and Pflieger, 2019; Kim et al., 2022; Stein, 1982). Secondly, perception gaps related to interdependencies involving environmental uses favor institutional side-effects such as non-complementarities, conflicts or overlaps (Amable, 2016; Bolognesi et al., 2021; Jacobi, 2017; Mathias et al., 2020). A policy instrument designed to regulate the impact of use x (e.g., habitat) on use y (e.g., drinking water) may affect another use z (e.g., fire) in an uncoordinated way because the interdependencies between x and z is not much perceived by actors in charge of x on y. Bolognesi and Nahrath (2020) conceptualize these side-effects as transversal transaction costs. On the long run, transversal transaction costs are a primary source of governance effectiveness limitation and are likely to escalate dramatically as the SES perimeter widens.

The figure 3 shows the perception of the impact intensity of the x-axis water use on the y-axis water use, variable *Intensity*. For instance, the second square on the right from the bottom-left shows that people perceive the impact of biodiversity protection on open water swimming to be moderate. The figure looks like a mosaic, meaning the relations are not symmetric. A given use can affect more than it is itself affected, and conversely. For instance, on average respondents perceive biodiversity effects on the hydrological cycle (3.88) to be lower than the hydrological cycle effects on biodiversity (4.7). In addition, the mosaic emphasizes that impact varies among relations. Some uses are more affected and affecting than others. These two properties of the figure are of first importance. They stress the necessity of a systemic perspective. All is not equal: connections exist, vary, and some uses are central while others not; but all remains interdependent.

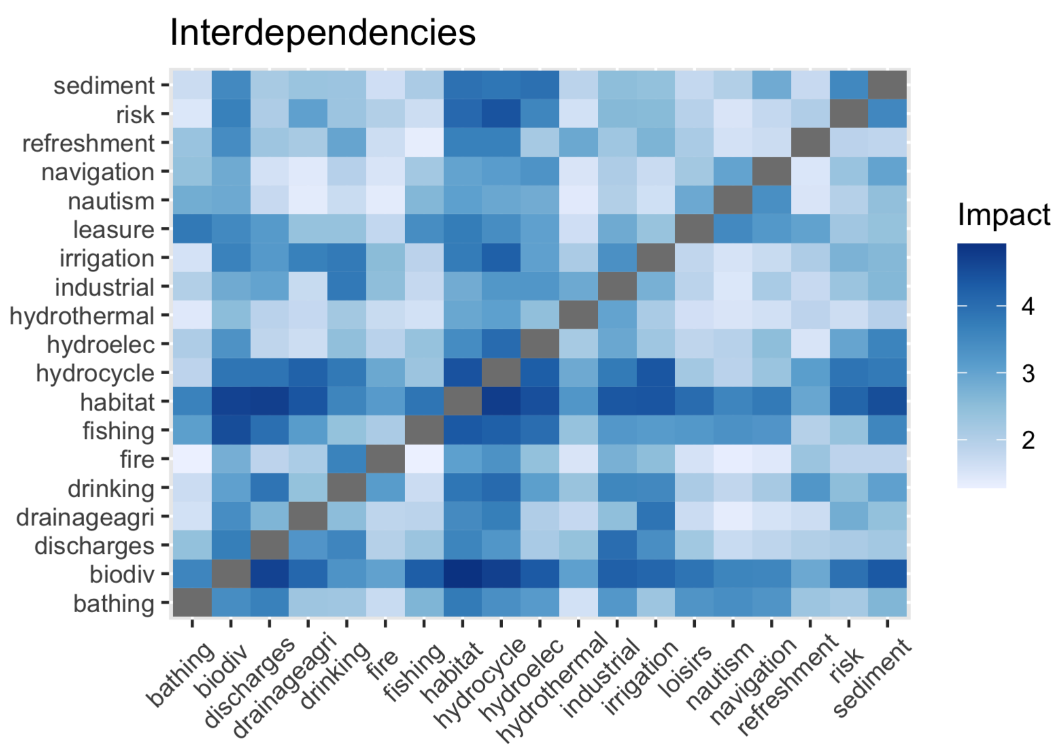


Figure 3: Average perceptions of the impact intensity among water uses.
Note: Each square is the average of responses to the question "According to you, what is magnitude of the influence of the [use x] on the [use y]?" The darker the color, the higher the average impact.

