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How to track corporations across space and time

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ABSTRACT

Globalization processes lead to supply chains that sprawl across space and time. Where and how products are produced and consumed shape the environmental and social conditions of regions, far and wide. Distance, fluidity, and complexity in supply chains mask their uneven impacts. Researchers have prioritized the study of 'sectors' (e.g. automobile manufacturing, garment production) over specific corporations (e.g. Toyota, Nike), even though these corporations `move and shape` the global economy. Research by NGOs reveals the importance of focusing on individual corporations to highlight unsustainable production practices and to foster transparency and accountability. This paper introduces a methodological framework, "TRAcking Corporations Across Space and Time" (TRACAST), to tell the 'story' behind a product by systematically linking companies across a supply chain and identifying environmental and social hotspots and key nodes of governance. TRACAST combines in-situ (e.g. interviews, surveys, fieldwork) and ex-situ (e.g. document analysis, mining of trade data) approaches. To illustrate its utility, we link Walmart, Lowe's, and The Home Depot in the United States to Russian logging companies via Chinese flooring manufacturers. TRACAST enables scholars studying the global flows of goods to engage deeply with questions related to specific corporations and how they affect people and the planet.

1. Introduction

Have you ever wandered into a store and wondered to yourself, where do the products we consume come from and under what conditions were they made? Globalization disconnects consumers from where and how goods are produced. Consequently, we often lack knowledge of how our consumption affects the environmental and socioeconomic conditions of distant peoples and places. Consider a global supply chain that produces the batteries in electronics sold by Apple, Dell, LG, and Samsung (Amnesty International, 2016). Cobalt mines in the Democratic Republic of Congo provide the raw material for a complex network of trading houses and smelters. These mines employ children in dangerous jobs and degrade the natural landscape. Battery component manufacturers in Asia purchase the refined cobalt, which ends up in computers sold by these transnational corporations.

This example illustrates both societal (child labor) and environmental (damage to the landscape) impacts of a global supply chain. But most consumers are unaware of the impacts in Africa related to a computer purchased elsewhere. In our integrated global economy, environmental and social burdens are often distributed unevenly across the production-consumption landscape (Harvey, 2006; McGrath, 2018; Smith, 2008; Werner, 2018). Impacts tend to occur 'upstream' in supply chains at points of resource extraction and manufacturing (Bartley and Child, 2014; Godar et al., 2016; O'Rourke, 2014). Some companies actively downplay or conceal the negative impact of their supply chains from consumers (Ibert et al., 2019), regulatory authorities, and certification auditors (Bartley, 2018; Lebaron and Lister, 2015).

Knowledge of these effects upstream in the manufacturing process influences the behavior of those branding, selling, buying, and regulating products. Corporations with name-brand products and retailers are sensitive to financial losses due to unflattering portrayals in the media of their suppliers (O'Rourke, 2014; Spar and La Mure, 2003). Environmental and social concerns increasingly influence which brands consumers purchase (Dauvergne and Lebaron, 2014; Rindell et al., 2014). These concerns are leading governments to enact regulation restricting imports of environmentally and socially unsustainable products (Bartley, 2018; Gibson and Warren, 2016; Prestemon, 2015). These actors all have a stake in knowing the 'story' behind a product.

Academics have theorized, conceptualized, and modeled these global flows of goods and services. Examples of different analytical frameworks include *global commodity chains* (Gereffi, 1994), *global value chains* (Gereffi et al., 1994), *filières* (Raikes et al., 2000), *global production networks* (Coe et al., 2008), *production-consumption systems* (Lebel and Lorek, 2008) and *product life cycles* (Hellweg and Milà i Canals, 2014). In the land change science literature, the complex links between geographically separated sites of production and consumption

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are called *teleconnections* (Seto et al., 2012) or *telecoupled systems* (Liu et al., 2013).

