Precursors of environmental compliance in a transitional economy: an empirical investigation of monitoring and enforcement in Chile

Adolfo Uribe[1][*] and Carlos Chávez[2, 3]

[1]PSI Center for Energy and Environmental Sciences, Paul Scherrer Institute, Villigen, Switzerland, [2]Escuela de Ingeniería Comercial, Facultad de Economía y Negocios, Universidad de Talca, Talca, Chile and [3]Interdisciplinary Center for Aquaculture Research (INCAR), Concepción, Chile

[*]Corresponding author. E-mail: adolfo.uribe-poblete@psi.ch
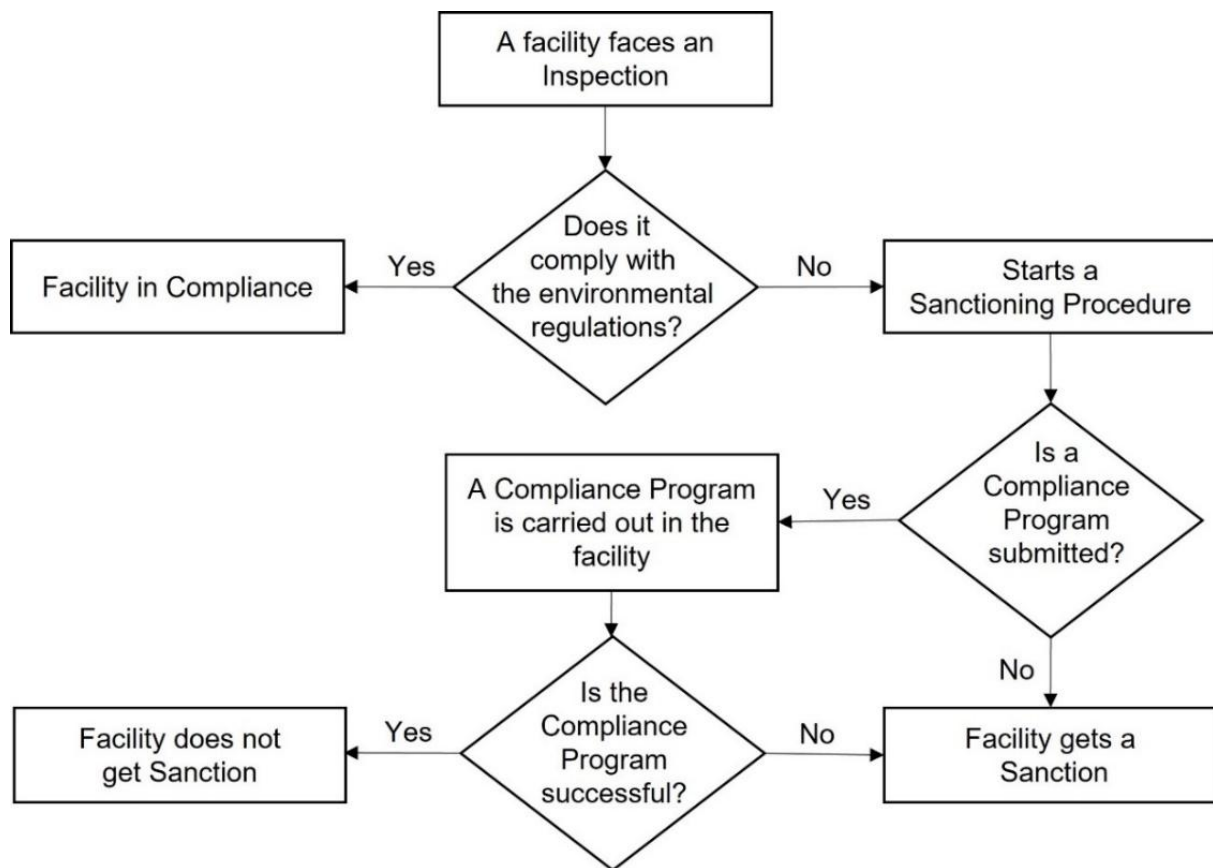
ONLINE APPENDIX

Figure A1. Monitoring and enforcement process of environmental regulations in Chile.

