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Using systems analysis to evaluate interventions towards sustainability in artisanal and small-scale gold mining

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Research question and methods

- Past interventions to address mercury use in ASGM (in Madre de Dios, Peru) had limited impacts on persistent challenges: How can systems-oriented analysis help advance understandings about ASGM in Madre de Dios and implications of different kinds of interventions?

- Systems-oriented, matrix-based, and networks oriented approach using the Human-Technical-Environmental (HTE) framework
- Drawing from the existing literature and extensive ethnographic field work and stakeholder engagement

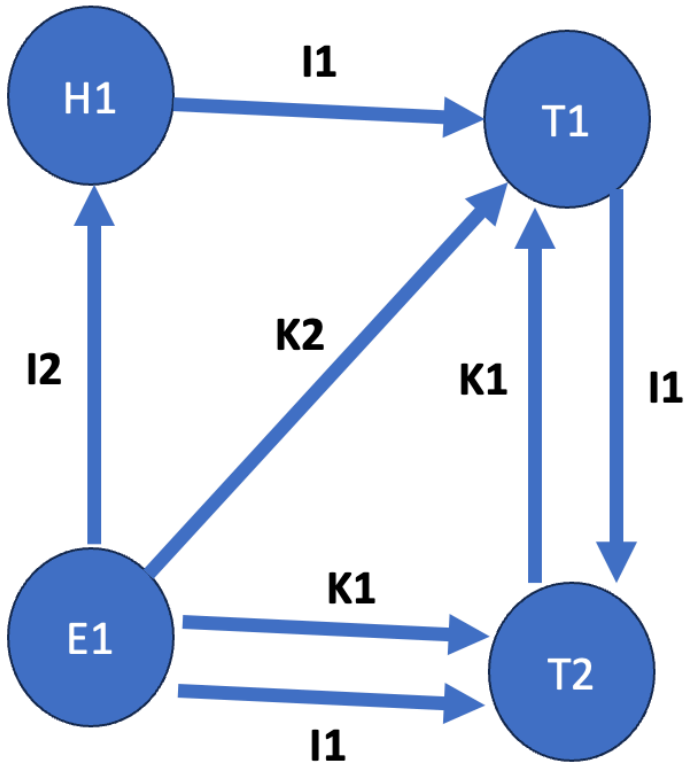
Systems-oriented HTE framework research steps

- Identify sets of system components that are central to a system from a sustainability perspective – 30 components in our analysis
  - Material Human, Technical and Environmental components
  - Non-material Institutions and Knowledge components
- Create a present-day base-case interactions matrix of a system (ASGM in Madre de Dios), which can also be shown as a network representation
  - Identify key components and pathways related to sustainability outcomes
- Validate base-case system description qualitatively, and testing against a past case
- Use the interaction matrix and network description to examine results of simulated future interventions
  - Examine changes in selected key pathways related to sustainability outcomes
  - Examine network centrality of components related to sustainability outcomes

