Industrial Symbiosis^2 Hubs 4 Circularity

UNIVERSITY OF TWENTE.

Analysing social infrastructure for circular sustainable transition in IS2H4C project

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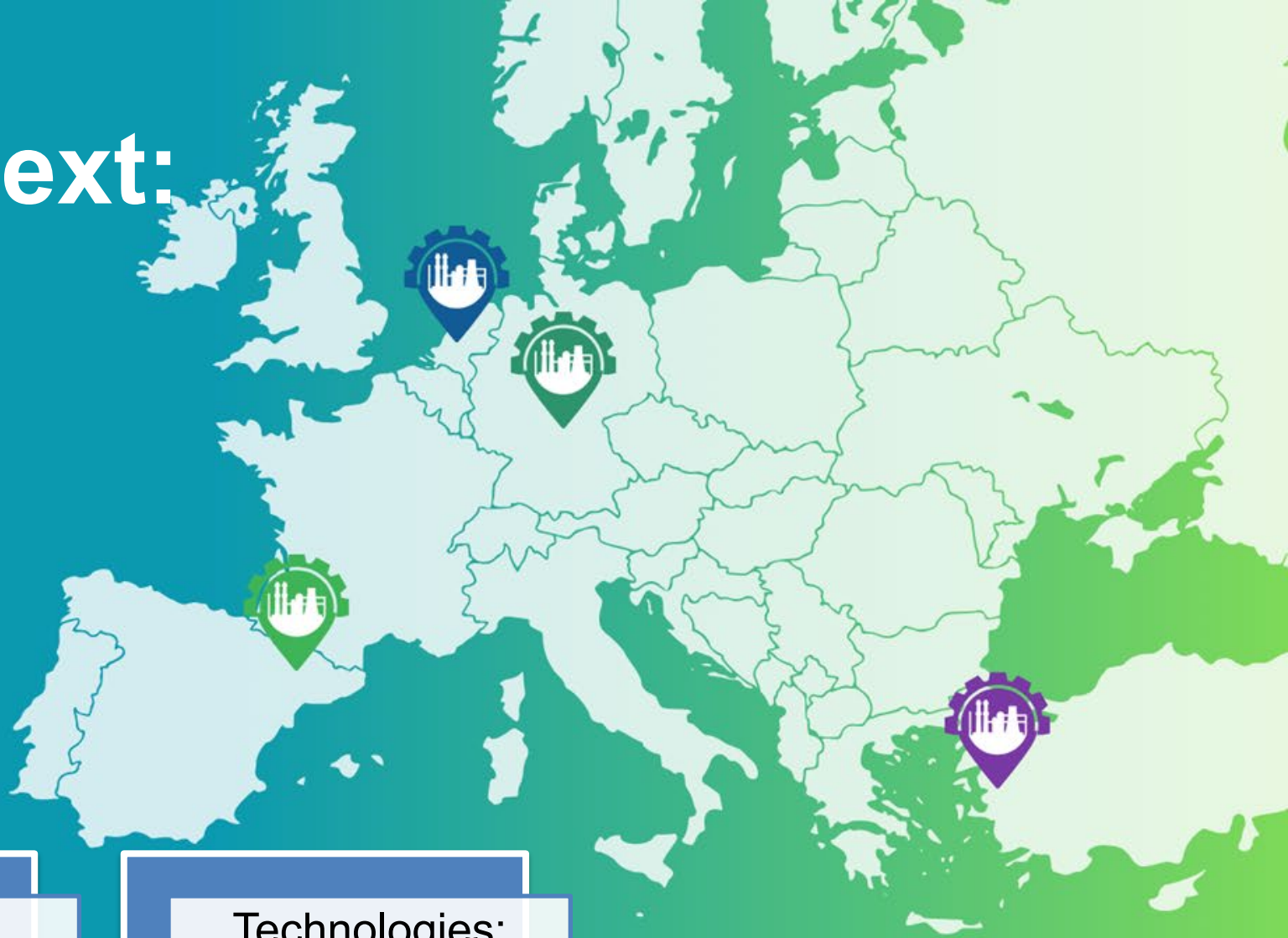
Funded by the European Union

This project has received funding from the European Union's HORIZON Innovation Actions programme under grant agreement number 101138473

Outline

1. Why is social infrastructure important in the context of industrial symbiosis?
2. From Industrial Symbiosis to Hubs for Circularity (H4C)
3. Step 1: What matters for engagement in H4C?
4. Step 2: How are stakeholders actually connected in H4C?
5. Step 3: How can communication help hubs for circularities to expand?
6. Further steps

Our Study Context: IS2H4C Project



4 pilot hubs (H4C): Basque, Netherlands, Germany, Türkiye.

34 partners; EU Horizon-Europe funding.

Technologies: hydrogen, CO_2 capture, waste-heat valorisation.

Why is social infrastructure important in the context of industrial symbiosis?

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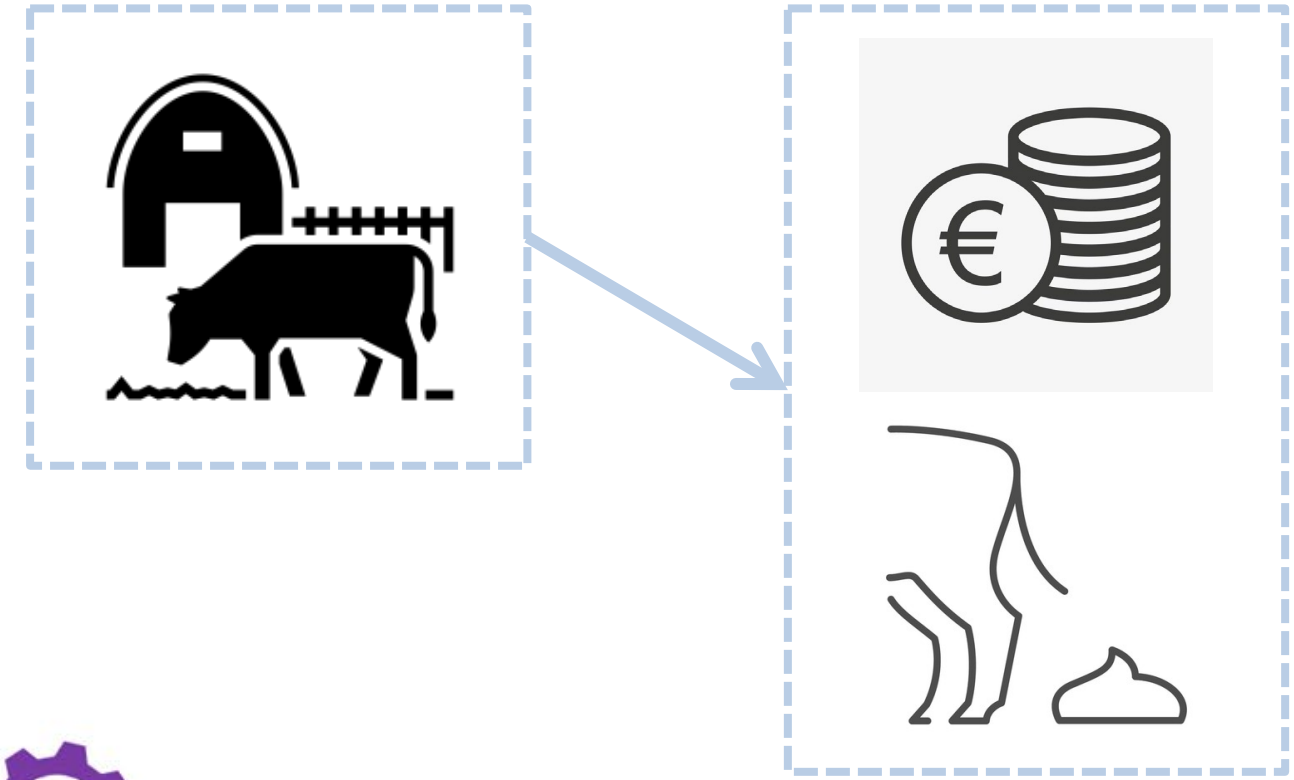