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes: Figure A1 shows the monitoring and enforcement process conducted by the SMA to ensure compliance with environmental permits across facilities that may hold multiple permits. According to SMA, 83% of facilities have only one environmental permit, 15% have between two and five environmental permits, and 2% have more than six environmental permits (SMA, 2018). For illustrative purposes, consider the "Central Tocopilla" power plant (Details in Spanish at https://snifa.sma.gob.cl/UnidadFiscalizable/Ficha/814), which began operations in 1998, was issued five environmental permits as new stages or regulations were implemented over time. These permits detail the requirements to meet national emission standards and act as a 'recipe' for environmental protection, though they rely on information self-reported by firms during the permitting process. As a result, they are often heterogeneous and have faced criticism for delays in processing and asymmetries in implementation (OECD, 2024), along with calls for increased public participation (ECLAC, 2022). Despite their heterogeneous nature, the common element across all facilities is that the SMA ensures compliance with these environmental permits.
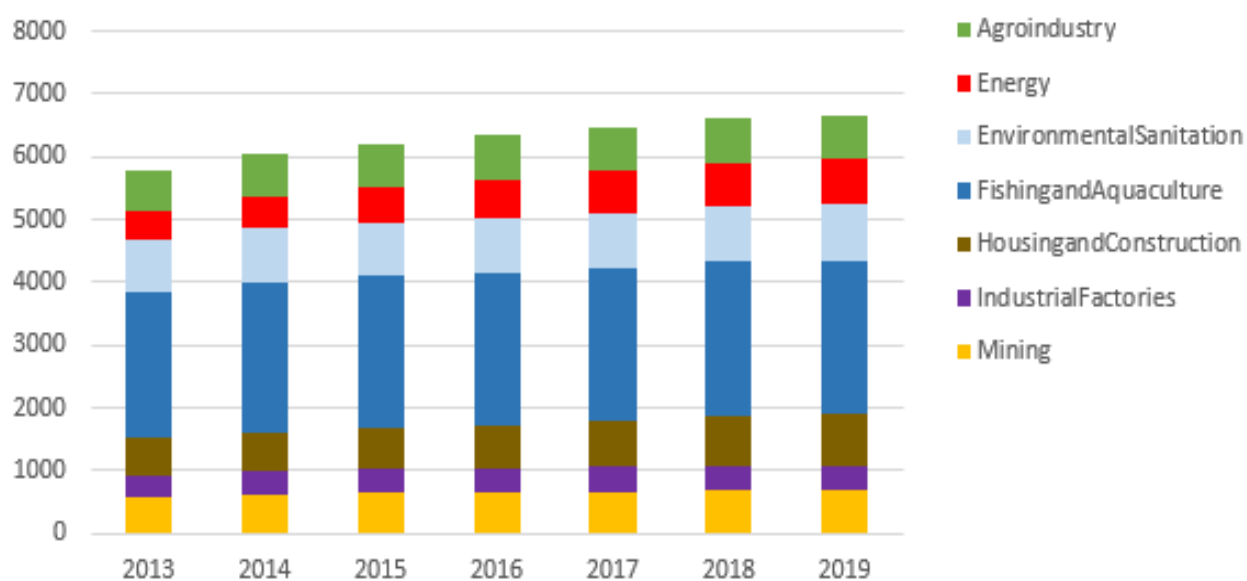
Figure A2. Number of facilities by sector per year, from 2013 to 2019.

Source: Own elaboration based on National Environmental Inspection Information System information.
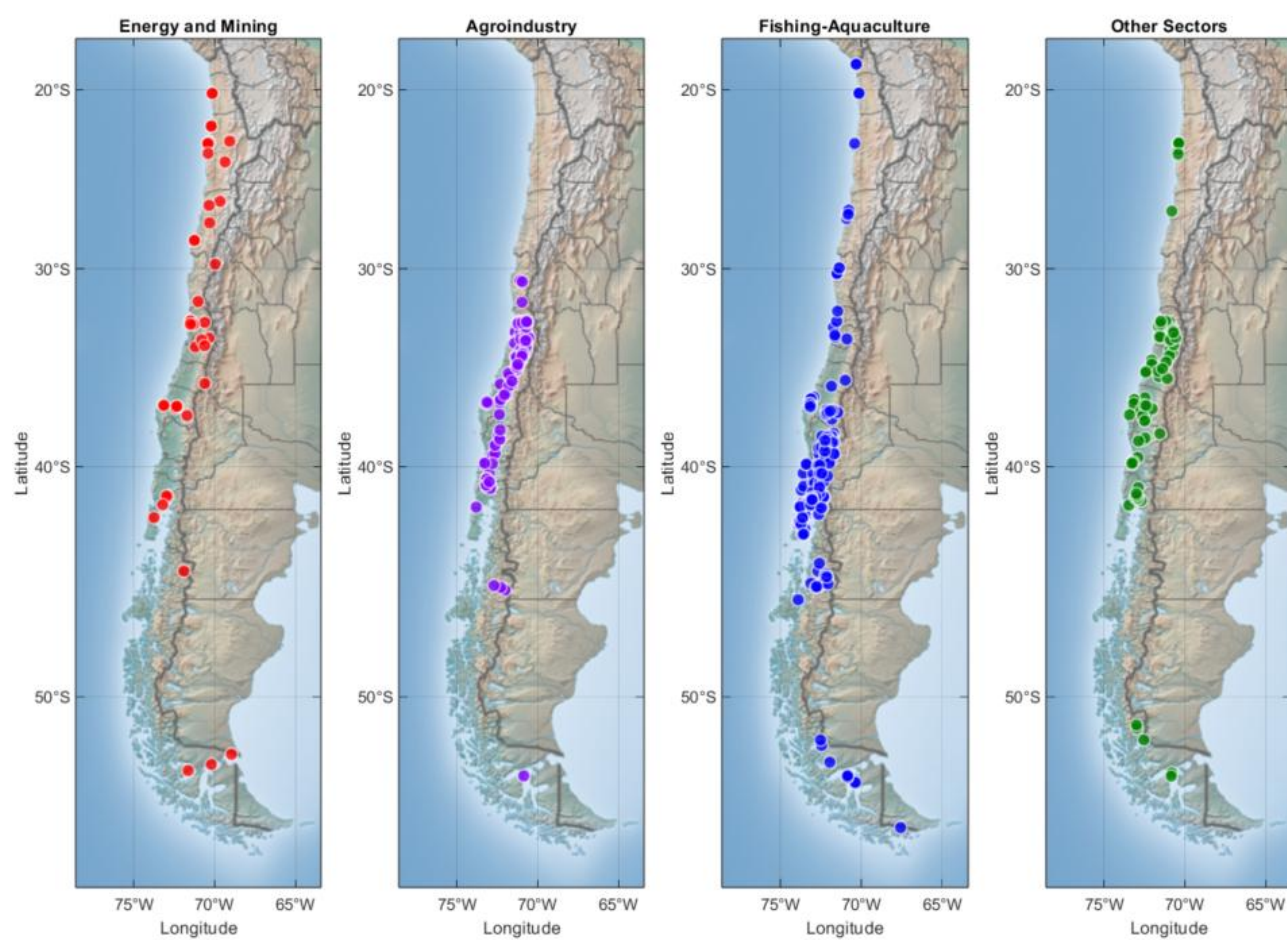
Figure A3. Facilities across Chile.

