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THE POLITICS OF CRUSTAL FAULTS: ISSUES AND CONTROVERSIES AROUND THE SAN RAMÓN FAULT IN CHILE

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Abstract: *The seismicity of Chile is mainly controlled by large subduction zones in the Nazca and South American plates' interface, ca. 150 km from the Chilean coast, which generated the well-known M_w 9.5 Valdivia (1960) and M_w 8.8 Maule (2010) earthquakes. Besides large subduction events, less-studied crustal earthquakes can cause great destruction due to their shallow hypocentres. Local scientists have indeed paid increasing attention to crustal seismicity, especially after the recent M_w 7.0 Pichilemu (2010) and M_w 6.7 Pisagua (2014) shallow intraplate earthquakes. Although the San Ramón Fault (SRF) is one of the Chilean crustal faults with slower slip rate (ca. 0.3-0.4 mm/yr), it is by far the most popular in the media and amongst politicians. Running for ~30km along the foothills of Santiago, the capital of Chile, the SRF has recently been classified as active, becoming a 'new' hazard for nearly 2 million* santiaguinos*. Moreover, some researchers have estimated that the next occurrence of the up-to-M_w-7.5 earthquakes in the SRF, with an 8000-year recurrence, is geologically imminent (± 500 yr). In this article, we discuss the rise of a conflict around the SRF. The conflict stems from an official narrative about the hazard that the fault represents and the policy (re)actions to this knowledge. We focus on the tensions generated amongst stakeholders (academics, policymakers, privates, and civil society). The discussion includes the scientific disagreement amongst academics regarding the fault's activity and seismogenic potential, and the political need for action as the SRF hazard becomes word-of-mouth and some stakeholders start demanding disaster risk mitigation. Touching upon disaster risk reduction and urban development issues, the conflict around the SRF unveils the challenges of seismic risk governance in the context of urban and crustal faults.*

Introduction

In this article, we present the case of the San Ramón Fault (SRF), a crustal fault system in central Chile. The controversies associated with the hazard characterisation of the SRF lie within and outside academia, expanding across stakeholder groups and taking earthquakes into the political arena beyond monitoring and building codes. Involving issues of disaster risk governance (DRG), land use, urban development, and environmental protection, the conflict around the SRF is challenging the historically successful Chilean model for seismic risk reduction.

Our research is based on academic and grey literature (*i.e.*, newspaper articles, technical reports, and policy documents) and a set of 9 semi-structured qualitative interviews (McCracken, 1988). These are conducted with experts representing different stakeholder groups, namely academia (5 interviewees), public sector (3), and local communities (1). We select interviewees by combining purposeful sampling (*i.e.*, interviewees are chosen intentionally to partly represent the different stakeholders and protagonists of the conflict) and convenience sampling (*i.e.*, according

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to the availability of participants considering the COVID-19 sanitary situation and the online format of the interviews).

The article is structured in three sections. The first provides a background of Chilean seismic risk governance (SRG), explores its suitability to address the issue of urban crustal faults, and introduces the SRF. The second section describes the conflict as a chronology of research and policy shaping an *official narrative* about the SRF's hazard, which we contrast against other results that bring about scientific (and therefore policy) dissent. In the final section, we discuss how earthquake-related research intendedly and unintendedly becomes politics, partly showing the limitations of the current DRG system. Thus, the SRF case invites to explore SRG beyond damage reduction to rethink urban governance from a disaster risk reduction perspective.

Background

As one of the most seismic countries in the world, Chile learnt early in its history the need to account for earthquakes in the development of buildings and infrastructure. The origin of institutional seismic risk reduction strategies can be dated to early 1900s when the devastating 1906 Valparaíso earthquake triggered the creation of the National Seismological Service two years later. Earthquake monitoring, advocacy for seismically resistant structures, the early (1930s) adoption of legally enforced seismic design prescriptions, and their continuous improvement after each damaging event have shaped a culture of delivering seismically safe constructions. Able to incrementally learn and improve practice and regulation, Chile is nowadays recognised as one of the most seismically resilient countries in the world (Stein and Toda, 2013).

Chilean seismicity is mainly determined by large subduction zones in the interface of the Nazca and South American plates, approximately 150 km away from the Chilean coast. In the last 120 years, 82 earthquakes with moment magnitude ≥ M_w 7.0 and 13 with M_w 8.0 ≥ have struck the country. These include the trans-oceanic tsunamigenic mega-earthquakes of Vallenar 1922 (M_w 8.5), Valdivia 1960 (M_w 9.5), and Maule 2010 (M_w 8.8). As the country develops and grows in population, infrastructure, and exposed assets, the perception that only mega-earthquakes are the destructive ones is starting to change.

