Sustainability Science in Practice: From Global Challenges to Interdisciplinary Collaboration in a Research Center

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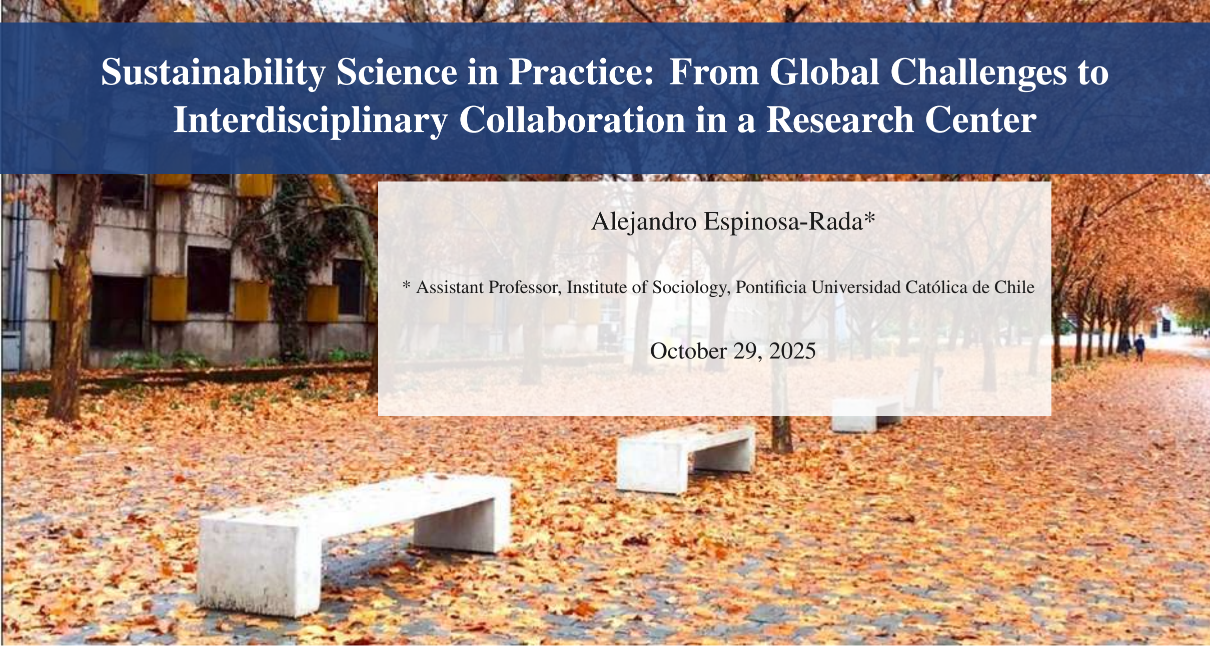

Solving Sustainability Challenges Requires Collaboration

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Figure: https://sna-ses.shinyapps.io/SSMviewer/

Complex societal problems cannot be solved by a single discipline.
Interdisciplinary collaboration is key to innovative solutions.

While interdisciplinary collaboration is essential, how do researchers actually connect across disciplines? Who collaborates with whom, and what patterns facilitate or hinder these collaborations?

Scientific Networks

Motivation

- **Macro:** Much of the social network literature on scientific networks tends to focus on **academic papers** as a means to explore scientific collaborations (Bellotti and Espinosa-Rada, 2025).
- **Micro:** Early studies in the sociology of science and knowledge have highlighted the importance of **social interactions** in the diffusion and production of knowledge (Coleman et al., 1957; Crane, 1972; Mullins, 1972; Collins, 1998; White et al., 2004; Bellotti and Espinosa-Rada, 2025)

Motivation

- **Multilayers:** The multiple ties of scientific networks have been classified by distinguishing between social and cognitive ties, which are often **difficult to disentangle** into more precise layers or to separate due to the intrinsic overlap between these dimensions (Mullins, 1972; White et al., 2004; Espinosa-Rada et al., 2024, 2025)
- **Mechanisms:** To better understand the complexities of social relationships in scientific settings, this study examines how factors such as **informal communication, scientific interests, specialization, and structural opportunities influence and constrain interdisciplinary scientific collaboration**.