Source: Own elaboration based on National Environmental Inspection Information System information.

Figure A4. Number of facilities by size from 2013 to 2019.

Source: Own elaboration based on National Environmental Inspection Information System information.

Figure A5. Number of facilities by zone from 2013 to 2019.

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes: NGR stands for Norte Grande (Far North) zone, NCH stands for Norte Chico (Near North), CEN stands for Centro (Central) zone, CES stands for Centro Sur (Central South) zone, and SUR stands for Sur (South).
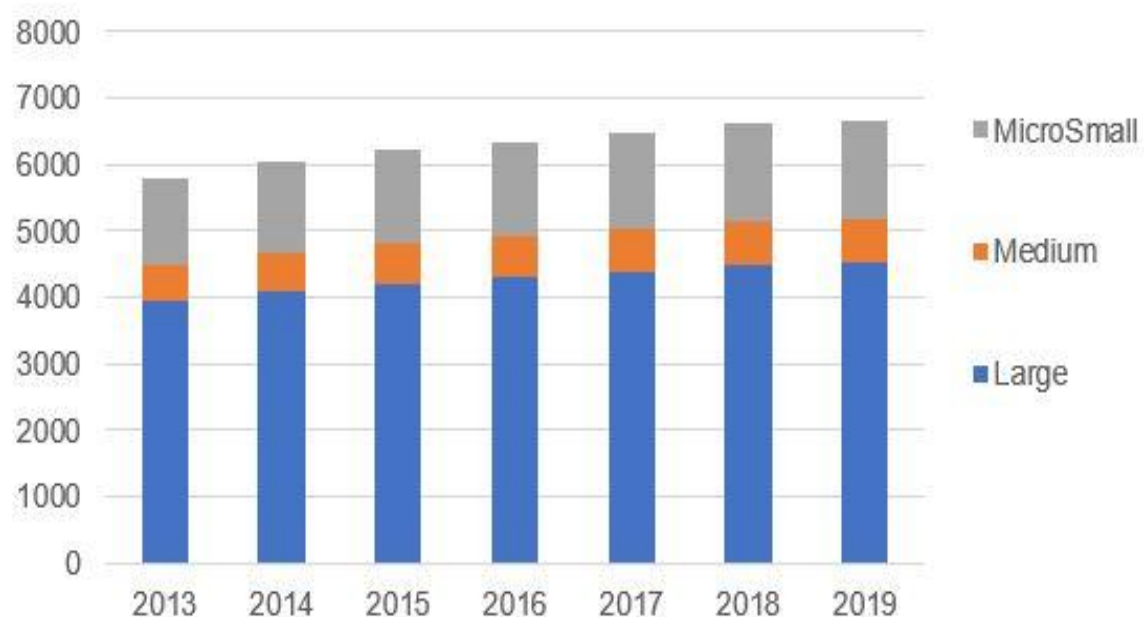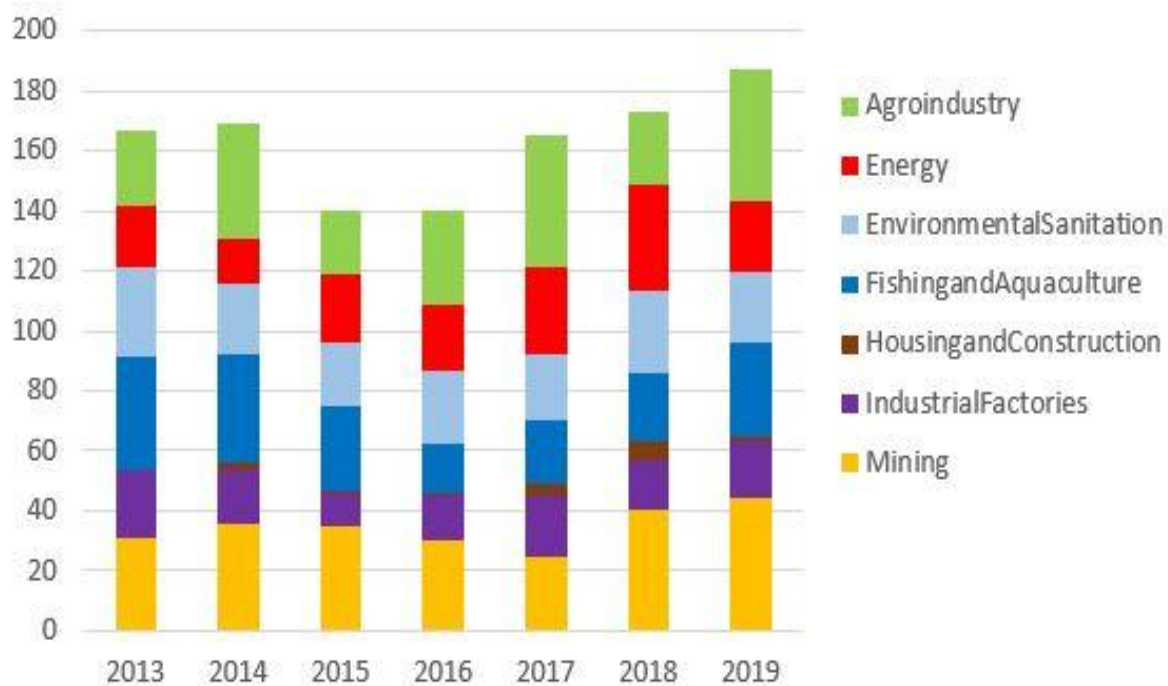
Figure A6. Number of facilities inspected per year.

