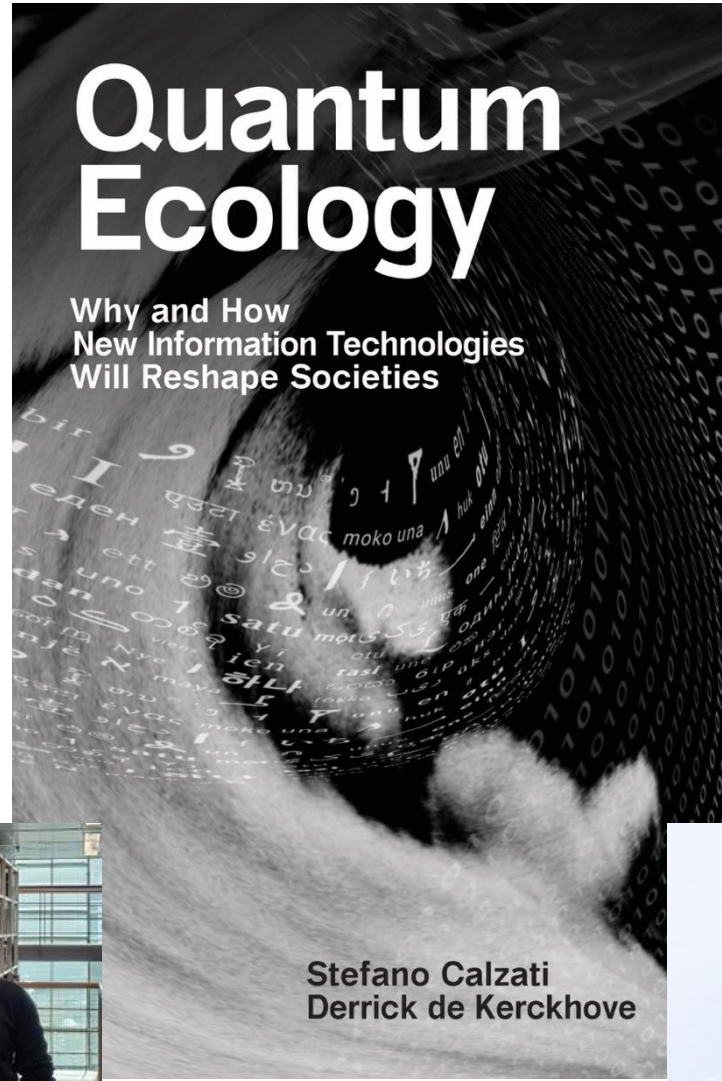


The background is a dark, abstract composition. It features a large, swirling, light-colored shape that resembles a hand or a cloud, reaching out from the right side. This shape is set against a backdrop of binary code (0s and 1s) that appears to be flowing or moving, creating a sense of depth and motion. The overall aesthetic is futuristic and technological.

Ecological Discussions on Quantum Technology and Policy

Dr Stefano Calzati

EASST 2026 Conference
8-11 September, Krakow



Quantum Ecology

[Calzati & de Kerckhove 2024](#), MIT Press

Onto-epistemological framework, whose pillars are *uncertainty, complementarity, nonlocality, superposition, entanglement*

Technological paradigm, pivoting around Quantum Information Technologies (QITs)



Ecology as a complex system

- “**An ecology has effects but not causes** in the ordinary sense of a direct relationship between cause and effect.” ([Calzati & de Kerckhove 2025](#))
→ complex system showing **emergent behaviours**
- **Complexity is an issue of framing**, “a way of observing systems, not an absolute class of systems.” ([Gershenson & Heylighen 2003](#))
→ Complexity is an **observer-observed entanglement** ([Calzati 2026](#))

3 technological ecologies of sens-making

1) **Language** → based on **meaningful world-sensing**
(e.g., law)



