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(De)naturalizing knowledge ecosystems: on the use of ecological metaphors in STS and innovation studies

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ABSTRACT

Ecological metaphors are ubiquitous but largely uncontested in discourses about the changing dynamics of knowledge production and circulation. Both formally and colloquially, scholars, policymakers, and entrepreneurs use the knowledge 'ecosystem,' and 'ecology' metaphors to describe science dynamics parallel to the way ecologists have understood the dynamics of natural systems. So far, STS has paid very little critical attention to the origins and implications of these metaphors. But, it is important to understand how using ecological metaphors frames technoscience culturally and politically. Four uses of the knowledge ecosystem and ecology metaphors emerge from disparate historical contexts and with different political-epistemic implications. As *analytic principle*, ecological metaphors pop up in early STS; around the same time, they circulate frequently as *management tools* for companies in knowledge management studies; a *policy model* in innovation studies expands the knowledge ecosystem to include epistemic interactions between companies, governments, and universities, akin to the materialization of technoscience at the science park; and as *socio-political framework*, knowledge ecologies challenge the hegemonic, globalized science system and present alternative, post-capitalist knowledge practices, grounded in experiences from the Global South. This genealogical multiplicity of ecological system metaphors problematizes their colloquial use in STI policy and scholarship. Thus, STS has to put its mouth where its money is: further naturalization of neoliberal science as the ecosystem is risky amidst accelerating socio-ecological crises. Besides contesting and refusing specific uses of ecological metaphors, the re-evaluation and renewal of knowledge ecologies should take both political-economic assumptions and ecological consequences seriously.

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Introduction

Ecosystems are everywhere. At least, one encounters this ecological metaphor more and more often in the worlds of science and innovation policy, university governance, and studies of knowledge. Politicians, policymakers, business leaders, and researchers join science, research, or innovation to 'ecosystem' and 'ecology,' to stress the promise of new interactions, solutions, and value. For example, recent policy briefs from Dutch and Belgian Ministers for Science and Economic Affairs present their 'ecosystem approach' to achieve 'societal impact' with science and innovation (Crevits, 2019; EZK and OCW, 2020). In the EU policy realm, the latest guiding principles for valorization urge to 'encompass the entire research & innovation ecosystem and its increasingly diverse range of actors' (Council of the European Union, 2022). Globally, different bodies mobilize 'knowledge ecosystems,' from the International Alliance of Research Universities emphasizing the value of fundamental research, to the International Network for the Availability of Scientific Publications striving for equitable research systems in developing countries (IARU, n/d; INASP, 2020).

More often than not, ecological metaphors are used to signal new modes of ordering – organizing, orienting, and executing – research and innovation practices. But to what end? Some view ecological metaphors in a progressive sense as a challenge to, or improvement of, the dominance of economistic or neoliberal discourses about university practices. Kinchin (2022) observes the rise of ecological metaphors in higher education studies as a critical alternative to the dominant 'industrial root metaphor' in the neoliberal university, which Wright (2016) likewise calls the 'anthropocenic knowledge economy' discourse surrounding scientific research. More descriptively, Klein (2023) interprets ecological metaphors as 'boundary discourse' in inter- and transdisciplinary research, where they afford the emphasis of *balance* between forms of expertise. While critical reviews of knowledge ecosystems in academic and policy debates have interpreted the eco-talk as a form of depoliticization. Ecological metaphors then offer an 'ahistorical, aconflictual, asocial and indeed aideological' framing that does not pay due to 'the complexity of the socially dynamic environment of knowledge and innovation' (Papaioannou et al., 2009, p. 320).

More regularly, such critical reflexivity is wanting when ecosystem and ecology are used metaphorically in science, technology, and innovation studies (STIS). And also from these few studies cited above, no coherent view emerges on how, why, and with what implications ecological metaphors are used to portray knowledge dynamics. To further comprehend the use of ecological metaphors in STIS, it makes sense to understand where 'knowledge ecosystem' and 'ecologies of knowledge' came from. The main contribution of the genealogical analysis, presented below, is the description of four singular uses of these systematic ecological metaphors, originating in distinctive

historical and practical contexts. The central question for this literature analysis is *how* do eco-metaphors permeate STIS? The discussion will also reflect on the adjacent issue of metaphorical power: to *what end* are these metaphors mobilized, for maintaining or challenging the status quo?

Thus, I describe both the social-epistemic characteristics and political implications of using ecological metaphors for knowledge production. First, I reflect on the ways metaphors are at work in technoscience and ecological ones in particular. Next, I set out the terms on which I have analyzed the literature on knowledge ecosystems and ecologies, and how I came to distinguish different genealogical threads. The body of the paper describes four genealogies and uses extensively. In the discussion, I compare the different and overlapping histories, epistemologies, and politics of the ecological metaphors for knowledge dynamics. In closing, I draw conclusions for STI studies, policy, and practice in the face of ecological destruction and much-needed socio-ecological transformation.

Analytic perspectives

Metaphors at work in technoscience

Like daily life, the practice of technoscience is brimming with figures-of-speech, myths, and metaphors. Principally, metaphors do work when they suggest one thing 'is like,' but 'is not,' this other thing. A metaphor allows to 'pick and choose the attachments we take seriously, and those we ignore' (Cowan and Rault, 2022, p. 11). A metaphor can therefore be judged on its *function,* rather than its correctness*:* 'what advantages and disadvantages it entails, what understandings it reveals and obscures' (Proctor and Larson, 2005). Metaphors, then, can be grasped as 'framing devices' that 'frame worldviews and political common sense' (van der Weele and van den Boomen, 2008, p. 2). Hence, the cultural and political situation of technoscience can be elicited by following metaphors in action – where they come from and what they are made of, how they are mobilized, and what they 'drag into' discourses. Consequently, metaphorical language has enjoyed ample attention in STS, the feminist branch especially, as demonstrated by special issues in *Configurations* (van der Weele and van den Boomen, 2008) and *Catalyst* (Cowan and Rault, 2022).

Central in these critical approaches to technoscience is a concern with metaphorical *power*. Metaphorical framing devices are most powerful when they pass unremarked and uncontested, and at the same time, the choice of metaphor can reveal whose interests are being served (Cowan and Rault, 2022). What to do about this, as an STI critic, depends partly on what one thinks metaphors *are like*: whether they reflect, construct, transform, resist, mediate, or manage reality (van der Weelen and van den Boomen, p. 3–4). One can,

firstly, explicate a metaphor's *multiplicity*, but typically STI critics are called upon to also *contest* uncontested language so as to deconstruct and thwart hegemonic relations embedded in discourse. Similarly, various authors have hailed the transformative potential of metaphor: 'paradigm change comes through the collective refusal of some metaphors, through the re-evaluation of others, and the introduction of new metaphorical frames and figures to reorient our work' (Cowan and Rault, 2022, p. 5).