Source: Own elaboration based on National Environmental Inspection Information System information.
Note: We count the number of facilities that faced at least one inspection by sector from 2013 to 2019.
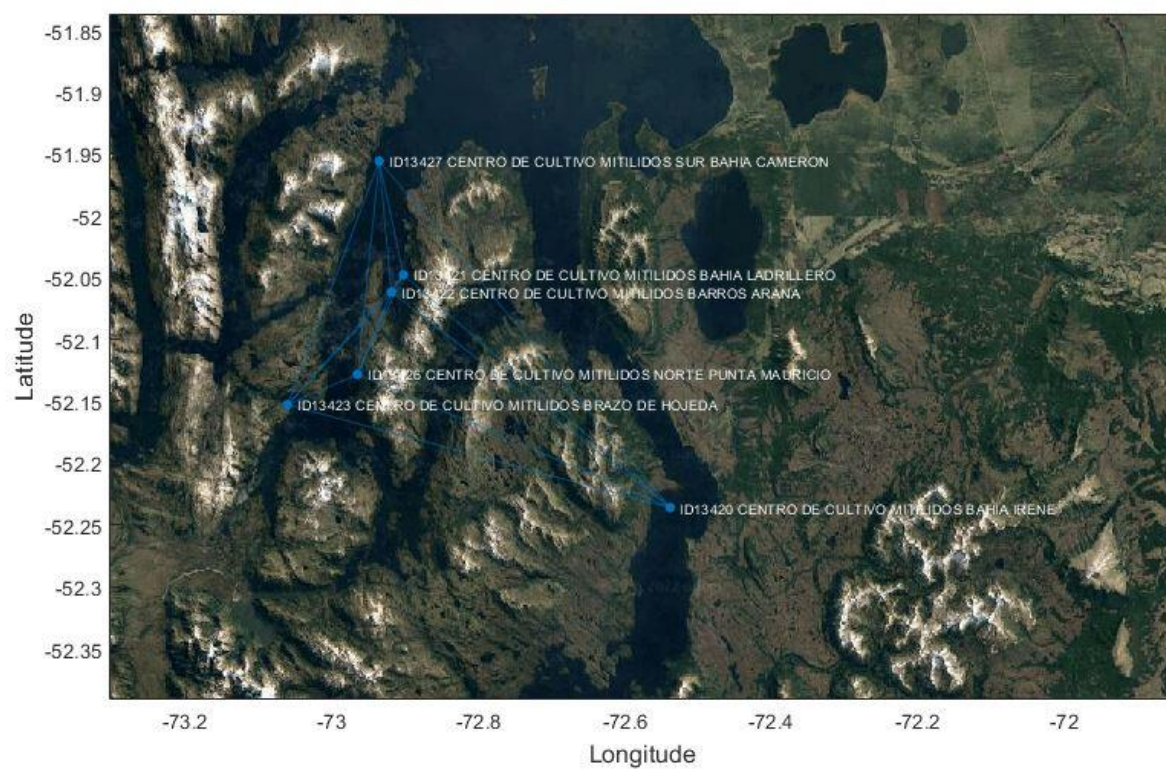
Figure A7. Facilities with same owner in fishing–aquaculture sector.

Source: Own elaboration based on National Environmental Inspection Information System information.
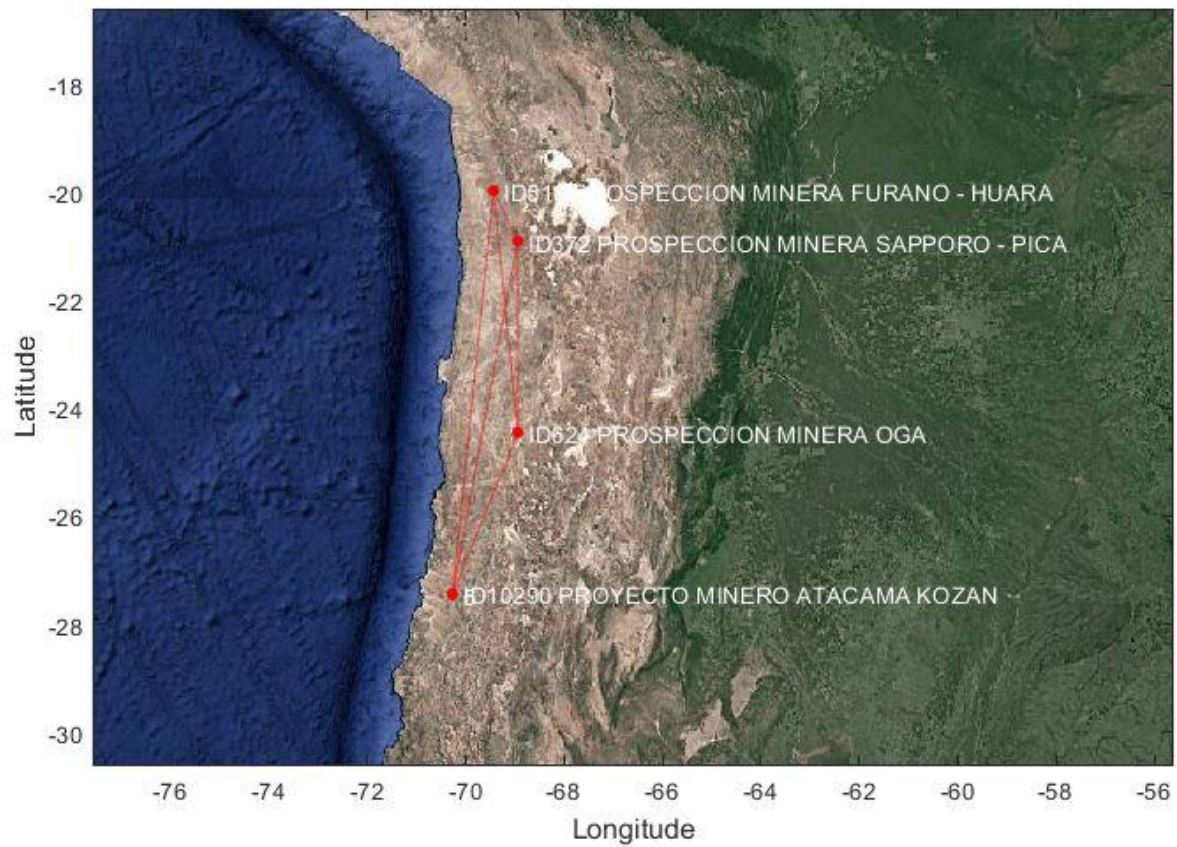
Figure A8. Facilities with same owner in mining sector.