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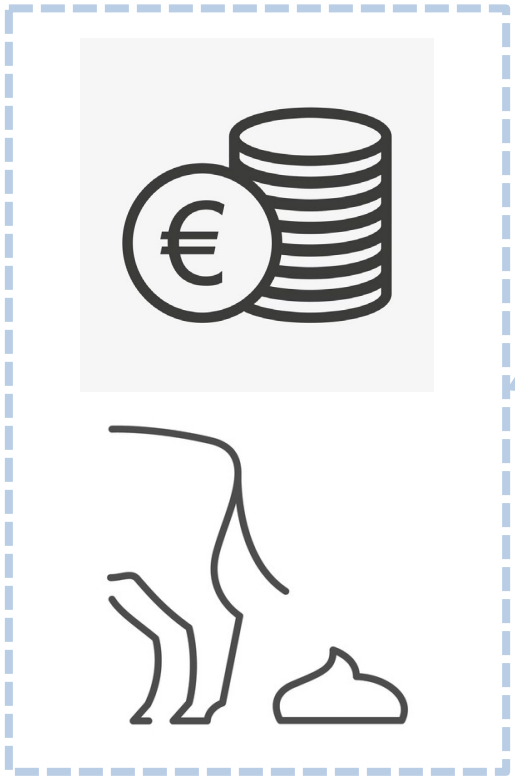

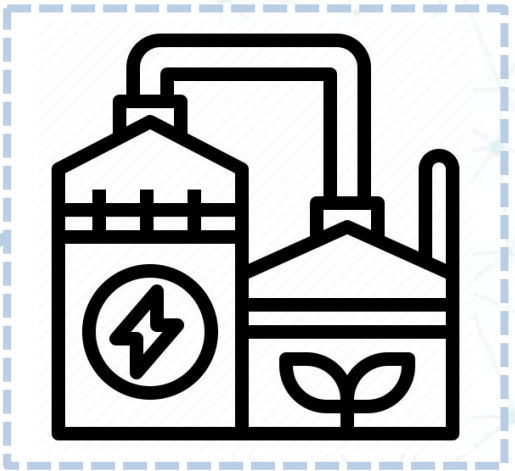

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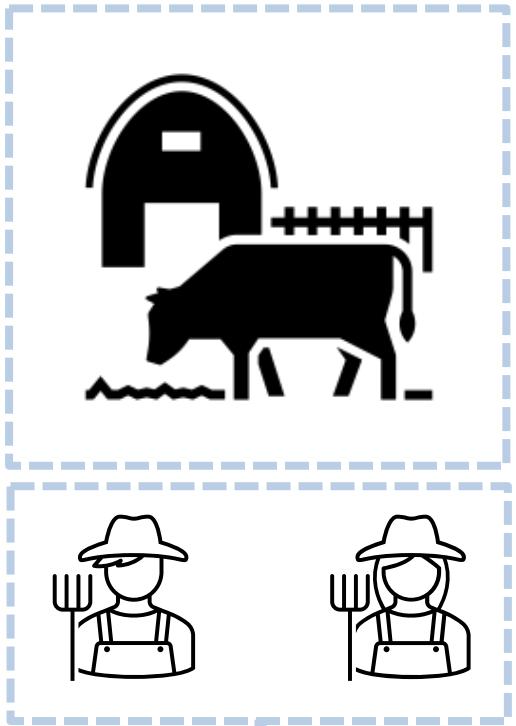
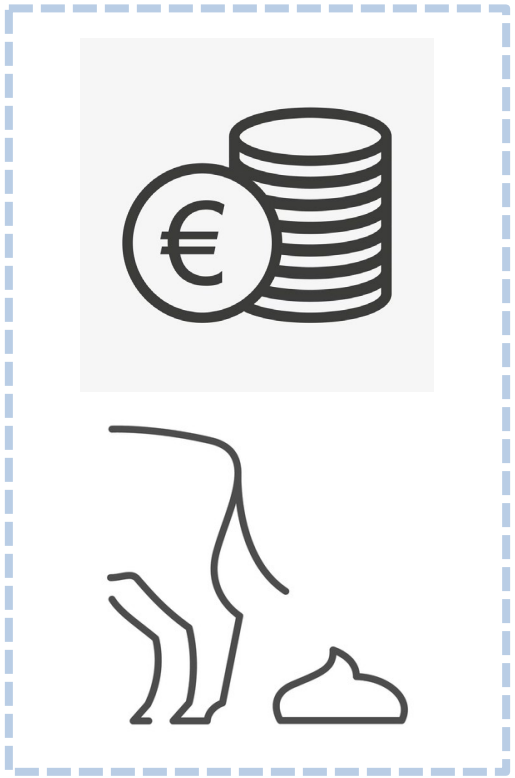
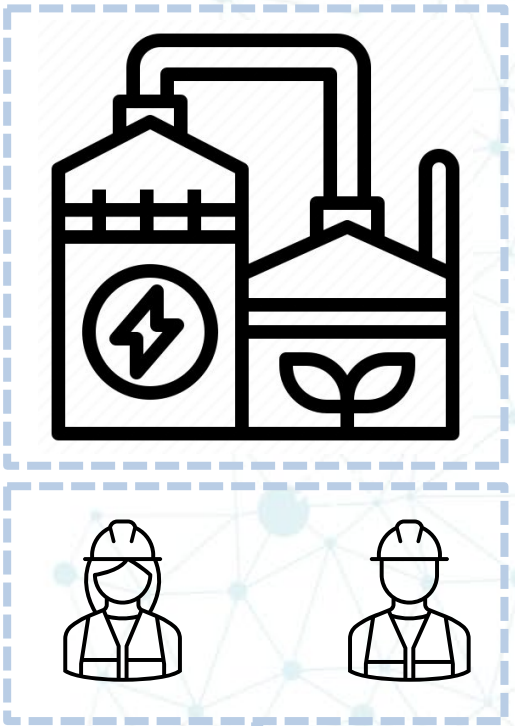