The environmental uses habitat, biodiversity, and hydrological cycle are perceived to be the most impacting and impacted in general (Figure 4). On the contrary, commercial navigation, urban refreshment, nautism, protection against fire, and hydrothermal power, which are all human uses, look isolated within the system. It reveals that a naturalistic perspective of the water cycle primarily drives the perception of uses interactions. In line with previous results on the perception scope, this result is surprising by what it does not show. Indeed, irrigation, discharge, industrial, and hydroelectric uses are not part of the most impacting uses. It is counter-intuitive as these final uses produce significant negative externalities on the rest of the system. Moreover, the hydrological cycle is perceived to be more impacting than impacted.

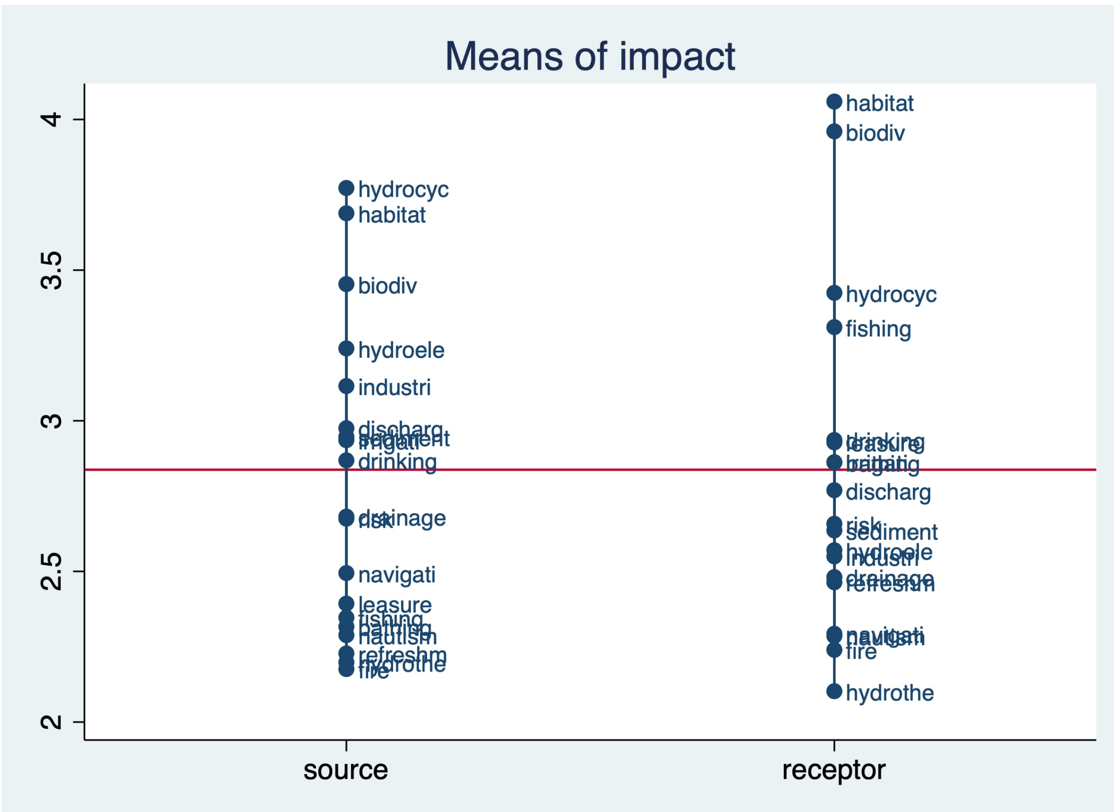


Figure 4: Average perceived intensity by uses as source and receptor of impacts
Note: relations are observed with the labeled uses as affecting (left, source of the relation) and affected uses (right, receptor of the relation).

Figure 5 reports standard deviation of the perceived impact for each relation. It brings information on how heterogeneous perceptions are. High standard deviation signifies polarized perceptions. This capital information reflects uncertainty and beliefs in the understanding of SES functioning. Such variations in uncertainty and beliefs are likely to shape coalitions and actors positions in the policy process and policy outcomes. Indeed, uncertainty complicates policy sequencing and increases the costs of policy options (Dewatripont and Roland, 1995; Dosi and Egidi, 1991; Knight, 1992; Lemoine and Traeger, 2016; ?). In addition, common beliefs structure coalitions that may conflict each other during the policy process (Lubell et al., 2020; Weible and Ingold, 2018). Results show that the polarization of the perceptions is shaped in a different manner than the perceptions of a relation and of its impact (Figure 1 and 3). They are of utmost importance as they give evidence that perception polarization follows a different logic than the perception of the SES functioning. This result stresses that the political economy of the SES is non-linearly connected to the understanding of the SES functioning. In an era in which the competition to access the resource intensifies, the map of polarization may anticipate new future water use conflicts.

