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Editorial

Political-industrial ecology: An introduction

Political ecology and industrial ecology have emerged as influential, but distinct, intellectual thought traditions devoted to understanding the transformation of nature-society relations and processes. Evolving from the pioneering work by physicists and environmental engineers in the late 1960s (e.g. Ayres and Kneese, 1969), industrial ecology emerged as a distinct field in the 1990s (Graedel and Allenby, 2003). It is a largely normative project that seeks to quantify and dematerialize the resource stocks and flows of industrial ecosystems, product life cycles, and societal metabolisms. To systematically dissect production-consumption processes across cradle-to-grave phases (e.g. extraction, manufacturing, use, reuse), industrial ecology deploys material flow analysis, life cycle assessment, environmental input-output modeling, amongst other methods, and has cultivated more abstract principles and practices such as industrial symbiosis and socio-economic metabolism. As the field has matured, industrial ecology has branched out by becoming more heterogeneous, not only in terms of topical foci and methodology, but also in terms of how it understands the material basis of societal transitions (cf. Vienna School of Social Ecology; Haberl et al., 2016). Nevertheless, the overwhelming focus of industrial ecology is on the *material* rather than *social* dimensions of resource use.

Political ecology emerged at roughly the same time (the term is usually attributed to Wolf in 1972) out of concern that environmental science and dominant narratives of environmental change were 'apolitical' in that they did not sufficiently consider the role of social and, especially, political economic processes in shaping these outcomes (Robbins, 2012). Its roots are much older than this, of course, with inspiration ranging from Humboldt and Marsh to Kropotkin and Marx. Political ecology has evolved to become a powerful thought tradition that now reaches across geography to cognate fields such as anthropology, environmental sociology, development studies, environmental history, and science and technology studies (STS). Political ecology investigates connections between political economy and environmental change, with special attention to issues of equity, power, access, and governance. Epistemologically and methodologically pluralistic, by explicitly questioning and destabilizing apolitical accounts of environmental change, political ecology is decidedly critical.

Despite the shared focus on nature-society relations, until recently, industrial ecology and political ecology have not substantively engaged each other. This is curious given that both fields study resource flows and their transformation. As Liverman et al. (2003, p. 273) lamented in a review on global change research, despite obvious synergies, "Relatively few geographers have been involved in the study of industrial ecology."

But geographers and political ecologists are starting to engage in new and exciting ways. This has been sparked by the potential of leveraging theoretical and methodological strengths of each field to more deeply explore how ecological, political, and socio-economic process shape the relationships between a product, commodity, or material process, its primary inputs and outputs, and the relevant social and ecological implications. This led Newell and Cousins (2015) to propose the creation of a new subfield, *political-industrial ecology*, to enable the cross-fertilization of ideas, epistemologies, and approaches between political and industrial ecology.

This editorial provides the opportunity to introduce a working definition, rationale, and process for this emerging subfield:

> Political-Industrial Ecology (PIE) represents a confluence between two thought traditions: political ecology and industrial ecology. PIE focuses on the ways in which *resource (e.g. material and energy) flows and stocks* shape (and are shaped by) environmental, socio-economic, and political processes and patterns over time and space. As part of a broader rebalancing of nature-society relations, PIE is committed to situating resource extraction, transformation, and consumption within their social and political economic context. This also includes a commitment to altering, reducing, or transforming these stocks and flows – as guided by principles of equity and justice. PIE embraces epistemological and methodology pluralism, which often (but not necessarily) entails scholars working collaboratively on particular projects. The friction between the varied epistemologies of political ecology and industrial ecology is highly useful as it yields unexpected and transformative understandings and approaches. This *useful friction* is made apparent by a dialectic and quasi-fusion between the respective qualitative and quantitative methodologies found in both fields, including modeling of resource flow and form, spatial analysis, historical materialism, ethnography, and more.