What is Scientific Collaboration?

The collaboration of scientists in research activity has become the norm.

(Beaver and Rosen, 1979)

There are five connotations always associated with the term collaboration: sharing, partnership, interdependency, power, and process

(D'amour et al., 2005)

Scientific collaboration can be defined as interaction taking place within a social context among two or more scientists that facilitates the sharing of meaning and completion of tasks with respect to a mutually shared, superordinate goal. Scientists who collaborate may also bring additional, individual goals to a collaboration.

(Sonnenwald, 2007)

Why Interdisciplinarity Matters

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- Many sustainability and societal challenges span multiple domains of knowledge (Lowe and Phillipson, 2006).
- Integrating perspectives and methods from different disciplines fosters innovation and novel solutions (Gibbons et al., 1994; Hollingsworth and Hollingsworth, 2000).
- Research funding and institutional priorities increasingly favor interdisciplinary approaches (Abramo, 2018; D'Este and Robinson-García, 2023).

Interdisciplinarity and Scientific Communication

Interdisciplinary Research (IDR)

- Science often works in the **"chaos of disciplines"** (Abbott, 2010)
- IDR enhances collaboration and societal relevance
- Recognised for:
  - **Scientific breakthroughs**
  - Addressing **complex societal problems** (Lowe and Phillipson, 2006)
  - **Fostering innovation** (Gibbons et al., 1994)
  - **Integrating knowledge to solve problems beyond single disciplines** (Jacobs and Frickel, 2009)
- To address complex problems, researchers often associate within scientific research centers that allowed them to work on common topics of interest.

Research question

How do shared expertise, disciplinary distance, and affective social ties influence interdisciplinary collaboration within a sustainability-focused research center?

Hypotheses

Interdisciplinary collaboration:

- $H1$: Individuals who have the same specialty are more likely to form collaborations.
- $H2$: Greater disciplinary distance between researchers decreases their likelihood of collaboration.
- $H3$: Non-work social ties (e.g., friendship, leisure activities) are positively associated with collaboration.
- $H4$: The effect of sharing similar specialty ties on collaboration is positive when researchers also share affective ties.

Case study: Sustainability Science

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Sustainability science seeks to address sustainable development challenges by understanding interactions between nature and society. It aims to unify evidence on (un)sustainability patterns ("science of sustainability") and deliver practical solutions ("science for sustainability") (Clark and Harley, 2019; Kates et al., 2001; Spangenberg, 2011; Kates, 2011; Vanhulst et al., 2025).

- Interdisciplinary approach to complex socio-ecological problems.

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- Interdisciplinary approach to complex socio-ecological problems.
- Roots in:
  - *World Conservation Strategy* (IUCN, 1980)
  - *Brundtland Report* (1987)
  - *Earth Summit*, Rio de Janeiro (1992)
  - *Budapest World Conference on Science* (1999)
  - Term formalised in *Our Common Journey* (NRC, 1999)
  - Recognised at:
    - 2001 *Challenges of a Changing Earth Congress*
    - 2002 *Johannesburg World Summit*

Data

- The Social Networks and Socio-ecological Sustainability Project (SNA-SES) was conducted by the Universidad Católica del Maule and the Social Networks Lab at ETH Zürich between 2022 and 2025 (Vanhulst & Espinosa-Rada, 2021).
- The original project was funded by the ANID/FONDECYT program (No. 1220560, 2022–2025). PI: Julien Vanhulst.
- The study collected bibliometric data from the Web of Science and investigated a research center located in Chile ($N = 66$) dedicated to study topics related to sustainability.
- We administered a survey and collected secondary data from public sources.
- An additional bibliometric dataset is available at: `https://sna-ses.shinyapps.io/SSMviewer/`

Multilayers (multiplex) (1/2)

Layer	Type	Question
DV: collaborators	knowledge	Who at your centre have been your closest research collaborators in the past two academic years?
co-authorship	knowledge	Bibliometric co-authorship from the last five years
friendship	affective	Who are your friends among your colleagues?
communication	knowledge	With whom do you usually talk about your research or professional work?
lazy	affective	With whom do you spend more leisure time inside or outside academic working hours?
interaction	unclear	Which researchers do you communicate with most frequently on a daily basis?
inspiration	knowledge	Which researchers have most inspired your own work?