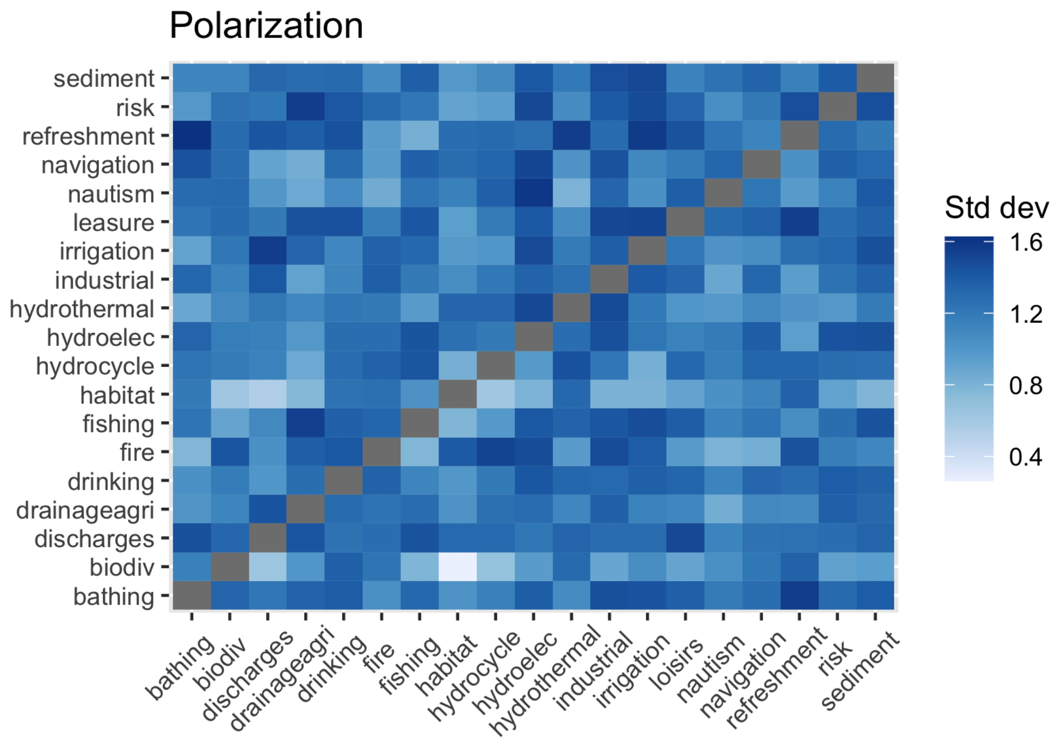


Figure 5: Standard deviation in the perception of the interdependencies of water uses.
Note: Each square is the standard deviation of responses with a value to the question According to you, what is magnitude of the influence of the [use x] on the [use y]? The darker the color, the higher the standard deviation in responses.

Variations in perception polarization look primarily driven by specific relations instead of uses (Figure 6), while perception likelihood and intensity are driven by uses. Indeed, variations in standard deviation do not change much whether uses are sources or receptors of the relations, and is relatively homogeneous among uses. The less polarized positions are more frequent when considering habitat and biodiversity. Respondents converge in how they perceive habitat is impacting or impacted. A sort of consensus also emerge around how biodiversity is affected by other uses. The uses impacts with the highest polarization degree are industrial use, hydroelectricity, drinking water and sediment management. These uses necessitates large infrastructures and catalyze conflicts in transition discourses, e.g., dams as a source of clean energy VS as a major disturbance for ecosystems, water withdrawal as a growth necessity VS sufficiency. Certainly, beliefs and economic interests within the SES play a role in explaining polarization. While the mapping of uses interdependencies perceptions reflect a naturalistic perspective of the SES, infrastructure are behind the mapping of perceptions polarization. The results indicate a dichotomy between the average perception of SES functioning and distribution of perceptions heterogeneity.