Corporations produce the myriad of goods that connect consumers to distant production geographies. Indeed, Dicken considers transnational corporations to be the primary "movers and shapers" of the global economy (2011, p. 109). Transnationals shape the geography of the economy by deciding where to invest (or not). Directly and indirectly through their suppliers, these firms exercise varying degrees of control over the conditions under which products are made and the corresponding socioeconomic and environmental impacts (Bartley, 2018; Gereffi et al., 2001; Rueda et al., 2017). To understand the relationship between global supply chains and consumption in shaping resource extraction patterns and processes in specific places, studies need to address the operations of (and interlinkages between) specific corporate actors.

Despite this importance, a recent review we conducted found that less than 1% of studies (27 out of ~11,000) on global commodity chains, value chains, production networks, product life cycles and the like identified and analyzed the supply chains of *individual corporations* (Goldstein and Newell, 2019).[1] Researchers have studied individual companies per se, but not their supply chain linkages.

This oversight hinders our ability to better understand globalization processes and their impacts. Some corporations voluntarily disclose their suppliers (Dingwerth and Eichinger, 2010; Mol, 2015), but the opacity and complexity of most supply chains present barriers to studying specific corporations. Importantly, companies will often sanitize data to remove what Ibert et al. (2019) refer to as the 'dark places' in a company's production network. Although emerging tools can trace how corporations direct goods through the global economy (Godar et al., 2015), academics lack a methodological framework suited to systematically unveil supply chains: their constituent companies; locations; socioeconomic and environmental impacts; and governance dynamics.

To address this gap, we introduce a methodological framework that enables researchers to reveal the 'story' behind a product by systematically identifying *linkages* between corporate actors, *hotspots* of environmental degradation and socioeconomic impact, and *key nodes* of governance. We call this methodological framework *Tracking Corporations Across Space and Time* (TRACAST), and to build it we have drawn upon theories, concepts, and data collection techniques from the supply chain literature, especially the work on global commodity and value chains, global production networks, and product life cycle assessment.

We illustrate the usefulness of TRACAST through a short case study of Russian wood supply and U.S. retailers, namely Walmart, Lowe's, and The Home Depot. This case study uncovers the connections between consumers who shop at these stores to forests and peoples in the Russian Far East. As the case study illustrates, the TRACAST methodological framework enables one to investigate the detailed innerworkings and impacts of entire supply chains without assistance from the corporations themselves or company-disclosed data.

TRACAST provides a novel, systematic approach to critically study the scale, operations, impact of individual corporations (and their supply chains linkages) rather than a generic sector or industry. We are hopeful that this methodological approach will enable innovative and creative work on these crucial actors of the global economy and how they influence the form, governance, and sustainability of supply chains.

[1] This review identified studies that met the following criteria: (i) specific companies were named; (ii) multiple companies were linked across a supply chain; (iii) previously unknown supply chains were revealed; and (iv) supply chains were rebuilt without the aid of corporate collaborators. We found 57 studies that met these criteria, 27 of which were in peer-reviewed journals.

2. TRAcking corporations across space and time (TRACAST)

TRACAST systematically combines heterogeneous data to reveal linkages between corporate actors in supply chains and determine where they operate. TRACAST empirically connects corporations to environmental and socioeconomic change at precise geographic locations and identifies hotspots where this change is most disruptive. By attributing responsibility for hotspots to corporations and their suppliers, TRACAST identifies those actors that function as key nodes that strongly influence the environmental and socioeconomic effects of a supply chain.

We developed TRACAST using insights taken from our own work analyzing supply chains and findings from the aforementioned literature review (Goldstein and Newell, 2019). Our case study on Russian hardwood supply chains required in-situ work in Russia, China and the U.S. (at various times between 2006 and 2013), and ex-situ analysis of supply chain linkages using customs data. This case study provided experience in how to scope studies to track supply chains, how to construct linkages between companies using disparate data, and how to use in-situ approaches to document environmental change, confirm linkages, and analyze findings. Our literature review exposed us to innovative data and supply chain tracking approaches. Reading this literature also revealed how different fields understand and study supply chains, which helped us conceptually embed TRACAST.