This theme issue—a collection of six research papers and one perspective essay (Breetz, 2016)—offers an exciting entrée into what PIE is and, especially, what it might become. Most of the contributors to this issue participated in formative sessions that explored the interface between political and industrial ecology. This included a panel session entitled 'Theorizing Political-Industrial Ecology' at the 2015 American Association of Geographers (AAG) conference in Chicago, which evaluated epistemological and methodological concerns associated with industrial ecology approaches, including narratives of ecological modernization, apolitical industrial ecologies, and the bifurcation of nature and society. The following year, at the 2016 AAG in San Francisco, four paper sessions on PIE further explored these issues through the presentation of empirical research on resource flows ranging from water, to e-waste, to biofuels.

The remainder of this editorial is divided into three sections. First, we briefly summarize historical antecedents of PIE, focusing on the uptake of

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industrial ecology concepts in recent geographic thought. Then, we introduce the six papers in this special issue, dividing them into two themes: 'Political-industrial ecology perspectives of resource geographies'; and 'Urban political-industrial ecologies.' We conclude with a synthesis and, drawing on Breetz's perspective essay, suggest future research avenues for this intriguing new subfield.

Political-industrial ecology: historical antecedents and foundations

The papers in this collection (and PIE more broadly) draw on previous scholarship in geography that has either engaged directly with industrial ecology concepts and practices or indirectly through a focus on stocks and flows of material and energy. Space limits a full review of this scholarship here. Rather, we identify and briefly describe three key research strands that have particular relevance for this collection of papers and for the development of PIE generally.

First, there are those aligned with the subfield of resource geography. This includes the work of Bridge (2002, 2008) who has long pushed economic geographers, including those working on global production networks (GPNs) to engage more substantively with extractive industries and to the "process of materials transformation in which environmental change and the organization/disorganization of matter and energy are *integral rather than incidental* (authors emphasis) to economic activity" (2008, p. 77). In the concluding paragraphs of an editorial with Jonas (Bridge and Jonas, 2002), Bridge even used the phrase 'critical industrial ecology,' which they credited to Jody Emel. Unfortunately this phrase was not further developed. Rather, it served as a rhetorical vehicle for their primary purpose: To call attention to "power geographies in and through which resource production and consumption take place" (p. 764). Among economic geographers, Gibbs and Deutz have engaged with industrial ecology most directly and substantively, especially through critical evaluations of eco-industrial parks and industrial symbiosis (Deutz and Gibbs, 2004, 2008; Gibbs, 2003; Gibbs and Deutz, 2005; Gibbs et al., 2005). Other notable examples of scholarship that interrogates the socio-economic and political dynamics of resource flows include: Huber's work (2010, 2017a) on the ecological underpinnings of industrial capitalism (through flows of oil) and his recent call for 'industrial political ecology'; Bergmann's (2013) integration of input-output modeling with critical geographies to excavate global connections and interrelations between distant carbon emissions, regions, and economies; and Baka and Bailis (2014) integration of material and energy flow accounting and political ecology to evaluate the governance processes shaping biofuel land use decisions.

The second research strand explores the boundaries between industrial ecology and political ecology through engagements with life cycle assessment (LCA) – its theory, methods, and how it is marshalled and deployed as a generator of metrics, standards, and other instruments of governance. Newell and Vos (2011) compared the carbon burden of coated-paper sourced in Indonesia vs. other geographic regions by coupling LCA with GIS. This enabled them to interrogate LCA modeling assumptions related to scale, system boundary, inclusiveness, and uncertainty. They argued that the LCA process itself, especially the spatial delineation of actors and sites through the life cycle phases of a particular resource (from extraction to end-use), was a useful exercise that could ground, link to, or support studies of global production networks, value chains, filiéres, actor-networks, and related approaches (Coe et al., 2004; Gereffi et al., 2005; Murdoch, 1998; Raikes et al., 2000). More skeptical of the emancipatory potential of LCA, Freidberg's (2013, 2014) work brings attention to ways in which LCAs work to govern supply chains and influence systems of sustainable food through a form of 'footprint technopolitics.' Similarly Mulvaney's (2014) paper, "Cadmium narratives in the life cycle of Photovoltaics," draws on global commodity chain analysis, political ecology, and science and technology studies (STS) to illustrate how the PV industry has used LCA to shape debates about cadmium pollution. More broadly, his work unveils tensions between green jobs and environmental justice.