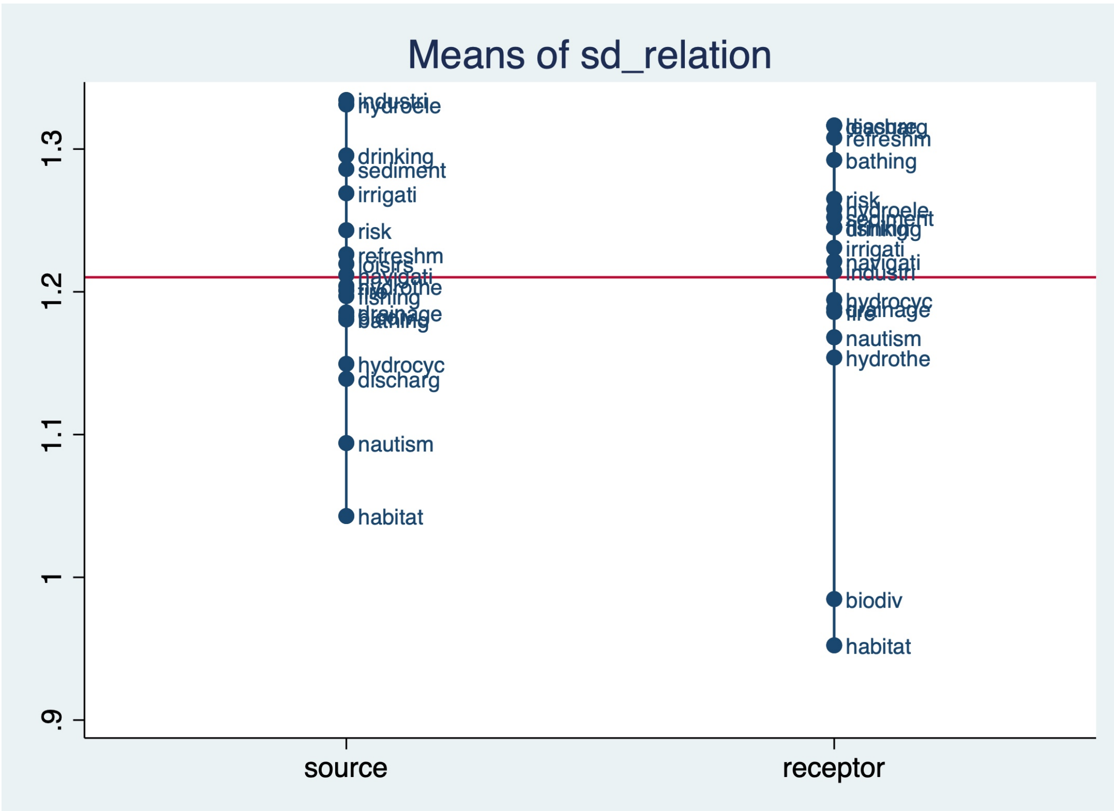


Figure 6: Average standard deviation in perceived magnitude of the relation per uses.
Note: relations are observed with the labelled uses as affecting (left, source of the relation) and affected uses (right, receptor of the relation).

4.2 Determinants of perceptions

Table 4 presents the estimates of the determinants of the perception probability, intensity and polarization (H.2). Results indicate that knowledge in environmental sciences associate with higher perception intensity of the SES interdependencies (H2.1.a), but not with the likelihood of perception. The latter is strongly and positively associated with the level of education, level that also correlates negatively with perception intensity (H.2.1.b). In addition, we found that having more frequently engagements in water-related topics or activities increases the likelihood of perceiving SES interdependencies (H2.1.c). Our results give evidence that general knowledge affects significantly perceptions and is necessary to conduct environmental transitions as it favors an extensive view of the SES perimeter and its functioning. Also, higher education degree tends to reduce perception polarization.

The presumed awareness of groups has mixed effects on perceptions. First, we tested if perceptions co-evolve with age but found no confirmatory evidence of this hypothesis (H.2.2.a). However, results confirm that the presence of an environmental use in the relation is significantly associated with perception likelihood and intensity (H2.2.b). Actors perceive the existence of externalities related to hydrological cycle, freshwater habitat and biodiversity, and they consider those externalities to be intense. The results hold whether the use receives or sources the relation. It suggests a naturalistic perception of water uses interdependencies. We observe that affiliation to a political or professional organization working on water increases perception polarization, and that the effect is greater with political affiliation (H2.2.c). It gives support to the role of group affiliation in structuring individuals positioning.