Besides large subduction and deep intraplate events, Chile also has less-frequent (and therefore less-studied) crustal earthquakes. Although less frequent, these events can cause great destruction due to their shallow hypocentres and proximity to populated areas. Local scientists have paid increasing attention to crustal seismicity, especially after the recent shallow intraplate earthquakes of Pichilemu 2010 (M_w 7.0) and Pisagua 2014 (M_w 6.7), respectively an aftershock and a foreshock of the subduction events of Maule 2010 (M_w 8.8) and Pisagua 2014 (M_w 8.2).

Current data suggest that slip rates of Chilean crustal faults range from 0.2 mm/yr in the volcanic forearc region to up to 7.0 mm/yr in the intra-arc region (Santibáñez *et al.*, 2019). One emblematic crustal fault is the Magallanes-Fagnano fault system (slip rate of 7.0 mm/yr), where a M_w 7.7 earthquake in Punta Arenas that killed six people in 1949. Further north, the Liquiñe-Ofqui fault system (slip rates between 4 to 25 mm/yr) runs for over 1200 km and produced a M_w 6.2 earthquake in 2007 which triggered a tsunami in the Aysén fjord that killed 10 people (Santibáñez *et al.*, 2019). Moreovoer, the Liquiñe-Ofqui fault system runs below Chile's largest hydroelectric power plant Ralco, representing an important risk to infrastructure and people in central-south Chile. However, it is the SRF, one of the faults with the slowest slip rate (~0.3 mm/yr) which is receiving most of the attention.

The San Ramón Fault

The SRF is a crustal fault system located in the foothills of Santiago, Chile's capital, demarcating the city's eastern limit in the Andes piedmont (Armijo et al., 2010). The SRF is a north-striking, west-verging, reverse fault part of the larger West Andean Thrust system. It runs in a north-south direction for ~30 km between the Mapocho (33.35°S) and Maipo (~33.6°S) rivers, with a depth of ~12 km, and is comprised of several fault segments in the order of 10 to 15 km long (Ammirati *et al.*, 2019; Armijo *et al.*, 2010; Estay *et al.*, 2016; Pérez *et al.*, 2014; Santibáñez *et al.*, 2019). The fault crosses at least six *comunas* of Santiago (Vitacura, Las Condes, La Reina, Peñalolén, La Florida, and Puente Alto) hosting nearly 2 million people in more than half a million dwellings. Recently classified as active, the SRF has become a *new* component of the city's hazardscape.

The trace of the SRF is partly visible and has been identified across Santiago's piedmont since mid-1900s. However, the fault's detailed mapping was ignored until the early 2000s when it was identified as an independent active fault capable of generating its own earthquakes (Armijo *et al.*, 2010; Easton *et al.*, 2018). Armijo *et al.* (2010) determined the SRF's slip rate in 0.13 to 0.4 mm/yr, with a long-term average slip rate of ~0.3 mm/yr. Armijo *et al.* (2010) also defined the SRF's geometry and estimated its characteristic earthquakes to be of magnitude 6.9 ≤ M_w ≤ 7.4 with a recurrence period of 2500 to 10,000 yr.