Source: Own elaboration based on National Environmental Inspection Information System information.

Figure A9. Budget of SMA in millions of nominal pesos ($Ch).

Source: Own elaboration based on National Environmental Inspection Information System information.

Figure A10. Number of inspectors and employees at SMA from 2013 to 2019.

Source: Own elaboration based on National Environmental Inspection Information System information.

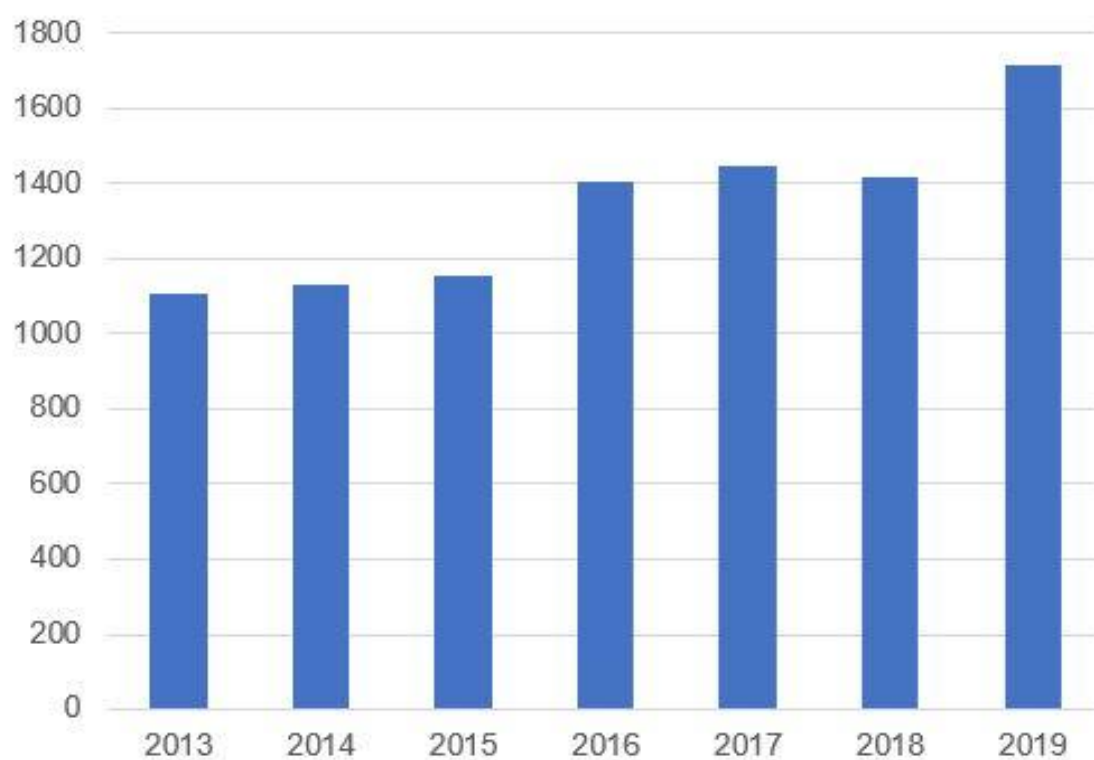**Table A1.** Number of facilities by size and sector included in this study

	Micro and Small	Medium	Large	Total
Agroindustry	152	77	487	716
Energy	125	87	494	706
Environmental Sanitation	176	92	625	893
Fishing–Aquaculture	673	233	1553	2,459
Housing–Construction	154	74	578	806
Industrial factories	71	35	301	407
Mining	131	58	494	683
Total	1,482	656	4,532	6,670

Source: Own elaboration based on National Environmental Inspection Information System information.