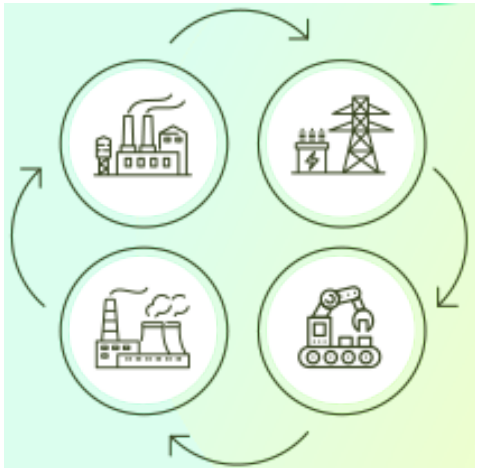
Why is social infrastructure important in the context of industrial symbiosis?

- enables **information flow**, allowing actors to discover by-products, needs, and matching opportunities they would never identify alone.
- builds **trust and legitimacy**, reducing perceived risks related to dependency, quality, and long-term commitment.
- integrates **non-industrial actors**, whose roles are essential for scaling, stability, and societal acceptance.
- explains **why similar regions show very different outcomes**, even when technical conditions appear comparable.

From *Industrial Symbiosis (IS)* to *Hubs for Circularity (H4C)*

Industrial Symbiosis (IS)

- Collaborative model: Exchange of materials, energy, water, by-products
- Success factors: Trust, coordination, geographic proximity
- **Social ties matter**: Enable knowledge sharing, reduce costs, build norms

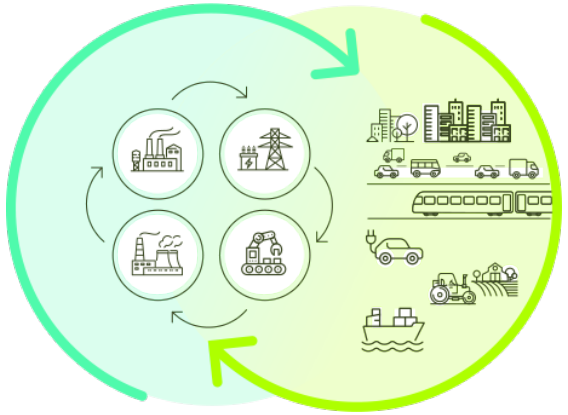


From *Industrial Symbiosis (IS)* to *Hubs for Circularity (H4C)*

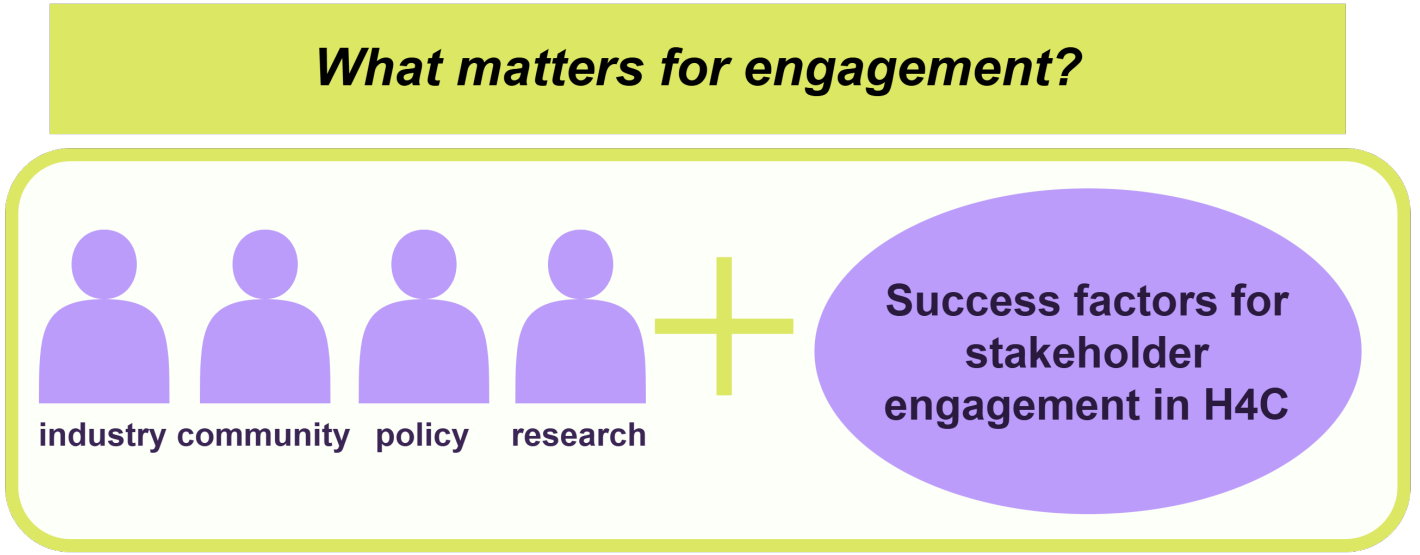
Why move beyond traditional IS?

- New models: **Hubs for Circularity (H4C) (example of Industrial Urban Rural Symbiosis)**
- Multi-actor
- Regional focus: Broader system boundaries, sustainability goals

Challenge: Social and organizational dimensions in H4C remain underexplored
Motivation: Understand how stakeholders **communicate**, **share knowledge**, and **collaborate**



Step 1: Knowing



- Analyzed *drivers, barriers, and enablers* affecting Hubs for Circularity (H4C) initiatives.
- Identified key stakeholder types in H4C context: Industry, Academia, Society, Policy.
- Introduced the FRONTIER framework of critical success factors for stakeholder engagement in H4C.