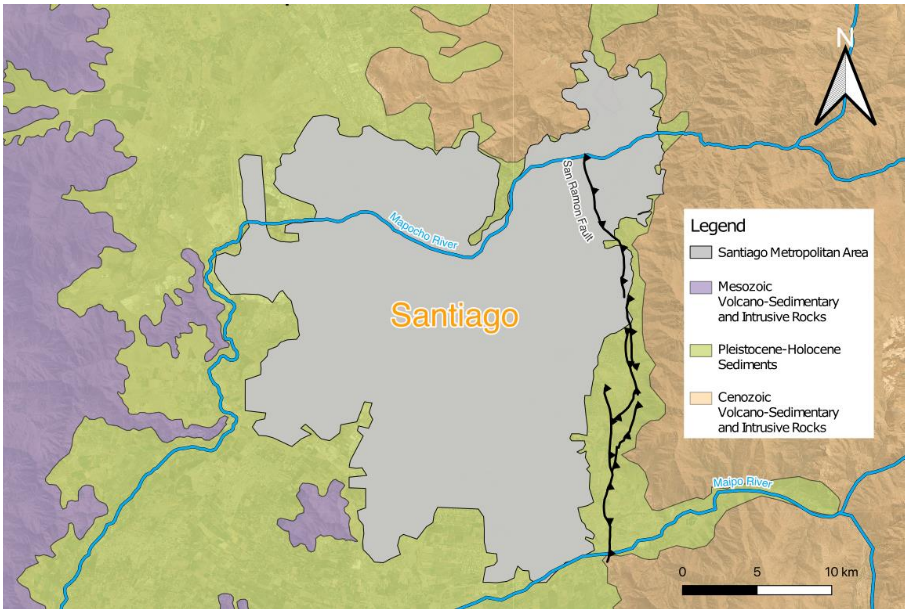

Figure 1.The San Ramón Fault (SRF) crosses Santiago's piedmont between the Mapocho and Maipo rivers, along six comunas *hosting nearly 2 million people and half a million dwellings.*

Using paleoseismological fault trenching, Vargas *et al.* (2014) documented two large earthquakes on the SRF in the last 17,000 to 19,000 yr, suggesting a recurrence of ~9000 ± 500 yr. Each of these events were estimated as M_w 7.5 and with surface displacements of ~5 m. This evidence supports that the next SRF earthquake—a thrust-type event of similar characteristics—is geologically imminent (± 500 yr). However, other evidence points to the possibility that the largest expected event could be significantly smaller. Besides along-strike segmentation, the SRF presents local kinematic complexity including normal, strike slip, and thrust faults, and potentially creeping domains. Unlike the ~M_w 7.5 event proposed by Vargas *et al.* (2014), Yáñez *et al.* (2020) predict a maximum event M_w 5.8 for normal and strike-slip events, and ≤ M_w 6.5 for thrust events. For these potential events, the expected fault slip would range between 20 and 80 cm.

The SRF's potential hazard is twofold. On one side, (crustal) earthquakes originating in the SRF have the possibility of surface rupture. This implies a high risk of building collapse as no regulation restricts urbanisation and construction on the fault's surface trace, and buildings are not designed for such effect. On the other side, an event on the SRF is expected to generate seismic intensities that exceed design levels, especially—but not exclusively—nearby the fault (Easton *et al.*, 2018; Estay *et al.*, 2016; Pérez *et al.*, 2014; Vargas *et al.*, 2014).

This information has challenged the understanding of Santiago's seismic hazard, which to the date has been mostly determined by subduction mega-thrust earthquakes occurring far from the city (Armijo *et al.*, 2010; Pérez *et al.*, 2014; Vargas *et al.*, 2014). The SRF thus arises as a challenge to business-as-usual disaster and seismic risk governance, which is fundamentally prepared and historically used to coping with large subduction events.

Chilean seismic risk governance system

Seismic risk governance (SRG) refers to how society organises to understand the seismic hazard and reduce the associated risks. Following the definition of DRG by the United Nations Office for Disaster Risk Reduction (UNDRR), SRG can be defined as the "system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee [seismic] risk reduction and related areas of policy" (UNDRR, 2023). Besides being effective in the outcomes it delivers, good governance "needs to be *transparent*, *inclusive*, *collective* and *efficient* to reduce existing disaster risks and avoid creating new ones" (UNDRR, 2023).

The Chilean approach to SRG can be characterised as reactive, technocratic, and detached from overall land use restrictions and urban planning (Rivera *et al.*, 2022, 2020). The term *reactive* refers to the conventional approach followed by SRG, which advances with a trial-and-error model. Frequent earthquakes provide empirical evidence of shortcomings in building regulation and construction practice. These are thus improved, reducing seismic risk as the next generation of infrastructure incorporates the lessons learned. Moreover, the SRG system is led by a homogeneous community of *technical experts*, mainly structural and geotechnical engineers in academia and industry, that collaborate closely to observe damage, discuss hypotheses, develop research, and implement learnings.

This technical community is self-regulated and self-convened, spurred by destructive events. Its direction and actions are set from within, pushed by research, professional experience, and commercial interests. The state interacts with the community to legally formalise building codes. Also, the state seldom raises requirements for reviewing existing or developing new codes, but in no case strategically drives SRG. Understood as a technical problem of physical damage to infrastructure, earthquakes are thus addressed through individual *technological fixes*—namely seismically designed (*safe*) structures The success of the technocratic approach has proved self-reinforcing. Consequently, it has partly hindered a more comprehensive, multi-disciplinary, inter-stakeholder understanding of earthquake-triggered disasters and approach to SRG.