	Perception	Intensity	Polarization
Expertise			
social	0.0932**	-0.0166	-0.00553
	(0.0364)	(0.0262)	(0.0164)
environment	-0.0405	0.0441*	0.0249
	(0.0424)	(0.0250)	(0.0156)
Individuals			
age	0.00533	-0.00727	-0.00483
	(0.0158)	(0.0106)	(0.00715)
education	0.344**	-0.336*	-0.208*
	(0.172)	(0.186)	(0.115)
Frequency water	0.807***	-0.206	-0.117
	(-0.229)	(0.199)	(0.129)
Affiliation (base = other)			
Political	0.932	2.103**	1.174**
	(0.762)	(0.903)	(0.496)
Professional	0.171	1.732***	0.974***
	(-0.753)	(0.335)	(0.222)
Environmental uses			
receptor	0.216***	1.854***	0.0633
	(0.0662)	(0.103)	(0.0741)
source	0.413***	1.062***	-0.00564
	(0.110)	(0.113)	(0.0806)
Controls			
Groups	Yes	Yes	Yes
Survey structure	Yes	Yes	Yes
Constant	-3.409**		-0.604
	(-1.343)	(0.690)	(0.689)
Observations	21 660	11 163	11 163
Pseudo R2	0.166	0.097	
R-squared			0.092

SE clustered at respondent level, Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Factors of perception probability, intensity and polarization

A noticeable result is that the perception likelihood, intensity and polarization patterns of association are different. It is of particular importance as it suggests that the strategies to include a relation in people's mental map should differ from one aiming at changing the importance of the perceived relation, e.g., increasing awareness VS adjusting erroneous or extreme perceptions. It also emphasizes that perceptions crystallizes actors interests and possible conflicts. Finally, the positive association of expertise in social sciences with perception likelihood is unexpected and deserves further inquiry. A possible interpretation is that the Geneva water systems consists of many anthropic uses that may require an understanding of the socio-economic system to perceive their interconnections within the SES.

4.3 Perceptions and policy preferences for participation and instruments

Table 5 shows how the intensity of the perceptions of SES relations associates with preferences for the scope of participation in collaborative governance. Results confirm that perceiving as intense a relation involving one environmental use is positively and significantly correlated with a higher preference for the participation of private citizens in the policy process; and the participation of associations if the environmental use source the relation (H.3.1). This effect of perception of the environmental externalities on the preference for broader participation is reinforced by the fact that the correlation of having environmental use in the relation and the preference for the participation of citizens and associations is significant and negative. It stresses that perceiving the externalities reverse the relationship. Results do not provide enough evidence to confirm the hypothesis of a positive relationship between perception intensity and the preference for state intervention in general (H.3.2). Nonetheless, we found that inclusion of government from the national level is significantly more desired when an environmental use is at the origin of the relation in the SES.

We observe that environmental use being included in the perceived relationship is not a sufficient condition for increasing the preference for broader participation. Perceiving the externalities is pivotal in driving the effect of perception on preference. As a support, it appears that, when environmental uses source the relation, estimates tend to be negative and significant. Singularly, the inclusion of regional authorities is preferred if the relation includes only environmental use. The latter observation might result from these SES interdependencies necessitating local arrangements between environmental offices.

	(1) Municipalities	(2) Rgl lvl	(3) Ntl lvl	(4) PPP	(5) Private	(6) Association	(7) Citizens
intensity	-0.0198	-0.0447	0.000592	0.0220	0.0779	0.0849	-0.0153
	(-0.42)	(-1.22)	(0.01)	(0.35)	(1.51)	(1.62)	(-0.27)
Environment							
recept	-0.338	0.347*	-0.291	0.0718	-0.0883	-0.162	-0.494**
	(-1.66)	(2.25)	(-1.70)	(0.45)	(-0.57)	(-0.94)	(-2.98)
recept ×intensity	0.113	-0.0550	0.0897	-0.0154	-0.000220	0.0278	0.136**
	(1.91)	(-1.41)	(1.55)	(-0.34)	(-0.00)	(0.54)	(2.71)
source	-0.132	0.330	-0.352*	0.0370	0.0564	-0.315*	-0.482**
	(-0.90)	(1.35)	(-2.28)	(0.24)	(0.32)	(-2.13)	(-3.19)
source ×intensity	0.0464	-0.0264	0.129**	0.0103	-0.0398	0.129**	0.169***
	(0.95)	(-0.37)	(2.78)	(0.19)	(-0.59)	(2.68)	(4.34)
recept × so	-0.0594	-1.265**	-0.00965	-0.199	0.0992	-0.452	-0.547
	(-0.19)	(-2.93)	(-0.03)	(-0.56)	(0.24)	(-1.13)	(-1.46)
recept × so ×intensity	-0.0226	0.247*	-0.0580	0.0376	0.00192	0.0695	0.0594
	(-0.33)	(2.37)	(-0.70)	(0.46)	(0.02)	(0.73)	(0.67)
Control							
Expertise	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individuals	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Env. uses	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Groups	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	10875	10551	10551	10367	10387	10471	10482
R^2	0.264	0.473	0.187	0.227	0.332	0.296	0.319

t statistics in parentheses, SE clustered at respondent level
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Perception of uses interdependencies and preference for participation