This malleable character and transformative potential of a metaphor stands in a tension to limitations emerging from its conceptual and material history. Obviously, metaphors travel continuously, during which 'their form and action may change. Metaphors in action may become weaker or stronger, get new interpretations, shift frames, clash or blend' (van der Weele and van den Boomen, 2008, p. 3; Louçã and Cabral, 2021). It might not be easy to unknot, then, to what extent transformations are due to trivial interpretations by specific actors or due to the intrinsic potentiality and material history of the metaphor itself. Metaphors are not simply abstract linguistic concepts but always carry along the 'worldviews, legacies, values, and problems of those who make them' (Cowan & Rault, p. 4). Discussing Tuck & Yang's influential claim that 'decolonization is not a metaphor,' Cowan & Rault admit that one can choose to ignore or instrumentalize such inheritance but that this might 'effortlessly reproduce ongoing legacies of injustice and violence' (ibid).

Use and abuse of ecological metaphors

Therefore, some discussion is warranted of the historical conditions in which the scientific concept of *ecosystem*, itself a metaphor, emerged and circulated. Famously, English ecologist Arthur Tansley introduced it in his paper 'The use and abuse of vegetational concepts' to clear up ambiguous language in the emerging study of natural systems (Tansley, 1935). Basing himself on engineering concepts, Tansley incorporated organic and inorganic factors into equilibrium-seeking systems. Notwithstanding his drive for clarity, historical studies of ecology have shown that the concept of the ecosystem has been neither static nor uncontroversial and that it has hovered between three metaphorical figures of machine, organism, and thunderstorm (Golley, 1993; Bocking, 1994; Keller, 2005). Importantly, a shift took place in the 1970s, when mechanistic physics was disregarded as a source of (metaphorical) inspiration in favor of complexity science: the field began to move from equilibrium and stability as central features of ecological systems toward complexity and resilience (Walker and Cooper, 2011; Cameron and Earley, 2015). Whereas the equilibrium-seeking image of the ecosystem idealized nature as in balance, the resilient ecosystem represented nature as instable, as a sequence of continuous extreme disturbances, to which species and biotic communities adapt more or less successfully.

Within the field of ecology, commentators have pointed out how many concepts served 'not just as description but as ethical imperative or political program: amalgams of nature and culture' (Bocking, 2015, p. 490). For example, the use of ecosystem in postwar North-American system approaches, inspired by cybernetics, reinforced technocratic politics and the metaphor of nature as a production system made possible ecosystem service management's pursuit of both environmental protection and business development (Taylor, 1988; Norton and Noonan, 2007). The ecological metaphor has also been contested within ecology, for example, because of the democratic deficit inherent in the 'economization of nature' or the cooptation of once leftist resilience theory into neoliberal policies of continuous crisis (Walker and Cooper, 2011; Cameron and Earley, 2015).

These historically adaptable ecological concepts also traveled, again as metaphors, to other worlds of practice and politics (Greer and Cameron 2015). In economics, especially, ecological system metaphors have been rapidly adopted to grasp the complexity of the market. 'Bionomics' rephrased the market economy in terms of a living, evolving ecosystem, and 'business ecosystem' was used to reinterpret competition in terms of predators and preys (Rothschild, 1992; Moore, 1993, 1996). The field of *evolutionary* economics, as pushed by Nelson and Winter (1982), viewed the economy not in neo-classical mechanistic terms (derived from physics) but as a self-evolving system with complex interdependencies. However, the pertinence of metaphors like selection environments and mutations to socio-technic dynamics was also challenged, because it would fail to capture the purposiveness and complexity of innovation (Freeman, 1991; Louçã and Cabral, 2021). In more economic subfields, the circulation of eco-metaphors has been contested, for example, in technology management, industrial ecology, and business studies (Korhonen, 2004; Hess, 2010; Oh et al., 2016).

Metaphors for changing knowledge dynamics in STIS

Within STS and innovation studies, plenty of metaphors, figures of speech, and buzzwords have circulated to grasp complex, systematic knowledge dynamics. Especially since the late 1980s, many different more and less figurative terms were introduced in academic and policy circles to signal changes in the systems of research and innovation. Terms like mode-2 knowledge production, techno-economic networks, post-normal science, hybrid forums, and triple helix, all describe in one way or another the inclusion of a wider variety of interactions between science and nonscientific actors (Elzinga, 2004; Schiemann et al., 2011). As metaphors proliferated, many lamented the 'old wine in new bottles' or the rediscovery of Bacon's *New Atlantis* (Weingart, 1997; Godin, 1998). Others criticized these discussions by emphasizing the lack of problematization of the political-economic conditions under which science was taking

place or by proposing alternative metaphors that resolved shortcomings (Klenk, 2018; Oudheusden, 2020). Amidst this hubbub, *ecological* metaphors for changing knowledge systems have received remarkably little critical attention.

Here, I will map out the mushrooming of knowledge ecosystem and ecology metaphors in the field of science and technology studies broadly conceived. Following the (feminist) STS tradition of metaphoric analysis, I unearth the historical conditions of emergence and multiple uses of largely uncontested ecological metaphors for knowledge dynamics (van der Weele and van den Boomen, 2008; Cowan and Rault, 2022). This analysis aims, at minimum, to demonstrate the *multiplicity* of the knowledge ecosystem metaphor to make it *contestable*. The issue at stake is what world the use of these metaphors makes possible, and what (power) relations they are challenging and/or naturalizing.

Research approach

To unpack the histories, epistemic perspectives, and normative orientations of ecological metaphors for knowledge dynamics, a literature search has been conducted in multiple steps between July and December 2022. First, the term 'knowledge ecosystem' (and linguistic variants) and, second, 'knowledge ecologies' and 'ecologies of knowledge' were used as queries in two publication databases – Web of Science (WoS) and Dimensions (DIM). This approach combined the authoritative and highly selective WoS with the newer but much more comprehensive and diverse DIM database (Visser et al., 2021). Table 1 below summarizes the number of results and removed duplicates. The limited overlap between DIM and WoS speaks to the value of combining databases. Next, all abstracts of the remaining 770 publications were reviewed to exclude papers without relevance to the topic of knowledge production and circulation, leading to a final database of 520 publications published between 1982 and 2022 (see Table 1).

This extensive body of literature was digested in two complementary ways. First, I focused on knowledge *ecosystems*, read review articles (6), backtracked foundational texts, and studied several recent case studies (11). Based on this exploratory approach, I decided to expand the literature search to *ecologies* of

Table 1. Literature sample.

Query	Database	Results	Duplicates	Exclusions	Selection
'knowledge ecosystem' OR 'knowledge ecology' OR 'ecologies of knowledge'	WoS (title, abstract, key)	314		−75	239
	DIM (title, abstract)	618	−162	−175	281
Total sample for review		932	−162	−250	**520**
1980–2018: 20 > citations					45
2019–2022: 7 > citations					29
Sample for text analysis				2	**72**

Table 2. Overview of thematic codes for text analysis.