The latter becomes evident as, although omnipresent, earthquakes are *detached from the territory*. Means for coping with earthquakes were formally removed from urban regulation and brought together into the first version of the seismic building code NCh433 in 1972. From then onwards, urban and seismic regulation would evolve in parallel, exacerbating the distance between the technical and the urban, reinforcing and consolidating the technocratic approach to, and narrative about, earthquakes.

The rise of a *new* seismic phenomenon such as the SRF becomes an opportunity to assess the suitability of this historically successful SRG model approach to address localised, *urban* earthquakes and seismic risk.

The San Ramón Fault's activity: history and controversies

The shaping of the official narrative

The conflict associated to the SRF stems from an *official narrative* about the hazard the fault represents for Santiago and the policies to be put forward to reduce its associated risk. The *official narrative* begins with the determination of SRF's activity and its ~0.3 mm/yr slip rate (Armijo *et al.*, 2010). Note however that this rate is significantly smaller than that of other crustal faults in Chile (e.g., the Magallanes-Fagnano fault system at 7.0 mm/yr and the Liquiñe-Ofqui fault system at 4 to 25 mm/yr).

Brought to the attention of authorities, information about the activity of the SRF triggered action from the Regional Secretariat (SEREMI) of the Ministry of Housing and Urban Planning (MINVU). SEREMI-MINVU made a bidding call for a study aiming to assess the seismic hazard associated with the SRF, with the explicit goal of incorporating it into Santiago's Metropolitan Regulatory Plan (PRMS). The study was assigned to a group led by Prof Gabriel Vargas Easton from the Faculty of Physical and Mathematical Sciences of University of Chile, and a local consultancy firm.

The project was developed between 2011 and 2012, allowing the group to dig and observe paleoseimological trenches. Results showed evidence of two earthquakes in the SRF in the past 17 to 19 thousand years, the last occurring ~8000 years ago, suggesting an earthquake recurrence of 9 ± 0.5 thousand years (Estay *et al.*, 2016; Vargas *et al.*, 2014). Researchers also estimated the cumulative displacement of these two earthquakes in 9.7 ± 1.2 m, determining that both events were similar in size and of estimated magnitudes $7.25 \leq M_w \leq 7.5$ (Vargas *et al.*, 2014). The evidence hinted that Santiago would be roughly today within the SRF's recurrence of an earthquake larger than M_w 7.0, with associated surface rupture in the order of 1 to 4 metres.

In terms of accelerations, different SRF earthquake scenarios show expected Peak Ground Accelerations (PGA) values up to 0.7 to 0.8 *g* around the fault's scarp and even exceeding 1.0 *g* at short distances to the fault. These accelerations are much higher than design code levels for Santiago (0.3 *g*) and than PGAs recorded in the city during the M_w 8.8 Maule earthquake of 2010 (~0.2 to 0.3 *g* with a peak of 0.56 *g*) (Ammirati *et al.*, 2019; Estay *et al.*, 2016; Pérez *et al.*, 2014; Vargas *et al.*, 2014).

Besides estimating dates and magnitudes of the two earthquakes observed in the trench, SEREMI-MINVU's study also recommended, amongst others, (i) restricting the use and urbanisation of a 300 m wide strip along the SRF's trace, which would be directly affected by a potential surface rupture, (ii) modifying land use regulation and the seismic design code NCh433, and (iii) postponing all construction permits and installation of critical infrastructure on the fault's surface trace meanwhile PRMS is updated (Easton *et al.*, 2018).

Although the recommendations have not been implemented, the 2012 SEREMI-MINVU's project generated evidence for further action. In May 2016, a scientific-academic roundtable was set up, which included the National Seismological Centre (CSN), CIGIDEN research centre, the Chilean Commission of Nuclear Energy, the National Geology and Mining Service (Sernageomin), and the professional associations (*Colegios*) of engineers, architects, and geologists (CEI 57, 2021). As a result of a closed-doors conversation with the Undersecretary of Interior, the group of University of Chile obtained funding to continue their SRF research. In July 2016, the National Emergency Office (ONEMI) directly assigned ~$460 million pesos (about £450,000) to a consortium between CSN and the SRF research team to monitor the seismic activity of the fault. CSN-ONEMI project run from August 2016 through March 2019 and comprised installing seven seismological stations and five Global Navigation Satellite System instruments to monitor the seismic activity and seismogenic potential of the SRF (Ammirati *et al.*, 2019; CEI 57, 2021).