Table 6 presents our results on the relationship between perception of the intensity of SES interdependencies and preferences for policy instruments. Results confirm that the perception of environmental externalities associates with the preference for policy instrument stringency (H.3.3). Preference for bans and precautionary principles are positively and significantly associated with the perceived intensity of relations involving environmental use as a source, and negatively associated when controlling for intensity. Again, the perception of the environmental externalities is pivotal in the relationship. We do not find negative associations with the less stringent policy instrument, like information-based regulation, subsidies, tax, or other market-based instruments. It suggests that these traditional instruments are not sensitive to the perception of SES interdependencies, probably because they are used in most instrument mixes.

Our results offer specific insights into the preference for the precautionary principle. We found that the preference for this specific instrument strongly depends on the perception of environmental externalities, i.e., the combination of intensity and environmental use (H.3.4). Indeed, the association is negative if it specifies only environmental use. However, when intensity is also considered (i.e., externalities are perceived), the association turns positive. The results are consistent in the three specified configurations, i.e., intensity combined to 1) environmental use as a receptor of the relation, 2) environmental use as a source of the relation, and 3) relation among environmental uses only.

	(1) subs	(2) tax	(3) market	(4) info_use	(5) info_resource	(6) ban	(7) precaution
intensity	-0.0108	-0.0513	0.0584	0.0989	0.136*	0.0633	-0.0603
	(-0.18)	(-1.06)	(1.42)	(1.63)	(1.98)	(1.29)	(-1.11)
Environment							
recept	-0.0831	-0.0795	-0.335	-0.324	-0.474*	-0.269	-0.282
	(-0.46)	(-0.37)	(-1.76)	(-1.47)	(-2.27)	(-1.52)	(-1.60)
recept × intensity	0.0304	0.0955	0.0710	0.0338	0.0561	0.0800	0.116*
	(0.59)	(1.39)	(1.49)	(0.54)	(0.87)	(1.57)	(2.32)
source	0.163	0.0307	-0.273	-0.211	-0.289	-0.435*	-0.295*
	(0.88)	(0.19)	(-1.49)	(-1.16)	(-1.68)	(-2.54)	(-2.12)
source × intensity	0.0225	0.0329	0.0439	0.0330	0.0543	0.122**	0.140**
	(0.35)	(0.55)	(0.79)	(0.50)	(0.87)	(2.71)	(3.14)
recept × so	-0.707	-0.0221	0.491	-0.932*	-1.260*	0.0434	-1.050**
	(-1.93)	(-0.06)	(1.24)	(-2.12)	(-2.52)	(0.12)	(-2.66)
recept × so × intensity	0.155	-0.0303	-0.149	0.196	0.266*	-0.0327	0.196*
	(1.87)	(-0.36)	(-1.73)	(1.89)	(2.19)	(-0.36)	(2.05)
Control							
Expertise	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individuals	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Env. uses	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Groups	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	10470	10470	10153	10530	10530	10477	10530
R^2	0.249	0.219	0.158	0.252	0.237	0.268	0.204

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Perception of uses interdependencies and policy instruments preferences