Table: Description of network layers, types, and corresponding survey questions.

Multilayers (multimodal) (2/2)

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Layer	Type	Question
DV: university (multilevel)	knowledge	What is your principal academic unit? Are there other units in your institution with which you collaborate (e.g., seminars, workshops, projects)?
disciplines	knowledge	What scientific discipline do you identify with? (OECD classification)
speciality	knowledge	Please specify your specialty (e.g., entomology within biology). Are there others in your organisation working in this specialty?
degrees	knowledge	Please specify you undergraduate degree.

Table: Network layers, types, and corresponding survey questions.

Methodology I: Stochastic Actor-Oriented Models (SAOMs)

- SAOMs model the evolution of a network $X(t)$ over continuous time t.
- Each actor i can change outgoing ties to maximize a **objective function**:

$$f_i(\mathbf{x}) = \sum_k \beta_k s_{ik}(\mathbf{x})$$

where $s_{ik}(\mathbf{x})$ are network statistics (e.g., reciprocity, transitivity, homophily) and β_k are parameters.

- Changes occur according to a **rate function** $\lambda_i(\mathbf{x})$, specifying the expected number of opportunities actor i has to modify ties.
- The probability of a tie change follows a multinomial logit:

$$P(X_{ij} \text{ changes} \mid \mathbf{x}) = \frac{\exp(f_i(\mathbf{x}_{\text{new}}))}{\sum_{\mathbf{x}'} \exp(f_i(\mathbf{x}'))}$$

- Parameters are estimated using **simulation-based methods** (e.g., Method of Moments), implemented in **RSiena**.

Methodology II

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- For the analysis we used stationary stochastic actor-oriented models (SAOMs) (Snijders and Steglich, 2015)
- We also consider the interdependency between two different levels (Snijders et al., 2013)
- Parameters are estimated by the method of moments using a stochastic approximation.

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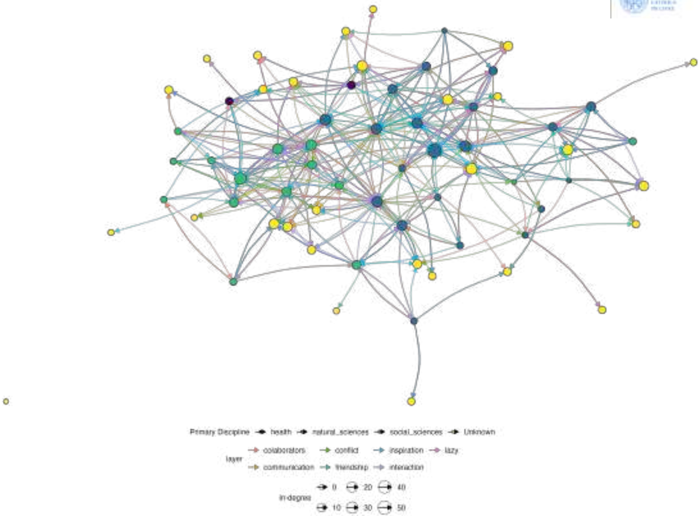
Directed Multilayer Network Colored by Primary Discipline



Network and Discipline Descriptive Statistics

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Network	Avg Deg	SD Deg	Density	Components	% Largest Comp	% 2nd Largest Comp	Avg Path Len	Clustering Coef
Friendship	4.776	4.441	0.036	10	86.57%	1.49%	3.505	0.320
Communication	4.567	4.563	0.035	7	91.04%	1.49%	3.011	0.255
Collaboration	4.000	3.219	0.030	6	92.54%	1.49%	3.574	0.205
Lazy	1.851	2.084	0.014	26	49.25%	8.96%	1.733	0.215
Interaction	2.836	2.739	0.021	15	79.10%	1.49%	2.809	0.200
Inspiration	3.045	2.956	0.023	15	79.10%	1.49%	1.967	0.255

Note: Multilayer network of informal communication in science.