ELSEVIER
Journal of Environmental Management
Volume 384, June 2025, 125324

Research article

Designing a stakeholder engagement framework with critical success factors for Hubs for Circularity

Aidana Tleuken [a], Patricia Rogetzer [a], Luca Fraccascia [a b], Devrim Murat Yazan [a]

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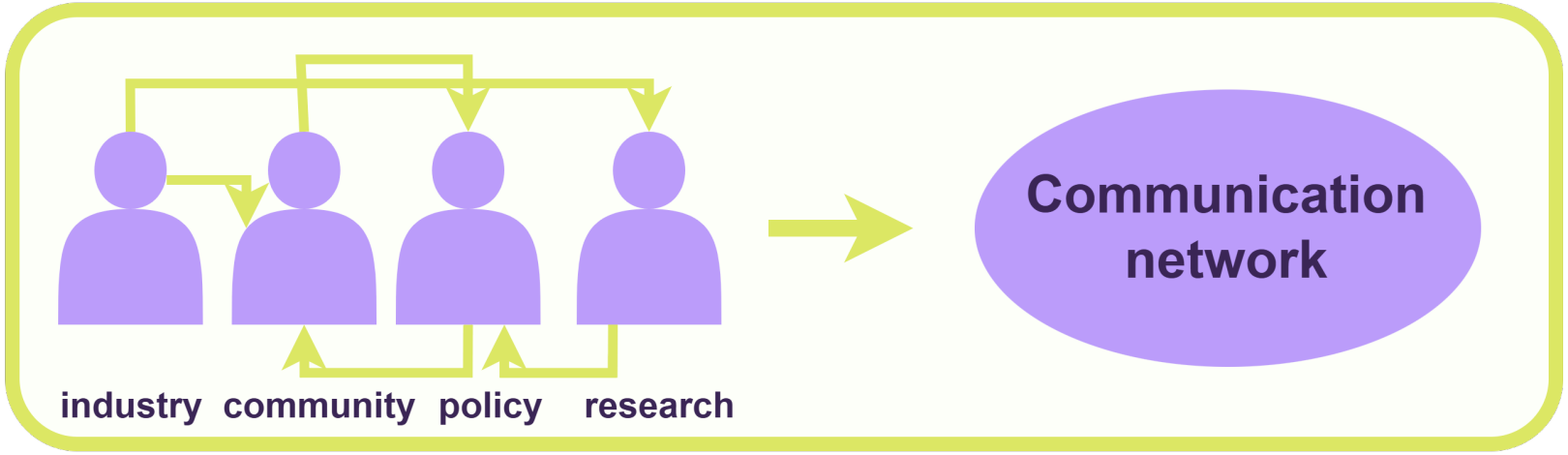
Step 2: Connecting

How are stakeholders actually connected?



- This research intended to analyze the communication patterns within industrial symbiosis networks using case study of four hubs for circularity in the IS2H4C project

Research Focus & Research Questions

Research gap

- Technical IS aspects well studied
- **Social and organizational dynamics** in regional IS and H4C: Underexplored, fragmented, limited empirical evidence, particularly about
  - Communication & info-sharing patterns
  - Roles of non-industrial stakeholders
  - Network structures in H4C

Contribution of our study

- Empirical analysis of **four H4C hubs** in the IS2H4C project
- Method: **Social Network Analysis (SNA), map communication** and **resource-flow layers**.

Social network analysis (SNA)

Centrality measures: to identify key actors

- *Degree centrality*: direct connections
- *Betweenness:* shortest path between other nodes
- *Eigenvector:* influence via connected nodes
- *Eccentricity*: max. shortest path to any node

Structural Holes Analysis

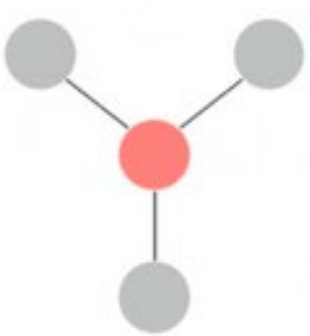
- Metrics: effective size, efficiency, constraint
- Brokerage roles

Core-Periphery Structure

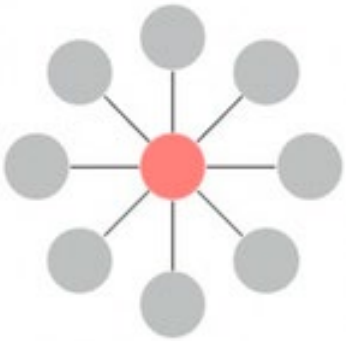
Detects central vs. peripheral nodes

These metrics help operationalize governance patterns – e.g., coordination (centrality), brokerage (betweenness), inclusion (core-periphery).”