2.1. Conceptual building blocks

We drew on a diverse set of literatures to construct TRACAST, namely the academic research on global commodity chains (GCCs), global value chains (GVCs), global production networks (GPNs), and life cycle assessment (LCA), combined with work on supply chain transparency by NGOs. Fig. 1 shows the influential literature streams, their contributions to TRACAST, and the concepts and approaches advanced by the methodological framework.

GVC, and its predecessor GCC, research studies how the coordination of firms form linear value or commodity 'chains' that produce goods. The conceptual basis for both is 'world systems' theory (Hopkins and Wallerstein, 1977), which sees core (advanced manufacturing) and periphery (extractive) economies locked in unequal exchange and value capture. GCC/GVC research formalizes a number of concepts related to this and strives to understand how actors (firms or nation-states) can occupy higher earning positions in the value chain. We build off three crucial features of the GCC/GVC work: 1) the *physical input-output structure* of sequential value-adding steps that produce a product; 2) the *territoriality* of where these steps occur; and 3) the *governance* dynamics within supply chains (Gereffi et al., 1994).

GPN theory eschews the notion of linear 'chains' of corporate actors in favor of diffuse networks of firm and non-firm actors (Coe et al., 2008; Yeung and Coe, 2015). We incorporate this idea of production networks, which captures a broader set of actors than often featured in GVC/GCC work and more aptly describes the dendritic supply chains that typify the global economy. Stemming from the field of economic geography, GPN theory is more attentive to the local contexts of where globalization 'lands' and how non-firm actors and conditions at those locations influence production practices. This GPN concept of *embeddedness* - how activities embed spatially and socially via social, political and economic structures (Hess, 2004) – is core to TRACAST.

LCA quantifies the environmental (and to a lesser degree social) impacts of products and services. Scholars, especially in the field of industrial ecology, have generated a number of useful supply chain concepts as byproducts of this work. TRACAST incorporates *life cycle thinking*, which takes a systems view that includes production, consumption and disposal when quantifying the environmental and social impacts of a product (Hellweg and Milà i Canals, 2014). We also expand on the idea of environmental and social *hotspots*, which can occur at different processes or stages of a product's life cycle. Methodologically,