With this project, 917 events of Richter local magnitude $M_L < 2.5$ were located in the Andes foothills around the SRF. These records were considered "consistent with the west Andean thrust and would be associated with the SRF *showing that the west Andean front is active*" (Ammirati *et al.*, 2019, p. 1997). Also, the SRF's length was estimated in 50 km, confirming the proposed scenario of a characteristic earthquake M_w 7.5 with surface rupture (Ammirati *et al.*, 2019).

Additional to the monitoring results and building on SEREMI-MINVU's and CSN-ONEMI's projects, a multi-disciplinary study of Santiago's urbanisation estimated that ~45% of the SRF's trace has not yet been urbanized (Easton *et al.*, 2018). This research supports recommendations given in SEREMI-MINVU's project: restricting occupation of the SRF's trace, updating PRMS and local planning instruments, and NCh433 building code.

The results of CSN-ONEMI's project were presented in April 2019 to ONEMI's authorities and a month later to the Roundtable of Seismic Risk coordinated by ONEMI as part of the National Platform for Disaster Risk Reduction. In December 2020, SEREMI-MINVU agreed to reassess the bidding call for a study that would respond to the queries about the feasibility of developing real estate projects and building in the areas around the SRF (CEI 57, 2021). However, no results came from that announcement.

Furthering this attention to the SRF, the most important and concrete policy milestones developed in 2021. On one side, crustal earthquakes became an argument for environmental protection of the Andes piedmont, eventually triggering the creation of a special inquiry commission in the Chamber of Deputies (CEI 57). On the other side, ONEMI began working on an emergency response plan for a potential earthquake in the SRF. We describe these milestones next.

Project Lomas de Peñalolén and CEI 57

The creation of CEI 57 was triggered by a conflict associated with the real estate project *Lomas de Peñalolén*, which threatened to raze part of the sclerophyll forest in the Andes piedmont. The local community has fought *Lomas* and advocated for the environmental protection and preservation of this forest for years. In late 2020, the SRF (and thus earthquakes) became part of this conflict as "a matter of chance", claims a representative of a grassroots organisation. "But not much, because the SRF is very present in the territory we inhabit and have defended. But the Fault was not our centre or one of our foci of attention for years".

Lomas consists of a gated community of 210 houses in ca. 13 ha of land in Peñalolén, east Santiago, with an investment of ~£25 million. Construction works for *Lomas* started in October 2019 and stopped almost immediately thanks to a legal protection resource presented by the local community, arguing for the protection of the piedmont forest. Together with COVID-19 sanitary restrictions, the project was paralysed until August 2020. As construction restarted, the SRF opened an alternative to contest *Lomas* when all *other* environmental arguments failed.

Local NGO *Colectivo Viento Sur* found an inconsistency in the environmental impact declaration of *Lomas*. The company behind the project acknowledged the existence and activity of the SRF after Armijo *et al.* (2010), and declared the distance of *Lomas* to the fault as 660 m. With this, *Lomas* would sit outside the 300 m strip identified in SEREMI-MINVU's 2012 study, meaning the land is, and will not be, affected by current or eventual prohibition of residential use because of the SRF (Inmobiliaria Pocuro SpA, 2017). Contacting Prof Vargas Easton in September 2020, *Viento Sur* accessed the file with the *official* fault's trace from SEREMI-MINVU's project and superimposed it with *Lomas* (Espinoza Riquelme, 2020). They found that, in reality, *Lomas* was not only 250 m away from the SRF, but also that one of the segments of the fault's trace crossed the project (Figure 2).

With this knowledge, a new protection resource against *Lomas* argued it had presented false information in the environmental declaration. The resource was presented in October 2020 by Deputy Tomás Hirsch, representative of Santiago's District #11, which encompasses 5 of the 6 comunas crossed by the SRF (all but for La Florida). Ultimately, this resource was also rejected, and construction works restarted a year later, in late 2021. Even the SRF argument was insufficient to save the forest.