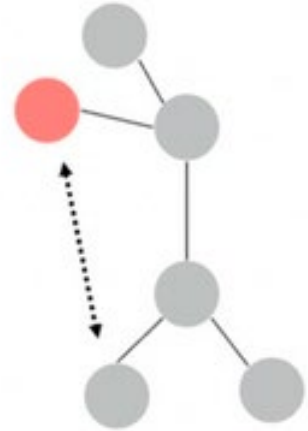
Degree centrality

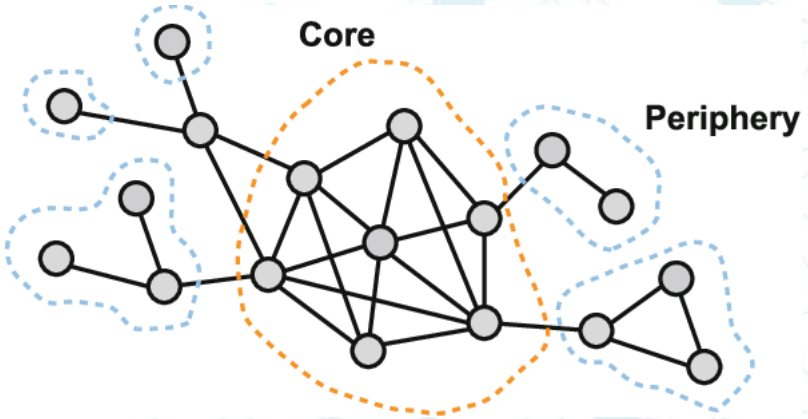


Betweenness



Eigenvector

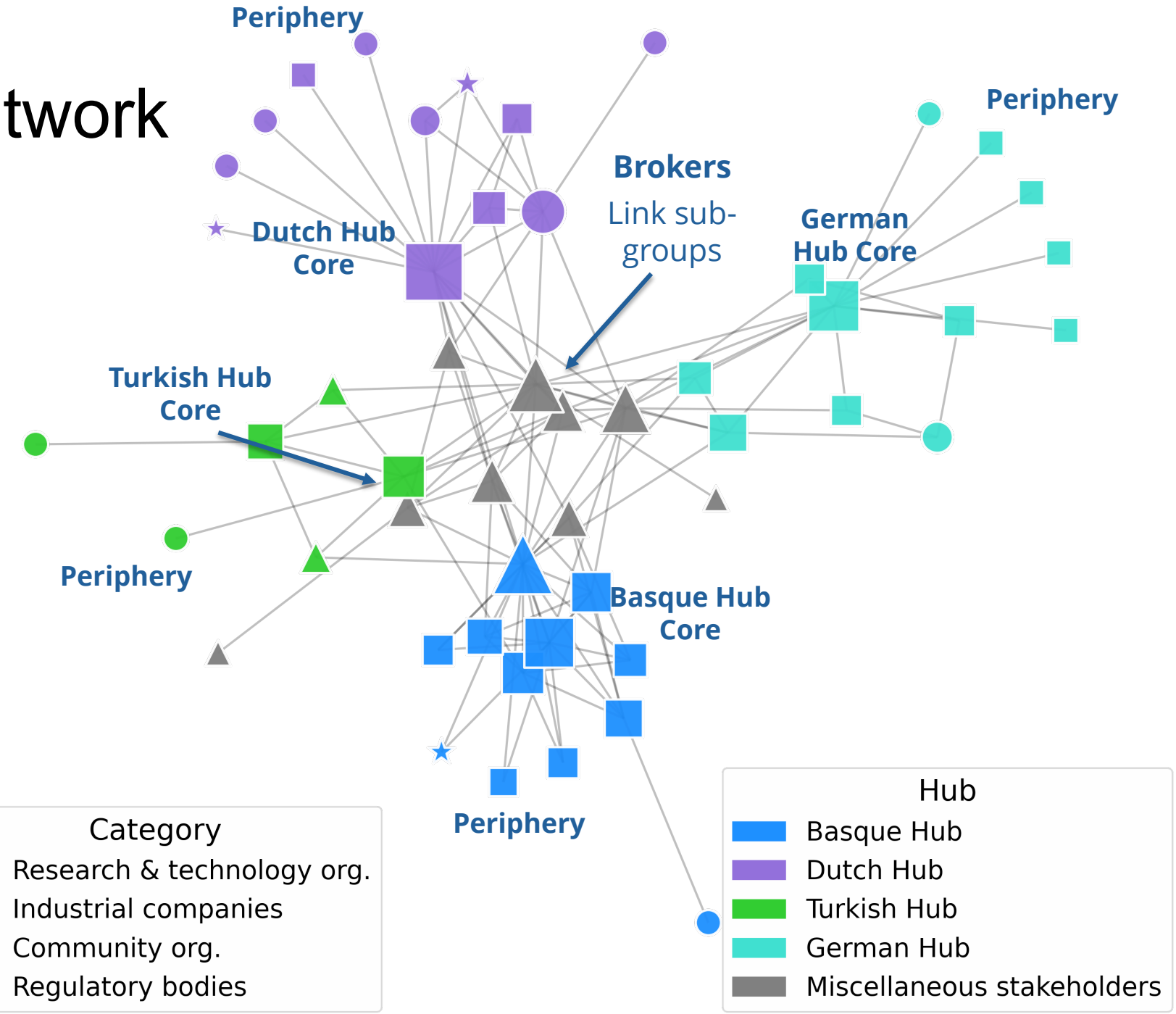




Communication network

Computed using NetworkX, Python

Data collected during workshop at GA of IS2H4C project (February 2025) + desk research



Structural characteristics of stakeholder communication networks in H4C

Characteristics	H4C networks	Traditional IS networks
Network structure & communication	Dual-layered: dense within hubs, sparse between; links often via research actors.	Dense inter-firm exchanges within industrial clusters.
Resource flows & geography	Resources local; knowledge and communication global.	Resources local and confined to industrial zones.
Stakeholder & knowledge roles	Mix of industry, research, community, and regulators.	Industry-led; others marginal or absent.
Governance	Multi-core, shared across stakeholder types.	Centralized around dominant firms or sectors.
Innovation & strategic focus	Systemic, cross-sectoral, sustainability-oriented innovation.	Firm-led eco-efficiency and cost reduction.

How do stakeholder types occupy positions in H4C networks and contribute to the ecosystem?

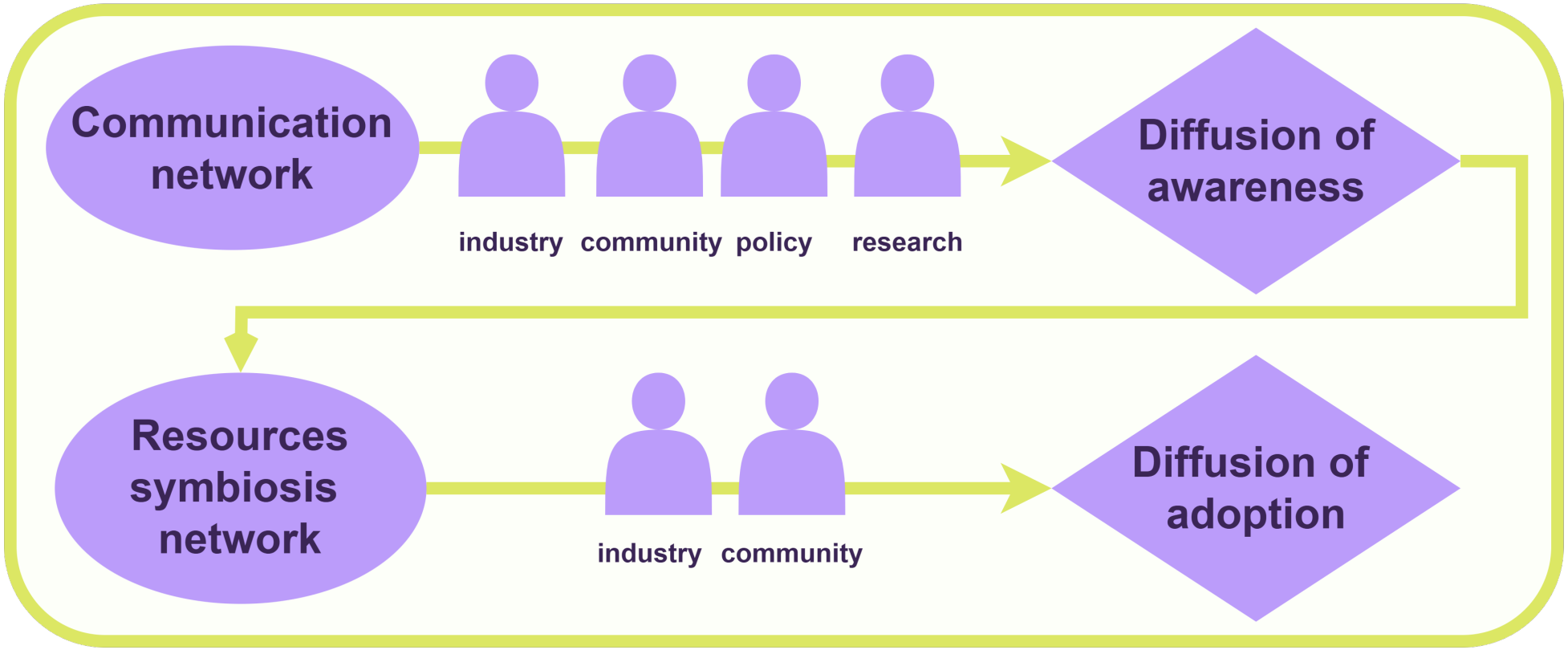
Actors	Characteristics
Industrial entities	Structurally central; act as anchor nodes.
Research & technology	Bridge actors enabling knowledge transfer.
Community actors	Central or peripheral depending on governance and engagement.
Regulatory bodies	Peripheral; influence through policy and funding.