HTE framework and network analysis

	H1	T1	T2	E1
H1		I1		
T1			I1	
T2		K1		
E1	I2	K2	K1,I1	

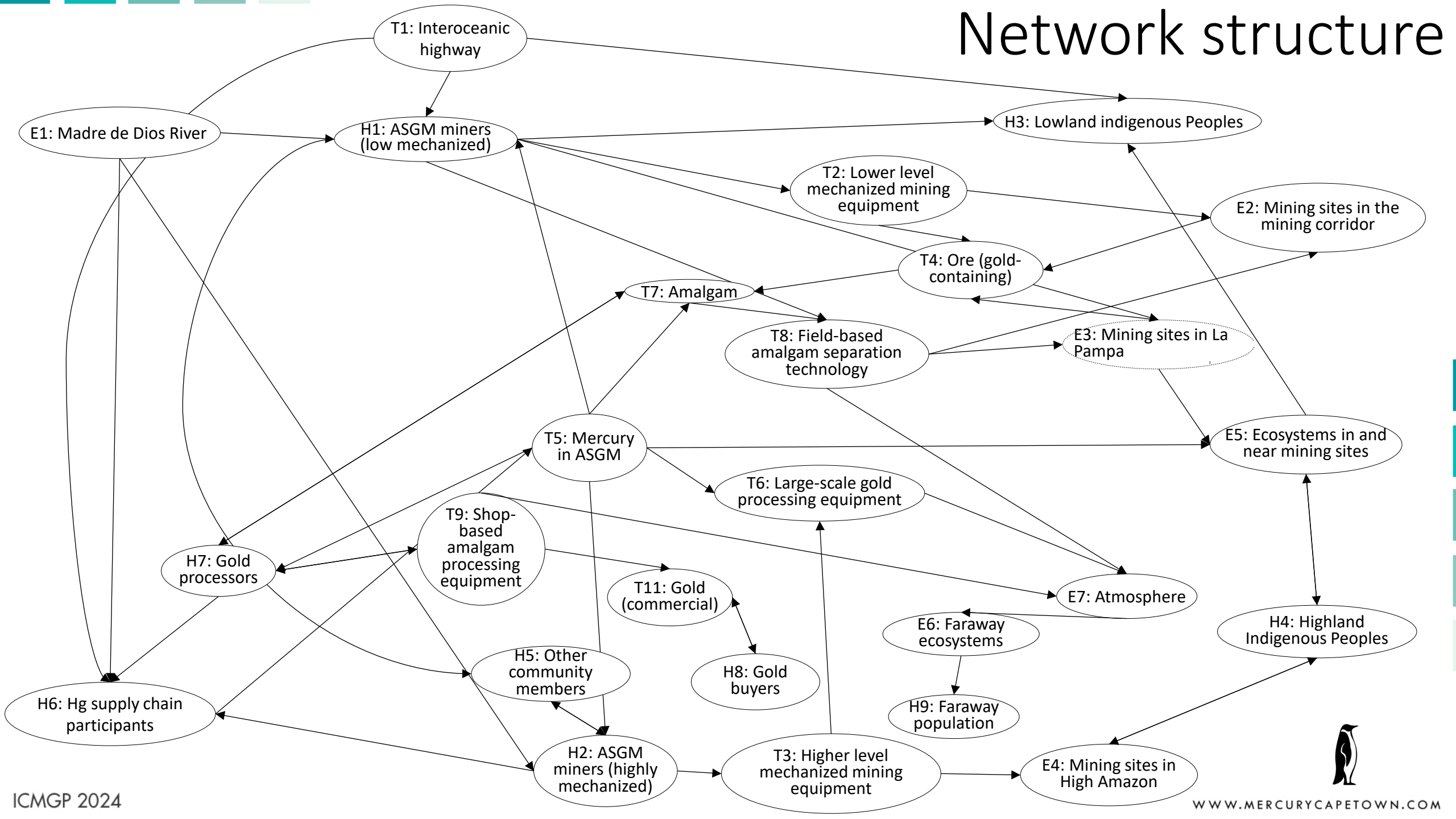
HTE matrix with one human component, two technical components, one environmental component, two institutional components, two knowledge components