Figure 2. Unlike what was declared in the environmental impact declaration (left), project Lomas de Peñalolén *actually sits on top of part of the* official *SRF's trace (right). Source: (left) Inmobiliaria Pocuro SpA (2017, p. 22); (right) Giesen (2021, p. 10).*

After this outcome, Deputy Tomás Hirsch proposed creating an inquiry commission in the Chamber of Deputies to "clarify the truth […] of whether there was falsehood and concealment of information" in *Lomas* (Espinoza Riquelme, 2020). Inquiry Commission CEI 57 was set to inquire about the acts of MINVU, ONEMI, Santiago's Regional Government, Sernageomin, and "any other pertinent authority" related to issuing construction permits and to inaction in updating PRMS considering the hazard that the SRF poses to Santiago (CEI 57, 2021, p. 1). CEI 57 met seven times between June and August 2021 with presentations by geoscientists and urban planners in the state, academia, and industry; authorities from ONEMI and SEREMI-MINVU; a representative from NGO *Observatorio Cordillera*; and the Major of Peñalolén.

CEI 57's final report was approved in October 2021. Its main conclusion is that there has been enough evidence, for sufficient time, for the government to act regarding the hazard posed by the SRF. For the Commission, the availability of "precise technical knowledge regarding the existence and risks of the SRF" is enough to develop a standard to guide urban planning and disaster risk management in Santiago (CEI 57, 2021, p. 75). "The conclusions to which we arrived is that there has been *state's negligence* for too many years. Knowing the information provided by academics and scientists, it *has not been acted upon with the urgency that corresponds*", claimed Deputy Tomás Hirsch, President of CEI 57 (GORE RM, 2021). This "passive acting without the necessary sense of urgency" (CEI 57, 2021, p. 76) mainly targets MINVU, which has the attribution to modify PRMS and had itself funded the 2012 study, remaining silent and inactive about the results for a decade.

The Commission's outcome had immediate repercussions. In November 2021, Santiago's Regional Governor issued SEREMI-MINVU with the request to start the necessary studies to modify PRMS after the SRF. The request was accepted by MINVU, which resolved to begin defining the technical standards that will allow designating the SRF and its surface trace as a risk area according to Chilean urban regulation, and therefore restricting its occupation. This action, however, has not meant much beyond the political gesture. In the first semester of 2022, MINVU opened two bidding calls to define the scope and quantify the costs of such technical studies that would be the input to modify PRMS. Both calls were desert and no further actions have been implemented through March 2023.

ONEMI's SRF emergency preparedness plan

Besides CEI 57, an important policy triggered by the attention to the fault is the development of an SRF earthquake emergency preparedness plan. This has been led by ONEMI's Sub Direction of Risk Management, in coordination with ONEMI's Metropolitan Regional Direction, since 2021. The plan is relevant for several reasons, most hinted by a representative from ONEMI:

> *"There is a great effort…because* ***it's the first plan that has scientific rigour in its justification****. It's not about 'I think that'. No, it's for real. With all the work that [Prof] Gabriel [Easton] has done, with a seismic roundtable composed of different* ***academic organisations that have validated each of the models*** *that have been done. Because also,* ***it's a very unknown hazard****.* ***We are assuming. We are also elaborating a plan only based on scenarios****. All plans are done based in scenarios, but most plans have a scenario that occurred once…* ***Here, it's a bet****. 'Ok, let's assume that the whole [SRF] activates. Let's assume that most of the effects will occur in the buffer zone of I-don't-know-what'. Therefore,* ***we have done a great effort in bringing together the academic with the technical****, and also of making the academic to understand that a series of aspects stemming from all the analyses can be very interesting,* ***but what we need is information to save lives****." (DRR expert, state, female)*

Much care has been put into the SRF plan, partly because there is no experience in dealing with such an event in Chile. Therefore, the evidence supporting the plan is purely *theoretical*. The hazard—urban crustal earthquake—is *new* in terms of the challenges it poses to disaster risk management and mostly emergency response (CEI 57, 2021). Whereas this challenge brings closer academics and disaster risk policymaking, stakeholder buy-in has proven difficult, especially across public administration:

> *"…it's hard when you ask a municipality to do a specific plan for the seismic variable of the SRF. 'Ok, and* ***what is the probability for that to occur?' 5% in the next 1000 years****. They will tell me* ***'well, no. What for?'****. And that is the answer you get at every level, not only municipalities. You go to authorities at the central level, and they say—this was said to us by an undersecretary once:* ***'why would I generate panic in the people if the probabilities for this to happen are 5% in the next 1000 years. I am not going to be responsible for this'****. But it can happen tomorrow!" (DRR expert, state, female)*

Scientific and policy dissent

In parallel to the *official narrative* backed up by CEI 57 and ONEMI's plan, research conducted by other groups also building on the work by Armijo *et al.* (2010) shows that the SRF's seismic hazard is smaller than expected (Table 1). With this information, the certainty about the urgency and the policy actions to be followed becomes contested.