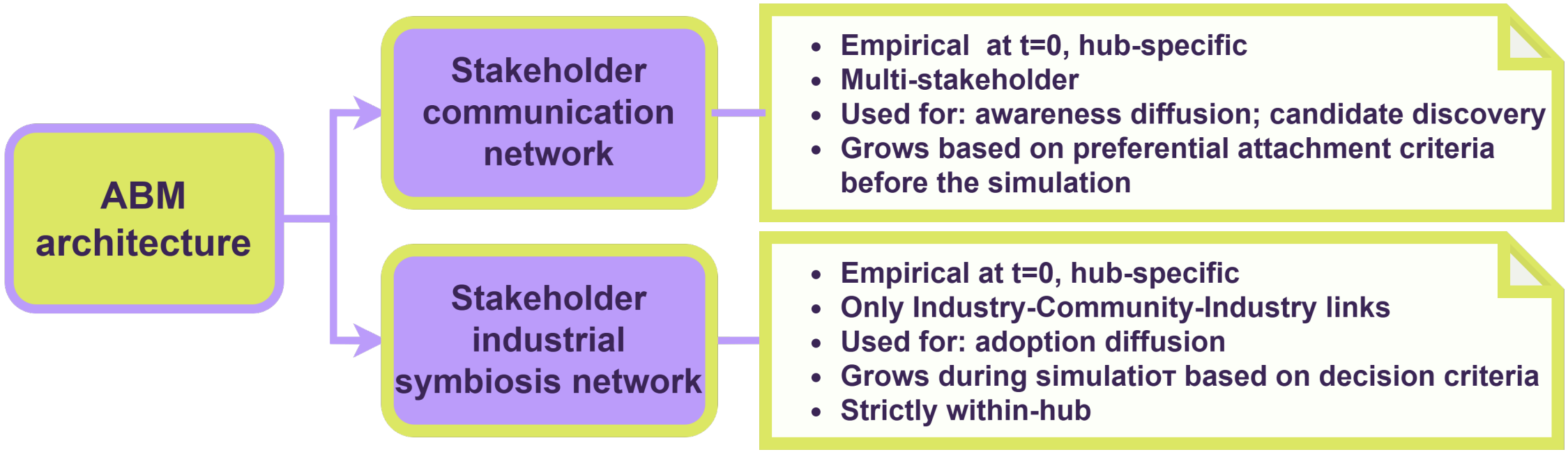
Stakeholder positioning reveals governance dynamics:

- Research actors act as informal regulators and mediators.
- Formal regulators' peripheral position highlights procedural bottlenecks delaying shared-infrastructure approvals.

Step 3: Diffusing

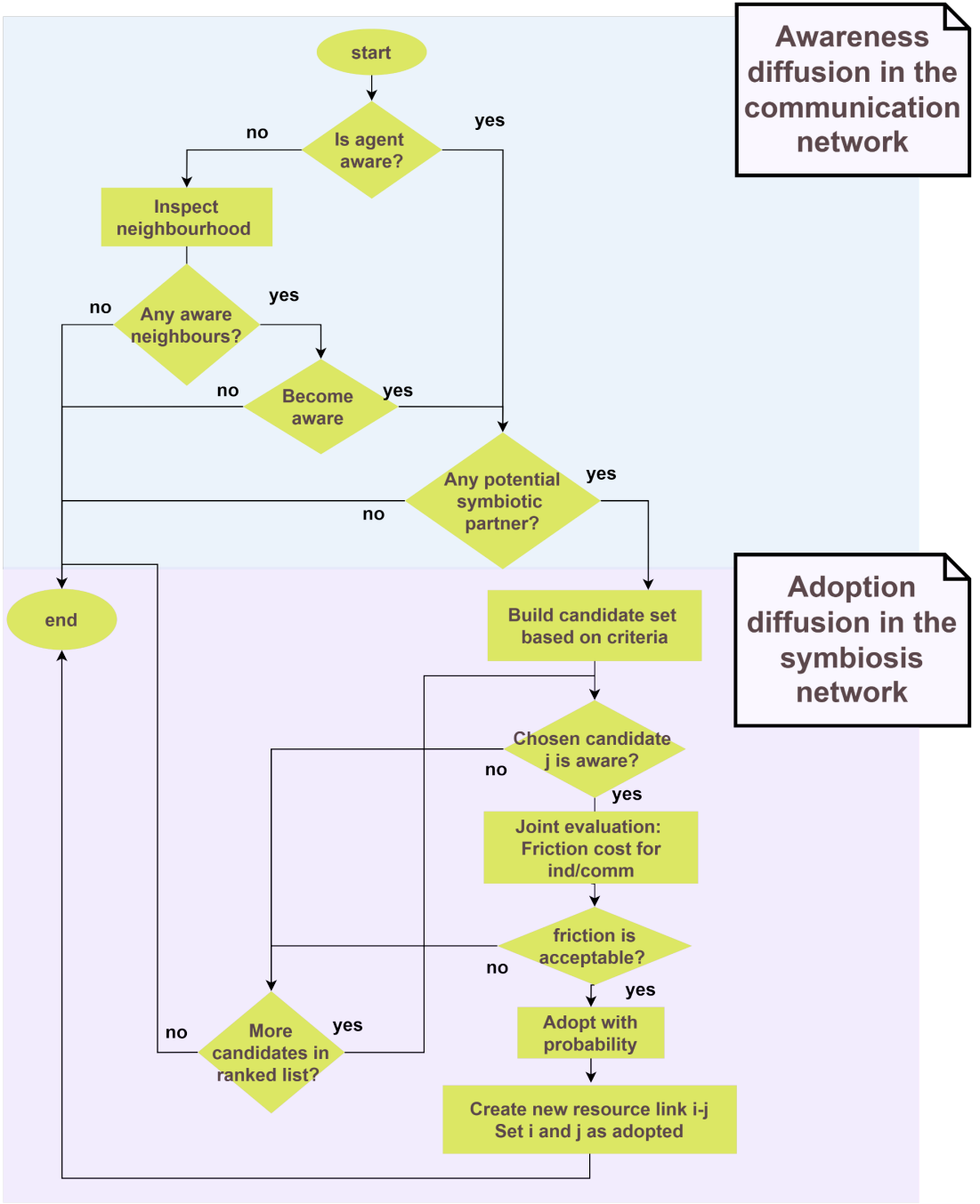
How does communication helps hubs to expand?