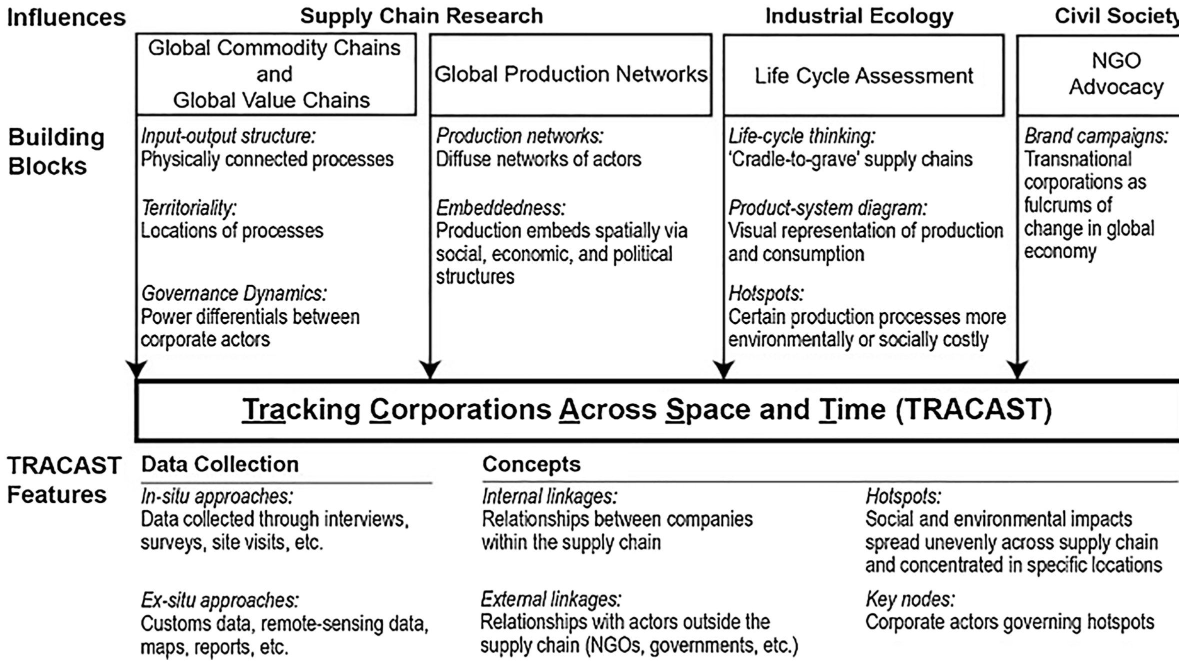

Fig. 1. The Building Blocks of TRACAST.

we use the *product-system diagram* (or 'system boundary diagram'), a key step in LCA to identify and visualize the key stages and processes in the lifecycle of a product supply chain.

From NGO research and activism on corporate transparency and monitoring, we take inspiration from the idea of investigating specific companies. We also highlight the approach pioneered by NGOs (e.g. Greenpeace, 2006), and expanded by Godar et al. (2015), of using commercial customs data to reconstruct transnational supply chains.

In TRACAST, we use the terms *product* and *good* interchangeably and define the supply chain as the interlinked corporate actors who move a good through some or all stages of its life cycle. Corporate actors in turn become nodes in the supply chain (Fig. 2). The product life cycle covers resource extraction, manufacture, retail, use, and end-of-life (landfilling, recycling, reuse, etc.). We do not treat distribution as a separate stage since it occurs between and within the other stages. Stages can occur in distant and distinct geographic locations and involve single corporate actors or multiple corporate actors. Stages can consist of multiple processes, for instance spinning and sewing in the manufacturing stage of a t-shirt, which can themselves occur at different locations.

The TRACAST definition of a supply chain includes all stages of the product life cycle and thus describes a complete *production-consumption system*. This definition is broader than the typical focus on manufacturing in GCC or GCV research (Bloomfield, 2017) and more comprehensive than most supply chains studied by NGOs, which often prioritize the factories and extractive frontiers where social and environmental change are most acute. The TRACAST supply chain captures the physical breadth of economic activity studied in industrial ecology (Hellweg and Milà i Canals, 2014) and the social forces entangling supply and demand articulated by production-consumption system scholars (Lebel and Lorek, 2008).

2.2. TRACAST concepts: linkages, hotspots, and key nodes

We call the relationships between actors in the supply chain *linkages*. These can be *internal* linkages, the consecutive links between companies producing goods. These can also be *external* linkages with influential actors outside the supply chain that affect a chain's structure, geography, and governance. Such external actors can be governments, unions, third-party assessors, banks, NGOs, and even the media (Coe et al., 2008).

TRACAST defines a location of negative socioeconomic or environmental impact in a supply chain as a *hotspot*. Although similar to the hotspot concept in environmental and social LCA that pinpoints