Themes	Codes	Justification
Ecosystem/Ecology *coherent and distinctive definitions in literature*	[analytic principle] [management tool] [policy model] [socio-political instrument] [research system] **excluded** [biodigital system] **excluded**	grounded
Knowledge (type) *organizations and actors that are considered part of a ecosystem/ ecology*	[industry & business] [science & technology] [government & policy] [local, indigenous & other]	
Knowledge (modality) *forms of knowledge that are defined or implied in use*	[codified] [digital] [tacit] [embodied] [commodified]	grounded
Knowledge circulation *models of epistemic interactions in ecosystem*	[linear] [cyclic] [integrated] + [linear- reverse] [loss]	Smit and Hessels (2021) + grounded
Value regime *ways in which 'value' is used*	[market] [efficiency] [fame] [civic] [green] [creativity]	Thévenot et al. (2000)
Value creation *processes that convert knowledge into value'*	[co-creation] [commercialization] [consumption] [commodification] [emancipation] [democratization] [application] [intervention] [decision-making] [use] [fail]	grounded

knowledge, as this was used interchangeably with *ecosystems*. At this point, a first hypothetical segmentation of the literature emerged that, subsequently, I tested and refined with a more systematic approach. A selection of highly cited papers (72), taking historical accumulations into account, was close-read and coded. The legitimacy of these quantitative thresholds was confirmed by the fact that all papers deemed significant in the first round were included.

In Atlas.ti, a thematic coding approach was used to collect knowledge ecosystem definitions and to track related approaches to knowledge and value (see Table 2). Initial distinctions between the uses of knowledge ecosystem and ecology emerged inductively. These were refined and tested in the systematic literature analysis until segmentation into four genealogies was reached. From the exploratory analysis, two discourses already emerged, viz. the discussion of knowledge ecosystems in relation to business and innovation ecosystems (e.g. Clarysse et al., 2014), and preceding debates in corporate knowledge management studies (cf. Thomson et al., 2007). Through the systematic citation analysis, the ecology metaphor in STS and the ecologies of knowledge tradition in postcolonial studies (Santos, 2007) were also included, both with clear relevance and theoretical sophistication. At this stage, two minor hypothetical definitions, viz. 'research (eco)system' and 'postdigital bioinformational' ecosystems, were excluded, respectively, for reasons of poor conceptual development and limited circulation.

For the thematic literature analysis, general categories of knowledge actors (scientific, industrial, governmental, and other) were taken as a starting point and a provisional distinction between knowledge circulation processes (linear, cyclic, and integrated) was based on Smit and Hessels (2021).

Subsequently, cross-cut analysis of these thematic codes leads to the inductive addition of, or division into, subordinate codes. For example, additional codes were created for the *modality* of knowledge in codified, tacit, digital or commodified forms and a new knowledge circulation code was added ('reverse linear') that challenges hegemonic epistemologies. To gauge the political implications of different metaphorical uses of ecosystem, I coded discussion of value and value creation in this subset of articles, based on the insight of valuation studies that politics is not just about 'how to accumulate value, but to define what value is' (Graeber, 2013). This allowed us to trace the inscription of ecological metaphors into diverse value regimes in public discourse, which represent 'foundational choices about what is to be counted, visible and present' (Bigger and Robertson, 2017). As initial differentiation, I followed the branched categorization into ideal types of market, industry, environment, public, creativity, and credibility regimes (Thévenot et al., 2000). The value *creation* codes were composed bottom-up based on the insight that valuation is much more diverse than value (Bigger and Robertson, 2017; Muniesa, 2017).

The following section is based on the discussion of these different analytical dimensions per genealogical strand, which I grasp as distinctively coherent uses of ecological metaphors in studies of knowledge. Each subsection describes a different genealogy along the three axes used in the literature analysis. First, it presents a definition of the knowledge ecosystem and its historical context of emergence. Second, the corresponding approach to knowledge is discussed, according to what actors are considered and by which modalities knowledge is supposed to circulate between them. Lastly, I reconstruct their value orientation in terms of the value regimes the ecological metaphor relates to.

Four genealogies of knowledge ecosystems and ecologies

The following sections describe four conceptual genealogies that were analytically discerned in the literature on ecological metaphors for knowledge production. These different renderings of the ecosystem and ecology concepts have been labeled as analytic principles, management tools, policy models, and socio-political frameworks, respectively. For each concept, the historical context of emergence in terms of practical and/or disciplinary concerns is discussed, followed by their respective approach to knowledge circulation and value creation. In the discussion, I compare the different conceptualizations to address the paper's second research question: what epistemic politics do studies of knowledge stimulate, perpetuate or reproach by using ecological metaphors?

Ecological metaphors as an analytic principle in STS

One of the historically first coherent uses of ecological metaphor to grasp dynamics around knowledge production is found in methodological debates

within the North-American history and sociology of science. In the 1980s, Charles Rosenberg introduced *ecologies of knowledge* as heuristic to stress, first of all to fellow historians, that complex interdependencies between institutional, economic, social, and intellectual dimensions should be taken into account in studies of science (Rosenberg, 1998). This principle resonated with the broader, epistemological, and ontological view of the then rising social studies of science: scientific research is not simply the abstract discovery of true facts, but rather the socio-material production of epistemic claims, bounded by institutional, economic, and cultural factors (Rosenberg, 1998). Indeed, Susan Leigh Star titled her book *Ecology of Knowledge* – first unaware of, but later complementary to Rosenberg's work – to advocate for a systemic approach to (understanding) science as an ecosystem, a 'set of linked interdependencies inseparable from personal troubles, public issues and social change agendas,' without exiling any 'dysfunctional parts' (Star, 1995, p. 2).

These authors use the ecological metaphor to prescribe an analytical principle of 'complex interdependencies between the social dimensions of science and its constitutive knowledge and material practices' (Akera, 2007). Early studies typically take scientific disciplines, university laboratories, or research departments as their empirical focus (Kohler, 1982; Rosenberg, 1998). While later studies push for the *democratization* of science studies by including the entire 'ecosphere: bugs, germs, computers, wires, animal colonies, and buildings, as well as scientists, administrators, and clients or consumers' (Star, 1995, pp. 13–14). Indeed, the affordance of the ecological metaphor is precisely to move beyond institutionalized forms toward grasping the 'loosely coordinated technical exchanges' that are increasingly important to multi-sited scientific and engineering work (Akera, 2007, p. 413). Knowledge ecologies are not only seen as improvement to traditional, isolated views of science but also as challenging the 'flat ontology' of actor-network theory (ANT), an alternative constructivist approach (Akera, 2007, p. 414). Knowledge ecology, by contrast, is used to emphasize multi-layered institutions and material infrastructures, or 'networks-without-voids' (Star, 1995, p. 27; Figure 1).