Network corresponding to the matrix

Selin and Selin, *Sustainability Science, 2023*

Network structure

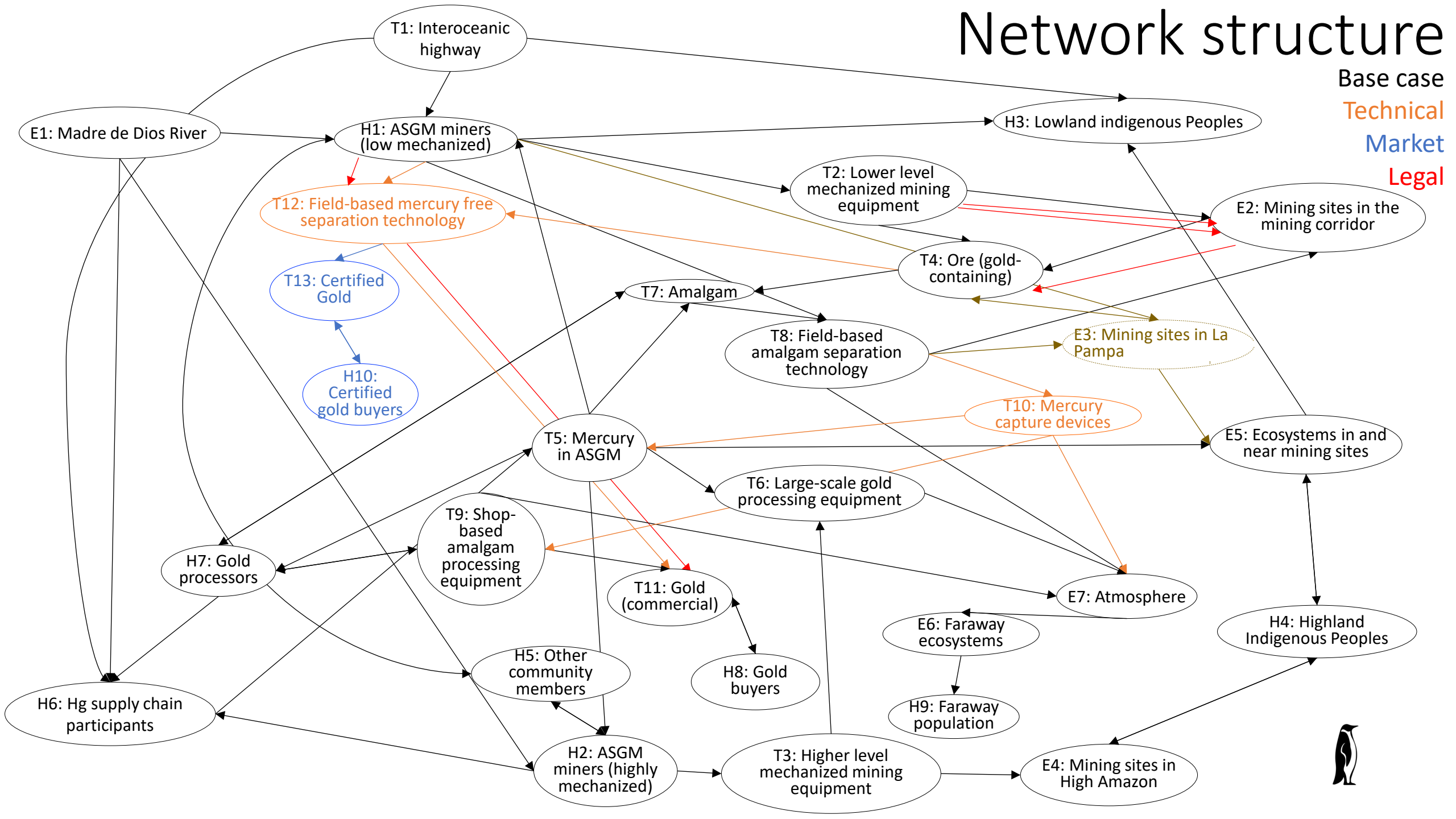


Interventions: Past and simulated

- System description and network test case case: Physical disruptions based on previous “Operation Mercury”
- Three prospective intervention cases
  - **Technology-focused** interventions disseminating low- and mercury free mining methods
  - **Market-based** interventions to create certification mechanisms for clean gold mining practices
  - **Legally-based** interventions to formalize mining and implement action plans under the Minamata Convention on Mercury
- For each case, we constructed a modified interaction matrix and network description, simulating the actions of an intervener by changing one or more components and/or interactions