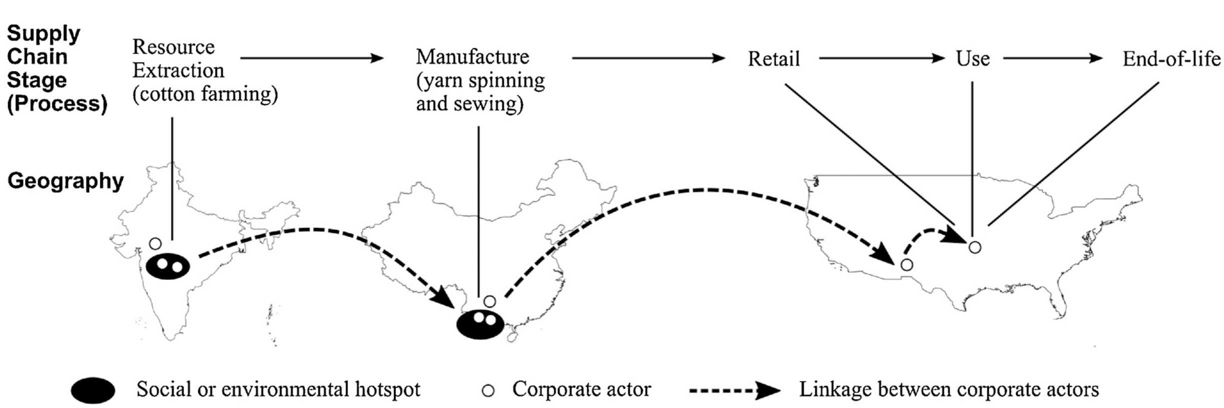

Fig. 2. Simplified supply chain for cotton shirt across the product life cycle.

Table 1
In-situ and ex-situ approaches in corporate actor tracking.

Approach	Observed Applications					Examples
	Building linkages	Determining supply chain locations	Identifying landowners	Documenting environmental and social change	Documenting source segmentation of materials	
Ex-situ approaches						
Customs data analysis	✓	✓				(Amazon Watch, 2016)
GIS analysis			✓	✓		(Godar et al., 2016; Greenpeace, 2010)
Document analysis	✓	✓				(Greenpeace, 2010)
Models		✓				(Godar et al., 2015)
In-situ approaches						
Interview	✓			✓	✓	(Ponte and Ewert, 2009)
Site visit	✓			✓	✓	(Mighty Earth, 2016)
Surveillance	✓			✓		(Environmental Investigation Agency, 2011a)
Survey	✓				✓	(Vagneron and Roquigny, 2011)

processes or life cycle stages (Hellweg and Milà i Canals, 2014), in TRACAST, a hotspot represents impacts embedded in specific geographic sites, including effects on local institutions, economic conditions, labor, and ecosystems.

The corporate actors controlling supply chain hotspots, either directly (the companies generating environmental and social disruptions) or indirectly (corporations that dictate terms to upstream suppliers), are *key nodes*. Key nodes act as critical control points in the governance of supply chains, and thus, represent opportunities to effect changes in the behavior of corporate actors. In related literature, key nodes are akin to the 'lead firms' and 'chain drivers' in GCC and GVC research (Gereffi, 1994), transnational corporations as 'movers and shapers' in the GPN literature (Dicken, 2011, p. 109), and 'upstream risks' in the literature on supply chain management (Bush et al., 2015).

2.3. TRACAST approaches: ex-situ and in-situ

GCC, GVC and GPN scholars and NGOs have developed an array of approaches to track corporations. Approaches fall into two categories: ex-situ and in-situ (Table 1). Ex-situ approaches use secondary data sources, such as customs data (also called 'bill-of-lading' data), annual investor reports, corporate sustainability reports, company websites, media reports, and confidential internal memos. In-situ approaches generate primary data through interviews, site visits, surveys, surveillance, and other types of field work.

Analyzing documents such as corporate reports, memos and websites to build linkages is a common ex-situ approach. Although valuable, manual document review is labor intensive and difficult to apply to complex supply chains with dozens of companies. Analysis of semi-structured and structured data can be an efficient ex-situ approach to construct linkages and identify hotspots. These data, such as customs data and remote sensing data, have standard forms, syntaxes, and characteristics that facilitate and expedite data combination, manipulation, and retrieval through automation. Researchers have mined these data directly for linkages and combined them with agricultural production and transport data to model supply chain locations (Smith et al., 2017).

With in-situ approaches, the investigator interacts directly with the supply chain through interviews, surveys and site visits. Time- and labor-intensive, this research tends to focus one or a few participants or study sites. Other in-situ research uses surveillance, either with or without prior consent. Surveillance can involve directly observing and documenting supply chain processes at industry sites, as exemplified by work of the NGO Environmental Investigation Agency, who pose as buyers (2011b). Surveillance can also include tracking the flows of goods manually by physically following a shipment or remotely using planted tracking devices.