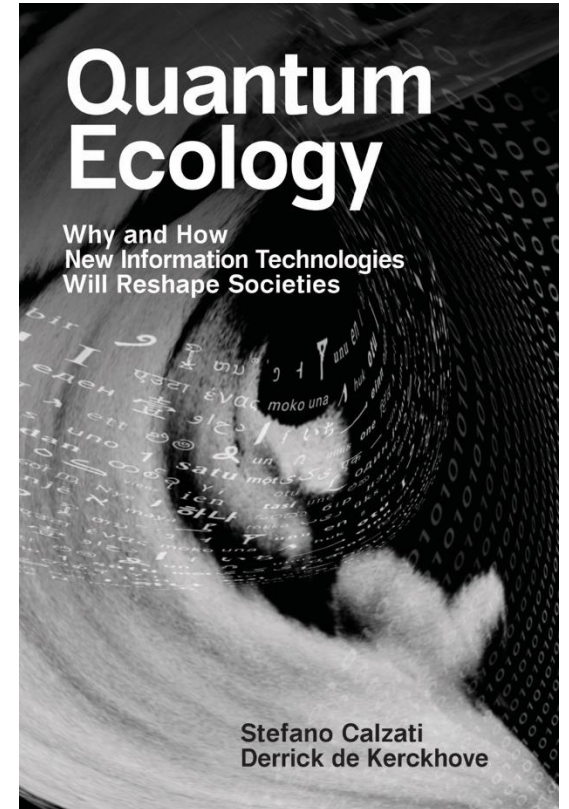
Partial onto-epistemological incommensurability

2) **Digital** → based on **computable world-sensing**
(formatting of sensing into 0s & 1s)



Partial onto-epistemological incommensurability

3) **Quantum** → based on a **probabilistic world-sensing**
(synthetic sensing)



Wigner's friend thought experiment

- 1) Wigner's friend performs the measurement of a particle (e.g., spin) inside a laboratory
- 2) For her, the measurement yields a definite outcome (e.g., spin up)
- 3) For Wigner, who is outside the lab and treats the entire scenario as a quantum system, the outcome is not definite yet, i.e., still in superposition

→ **Configurational realism**: Different observers can assign different "real" states to the same system → **no observer-independent physical phenomenon**.

→ **Relational epistemology**: Two observers can hold **complementary** but **equally valid** knowledge claims about a phenomenon.

→ **Nested inconsistent onto-epistemological configurations** ([Frauchiger & Renner 2018](#))



Implications – 1

Problem-opening approach to ethics of techs



“Technology is neither good nor bad; **nor is it neutral.**” ([Kranzberg 1985](#))

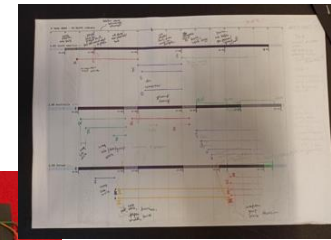
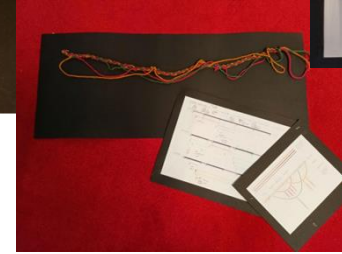
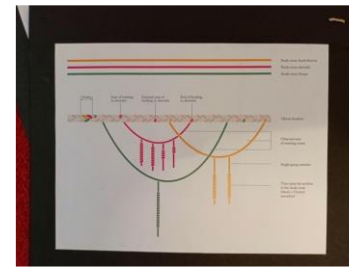
Technology as “**pharmakon**” (at once, good and bad; both poison **and** antidote).

→ its use in complex scenarios produce **value-laden entanglements** (good **and** bad) and **uncertain consequences** (intended **and** unintended).