Discipline	Count	Percent
Natural Sciences	35	52%
Social Sciences	19	28%
Humanities	5	8%
Health	3	4%
Computer Science	1	2%

Note: Based on declared primary and secondary disciplinary affiliations.

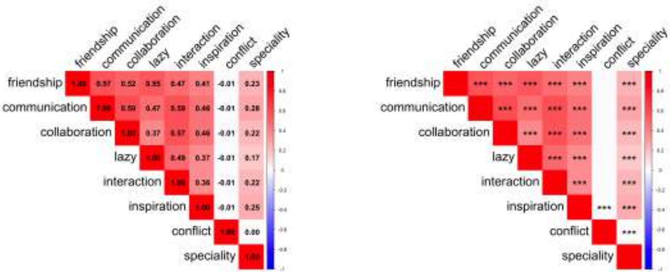

Figure: Pearson correlations among multilayer networks of scientific ties with significance levels according to quadratic assignment procedure, where $^{***}p < 0.001$, $^{**}p < 0.01$, and $^{*}p < 0.05$.

Balance of Affective and Knowledge Ties by Individual

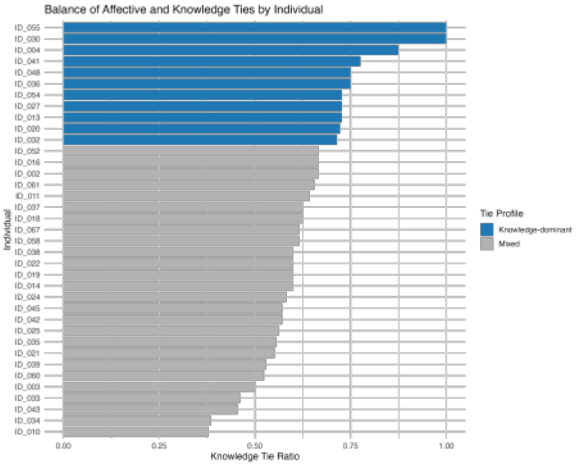

Figure: Knowledge Tie Ratio per Individual, colored by tie profile (threshold = 0.7).

Tie Profile	Count	Percent
Knowledge-dominant	15	40.5%
Mixed	22	59.5%

Note: Classification based on ratio of knowledge-oriented ties.

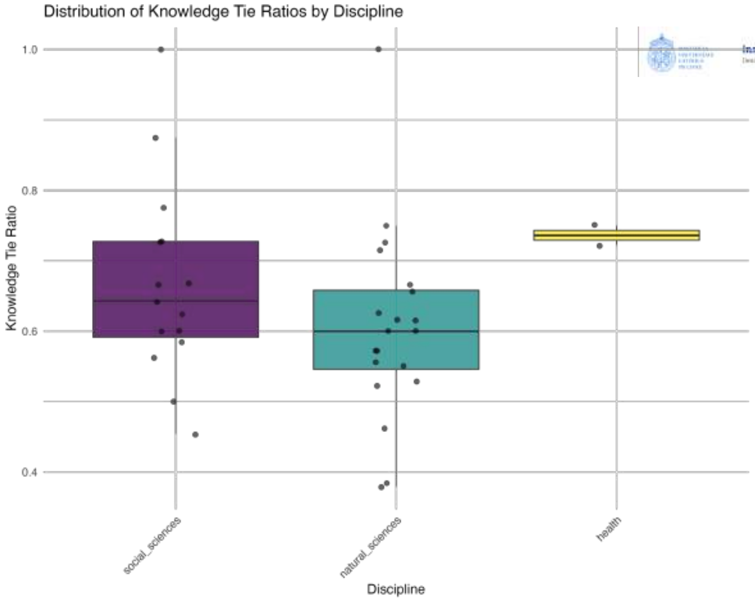

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Figure: "Do individuals from some disciplines rely more on affective vs. knowledge-based informal ties?"