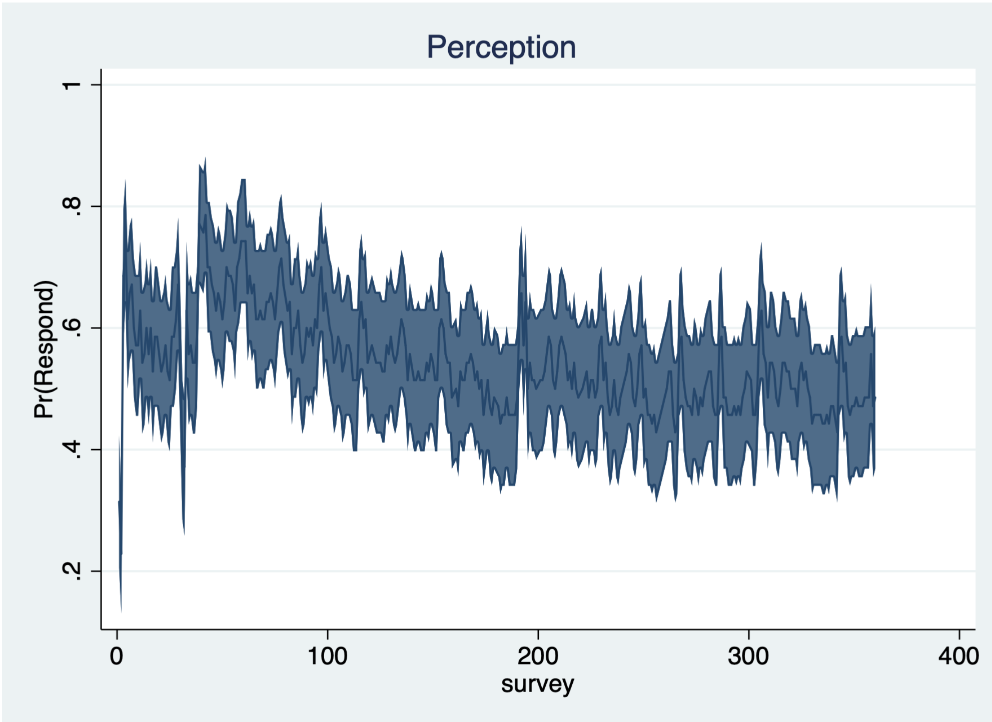
5 Discussion and conclusion

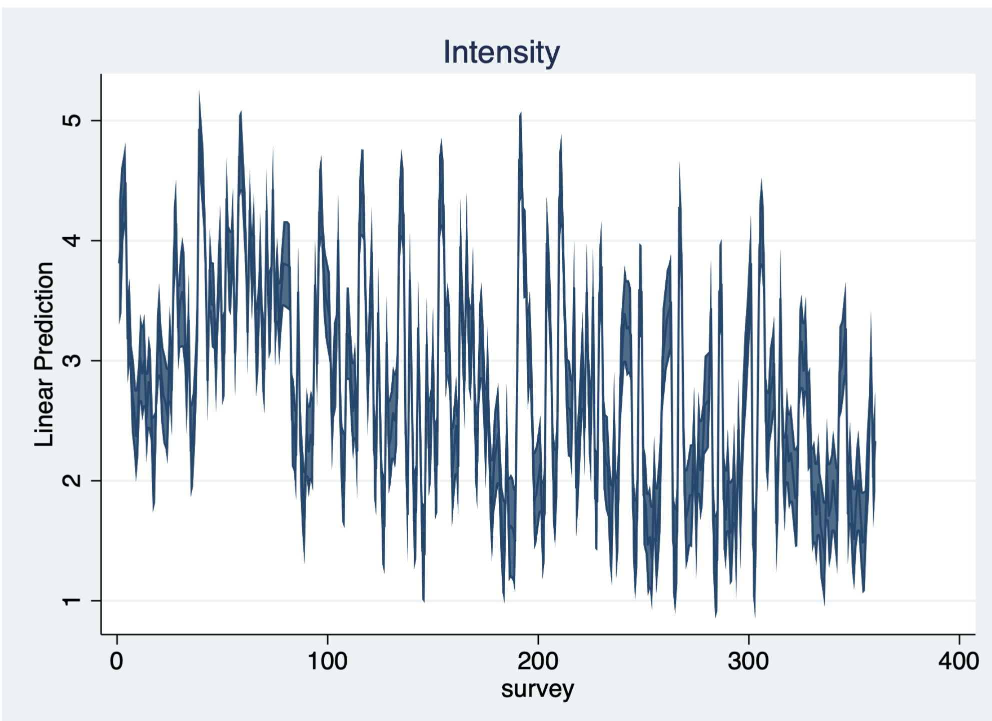
This paper provides an analysis of the perceptions of SES interdependencies, their determinants, and their effects on policy preferences. We use fine-grained measures of the likelihood, intensity, and polarization of the perceptions of water uses interdependencies by stakeholders in the Geneva region retrieved from an original survey designing a system of 342 possible water uses interactions. We provide four main results. Firstly, there are large variations of perceptions across uses and the perceptions dimensions. Secondly, the variation of perceptions likelihood and intensity depict a naturalistic perspective of water uses interdependencies, but an infrastructure-based view shapes perception polarization. Thirdly, actors' knowledge and affiliation, and water use types significantly affect the three perception dimensions through different patterns. Fourthly, the perception of environmental externalities shape policy preferences significantly.