The emerging use of this rendering of knowledge ecology reflects developments in science studies to expand the scope of relevant actors in knowledge production. As the production of scientific knowledge is the field's main interest it remains primarily interested in the epistemic practices of *scientis*ts and *engineers* and the familiar institutions in which these take place. Also, the concept of knowledge circulation is quite advanced. Colloquial words like knowledge 'transfer' or 'diffusion' are rejected or reformulated in to such terms as 'associative and dissociative' processes of 'extension and realignment of institutionalized practices,' to emphasize that in a knowledge ecology relations are *metonymic* rather than causal (Akera, 2007, p. 427). Thus, knowledge travels not linearly as well-packaged facts, but rather concerns a situated, social process in which practical, cultural, and economic aspects need to be

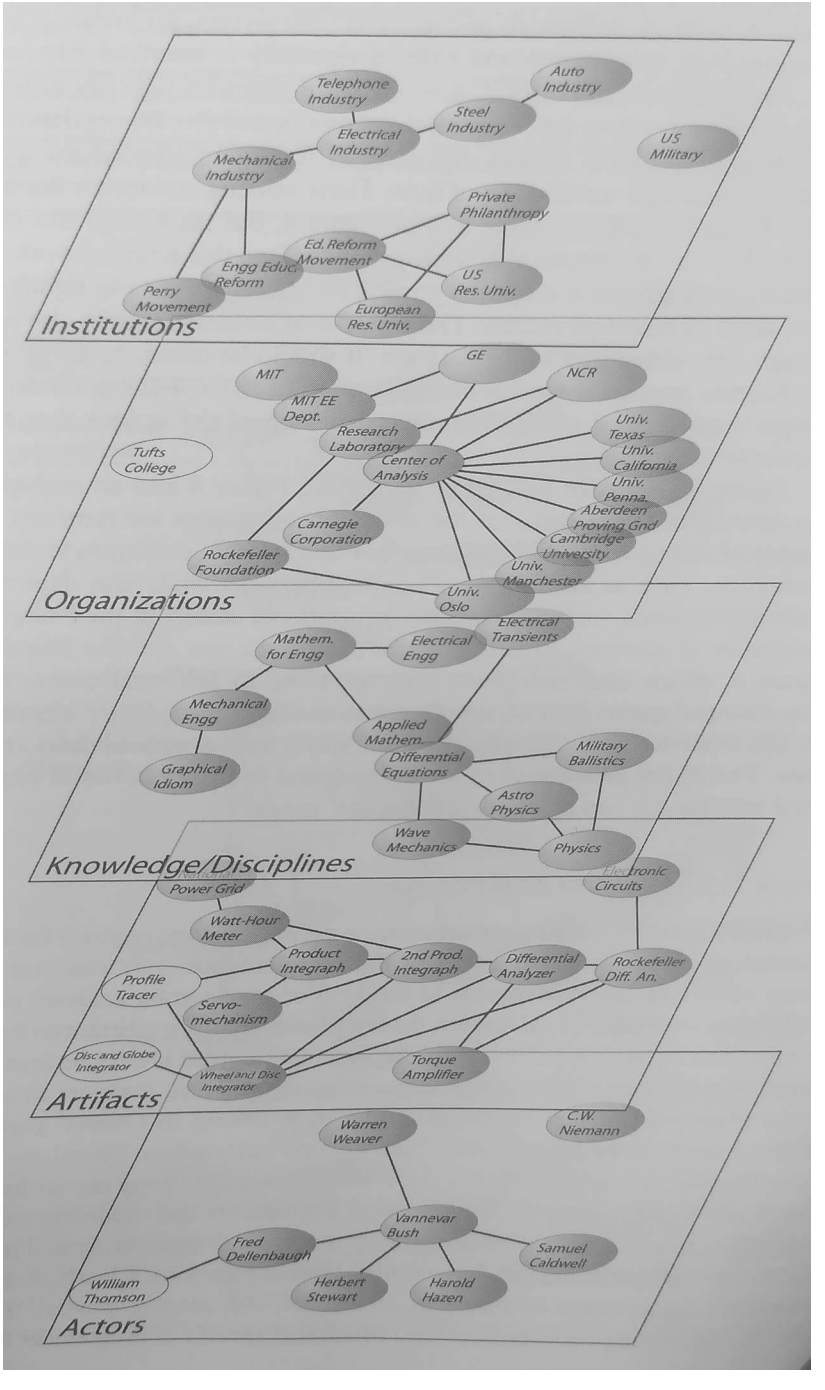

Figure 1. Interpretation of a historical case study as knowledge ecology (Akera, 2007). Copyright: *SAGE Publications* (License number: 5943100584658).

transported as well and knowledge can get lost in the process, i.e. the 'successive reproduction of prevailing institutions, [as well as] the articulation of new ones' (Akera, 2007, p. 428).

In terms of value orientations, authors plying the knowledge ecology as an analytic principle are mostly concerned with intra-scientific heuristic values. Still, this has some wider implications. For example, the awareness that 'needs of society intrude upon the internal texture of academic discourse' suggests that values shape what research (direction) is considered plausible (Rosenberg, 1998). And, attention to the question who benefits from science raises political-economic ('who owns the means of knowledge production'?) and social justice issues (gender, race, class) (Star, 1995). But, used as an analytic principle, ecological metaphors allow for an agnostic stance toward, which values *should* play a role.

To conclude, the *knowledge ecology as an analytic principle* first and foremost covers the production of scientific knowledge as it is used by scholars who aim to open up the (academic) analysis of science and technology. Its attention to democratization and metonymy suggest socially progressive orientations are possible but also allows for a more pragmatic and agnostic stance.

Ecological metaphors as knowledge management tool

Knowledge ecologies appeared in the knowledge management literature around the same time as its use in science studies. Historically, a 1998 reprint of Rosenberg's ecology of knowledge article in an edited volume on 'the rise of the knowledge worker' connects the two (Rosenberg, 1998). The professional and scholarly field of knowledge management acknowledges that 'knowledge work' has always been around but also observes a new level of intensity in the attempts of the business community to apply 'managerial practices of commerce … to the collection, use and assessment of knowledge' (Cortada, 1998, p. 4). The studies of knowledge work aligned with new imaginaries such as the knowledge society or economy in which knowledge figured as a valuable asset for companies in a globalizing economy (Drucker, 1993; Godin, 2006). Innovative Japanese 'knowing organizations' often served as paradigm in this context (Nonaka and Takeuchi, 1995).

In this context, the ecosystem is wielded as a *management tool* to understand, streamline and improve the ways in which commercially relevant knowledge circulates between units within one company (Bowonder and Miyake, 2000; Bray, 2007). This use of the knowledge ecology concept traces back to two influential American and Japanese management traditions: the works of Davenport and Prusak (1997) on 'information ecologies' and Nonaka and Konno's (1998) concept of 'ba,' or the 'context, situation and semantic space in which knowledge is created, shared, utilized and memorized as knowledge asset or intellectual capital' (Konno and Schillaci, 2021, p. 494). Concurrent with the ecological perspective on the organization was the rise of ICT, so that digital infrastructures are often implied in, or explicated as, knowledge ecologies (Slavazza et al., 2006; Thomson et al., 2007). Although I limit discussion here to *intra-organizational*

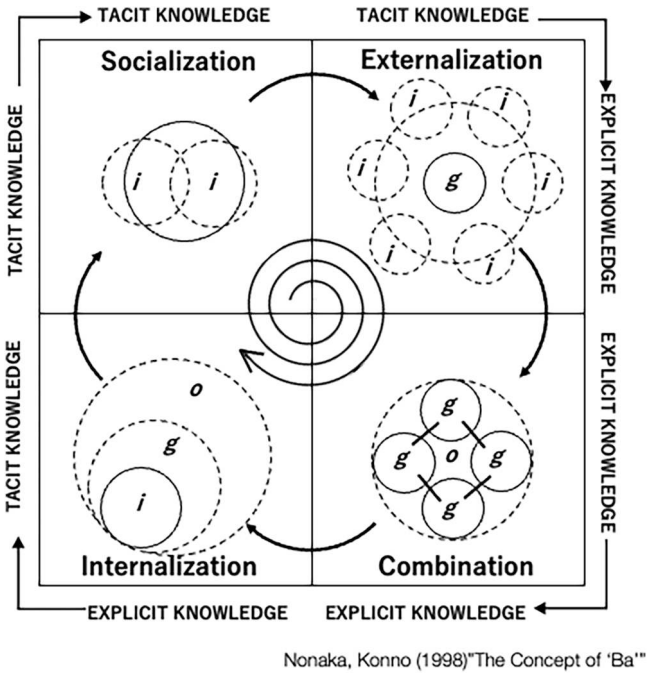

Figure 2. SECI model of an in-company knowledge ecosystem (Nonaka and Konno, 1998). Copyright: *SAGE Publications* (License number: 5943100429351).

knowledge ecologies, later studies problematized this conceptual limitation and opened the way toward inter-organizational ecologies and the inclusion of technoscience (Sharma and Bhattacharya, 2013; Konno and Schillaci, 2021).