Network structure

Base case
Technical
Market
Legal



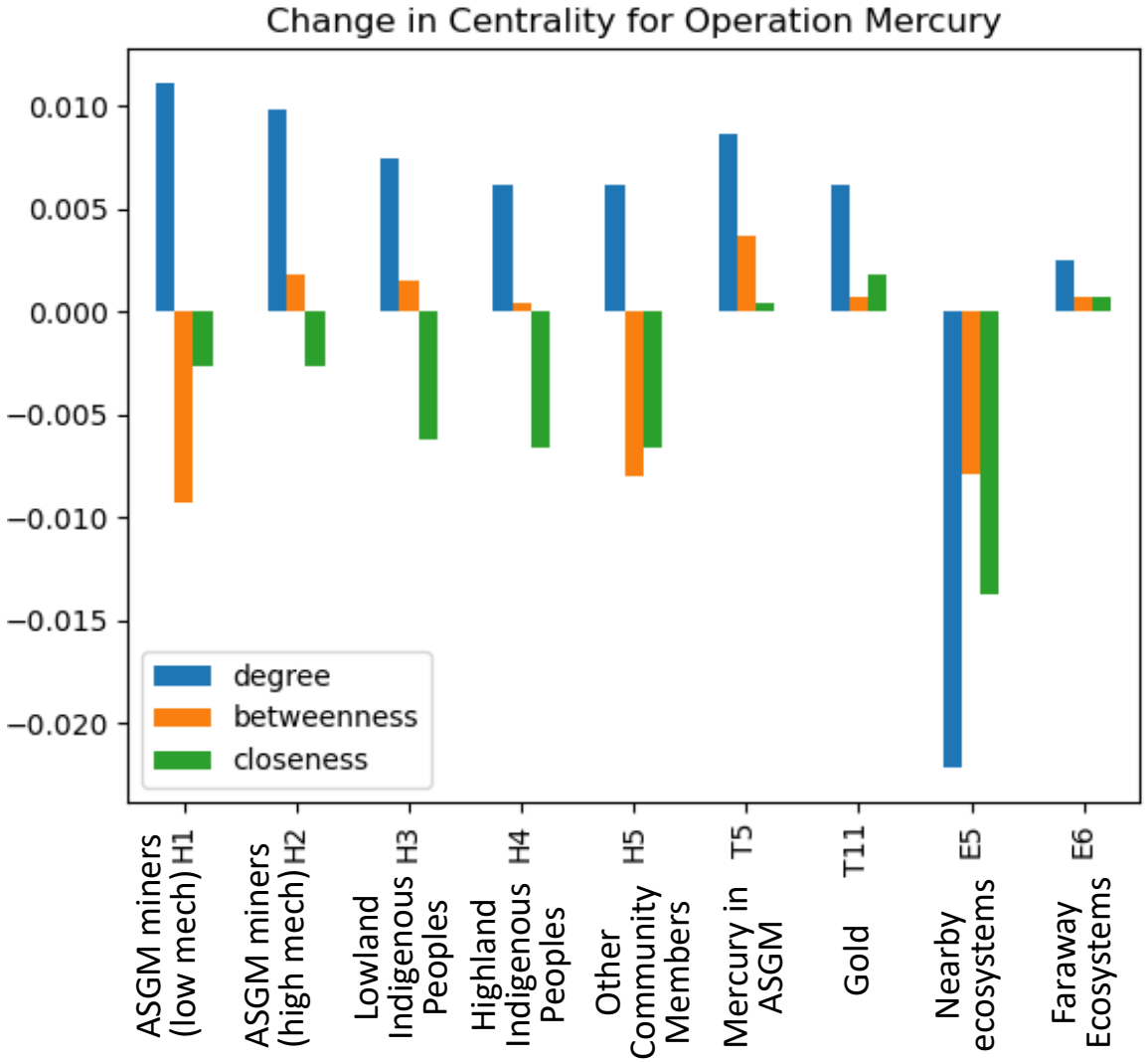
Selection of key pathways and sustainability aspects