Yáñez *et al.* (2020, p. 1) acknowledge that "scattered seismicity has been observed in the western flank of the Andes foothills; however, *its link with the SRF is still unclear*, despite efforts made by deploying local seismic networks (Ammirati *et al.*, 2019; Estay *et al.*, 2016; Pérez *et al.*, [2014]). […] However, these evidences are *inconclusive in terms of the most likely seismic scenario* (magnitude, slip parameters, and recurrence) since it remains unknown how much the bedrock is displaced and deformed in depth along the SRF" (Yáñez *et al.*, 2020, pp. 1–2). Although careful of explicitly associating activity to SRF, Yáñez *et al.* (2020) conclude that observed sediment deformation "presents evidences of tectonic activity, most likely associated with SRF activity as already proposed by other researchers (Ammirati *et al.*, 2019; Vargas *et al.*, 2014)" (Yáñez *et al.*, 2020, p. 17).

Although Yáñez *et al.* (2020) hint an overall agreement about the fact that the SRF is indeed active, dissent regarding the hazard it represents persists (Table 1). These results also bring a halt to policy recommendations. From a seismic code point of view, it is questionable to incorporate the SRF due to its low activity (*i.e.*, slip rate and return period). It is not a matter of considering crustal earthquakes or not as, for example, the code does consider a higher hazard level for the zone around the Magallanes-Fagnano (crustal) Fault System due to its seismicity and the evidence of the 1949 M_w 7.7 crustal earthquake of Punta Arenas. Additionally, an interviewee argues, modifying the code would not change much, as "the SRF is almost totally populated, so from a code point of view, we won't change much, because the houses are already built" (engineer, academic, male). Indeed, NCh433 modifications are not retroactive.

Reference	SRF segmentation	Expected earthquake	Surface rupture	Estimated PGA	Earthquake recurrence
Armijo *et al.* (2010)	~30 x 15 km^2	6.9 ≤ M_w ≤ 7.4	1 to 4 m	Not assessed	2500 - 10,000 yr
Vargas *et al.* (2014)	15 to 35 x 15 km^2 (single segment)	7.25 ≤ M_w ≤ 7.5	~5 m	> 1 *g* @short distances, 0.5 *g* @1 km, 0.4 *g* @5 km, 0.3 *g* @10 km from SRF	9000 ± 500 yr
Pérez *et al.* (2014)	30 x 16 km^2	M_w = 6.9	None	0.7 to 0.8 *g* around SRF scarp, ≤ 0.2 *g* in the 10 km nearby SRF	Not discussed
Estay *et al.* (2016)	At least four segments 10 to 15 km long	6.2 ≤ M_w ≤ 6.7	4 m average	≤ 0.8 *g*, > 0.5 *g* in hanging wall, > 0.3 *g* at 10 km or less from SRF scarp	~9,000 yr
Ammirati *et al.* (2019)	50 x 20 km^2	M_w = 7.46	4.9 m	0.7 ± 0.3 *g* or 0.8 ± 0.4 *g*	Not discussed
Yáñez *et al.* (2020)	Multiple segments of maximum length ~10 km	M_w ≤ 5.8 (normal and strike-slip events) M_w ≤ 6.5 (for thrust events)	20 to 80 cm	0.33 to 0.55 *g* @5km, 0.08 to 0.12 *g* @25 km	20,000 yr

Table 1. As research about the SRF advances, dissent about the hazard it represents persists. However, the official narrative only considers the worst-case scenario.

The expected high accelerations in the vicinity of SRF also justify restricting land use. However, this policy recommendation is also contested. Local poor soil conditions of northwest Santiago imply that far from the fault, seismic accelerations at least as high as those estimated nearby the fault could be expected (Ammirati *et al.*, 2019). Applying the high accelerations criterion would then also imply restricting construction in this area. However, advocacy only focuses on the SRF vicinity. "If with those arguments we don't have to build there, it is quite limiting… And if it were by considering all the crustal faults in Chile, then we better go and live in Argentina" (engineer, academic, male).