The third strand of research centers on a conceptual metaphor that both thought traditions use as the basis for theorizing and model-making: metabolism, especially at the urban scale. Newell and Cousins (2015) identified three ecologies of urban metabolism scholarship (political ecology, industrial ecology, and urban ecology), each of which privileges a particular (and partial) dimension of urban space. They argue that the melding of these ecologies to form political-industrial ecology will yield a richer, deeper, and politically-engaged conceptualization of the urban. In a companion paper, Cousins and Newell (2015) use a PIE approach to analyze the water supply infrastructure of Los Angeles. Similar to the approach taken by Newell and Vos (2011), GIS provides the means to insert spatiality into industrial ecology methods (i.e. LCA), which they then combine with interviews and historical analysis to simultaneously interrogate the carbon calculus that drives urban climate governance and advance efforts to quantify the uneven burdens associated with urbanization processes. Similarly, Pincetl et al. (2012) have combined elements of industrial ecology, political ecology, and urban planning to extend a city's metabolism beyond the quantification of inputs and outputs. Also focusing on the Los Angeles region, Pincetl et al. (2016a,b) have done extensive work delineating the city's water and energy metabolism and the environmental and social justice dimensions of this resource production-consumption dynamic.

Theme #1: Political-industrial ecology perspectives of resource geographies

The first three papers in this issue focus on the political, socio-economic, and biophysical processes associated with a particular resource flow (i.e. global commodities, vanadium – a rare earth metal, and nitrogen fertilizer). These authors primarily come out of economic and resource geography traditions and engage with PIE concepts from this context.

Bergmann (2016) views PIE scholarship as a means to bridge nature-society divides that persist in economic geography through the development of quantitative, relational, and disruptive representations of global commodities and economies. Blending input-output modeling (a familiar methodological approach in industrial ecology and ecological economics) with critical geography, Bergmann maps trade flows of the global economy. He destabilizes and liberates the commodity as single value by counterpoising price with embodied carbon, land area harvest, and labor time. Bergmann then asks us consider these four metrics side-by-side, relationally and simultaneously; this reveals regional disparities, trade imbalances, and ecological shadows. As a collective, these metrics begin to offer a more synthetic representation of the capitalist space-economy and prod us to consider more progressive geographic futures.

The paper by Deutz et al. (2017) delineates a political-industrial ecology (PIE) of vanadium, a 'security risk' metal used to make energy storage cells. The authors use PIE to evaluate the potential extraction of vanadium from steel residues from three lenses: environmental, technological, and stakeholder. Based on semi-structured interviews, the case study illustrates how stakeholder interests intertwine with regulatory issues and environmental and technological challenges. This socio-ecological-technical assemblage effectively shapes the potential for vanadium recovery. More broadly, the paper critically evaluates industrial symbiosis, a well-codified research area in industrial ecology. Industrial symbiosis refers to mutual exchange relationships in which waste (e.g. materials, energy) from one industrial process can be used as 'feedstock' for another, usually in a geographically proximate location (Chertow, 2000). This form of cradle-to-cradle thinking has many parallels with the so-called circular economy, in discourse and in practice (Ghisellini et al., 2016).

Through a case study of nitrogen fertilizer production in the southern United States, Huber (2017b, p. 2) makes a case for analysis of the *industrial class* in political ecology, which has been "conspicuously, and problematically, absent." In contrast to the other papers, Huber calls for *industrial political ecology,* which he views as differing from PIE in that it does not engage industrial ecology research methods per se. Rather, industrial political ecology asks traditional political ecology questions in industrial settings, the so-called "hidden abodes" of capitalism (Huber, 2017a). This shifted gaze allows Huber to challenge conventional claims that climate change is primarily driven by the additive impacts of millions of dispersed consumer choices. Instead, Huber asserts that the classes controlling processes of industrial metabolism (in his case, the nitrogen fertilizer factory owners), through relentless pursuit of value and profit, have a far greater impact on the climate. As such, an industrial political ecology approach can provide new opportunities for "ecologizing" class analysis by examining the linkages between control over processes of industrial production and environmental degradation.