TRACAST is a hybrid methodology that takes advantage of the complementary nature of in-situ and ex-situ approaches. Ex-situ approaches are particularly useful in revealing internal linkages from international trade, identifying environmental hotspots, and scoping TRACAST studies. In-situ approaches can build internal linkages domestically, document impacts to people and planet on the ground and explore influential external linkages. Moreover, it is ultimately the in-situ work by journalists, locals, NGOs and academics revealing social and environmental change that provides the impetus to study certain supply chains and places. Effectively, these hybrid approaches can often uncover more supply chain linkages and lead to a fuller understanding of how supply chains affect distant locations.

3. Methodological steps in TRACAST

TRACAST is a methodological framework to investigate specific corporate supply chains, by allowing researchers to identify supply chain nodes, uncover and validate corporate linkages across these nodes, and find hotspots (Fig. 3). TRACAST consists of four sequential

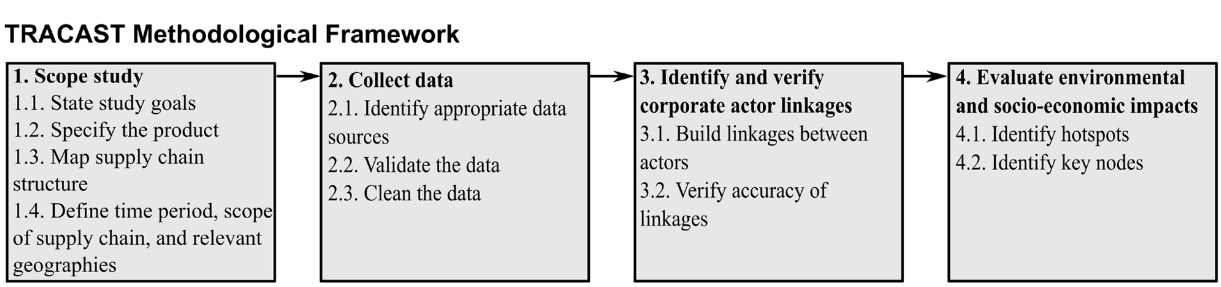

Fig. 3. General workflow of the TRACAST framework.

steps: (i) Define the study scope; (ii) collect data; (iii) identify and validate corporate actor linkages; and (iv) evaluate and incorporate environmental and socioeconomic impacts. This framework is iterative, revisiting previous steps as knowledge increases.

3.1. Step 1: scope study

Scoping the study involves stating study goals, specifying the product(s) of interest, mapping the supply chain structure, and developing a clear idea of the supply chain that will be studied. The outcomes are a product-system sketch and a clear definition of geographic and temporal scope of analysis that can fulfill these goals.

3.1.1. State study goals

This step entails clarifying the goals of the study. This could relate to specific problems, regions, companies, products or a combination thereof. An example of all four might be to link production of Apple products to artisanal tantalum mines in the Democratic Republic of Congo that denude the landscape. Broader interests could also drive a study, such as understanding the efficacy of corporate self-governance in the forestry sector. One can study how supply chain configurations shift (and their corresponding impacts) by performing a time series analysis (e.g. 2010–2020) of the data collected. Knowing which supply chains, regions or periods are suitable subjects usually requires previous researcher or practitioner knowledge. Indicative evidence from secondary sources, such as news articles or contact with effected populations, can assist less experienced investigators (Johnson and Lawson, 2016). The choice of project goal(s) influences the other aspects of the study scope, and critically, shapes the methods and data you need. For instance, studying deforestation lends itself towards cadastral maps and remote-sensing data, while an investigation of labor concerns requires factory visits and interviews. The tractability of this should be weighed when developing study goals, and these goals might change as the study develops.