Research & design

Research

- 1) **Identification** of a case study (e.g., TU Delft campus)
- 2) **Framing** of the case study (e.g., how it is presented; how it works; etc.)
- 3) **Data-value entanglements** (e.g., values in/excluded; data in/excluded)
- 4) **Open-ended scenarios** (e.g., possible un/intended consequences)



Design

a) Project journal

b) Artefact (e.g., physical/digital object exposing/redressing the tensions identified)

c) Author's statement describing the artefact

Implications – 2

Quantum-driven approach to QIT regulation

- Operationalisation of quantum **principles** and **phenomena** as resources for:

→ **Complexity-informed** policymaking (cf. [Myeong 2025](#); [Renda 2025](#))

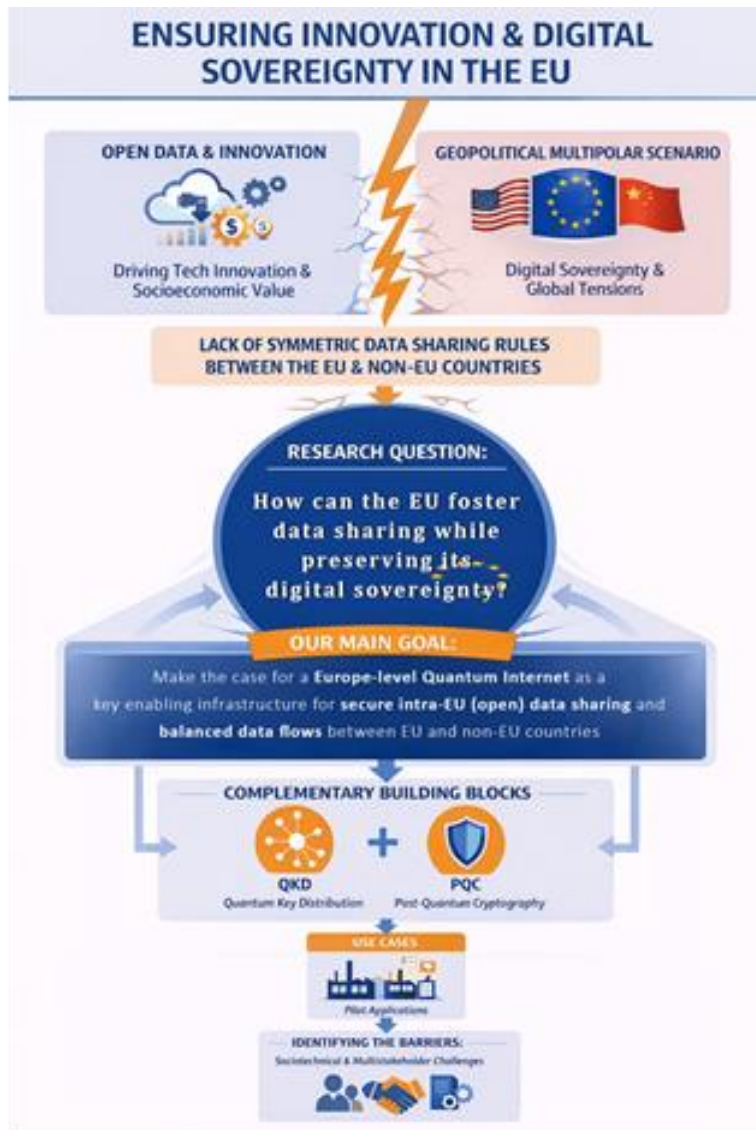
→ Regulating QITs as a “**wicked**” policy issue ([Head 2022](#); [Moloney & Al-Kuwari 2025](#))

EU quantum internet for fair(er) data sharing

- Currently, **we miss symmetric cross-border data sharing frameworks** between the EU and non-EU countries ([Voss & Pernot-Lepay 2023](#))

→ How can the EU keep enacting **internal data sharing**, while also preserving its **outward data sovereignty**?