Stationary SAOM (1/3)

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Effect	par.	(s.e.)
basic rate parameter coll	30.000	(N.A.)
coll: outdegree (density)	–1.634**	(0.584)
coll: reciprocity	1.174†	(0.606)
coll: GWESP I → K → J (69)	0.965*	(0.394)
coll: indegree - popularity	–0.045	(0.059)
coll: outdegree - activity ($\sqrt{}$)	–0.247	(0.176)
coll: age alter	0.057	(0.087)
coll: age ego	–0.245*	(0.097)
coll: age ego x age alter	0.077	(0.067)
coll: same belongs-department	0.016	(0.165)
coll: same belongs-center	–0.471*	(0.183)
coll: reciprocity x GWESP I → K → J (69)	–1.079	(1.358)

Stationary SAOM (2/3)

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Effect	par.	(s.e.)
coll: H_1 specialties	0.878**	(0.327)
coll: H_2 sim-degrees	0.544**	(0.207)
coll: H_2 main-discipline	–0.690**	(0.267)
coll: H_3 friends	1.518***	(0.239)
coll: H_3 lazy	–0.704*	(0.305)
coll: interaction	1.896***	(0.265)
coll: inspiration	0.973***	(0.249)
coll: coll-bib	0.251*	(0.104)
coll: author-network-position	3.513**	(1.276)
coll: H_4 friends x specialties	–1.533**	(0.486)

Stationary SAOM (3/3)

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Effect	par.	(s.e.)
basic rate parameter university	10.000	(N.A.)
university: outdegree (density)	1.401	(3.224)
university: GWDSP I $\rightarrow$ K $\leftarrow$ J (69)	0.859	(0.785)
university: indegree - popularity ($\sqrt{}$)	–4.750	(2.911)
university: outdegree - activity	0.636**	(0.211)
university: age ego	–0.161	(0.111)
university: prime-uni alter	0.682*	(0.328)
university: non-department alter	–0.289	(0.301)
university: coll to agreement	2.040***	(0.527)

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;

convergence t ratios all < 0.04.

Overall maximum convergence ratio 0.1.

Summary of Hypotheses Testing

- **H1:** Supported. Having the same scientific specialty is positively related to collaborative ties.
- **H2:** Partially supported. Having a bachelor's degree in the same discipline is positively related to collaborative ties. However, if two individuals identify with the same discipline, the effect is negative.
- **H3:** Supported. Affective ties are positively related to collaborative ties in friendship, but not in leisure time.
- **H4:** Supported. A significant interaction between friendship ties and same specialty is associated with less collaboration.

Discussion

- **Disciplinary** background (specialty, degrees) still shapes scientific collaboration.
- **Interdisciplinarity** is related to research conducted by individuals who identify with different disciplines, as sharing the same disciplinary identification can negatively affect collaboration.
- **Informal ties** moderate collaboration, suggesting that emotional or social ties can facilitate scientific work, but only in certain relational contexts.
- Interdisciplinary collaboration may be facilitated when **affective ties connect researchers across different specialties**, rather than being concentrated within the same specialty.

Conclusion

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- Scientific collaboration is shaped by more than formal outputs like publications; it is deeply embedded in **social relations and informal communication**.
- **Interdisciplinary research** emerges not just from shared expertise, but through daily interaction, inspiration, and the trust fostered by friendship and communication.
- These results reinforce classic insights from the sociology of science, emphasizing that the **invisible college** remains vital in structuring scientific work.

Next steps

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- Refine the model specification and theory, and adjust details or any remaining unconsidered dimensions.
- We are considering exploring the interdependency of all layers within a common framework. As this task is likely very complex, we are evaluating the necessity of developing a new statistical model for complex multilayer networks.

Main takeaway

*Understanding the **informal dynamics of collaboration** is essential for supporting meaningful and sustained interdisciplinary efforts, particularly in research centers addressing complex societal challenges such as sustainability.*

Project Collaborators: Seed Fund UC-UNSW 2024 (2025-2026)

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Thank you!

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