Central to this use of the ecological metaphor for knowledge management, is the questioning of a static codified view of knowledge. Instead, authors propose a 'more holistic' perspective on knowledge as 'a fluid mix of framed experience, values, contextual information, and expert insight' (Snowden, 2000). A lot of attention therefore goes to the integration of codified or articulated knowledge with *tacit* knowledge, as the basis for organizational strategies (Bowonder and Miyake, 2000). The Japanese *knowing organization* scholars elaborated this in the influential 'SECI model' that describes the process of knowledge creation in a firm as a continuous spiral of Socialization (acquire tacit knowledge of users' experiences), Externalization (explication in words and concepts through dialogue and thought in 'ba'), Combination (systematize explicit knowledge, e.g. into prototypes) and Internalization (converting explicit knowledge again into new experiences and tacit knowledge) (Nonaka and Takeuchi, 1995; Konno and Schillaci, 2021). Looking back, Chatti (2012) argues that this ecological view (still) represents a linear and static view of knowledge creation as a predetermined technology-dependent process, ignoring processes of error correction or unlearning (cf. Sharma and Bhattacharya, 2013; Figure 2).

Whenever *knowledge ecology* is used as a *management tool*, knowledge is consistently rendered the main *asset* or resource for a firm's value creation. Knowledge is managed and mobilized to expand market share, increase sales or reduce costs. Thus, it is about 'exploiting knowledge assets to the fullest potential' (Sharma and Bhattacharya, 2013, p. 102) or how to 'acquire, develop, measure, distribute and provide a return on their intellectual assets' (Snowden, 2000, p. 264). The overarching goal is to improve competitive advantage and growth of a firm, or the possibility to turn out profits at the expense of competitors. Subordinated to this economic frame of accumulation are values like efficiency, productivity, innovation, decision-making, and customer relations as well as 'organizational resilience' in 'hyperturbulent environments' (Bray, 2007). The dominance of the market value regime leaves little place for cultural values, environmental concerns or citizens beyond a role as consumer.

To conclude, the *knowledge ecosystem as a management tool* is concerned with optimizing the use of knowledge in companies in ecological terms and is motivated by the belief that knowledge can be an asset for a firm's long-term economic sustainability and value.

Ecological metaphors as science & innovation policy model

As awareness grew that knowledge assets do not only reside *within* the firm, but also in a larger web of actors and organizations, the ecosystem metaphor also started to be used in a wider sense as *model* for science and innovation policy. Important voices in the context of a globalizing and digitalizing knowledge economy were Chesbrough's *open innovation* business model and Moore's *business ecosystem* strategy, who called on (tech) companies to let go of control and combine internal and external ideas, value and ecosystems (Moore, 1996; Chesbrough, 2003). Scholars in regional studies and economic geography connected these open business models to innovation policy, interpreting ecosystems literally as 'territorial innovation models' for regional development (Moulaert and Sekia, 2003; Scaringella and Radziwon, 2018). Subsequently, this came connected to the call on, and desire of, universities to engage more with their environments, as formulated in the triple- and quadruple helix models, which de- and prescribed increased interactions and blurring boundaries between university, industry, and government to achieve socio-economic development (Miller et al., 2016).

Employed as policy model, the ecological metaphor is used to highlight both the importance of inter-organizational processes as well as knowledge organizations to (technological) innovation. One prominent definition speaks of 'geographical hotspots' around public research organizations where interdependent, heterogeneous actors and organizations together generate, cocreate and exchange knowledge in a pre-competitive setting (Clarysse et al., 2014; Valkokari, 2015).

This definition builds on American examples like Silicon Valley and is further developed in European case studies of the High Tech Campus Eindhoven and the Flanders start-up region (Borgh et al., 2012; Clarysse et al., 2014).

Co-location or geographical proximity is emphasized here, facilitated by the territorial affordance of the ecosystem metaphor (Scaringella and Radziwon, 2018). Another strand in this literature, however, de-emphasizes the territorial aspect and instead underlines the virtual or emotional proximity achieved through digital means (Grabher et al., 2009; Radberg and Lofsten, 2023). This *virtual collective* reformulation of the knowledge ecosystem allows authors to employ the concept in a wider variety of situations and scales, from public–private research programs to global digital platforms (Ketonen-Oksi and Valkokari, 2019; Abbate et al., 2022). Notable for territorial and virtual ecosystems is the special attention for public research organizations, as well as the inclusion of boundary and governmental organizations, such as regulatory authorities, standardization bodies and legal institutions (Thomas and Autio, 2020; Figure 3).

Following this central role of public research actors, it is often generation of 'new' and 'pre-competitive' knowledge in decentralized networks that is of concern when the ecosystem is discussed as policy model (Järvi et al., 2018). In contrast to the knowledge management tool, the creation of knowledge in pre-commercialization settings is not directly commodifiable into patents but rather provides a 'shared resource' or 'knowledge base' that no partner could have created independently (Thomas and Autio, 2020; Cobben et al., 2022). Again, the importance is acknowledged of tacit knowledge, now to be

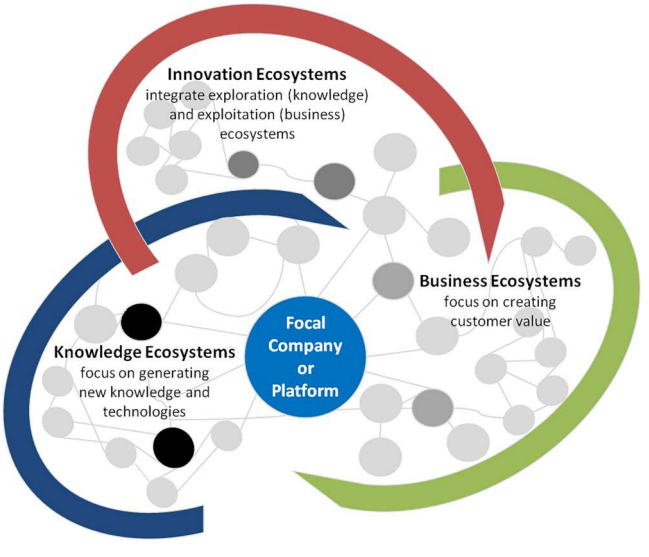

Figure 3. Knowledge ecosystem in relation to business and innovation knowledge ecosystems (Valkokari, 2015). Source: https://www.timreview.ca/article/919.

transferred between university and industry, 'embodied' in mobile personnel (Attour and Lazaric, 2020; Ghazinoory et al., 2021). This relates to what some economic geographers have called the 'local buzz, global pipeline' model (Bathelt et al., 2004): localized face-to-face interactions as well as the circulation of codified scientific knowledge globally The overall emphasis on interactivity between actors leads many studies to describe knowledge circulation in cyclical terms as processes of collaboration, co-creation, sharing and collective learning (Aksenova et al., 2019; Abbate et al., 2022). Still, some studies assume a linear relation from scientific knowledge production to commercial development and exploitation (Clarysse et al., 2014), stimulated by boundary spanners or brokering organizations (Miller et al., 2016).