Table A2. Number of facilities and proportion that are inspected by sector per year

Sectors		Years						
		2013	2014	2015	2016	2017	2018	2019
Agroindustry	Num. Facilities [a]	657	672	683	692	702	712	716
	Inspected Facilities [b]	25	38	21	31	44	24	44
	Proportion [c]	3.8%	5.7%	3.1%	4.5%	6.3%	3.4%	6.1%
Energy	Num. Facilities	446	506	569	612	646	684	706
	Inspected Facilities	21	15	23	22	29	36	23
	Proportion	4.7%	3.0%	4.0%	3.6%	4.5%	5.3%	3.3%
Environmental Sanitation	Num. Facilities	833	846	860	872	880	890	893
	Inspected Facilities	30	24	21	25	22	27	24
	Proportion	3.6%	2.8%	2.4%	2.9%	2.5%	3.0%	2.7%
Fishing–Aquaculture	Num. Facilities	2,322	2,386	2,420	2,439	2,449	2,454	2,459
	Inspected Facilities	37	36	28	16	21	23	31
	Proportion	1.6%	1.5%	1.2%	0.7%	0.9%	0.9%	1.3%
Housing–Construction	Num. Facilities	604	623	646	681	728	781	806
	Inspected Facilities	0	2	1	1	4	6	2
	Proportion	0.0%	0.3%	0.2%	0.1%	0.5%	0.8%	0.2%
Industrial factories	Num. Facilities	364	384	391	393	399	406	407
	Inspected Facilities	23	18	11	15	20	17	19
	Proportion	6.3%	4.7%	2.8%	3.8%	5.0%	4.2%	4.7%
Mining	Num. Facilities	566	613	640	652	661	679	683
	Inspected Facilities	31	36	35	30	25	40	44
	Proportion	5.5%	5.9%	5.5%	4.6%	3.8%	5.9%	6.4%
Total	Num. Facilities	5,792	6,030	6,209	6,341	6,465	6,606	6,670
	Inspected Facilities	167	169	140	140	165	173	187
	Proportion	2.9%	2.8%	2.3%	2.2%	2.6%	2.6%	2.8%

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes:
[a] Num. Facilities shows the number of facilities per sector included in our study for each year.
[b] Inspected Facilities shows the number of different facilities inspected each year. If a facility is inspected more than once during the same year, it is counted only once in that year.
[c] Proportion is the product from *(Inspected Facilities) *100 / (Num. Facilities)*.

Table A3. Inspections and compliance outcomes by sector during 2013–2019

Sectors	Inspections [a] (1)	Inspections in Compliance [b] (2)	Inspections in Non-Compliance [c] (3)
Agroindustry	227	124 (55%)	103 (45%)
Energy	169	108 (64%)	61 (36%)
Environmental Sanitation	173	84 (49%)	89 (51%)
Fishing–Aquaculture	192	103 (54%)	89 (46%)
Housing–Construction	16	5 (31%)	11 (69%)
Industrial factories	123	72 (59%)	51 (41%)
Mining	241	136 (56%)	105 (44%)
Total	1,141	632 (55%)	509 (45%)

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes:
[a] Inspections in column 1 shows the total number of inspections in each sector during the 2013–2019 period.
[b] Inspections in Compliance in column 2 shows the number of inspections that found facilities in compliance in each sector.
[c] Inspections in Non-Compliance in column 3 shows the number of inspections that found facilities in non-compliance in each sector.
In parentheses are the proportions in each status, with base the column 1. In this table *Inspections = Inspections in Compliance + Inspections in Non-Compliance.*

Table A4. Number of fines, aggregate number of fines, and average fines (US$) by sector during 2013–2019

Sectors	Num. of fines (1)	Aggregate amount of fines (in 1,000 US$) (2)	Average fine (in 1,000 US$) (3)
Agroindustry	30	4,704.1	156.8
Energy	11	11,634.8	1,057.7
Environmental Sanitation	14	3,028.3	216.3
Fishing–Aquaculture	13	5,546.8	426.7
Housing–Construction	1	99.5	99.5
Industrial factories	14	2,102.3	150.2
Mining	21	56,582.6	2,694.4
Total	104	83,698.4	804.8

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes: We consider facilities that have completed a sanction procedure and received a fine from the SMA. Each fine may account for multiple infractions of varying severity levels.
Average Fine = Sum of Fine / Num. of Fines.

Table A5. Number of infractions by severity of infractions and sector during 2013–2019

Sectors	Num. of fines	Av. fine (in 1,000 US$)	Total num. infractions	Num. infractions Severity Low	Num. infractions Severity Middle	Num. infractions Severity High
	(1)	(2)	(3)	(4)	(5)	(6)
Agroindustry	30	156.8	113	87 (77%)	25 (22%)	1 (1%)
Energy	11	1,057.7	44	25 (57%)	14 (32%)	5 (11%)
Environmental Sanitation	14	216.3	112	61 (54%)	51 (46%)	0 (-)
Fishing–Aquaculture	13	426.7	97	85 (88%)	12 (12%)	0 (-)
Housing–Construction	1	99.5	1	0 (-)	0 (-)	1 (100%)
Industrial factories	14	150.2	78	57 (73%)	20 (26%)	1 (1%)
Mining	21	2,694.4	153	71 (46%)	73 (48%)	9 (6%)
Total	104	804.8	598	386 (65%)	195 (33%)	17 (3%)

Source: Own elaboration based on National Environmental Inspection Information System information.
Notes:
[a] We consider facilities that have completed a sanction procedure. A facility found to be non-compliant may face a procedure that considers multiple infractions of varying severity levels within the same process.
[b] In parentheses are the proportions of type of infractions by severity, with base the column 3. In this table *Total num. infractions = Num. infractions Severity Low + Num. infractions Severity Middle + Num. infractions Severity High.*
[c] The SMA classifies infractions into three severity levels: high, medium, and low, as defined by Law Num. 20,417. High-severity infractions involve irreversible environmental damage, severe public health impacts, or intentional obstruction of regulatory goals, such as providing false information or bypassing the Environmental Impact Assessment System (SEIA). Medium-severity infractions include reparable environmental damage, public health risks, or non-compliance with measures to mitigate a project's adverse effects, such as not implementing urgent corrective actions imposed by the SMA or committing repeated minor violations. Low-severity infractions cover violations of mandatory provisions without significant impact, such as delays in submitting required reports. This classification ensures fines correspond to the infraction's severity and potential impact.