ABM architecture
Stakeholder communication network
Empirical at t=0, hub-specific
Multi-stakeholder
Used for: awareness diffusion; candidate discovery
Grows based on preferential attachment criteria before the simulation
Stakeholder industrial symbiosis network
Empirical at t=0, hub-specific
Only Industry-Community-Industry links
Used for: adoption diffusion
Grows during simulatioт based on decision criteria
Strictly within-hub

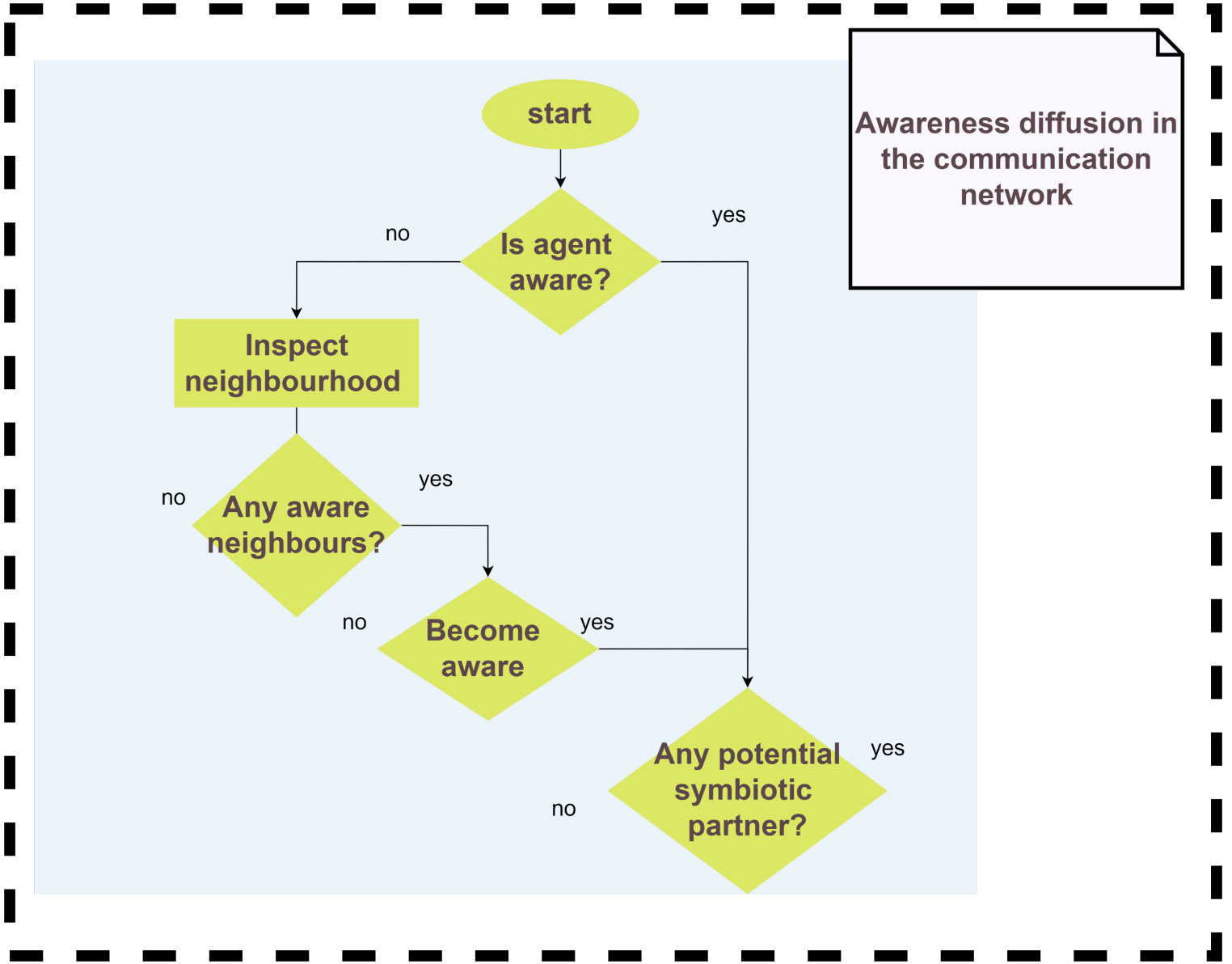
Decision-making algorithm

- Awareness diffusion in the communication layer (about industrial symbiosis opportunities nearby)
- Adoption diffusion in the resource exchange layer (involving into industrial symbiosis)