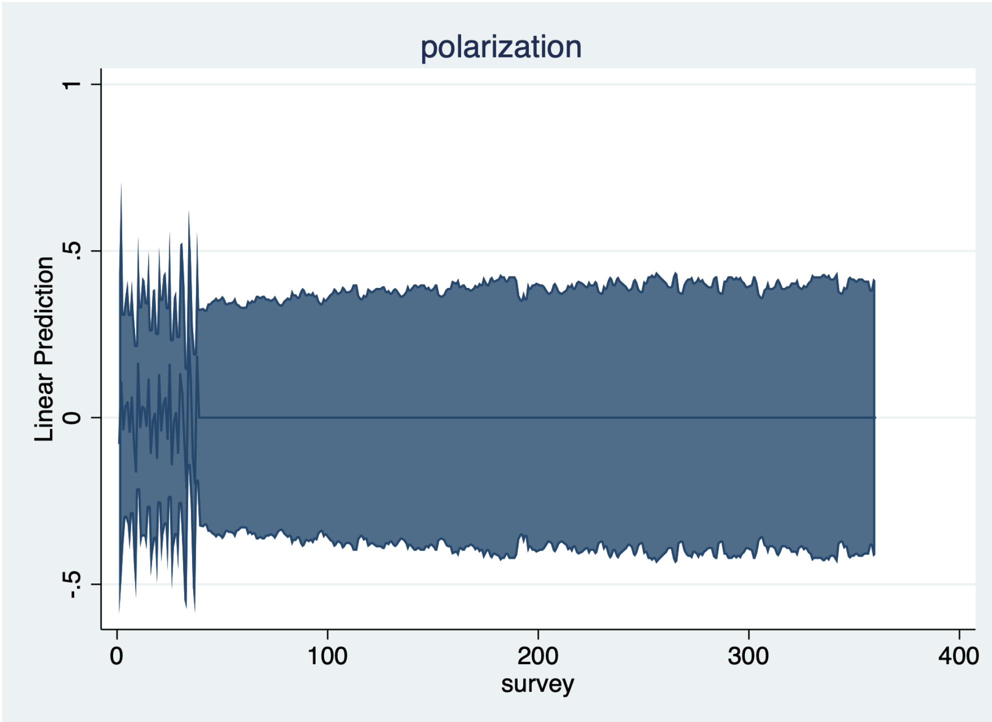
In terms of explanatory mechanisms of SES interdependencies perceptions, results indicate that the perception of the SES tends to get wider and more nuanced as knowledge and awareness increase, i.e., education degree, frequency of involvement in water-related activities and expertise in environmental sciences increase. In the same vein, we found an attention effect as relationships including environmental uses are significantly more perceived in terms of probability and intensity. If hydrological cycle, habitat or biodiversity uses source the relation, it increases by 51 % the likelihood of perception and by 189 % its perceived intensity. Actors affiliation has a large impact on the intensity and polarity of their perception, giving support to the role of political-economy factors in beliefs formation. The main explanatory mechanism linking the perceived intensity of a relation with policy preferences is the environmental externalities and demand for regulation one. We have convergent results showing that the higher he perception of an externality the higher the preference for a broader participation in collaborative governance (i.e., associations and private citizens) and for more stringent policy-instruments (i.e., bans and precautionary principle).

Our findings have important policy implications for environmental transitions. They emphasize the importance of focusing on connectivity among SES components and that perception dimensions are likely to evolve differently. It is of utmost importance to notice that the perception of the SES interdependencies is not as extensive as expected. Many relations are under-perceived, which limits the ability to frame integrated and coherent environmental policy regimes, e.g., by increasing institutional non-complementarities and collaboration risks (Bolognesi and Nahrath, 2020; Shrestha and Feiock, 2021). Similarly, misalignment of perceptions dimensions produces mixed effects on the policy-making (Weible et al., 2018). For instance, if actors agree that environmental uses are important (perception intensity), infrastructure-based uses will likely shape debates and political efforts allocation (perception polarization). This general implication emphasizes a fundamental misalignment in the water system perception. Perceptions of its functioning relate to a naturalistic perspective, while political-economy interests and divides relate to an infrastructure-based view. Further research is needed to investigate this misalignment and its consequences regarding barriers for framing and implementing transformative environmental transitions, especially has we have shown that the perception of SES interdependencies affects preference for participation and policy-instruments..

A Appendix 1: Survey fatigue effect on outcome variables






polarization
Linear Prediction
1
.5
0
-.5
0
100
200
300
400
survey

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