Theme #2: Urban political-industrial ecologies

The second set of papers represent PIE perspectives on the production of urban natures and those "interwoven knots of *social process, material metabolism* and *spatial form"* (Swyngedouw and Heynen, 2003, p. 906, original emphasis). All three papers use 'urban metabolism' as an integrative lens to explore production-consumption networks and the material politics of the resource flows – namely waste, water, and energy – that shape urban resource geographies. Methodologically, the papers draw from ethnographic and qualitative approaches as well as traditional industrial ecology methods such as LCA.

Guibrunet et al. (2016) conceptually and methodologically engage with two fundamental industrial ecology concepts —'flows' and 'system boundaries'—to politicize urban waste metabolisms in two cities: Mexico City and Santiago de Chile. By probing the underlying assumptions of each concept, the authors offer a politically-oriented method for PIE—one that opens up new insights into material flows and their analysis. Rather than approaching urban metabolic flows in a quantitative and functionalist manner, typical of industrial ecology, they deploy a qualitative and place-based technique that confronts the apolitical and 'black boxed' nature of conventional material flows research. Specifically, through a detailed analysis of the experiences of formal and informal actors shaping urban waste metabolisms, the authors reveal how flows and system boundaries are heterogeneously assembled and influenced by intermediaries that blur established institutional and geographic confines. Their analysis thus reveals the importance of integrating political ecological commitments with industrial ecology to simultaneously capture the materiality of resources and their associated impacts on environmental justice.

Cousins (2016) develops PIE by offering 'volume control' as a conceptual frame to understand how techno-political interventions are organized around overcoming problems related to the volume of resources flowing and circulating into, within, and out of urban and industrial systems. He uses stormwater governance as a vehicle to show how these interventions develop through three primary practices that (re)assemble stormwater as a resource: scientific and technical practices of calculating and inscribing resource metabolisms; legal practices; and citizen enrollment. While the analytical treatment placed on volume highlights the mass and quantity of resources metabolized through urban and industrial processes, the emphasis placed on control illustrates how power dynamics influence the flow and distribution of resources and exerts authority over people's relationship to resources. Practices of industrial ecology (e.g. calculating and urban metabolism) are shown to shape the political ecology of a city, but the contribution also reveals the relational politics of urban resource governance.

In the final paper in this collection, Pincetl and Newell (2017, p. 2) make the case for a political-industrial ecology of cities to "track resource flows across space and time, and to decipher intertwined social and environmental dynamics" that reveal inequities within the city and in "distant areas from which these flows originate." In line with research on planetary urbanization (Brenner, 2014; Merrifield, 2013) and urban teleconnections (Seto et al., 2012), the authors argue for theorizations of the city that capture the linkages through material flows with distant places and spaces. Similar to Kitchin (2014) and others, Pincetl and Newell are sharply critical of 'smart city' monitoring and top-down approaches, which poorly capture how cities actually function. Rather, the authors propose a PIE methodology that combines spatially-explicit 'big data' and LCA with historical, socio-demographic, contextual, and policy analyses to empirically ground these theorizations. Case studies of the political-industrial ecology of water and energy in Los Angeles illustrate how this methodology reveals the ways in which the region's wealthy residents use of an inequitable share of these resources, while being shielded from the environmental and social ramifications of this consumption.

Synthesis and future directions

As noted at the outset, we envision political-industrial ecology (PIE) as a new subfield for the Anthropocene, one dedicated to the study of the *relations between material and energy stocks* and *flows and socio-ecological, political, and economic processes.* This speaks to an enduring theme within resource geography: that natural resources are a social category that gain (and lose) value based on their abilities to meet societal needs at specific times and places (Bridge, 2009). What distinguishes PIE from other ongoing efforts is the dedicated focus on resource stocks and flows and the direct engagement with (and useful friction between) two influential but previously isolated nature-society thought traditions: industrial ecology and political ecology. It is our claim that these two traditions complement each other and that respective strengths can be harnessed for a richer and more inclusive understanding of the metabolic relations between society, nature, and space.