Table A6. Compliance program presented by sector during 2013–2019

Sectors and Years	2013	2014	2015	2016	2017	2018	2019	Total
Agroindustry	2	5	23	22	14	8	8	82
Energy	5	9	5	5	4	3	9	40
Environmental								40
Sanitation	1		9	6	7	9	8	
Fishing–Aquaculture	6	9	11	16	7	6	7	62
Housing–Construction	1	3	5	8	1	5	10	33
Industrial factories	1	4	8	9	4	8	9	43
Mining	5	4	7	12	8	11	7	54
Total	21	34	68	78	45	50	58	354

Source: Own elaboration based on National Environmental Inspection Information System information.

Table A7. Coefficient estimates Logit model for submitting a Compliance Program

Variables	Compliance Program
Predicted probability	0.781
Sectors (base: Fishing–Aquaculture)	
Agroindustry	-0.207
	(0.378)
Energy	0.187
	(0.496)
Environmental Sanitation	0.345
	(0.419)
Housing–Construction	-
Mining	-0.539
	(0.434)
Industrial factories	-0.487
	(0.424)
Size (base: Medium)	
Micro and Small	-1.198
	(0.370)
Large	-0.168
	(0.251)
Macrozone (base: South)	
Norte Grande (Far North)	0.224
	(0.476)
Norte Chico (Near North)	0.0834
	(0.525)
Centro (Central)	-0.390
	(0.460)
Centro Sur (Central South)	-0.950
	(0.440)
Age	-0.0128
	(0.0242)
Log Poverty	0.367
	(0.265)
Log Density	0.0421
	(0.0710)
Num. infractions – severity low	0.0323
	(0.0355)
Num. infractions – severity middle	-0.00799
	(0.0514)
Num. infractions – severity high	0.491
	(0.350)
Relapse	0.361
	(0.778)
Complaint	-0.282

	(0.267)
Year (base: 2013)	
2014	0.353
	(0.283)
2015	0.693
	(0.352)
2016	0.282
	(0.417)
2017	-
2018	-
2019	0.789
	(0.501)
Constant	0.405
	(0.832)
Observations	199

Note: Standard errors in parentheses.

Table A8. Summary statistics

A. Summary statistics main variables

Variable (Panel Model)	Obs	Mean	Std. dev.	Min	Max
Inspection	44,113	0.026	0.159	0	1
Compliance	2,873	0.7	0.458	0	1
AnyViolation_3y	44,113	0.032	0.175	0	1
Fined_3y	44,113	0.004	0.061	0	1
Compliance Program	44,113	0.018	0.133	0	1
Age	44,113	15.811	5.05	3	30
Prioritized Area	44,113	0.272	0.445	0	1
Log Poverty	44,113	2.342	0.704	-2.698	4.089
Log Density	44,113	3.176	2.778	-9.21	9.766
Log Budget per Facility	44,113	-1.947	0.858	-3.279	0.433
Fined_Spillover_Comune_3year	44,113	0.128	0.334	0	1
Fined_Spillover_Sector_3year	44,113	0.741	0.438	0	1
Fined_Spillover_Comune&Sector3year	44,113	0.055	0.227	0	1
Fined_ Spillover_SameOwner_3year	44,113	0.012	0.111	0	1

Variable (Cross Section Model)	Obs	Mean	Std. dev.	Min	Max
Fine 1000US	104	804.792	1,944.346	.815	12,023.466
Num Infractions	104	5.75	6.388	1	50
Num LowInfraction	104	3.712	5.565	0	50
Num MiddleInfraction	104	1.875	2.557	0	12
Num HighInfraction	104	.163	0.593	0	5
Relapse	104	.048	0.215	0	1

B. Summary statistics facilities characteristics

Size	Freq.	Per cent	Cum.
MicroSmall	1,482	22.22	22.22
Medium	656	9.84	32.05
Large	4,532	67.95	100.00
Total	6,670	100.00	

Sector	Freq.	Per cent	Cum.
Agroindustry	716	10.73	10.73
Energy	706	10.58	21.32
Environmental Sanitation	893	13.39	34.71
Fishing and Aquaculture	2,459	36.87	71.57
Housing and Construction	806	12.08	83.66
Mining	683	10.24	93.90
Industrial factories	407	6.10	100.00
Total	6,670	100.00	

Macrozone	Freq.	Per cent	Cum.
Norte Grande (Far North)	479	7.18	7.18
Norte Chico (Near North)	468	7.02	14.20
Centro (Central)	1,642	24.62	38.82
Centro Sur (Central South)	1,279	19.18	57.99
Sur (South)	2,802	42.01	100.00
Total	6,670	100.00	

Source: Own elaboration based on National Environmental Inspection Information System information.

Table A9. Mean marginal effects for inspections

Variables		Inspection
	Predicted probability	0.0259
Monitoring and Enforcement (ME)		
	Inspection_lastyear	-0.0299
		(0.0036)
	Fined_3y	-0.0071
		(0.0086)
	Compliance Program	-0.0009
		(0.0047)
Facility's characteristics (FC)		
	Size (base: Medium)	
	Micro and Small	0.0008
		(0.0021)
	Large	0.0008
		(0.0020)
	Sectors (base: Fishing–Aquaculture)	
	Agroindustry	0.0092
		(0.0026)
	Energy	0.0029
		(0.0026)
	Environmental Sanitation	0.0002
		(0.0023)
	Housing-Construction	-0.0119
		(0.0028)
	Mining	0.0060
		(0.0024)
	Industrial factories	0.0035
		(0.0027)
	Age	-0.0003
		(0.0001)
Location (LO)		
	Prioritized Area	0.0035
		(0.0014)
	Macrozone (base: South)	
	Norte Grande (Far North)	-0.0018
		(0.0027)
	Norte Chico (Near North)	0.0001
		(0.0027)
	Centro (Central)	0.0012
		(0.0025)