A **Europe-level Quantum Internet** as the sociotechnical infrastructure establishing the **boundaries of a European data polity** ([Calzati et al 2026](#))



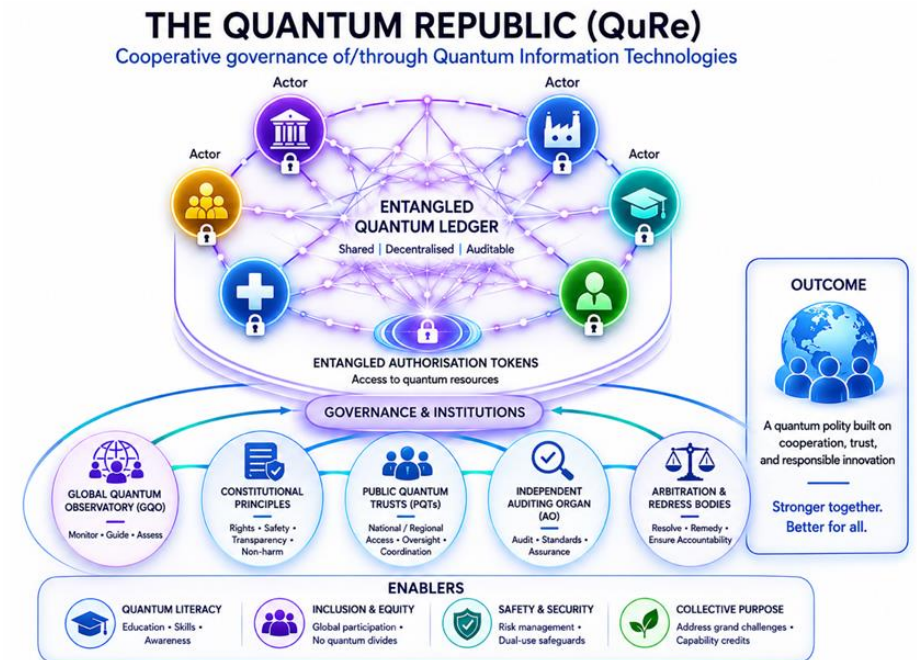
Quantum Republic (QuRe)

How to operationalize a **pharmakological** governance **of/through** QITs? (Calzati & Travagnin, under review)

- *Nuclear Non-Proliferation Treaty & Quantum Game Theory* ([Calzati & de Kerckhove 2024](#); [Kop 2025](#); [Perrier & Aboy 2026](#))
→ Quantization of game theory can generate **better-than-classical outcomes for negotiating dilemmas** ([Eisert et al 1999](#))
- +
- **Republican approach** to technology governance
(Susskind 2022; [Calzati & van Loenen 2023](#); [Hoeksema 2024](#))
→ A republican governance seeks to enable a **systemic distribution of power, mutual accountability, and collegial decisions**

Hybrid (quantum & classical) design

- **Quantum game theory-based distributed ledger:**
 - Authorisation tokens (entangled qubits) to access and use shared quantum computation
 - Quantum zero-knowledge proof to validate declared computation
 - *Cooperation* boosts computational power for all actors; *defection* triggers a shared computational cost
- **Institutional arrangements** (based on digital republicanism):
 - *Treaty+global quantum observatory* (→ IAEA; [Kop 2025](#))
 - *public quantum trusts* (→ public data trusts; [van der Sloot & Keymolen 2022](#))
 - *bodies of arbitration* (→ [Calzati & van Loenen 2023](#))
 - *quantum registry* (→ [OECD 2026](#); cf. patents)
 - *auditing organ* (→ Susskind 2022)
 - *quantum communes* (→ Susskind 2022; [Calzati & van Loenen 2023](#))



Limits & further work

- **Low TRLs** of quantum computing and quantum communication
- Hard **verifiability** of quantum computation (even under ideal conditions)
- **Lack of auditing**
 - standards and benchmarks as pathway (cf. earlier propositions)
- **QGT remains theoretical and based on rational agents**
 - simulation of complex scenarios (e.g., information asymmetries, real-like geopolitical conditions, time-dependent scenarios, non-rational behaviours, cf. [Pothos & Busemeyer 2022](#))

Thank you

<https://stefanocalzati.com>

[*Digital Society Topical Collection*](#)

Untangling the Quantum Ecology:
Charting the Impact of Quantum Theory and
Quantum Technologies on Technoscience and
the Digital Transformation

(Mi Lin, book cover's artist, [Milandia 瀾瀾之域](#))

Quantum Ecology

Why and How
New Information Technologies
Will Reshape Societies

Stefano Calzati
Derrick de Kerckhove