Collectively, the six papers in this theme issue represent an initial experimental blending of elements (conceptual, methodological, topical, and otherwise) of these two ecologies and a set of concepts, categories, and methodologies upon which PIE can build. The final contribution—a perspective essay by Breetz (2016)—introduces a helpful three-part typology (integrative, complementary, and critical) by which to categorize these epistemologically- and methodologically-varied contributions, as well as a categorical framing for future PIE research. Integrative research combines industrial ecology methods with social science and ecological analysis to "better account, either quantitatively or qualitatively, for the socio-political dynamics that shape supply chains and industrial ecosystems across time and space" (Breetz, 2016, p. 2). The Bergmann (2016) paper does so by combining input-output analysis with spatial analysis, economic geography, and critical theory. Another example of this integrative approach is the paper by Pincetl and Newell (2017). Complementary research, meanwhile, "speaks to" or "builds on" the findings or frameworks of industrial ecology. An example of this approach is the paper by Deutz et al. (2017) paper, which uses interviews to unpack the industrial symbiosis of vanadium. Finally, there are critical approaches, which may examine the production of knowledge in industrial ecology. As an example, the Cousins' (2016) paper uses historical and broadly ethnographic methods, to examine how urban metabolisms are calculated and applied as technocratic tools to control the volume of resources circulating through society.

From the theme issue papers, some initial tenets for PIE also emerge. First, there is the engaged commitment to epistemological and

methodological pluralism, which recognizes multiple forms of expertise. Among other things, this carves out intellectual space to invigorate and advance interactions between the social and biophysical sciences. Precedents exist within political ecology and geography.

Notably, Turner and Robbins (2008) reviewed the links between land-change science and political ecology, arguing that a focus on the convergence between the two fields through problem framing and methods can shape a hybrid approach. Turner (2016) also indicated that while political ecology's commitments to the biophysical sciences remain limited, there is more activity looking to foster integration than is typically recognized, such as 'critical physical geography' (e.g. Lave et al., 2014). Others such as Barnes and Sheppard (2010) have long advocated for a more pluralistic geography centered on dialogue, translation, and the creation of 'trading zones.' Pluralism certainly risks eclecticism as engaging with diverse methods and approaches can be difficult to harmonize within one hybrid approach (Wyly, 2009). But as the papers in this volume demonstrate, PIE offers an explicit space to recognize and engage with the rather different epistemological inclinations of industrial ecology and political ecology (Newell and Cousins, 2015).

Second, PIE represents an explicit focus on environmental justice and normative approaches towards nature-society interactions. This borrows from political ecology's normative adherence to social justice and to the transformation of political and economic systems that undermine social and ecological conditions. Industrial ecology's normative approach is also retained, while pointing research questions towards systemic and purposeful changes that can guide transitions. These normative commitments provide a platform for PIE to develop distinct perspectives on how society can (re) structure new types of metabolisms that serve new social-ecological functions. Political ecology's emphasis on social and spatial processes, as well as the power relations that shape transitions, can contribute important geographical insights into the application of IE approaches that seek to guide transitions and reveal specific patterns of environmental injustice and inequality (Lawhon and Murphy, 2012). Whether drawing attention to the ways social differentiation influences access and control over resources and their associated material transformations (Huber this volume) or the ways political ecological analyses of material flows can highlight issues of environmental justice (Guibrunet et al., 2016), PIE highlights the environmental injustices embodied within the circulation and transformation of resource flows.

These initial themes and tenets are only a starting point for PIE. This editorial has been crafted with the discipline of Geography and cognate social sciences in mind and the papers in this special issue have been written largely by geographers. But there are also exciting interactions and collaborations underway with industrial ecology and beyond. PIE welcomes the integration of the social and biophysical sciences, alongside the study of material and energy flows through industrial ecosystems, to develop more sustainable and just social-ecological relationships. We hope the contributions and debates around PIE generate the creative collaborations between researchers and in developing new research agendas. Please join us as we seek to develop more environmentally just and socially inclusive futures than political ecology and industrial ecology can achieve by working alone.

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