An urban advisor of a municipality crossed by the SRF acknowledges that ONEMI's initiative for emergency preparedness responds to political pressures rather than considering the (technical) matter appropriately. The SRF turns into responding to the needs for *doing something*:

> *"They say, 'look, there's a fault…from I-don't-know-when, that 8000 years ago had a movement displacing land 3.5, 5 m'...* ***So what?*** *'We have to do a 300 m strip where nothing else can be built'. But I say, 'look, if the earthquake is [magnitude] 7.5, very shallow, you reach Pudahuel with destroyed buildings. I don't think it is a 300 m strip'.* ***It's like, politically, let's do something. Let's put 300 m. But please, 300 m can be nothing!*** *…Then, it's the information, the transparency, the correct decisions, well-established, and* ***not the thing that messes with politics. Which says 'let's do something. If not, people will say we did nothing. Worst case, if an earthquake comes and everything collapses, at least we did something, we reacted'*** *" (architect, public sector, male)*

Besides large accelerations, it is the potential surface rupture that an SRF earthquake would trigger. A vertical deformation of up to 5 m would be associated to the largest estimated events in the SRF, magnitude M_w > 7.0 (Table 1). However, the hypothesis that the observed and expected slip could be the result of multiple, smaller events has not been discarded (Ammirati *et al.*, 2019; Armijo *et al.*, 2010). These smaller events would have slips in "the order of ~1 m or less" (Armijo *et al.*, 2010, p. 19), and although can cause damage, they would not reach surface rupture (Ammirati *et al.*, 2019). Estay *et al.* (2016) also constrain the capacity of surface rupture, providing evidence that it occurs in different places and therefore the potential surface rupture becomes an area rather than the SRF's surface trace line (Yáñez *et al.*, 2020). Dissent persists.

Discussion and concluding remarks

Selected research has shaped an official narrative about the SRF's activity, the hazard it represents, and the policy (re)actions to be followed. Recommendations target Santiago's planning instrument (PRMS), restricting urbanisation along (the 30 to 50 km of) the SRF, and updating the seismic design code. This line of thought has been partly developed with public funding sponsored by MINVU, ONEMI, and CSN. Additionally, Congress and the Regional Government have supported this version, demanding action to update PRMS, reassess construction permits, and improve urban risk management (CEI 57, 2021). In parallel, other research shows that the SRF's hazard is actually smaller. As the governance system is unprepared for prospecting and understanding new disaster risk issues, and incorporating science into policymaking, a conflict arises.

Science, on one side, keeps the debate alive by furthering the understanding about the SRF and highlighting the need to study crustal earthquakes. On the other side, research informs, advocates for, and triggers short- (*e.g.*, freezing construction permits) and long-term (e.g., modifying PRMS) policymaking. Additionally, earthquakes become an argument for environmental protection, leaving the scope of building codes and mingling with urban and environmental law. Altogether, the SRF case challenges business-as-usual regarding land use regulation, urban planning, disaster emergency preparedness, seismic risk reduction, and environmental management.

The symbolic outcome of CEI 57 is that a legislative, bureaucratic instance has settled a scientific dissent, configuring and consolidating an *official narrative* about the SRF, now a *legally active fault*. This sets a precedent, making the scientific dissent somehow irrelevant. CEI 57 has formally declared the political commitment and responsibilities of the Chilean state and its DRG system to address and reduce the risk associated with the SRF, eventually making the policy modifications that correspond. Regardless of the reasons, contesting this action would attempt against disaster risk reduction policy, furthering the conflict in terms of knowledge authority and validity.

The attention to the SRF has triggered positive outcomes, such as starting the conversation about Santiago's urban planning policy with a seismic risk reduction perspective and the fact that geological faults should be considered in urban environmental management. Nevertheless, the lack of established mechanisms and protocols to interpret and act upon *new* knowledge and incorporate it into policy has damaged the conflict's governance. Although the overall outcomes of the SRF case are desirable, the processes leading to them show issues in terms of recognition, representation, and participation of different stakeholders. Does the end justify the means?

The SRF conflict shows shortcomings in the DRG model: it cannot react to an event that has not yet happened, it requires expertise and involvement of communities besides seismic experts, and connects with weak urban and environmental regulation that has not accounted for earthquakes thus far. Dealing with the SRF requires a different, more holistic approach capable of treating a matter of *urban governance* with a *perspective of disaster risk management and reduction*. Such an approach should oversee both outcomes and processes simultaneously, as both of these dimensions are interrelated, equally important, and result incomplete and insufficient by themselves.

The challenge of communicating scientific results and informing policy remains as the need for better, more comprehensive ways of relating with nature persists. With the SRF, crustal earthquakes become mobilising subjects for rethinking DRG, urban policy, and engaging science into (urban) policy- and decision-making.

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