This linear residue is strengthened by an implicit overarching value orientation toward economic value creation (Papaioannou et al., 2009). In various instances, the success of a knowledge ecosystem is measured in terms of its development into, or fruitful exploitation in, a business and/or innovation ecosystem (Khademi, 2020). The virtual collective modification reiterates these value assumptions, as knowledge ecosystems are presented as engines for national competitiveness, growth and well-being (Järvi et al., 2018; Aksenova et al., 2019). The addition of well-being does show that alternative values or purposes are sometimes discussed. But as Cobben et al. (2022) remark, non-economic goals like sustainability, social impact and responsibility have so far not been extensively taken into account. Still, some commentators hope that the rising attention for sustainability will spark a shift from the dogma of exchange value toward concepts of value-in-use or 'purposeful value creation' (Ketonen-Oksi and Valkokari, 2019).

To conclude, the knowledge ecosystem as a *policy model* focuses primarily on the knowledge interactions between science, business, and government and is (still) closely tied to the objectives to generate competitive advantage for companies and/or overall economic growth.

Ecological metaphors as framework for social movements

Globalization of the economy was the direct backdrop to the previous two uses of knowledge ecosystems that, in fact, seem to have employed the ecological metaphor as an instrument in management and policy to align knowledge production with this wider expansion of neoliberal practices. Simultaneously, scholars from the majority world adopted an ecological metaphor for knowledge dynamics to make sense of, and support, the emergence of a social movement that promoted anti-capitalist alternatives to globalization. Concretely, this concerned experiences at successive World Social Forums – international meetings of civil society organizations – that were organized in Porto Alegre, Brazil from 2001 onwards (Santos, 2008). Subsequently, Boaventura de Sousa Santos has been central in elaborating these experiences theoretically into the 'ecologies

of knowledge' as a counter-hegemonic epistemic framework. Since, this approach has been further developed in higher education, postcolonial and international studies by mostly South-American and African authors. Aims are to 'call into question taken-for-granted power structures in the knowledge production and transmission environment' (Zondi, 2018), counter the 'epistemicide,' or cognitive colonialism, committed by Northern countries (Guzman-Valenzuela and Gomez, 2019; Sharma, 2021), and promote Southern epistemic practices (Santos and Meneses, 2019; Ndlovu-Gatsheni, 2021).

In this context, actors use the ecological metaphor as socio-political framework to underline epistemic pluralism, first in general as epistemology, and second, knowledge ecology is used to describe particular instantiations of such plurality. In the general sense, it is formulated as a counter-epistemology to the 'monoculture' of modern and Western science that claims one objective truth (Santos, 2007, 2009; Andreotti et al., 2011; Sharma, 2021). Instead, when the ecological metaphor is used to frame and guide social movements, it acknowledges the existence and legitimacy of countless ways of knowing, substantiated by ontological, cultural bio- and/or social diversity (Ndlovu-Gatsheni, 2018; Zondi, 2018; Giatti, 2019). In specific situations, ecologies of knowledge are 'assemblages of diverse knowledges in dialogue and interaction,' between which no a priori hierarchies exist (Guzman-Valenzuela and Gomez, 2019). Ultimately, 'ecologies of knowledge' are discussed as collective, horizontal constructions that contribute to social justice strategies (Santos and Meneses, 2019).

Following these pluralist aims, the ecological metaphor is used to recover silenced voices and reinforce subjugated knowledges, such as lay, indigenous, practitioner, artisanal, etc. knowledges. Scientific traditions are not deliberately discredited, but these authors do explicitly recognize different theoretical renderings of knowledge as such. The criteria for what counts as credible, rigorous, and valid knowledge are plural and embedded in socio-cultural systems and political economies of knowledge production (Guzman-Valenzuela and Gomez, 2019; Walker and Boni, 2020). In a specific ecological exercise, relevant knowledges are identified ('artisanship of practices') and compared to identify each their 'ignorances,' bring out interdependencies, and enable pluralistic learning ('translation') (Santos, 2009; Andreotti et al., 2011). Lastly, knowledge relates directly to action as it is only in intervention that the relative importance of different knowledges becomes clear (Santos, 2007). Again distancing themselves from modern epistemic ideals (e.g. the representational idiom of truth), these authors transform this conceptual insight into practical methodologies that emphasize the participation of broader social groups and the inclusion of nonscientific knowledges. Approaches like participatory action research (PAR), transdisciplinary practices, or the idea of the 'pluriversity' can undo cognitive exclusions and lead to non-extractive and convivial relations (Pezzani and Heller, 2013; Ndlovu-Gatsheni, 2018, 2021; Giatti, 2019; Mason et al., 2021; Figure 4).

In terms of value orientation, this socio-political use of the ecological metaphor tags on to worldwide struggles against interrelated forms of domination (e.g. racist, sexist, and capitalist) to provide an epistemic dimension to global solidarity. As is often repeated in this literature: 'no social justice without cognitive justice' (Santos and Meneses, 2019). The pluralist affordance of knowledge ecologies functions as a strategy for the *democratization* of knowledge, not just in terms of equal distribution but especially in terms of emancipation of alternative and subjugated knowledges. Non-epistemic values and concerns, relevant to specific social and political struggles, define the selection and evaluation of relevant knowledges (Santos, 2009; Andreotti et al., 2011). Thus, these authors challenge head-on the hegemony of the market as valuation principle (Sharma, 2021). Recently, some have extended the cognitive justice rationale behind their use of knowledge ecology to include ecological justice. Whereas, technoscience would sustain 'the global conditionings of unsustainability and scarcity,' the ecological pluralist approach would more fully recognize 'planetary human entanglements' in support of just transitions (Giatti, 2019; Ndlovu-Gatsheni, 2021).