	Centro Sur (Central South)	0.0007
		(0.0023)
	Log Poverty	-0.0015
		(0.0011)
	Log Density	0.0004
		(0.0003)
Budget (B)		
	Log Budget per Facility	0.0038
		(0.0011)
Conditional random effects		
	mean_ Inspection_lastyear	0.2048
		(0.0060)
	mean_ Fined_3y	0.0067
		(0.0140)
	mean_ Compliance Program	0.0136
		(0.0065)
		(0.0058)
Fixed Effect	Year (base: 2014)	
	2015	-0.0057
		(0.0027)
	2016	-0.0079
		(0.0029)
	2017	-0.0050
		(0.0030)
	2018	-0.0042
		(0.0031)
	2019	-0.0026
		(0.0030)
Observations		37,443
Number of ID		6,606

Note: Standard errors in parentheses.

Table A10. Conditional fixed effects for inspections

Variables		Inspection
Monitoring and Enforcement (ME)		
	Inspection_lastyear	-1.083
		(0.114)
	Fined_3y	-0.326
		(0.293)
	Compliance Program	-0.0743
		(0.143)
Location (LO)		
	Log Poverty	0.267
		(0.182)
Budget (B)		
	Log Budget per Facility	0.645
		(0.269)
Year Fixed Effect		Yes
Observations		3,785
Number of ID		653

Note: Standard errors in parentheses.

Table A11. Mean marginal effects for compliance

Variables		Compliance
	Predicted probability	0.6920
Monitoring and Enforcement (ME)		
	Inspection_lastyear_Predicted	-0.0177
		(0.0146)
	Fined_3y	0.1761
		(0.0475)
	Compliance Program	-0.0232
		(0.0203)
Facility's characteristics (FC)		
	Size (base: Medium)	
	Micro and Small	-0.0244
		(0.0388)
	Large	0.0283
		(0.0314)
	Sectors (base: Fishing–Aquaculture)	
	Agroindustry	-0.0794
		(0.0329)
	Energy	-0.0602
		(0.0413)
	Environmental Sanitation	-0.2115
		(0.0446)
	Housing–Construction	-0.7338
		(0.0735)
	Mining	-0.1945
		(0.0602)
	Industrial factories	-0.0815
		(0.0439)
	Age	0.0030
		(0.0022)
Location (LO)		
	Prioritized Area	0.0116
		(0.0246)
	Macrozone (base: South)	
	Norte Grande (Far North)	0.0596
		(0.0462)
	Norte Chico (Near North)	-0.0315
		(0.0532)
	Centro (Central)	-0.0144
		(0.0415)
	Centro Sur (Central South)	0.0157
		(0.0359)
	Log Poverty	0.0035
		(0.0196)
	Log Density	0.0187
		(0.0061)
Spillover		
	Fined_Spillover_Comune_3y	-0.0089
		(0.0309)
	Fined_Spillover_Sector_3y	0.0492

		(0.0492)
	Fined_Spillover_Com&Sector_3y	0.0027
		(0.0453)
	Fined_ Spillover_SameOwner_3y	0.1334
		(0.0674)
Conditional random effects		
	mean_ Inspection_lastyear	0.1342
		(0.0388)
	mean_ Fined_3y	-0.5501
		(0.1128)
	mean_ Compliance Program	-0.7149
		(0.0423)
	mean_ Fined_Spillover_Comune_3y	-0.0536
		(0.0719)
	mean_ Fined_Spillover_Sector_3y	-0.5484
		(0.2726)
	mean_ Fined_Spillover_Com&Sector_3y	0.0535
		(0.1028)
	mean_ Fined_ Spillover_SameOwner_3y	0.0568
		(0.1319)
Fixed Effect	Year (base: 2014)	
	2015	-0.0193
		(0.0270)
	2016	0.0547
		(0.0272)
	2017	-0.0168
		(0.0325)
	2018	-0.0123
		(0.0326)
	2019	0.0165
		(0.0316)
Observations		2,355
Number of ID		1,021

Note: Standard errors in parentheses.

Table A12. Conditional fixed effects for compliance

Variables		Compliance
Monitoring and Enforcement (ME)		
	Inspection_lastyear_Predicted	-0.0518
		(0.200)
	Fined_3y	1.233
		(0.597)
	Compliance Program	-0.361
		(0.260)
Location (LO)		
	Log Poverty	0.113
		(0.481)
Spillover		
	Fined_Spillover_Comune_3y	0.0798
		(0.440)
	Fined_Spillover_Sector_3y	0.812
		(0.786)
	Fined_Spillover_Com&Sector_3y	-0.794
		(0.744)
	Fined_ Spillover_SameOwner_3y	0.999
		(0.873)
Year Fixed Effect		Yes
Observations		548
Number of ID		140

Note: Standard errors in parentheses.

References

ECLAC (2022) Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean. Implementation guide. Available at https://repositorio.cepal.org/entities/publication/86cae662-f81c-4b45-a04a-058e8d26143c.

OECD (2024) *OECD Environmental Performance Reviews: Chile 2024.* Paris: OECD Publishing. Available at https://doi.org/10.1787/5bc65d36-en.

SMA (2018) Memoria de Gestion 2014-2018 Superintendencia del Medio Ambiente Chile. Available at https://portal.sma.gob.cl/index.php/download/memoria-de-gestion-sma-2014-2018/ (in Spanish).