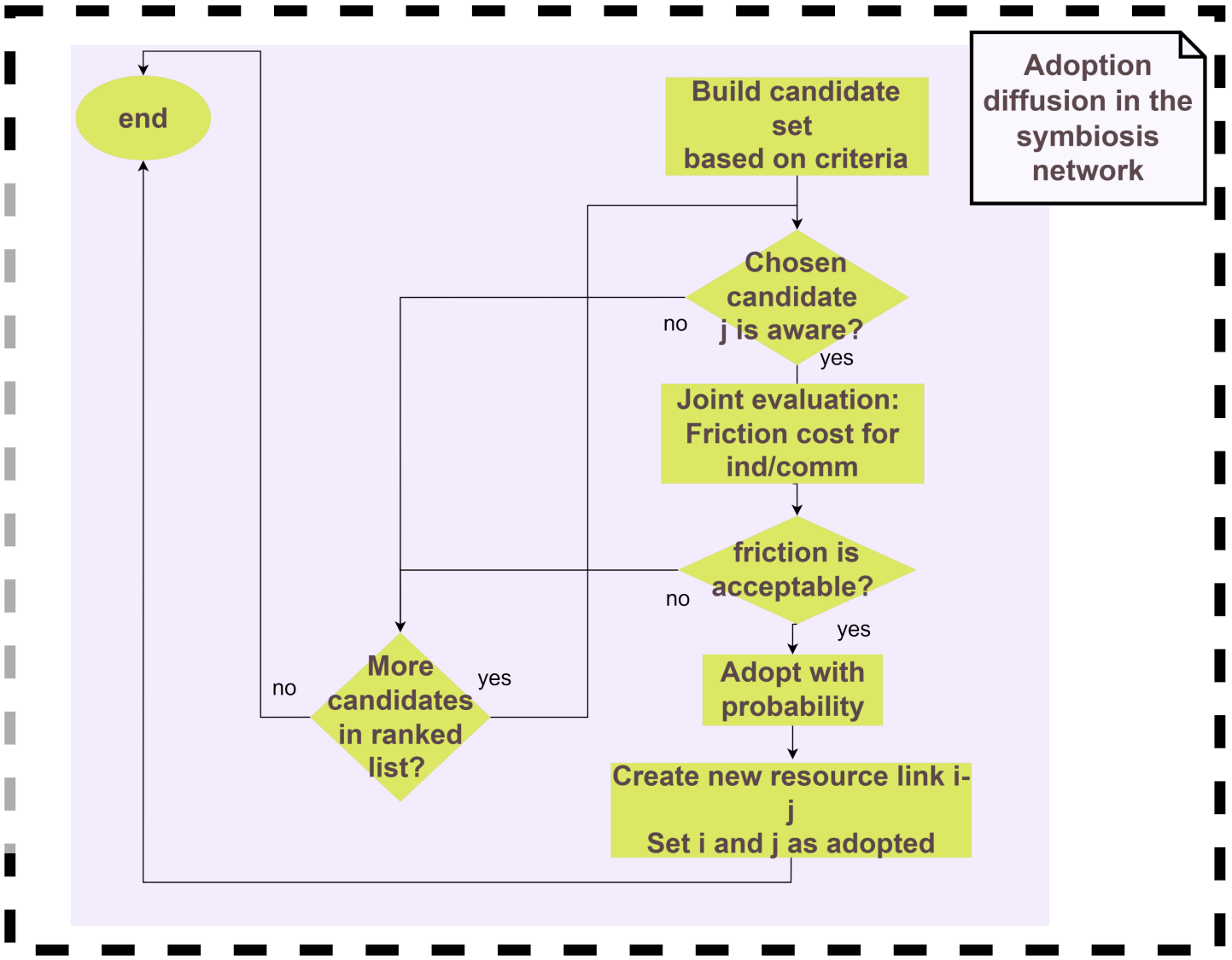
Form an awareness link if:

- Agents are in the same hub,
- One of the agents is aware of symbiotic opportunities



Form an adoption link if:

- Agents are in the same hub,
- Agents are either Industry or Community,
- Agents are aware,
- They are connected in the communication network,
- At least one of them is synthetic (new to network),
- They haven't already adopted with each other,
- Acceptable friction cost



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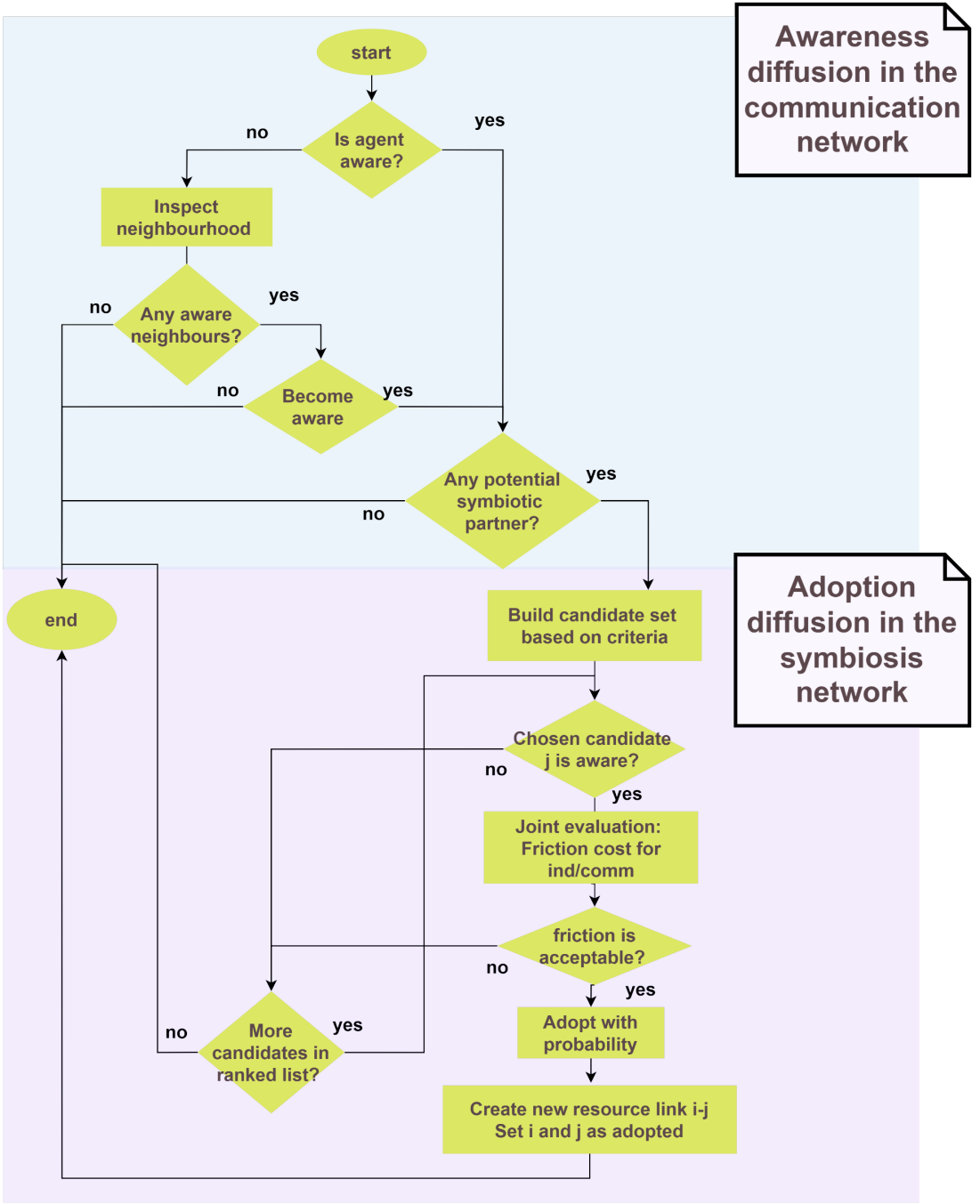

Further steps

- Step 4: Research economy-wide effects of H4C using input-output modeling.

THANK YOU!

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