To conclude, *knowledge ecology as framework for social movements* shares some epistemic insights and principles with the other concepts, such as its

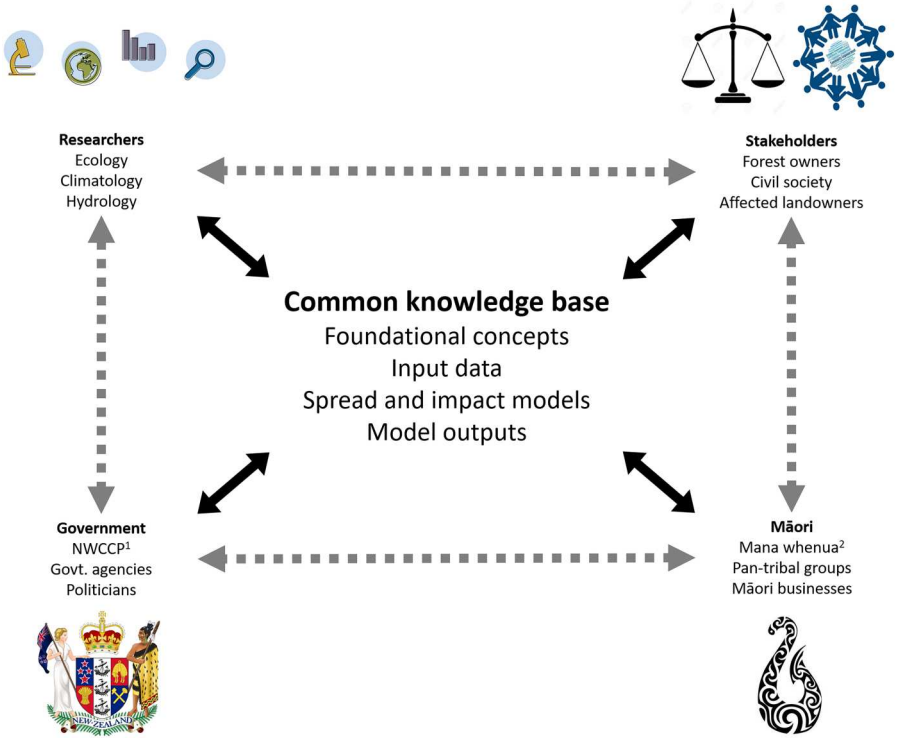

Figure 4. Pluralistic knowledge ecosystem for a case study on New Zealand forest management (Mason et al., 2021). Copyright: *Springer Nature* (License number: 5943091350232).

focus on pluralism, heterogeneity, intervention and democratization. But, this use of the ecological metaphor is explicitly counter-hegemonic and challenges the socio-political order in and around science, technology, and innovation.

Discussion

The four different uses of knowledge ecology and knowledge ecosystem overlapped historically, and sometimes also conceptually. This segmentation is, ultimately, a construct of the questions asked by this study and thus ideal typical to a certain degree. It is no indisputable result and some authors can be found to move at and over the borders between the knowledge ecological discourses (e.g. Massumi, 2000; Konno and Schillaci, 2021; Mason et al., 2021). However, recounting, diagonally, the historical conditions of emergence, approach to knowledge and perspective on value, allows us to draw out diverse political implications of these distinctive uses of ecological metaphors for knowledge production.

Historical conditions of emergence

The genealogical differentiation of eco-metaphors has been largely disciplinary in nature, following the use of academic publication databases. As a result, the analysis touched upon debates about the social construction of knowledge in social studies of science and technology, about new business models and regional development in economic geography and knowledge management studies, and about issues of epistemic inequalities and global justice in postcolonial and higher education studies.

Regardless of this disciplinary diversity, the relatively synchronic emergence of the eco-metaphors around the turn of the millennium lines up with the globalization of the economy, following the disintegration of the Soviet Union and integration of the European Union in 1992. Capitalist relations and neoliberal governmentalities spread, in the slipstream of the outsourcing of material production from the Global North to countries in the Global South. In reverse, the economies in the North were perceived to de-materialize, further catalyzed by the digitalization of many spheres of life. These developments increased the attention for and significance of cognitive (or post-Fordist) labor, as well as the localized interactions between businesses and universities, facilitated by the state, in science and technology parks (Moulaert and Sekia, 2003; Scaringella and Radziwon, 2018).

In this historical context, concepts such as the knowledge society, learning economy and knowing organization arose, which align closely with the renderings of the knowledge ecosystem by the employment as *management tool* and *policy model*. Unlike the *socio-political framework*, which explicitly called out globalization and sought, against the current, post-capitalist alternatives. These disparate assessments of the 'global situation' correspond with their respective epistemic geographies in the South or the North (Tsing, 2000).

Heterogeneous and situated knowledges

All knowledge ecology concepts stress the existence of heterogeneous actors but they differ in how strong they elaborate this pluralist position. A weaker epistemic pluralism allows a multiplicity of knowledge *sources or types*, for example, the *policy model* includes circumscribed business, scientific, consumer, and governmental actors in knowledge production, and the *management tool* highlights especially tacit and embodied knowledge within different company units. The *socio-political framework*, on the other hand, emphasizes a stronger plurality of knowledge: knowledge itself is multiple, and the criteria to distinguish what counts as such can vary in place and time. And whereas the *analytic principle* and *policy model* focus on technoscientific practices amidst a complex whole of relations and across scales, the *socio-political framework* explicitly decenters science and technology by treating local, indigenous, artisanal, and other knowledges on equal footing.

Another shared but flexibly interpreted feature is the situatedness of epistemic practices. The *analytic principle* and *socio-political framework* demonstrate a strong theoretical awareness that the production of knowledge is embedded in social, political, economic, cultural, and emotional relations. The *management tool* and *policy model* lack such an epistemological understanding but do emphasize the specific situation of knowledge production in, respectively, competitive and pre-competitive collaborative settings. This economically oriented literature puts effort in conceptualizing knowledge circulation and emphasizes the importance of tacit and embodied knowledge versus digital and codified infrastructures. Phrased otherwise as the 'global pipelines, local buzz' principle, it resonates with the 'extension and realignment' insight of the *analytic principle* that knowledge can only travel when its socio-material context moves with it. The ecosystem as *socio-political framework,* lastly, turns things around by starting from a specific social struggle as the situation for which different knowledges need to be identified, compared, and applied. This entails a more radical, integrative approach that questions power relations and knowledge hierarchies.

Values and valuation

The two value regimes of market and civic were, overall, most present in the knowledge ecology literature (Thévenot et al., 2000). Used as *management tool*, ecological metaphors straightforwardly characterize value in dominant economic, i.e. capitalist, terms. In this understanding, knowledge is the substance of innovation, the basis for competitive advantage and a resource for new value creation. Valuation is monetary in nature and takes place in market practices such as commodification, commercialization, and consumption.

Importantly, this was also the main regime mobilized when the metaphors were used as *policy model*, even though this also prominently includes non-commercial actors such as universities or governmental agencies. In these discourses, then, ecological metaphors seem to be used to further naturalize power relations in the neoliberal knowledge society (Drucker, 1993). But, recently, some authors have called out this predominant market focus that excludes other, e.g. civic and green, valuations, with some putting their hopes on a more value-inclusive 'green growth' future.

Ecologies as *socio-political framework*, on the other hand, are explicitly counter-hegemonic and denounce the capitalist value form altogether. Instead, ecological metaphors activate the civic regime of value to emphasize how knowledges can be valuable in terms of democratization, social justice, and global solidarity. Knowledge appears as a means to these emancipatory ends, an instrument or weapon for social change. Valuation does not take place on the market but as acts of 'translation,' a situated comparison of different knowledges' practical effects for a particular struggle.