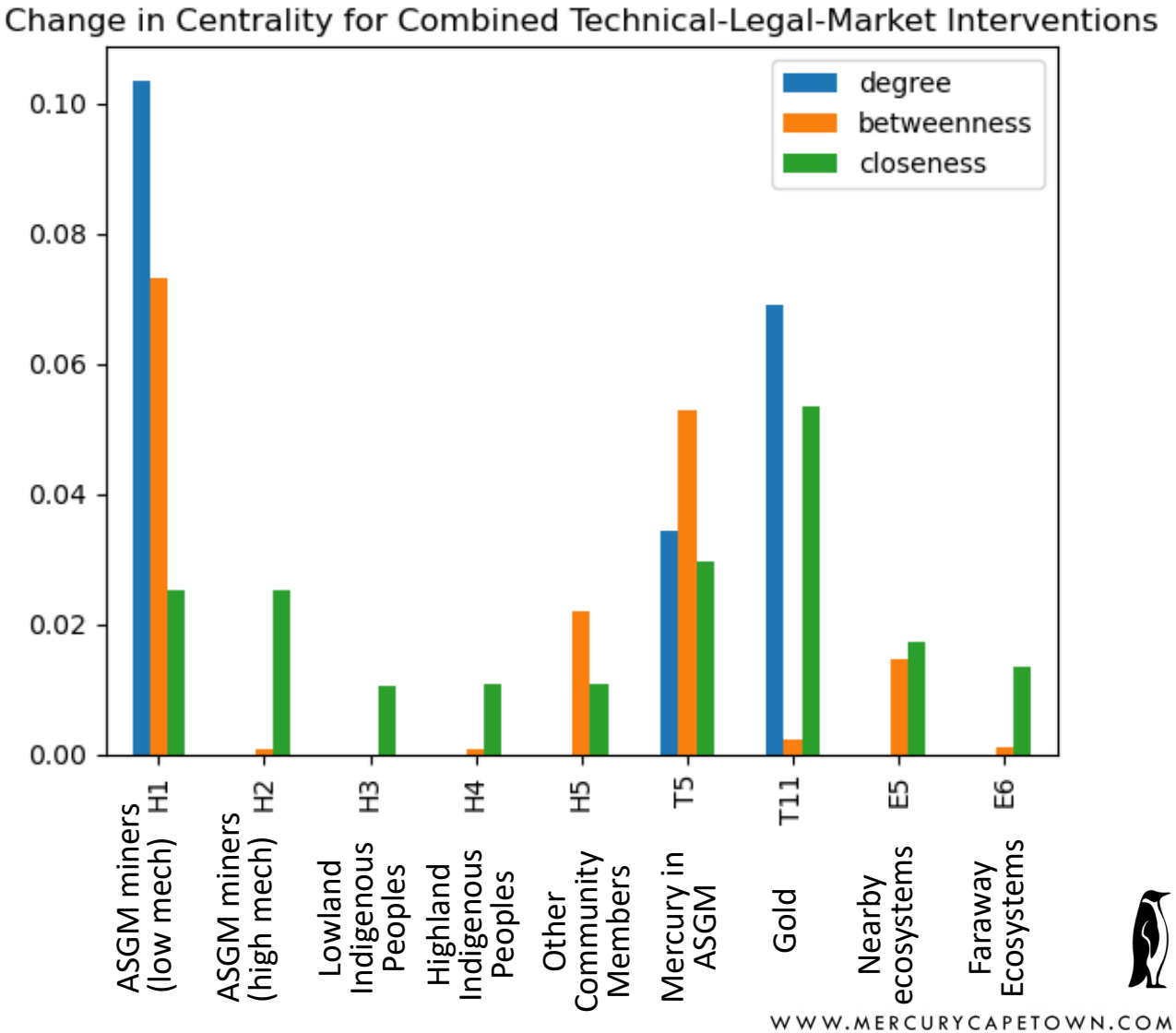
Selection of analyzed pathways and components	Sustainability aspects
Pathways between ASGM miners (H1/H2) and gold buyers (H8/*H10); pathways influencing and centrality measures of gold (T11)	**Livelihood**: ability to earn an income
Pathways influencing Indigenous peoples (H3/H4) and other community members (H5); pathways influencing and centrality measures of ASGM miners, indigenous peoples, and other community members (H1/H2/H3/H4/H5)	**Societal**: impacts on non-mining populations
Pathways between mercury used in ASGM (T5) and faraway ecosystems (E6); pathways influencing and centrality measures of ecosystems in and near mining sites (E5), centrality measures of mercury used in ASGM (T5)	**Environmental**: local and long-range impacts on ecosystems

Network analysis of centrality

- Network centrality as a way to measure the degree to which a particular component is central to a network – H, T and E components
  - Degree centrality: Number of connections that each individual node has in a network
  - Betweenness centrality: How often an individual node lies on the shortest pathways between other nodes in the network
  - Closeness centrality: How close or distant an individual node is to other nodes in a network
- Networks with a few highly connected nodes robust to random failures (e.g. resilient), yet vulnerable to targeted attacks on nodes central to a system
- Nodes with high centrality could be important leverage points for interventions aiming to change how a system functions

Results: Centrality of components





Implications and Future Work

- A complex case but systems-oriented analysis can help think through both intended and unintended consequences of specific interventions
- Further work to assess details of technical, market, and legal interventions in Madre de Dios and other mining areas
- Further explore how different kinds of network centrality measures can inform both analysis and policy-making
- Further analysis of how ASGM cases can feed into the literature on sustainability transitions and transformations (ecological modernization)

More on the HTE Framework and mercury

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Thank you! Questions?