As an *analytic principle,* the knowledge ecosystem describes *how* different measures of value impinge upon epistemic practices, without prioritizing any particular value regime. This more agnostic position with respect to epistemic hegemony often seems inclined toward the civic value regime (e.g. democracy and gender issues) but does not condemn market valuation either.

The 'green' value regime, centered on sustainability, was less present than the ecological metaphor might make one expect. This highlights the conspicuously absent discussion of the physical, geological, atmospheric, and more-than-human embeddedness (and effects) of knowledge production and circulation. This reproduces the externalization of nature in neoclassic economy and, in reverse, the ambiguous presence of humans in natural ecosystems (Cameron and Earley, 2015). Only some recent papers suggested that knowledge ecologies, as *policy model* or as *socio-political framework,* could also include this territorial or ecological aspect.

Politics of eco-metaphors for knowledge dynamics

Ultimately, these disparate approaches to value uncover the *politics* of knowledge ecosystems and ecologies because the 'choice of what to include in and exclude from the representation of value is always political' (Bigger and Robertson, 2017, p. 70). Metaphors are a useful site for such political analysis, as they reveal the framing of a particular issue, here the dynamics of knowledge in society.

Like in ecology itself, ecosystem metaphors are used in STIS to capture a process that otherwise is difficult to grasp fully in 'literal' terms (Proctor and Larson, 2005). In this case, it concerns the buzzing microscale interactions and processes of many thousands of heterogeneous human and non-human actors that somehow leads, at macroscale, to a stable or resilient socio-

technic dynamics with some emergent direction to it. Knowledge ecosystems are used to understand this by analogy to natural systems. But the term knows its own multiplicity in ecology and does not prescribe the framing or interpretation of knowledge dynamics.

It is clear now, at least, that the ecosystem metaphor can be used to make historically specific relations between scientific and other actors in current capitalist societies come across 'natural,' as if industry-university links simply exist out there the way predator-prey relations do. While any metaphor might assist in grasping complexity, the choice to use ecological language also naturalizes a hegemonic order of knowledge production that benefits companies and shareholders in Northern societies above all (Harvey, 2007; Walker and Cooper, 2011). On the other end, the ecological metaphor has been invoked to put a spotlight on, and *de*naturalize, these hierarchical power relations in the global epistemic system. This counter-hegemonical use of knowledge ecologies aims to 'shake things up,' transform dynamics between different knowledge producers and upset power relations (Cowan and Rault, 2022).

Paradoxically, then, the ecological metaphor serves both *naturalizing* and *denaturalizing*, hegemonic and counter-hegemonic, purposes with respect to the understanding of complex knowledge dynamics. Hence, the primary tension between the *management tool* and *policy model* on one side, and *socio-political framework* on the other, is an important result of this study. It is this critical comparison of metaphorical multiplicity that explicates 'naturalized' elements of social systems and actually makes possible the contestation of non-controversial parts of the hegemonic value regime. With this in mind, the apparent reluctance to 'take sides' (Star, 1995) when ecology is used as *analytic principle* fails to make existing power relations contestable, identified as a political limitation of STS more generally (Lave et al., 2010).

Conclusion

The main goal of this genealogical analysis has been to make the increasing colloquial use of eco-metaphors visible and *contestable* in the realm of knowledge production. An important result is the differentiation of four historical trajectories in the scholarly literature that reflect different ways of using ecosystem and ecology for the complex dynamics of knowledge in society. The *analytic principle* situates scientific practices in societal relations, the *management tool* emphasizes the pivotal circulation of knowledge within firms, the *policy model* focuses on triple-helix-like interactions between universities, businesses, and government, and the *socio-political framework* challenges the hegemonic organization of science and the economy by contrasting it to social struggle and epistemological pluralism.

These multiple uses of the ecological metaphor in STS and innovation studies demonstrate metaphorical power, in its naturalizing, contesting and

transformative capacity. I have followed feminist STS approaches to metaphorical analysis that elicits the cultural and political situation of technoscience (van der Weele and van den Boomen, 2008). Analyzing knowledge ecosystem literature made explicit what one might 'drag into' a discourse when recycling ecological metaphors (Cowan and Rault, 2022). For STIS scholars and policymakers, the analysis of four different uses implies choice: to reuse, refuse, reevaluate, or reinvent ecological metaphors. Importantly, different uses of the metaphor put different things at stake: the use of ecologies of knowledge as socio-political framework, as initiated by Santos (2007), precisely problematizes the techno-economic networks and political-economic dynamics that other knowledge ecosystem metaphors either implicitly legitimize or explicitly promote.

Specifically, then, I want to *contest* ecological metaphors from a political-economic point of view (Tyfield et al., 2017). As such, I target the common suggestion that invoking ecosystems to reorganize knowledge production is self-evidently benign or that its 'natural' undertone implies transformative socio-ecological action. This is the promise of mission-driven and transformative research and innovation policy frameworks that employ ecosystems as policy instruments to steer scientific and technological development toward public values and the resolution of challenges like the climate crisis (European Commission and Mazzucato, 2018; Schot and Steinmueller, 2018). But, it is precisely in these contexts that critical reflection on political-economic assumptions is lacking, so that ecological metaphors will mostly reinforce existing power relations and profit incentives.

Amidst accelerating ecological destruction, the (ab)use of ecological metaphors is not the most urgent issue. Still, criticism and transformation of the underpinning economic and epistemic systems that created this planetary predicament is much needed. Of course, the hegemonic neoliberal knowledge system geared toward profit and economic growth at the expense of ecological care and global equality has been under fire for longer (Lave et al., 2010). Increasingly, political-economic criticisms also aim to reframe and rephrase our dealings with STI in society, by exploring post-growth scenarios for example (de Saille et al., 2020). For such transformative endeavors, the language we use matters a great deal, not only because it indicates what side we are on but also because metaphors can play constructive roles as 'guiding tools' that direct practices to other worlds (Klenk, 2018). Famously, Donna Haraway's *cyborg* is such an intervention, that wields the power of metaphor (and science fiction) to criticize the patriarchal, white and capitalist status quo *and* imagine other possible worlds and technoscientific relatedness.

It is doubtful whether the knowledge ecosystem and knowledge ecology can play such a transformative role, taking their loaded histories into account. Still, this conceptual genealogy can be a tool for political-economic

criticisms and recurrent denaturalization of STI systems by always asking: What does the eco-prefix add in this particular situation, and what interests, practices, and relations does this language assume and naturalize? At the same time, the ecologies of knowledge as framework for social movements can offer the inspiration to imagine (and realizing) more equitable and less extractive socio-epistemic relations. And, at the intersection of STS and political ecology, metaphors can help create space for plural epistemic practices that prioritize global socio-ecological needs, for example by also asking what physical and ecological relations and effects knowledge metaphors imply (Turnhout, 2024). That is, we should echo and extend Santos' (2014) 'no global justice without cognitive justice' to include 'ecological justice'. In this way, STS might help finding powerful words that allow open discussions in heterogenous settings, that counter hegemonic closure of epistemic practices, and that pluralize the political, economic, and ecological valuations that we take into account in (studies of) science, technology, and innovation.

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