3.1.2. Specify the product

The choice of product to study has an important influence on the data demands and feasibility of the study. Tracking the supply chains of complex products, such as computers or automobiles, is usually more demanding than those with fewer components, such as t-shirts. If the focus is a commodity without consideration of a predefined brand, then specifying one product that relies on that commodity can make the scope of the study manageable. An example would be choosing cotton in the global supply chain for t-shirts sold in Canada, rather than studying all products that use cotton throughout the world. Another way to limit the scope of the study of a commodity with multiple uses is to predefine a corporate actor. An example would be studying the global supply chain for cotton t-shirts sold by the retailer Zara. We recommend specifying the product in detail to narrow the study scope and aid data collection.

The United Nation's (UN) Harmonized Series (HS) codes are standards for calculating tariffs on international trade and are useful for precisely defining a product (United Nations, 2017). HS codes define goods at 2, 4, and 6-digit levels, with increasing digits ('lower levels' in HS terminology) providing increasing specificity. The first two digits describe the 'HS Chapter' (e.g. 52 for 'Cotton'), the second pair describe the 'HS Heading' (e.g. 09 for 'Woven fabrics of cotton…'), and the final combination describe the 'HS subheading' (e.g. 11 for 'unbleached, plain weave'). At the 6-digit level, the HS codes generate detailed descriptions. An example is the code 520911, which represents 'Fabrics, woven; containing 85% or more by weight of cotton, unbleached, plain weave, weighing more than 200 g/m^2.' Some countries have extended the HS codes to increase specificity, but these are not standardized internationally.

3.1.3. Map supply chain structure

Having specified the product, the next step is mapping the supply chain structure by delineating the individual processes or stages in the supply chain for the product and listing physical inputs and outputs. The resulting structure is akin to the 'physical input-output structure' described in GCC and GVC studies (Gereffi et al., 1994) and the 'production circuit' in GPN studies (Dicken, 2011). In addition to a written description, we recommend generating a product-system diagram, which is similar to the *process flow diagram* in LCA studies (ISO, 2006). This product-system diagram visually represents sequential processes transforming outputs from earlier processes to goods or products. These could relatively simple linear chains or convergent branched structures, as when multiple components come together during manufacturing. Multiple product-system diagrams might be necessary if a study spans periods when new important production processes reorganize supply chains (e.g. introduction of lead recycling in the battery industry). This product-system diagram provides insight into the supply chain processes and aids in the identification of the most salient processes for analysis (i.e. where social or environmental effects might be most intense).

3.1.4. Define time period, scope of supply chain, and relevant geographies

With the supply chain delineated, it is possible to define the study in terms of temporal scope, supply chain coverage, and geography.

Start by clearly delineating the timeframe of analysis. The temporal scope depends on the focus and purpose of the study. Limiting the temporal scope enhances study tractability. However, the period must be long enough to capture dynamics in supply chain geography based on price, resource availability, and other factors. Examples include focusing on a defined time series, such as a 10-year period to capture changes related to a specific policy (e.g. abolition of garment quotas) or event (e.g. acute deforestation). The outcome of this step is a defined time period to guide data needs and help scope the study.

Scoping the supply chain coverage involves explicitly stating what portion of the supply chain you will examine. You could state this in terms of supply chain stages: raw material extraction to retail stages. Alternatively, specific processes might be of interest, such as yarn spinning and sewing processes in the manufacture of the shirt in Fig. 2. Multiple supply chains structures might be of interest if a study covers multiple time periods so as to capture industrial restructuring.

The scope of the supply chain sets the geographic scope of the study. For domestic supply chain processes or stages that take place entirely within one country, national production data and marketing databases can help locate regions where specific stages occur. For transnational supply chains, bilateral trade statistics are a source of data. The UN-Comtrade database of vetted data generated by national statistics agencies, covers global bilateral trade since 1962 by mass and value (United Nations, 2017). Here again, HS codes can help. Focusing on shirt production in China in Fig. 2, bilateral trade data can identify relevant upstream and downstream countries by finding major exporters of cotton (HS 520100) to China and importers of cotton shirts (HS 520911) from China. Repeating this step for the identified upstream and downstream countries expands the supply chain geography, until you capture the locations of all stages relevant to the study aims. Studies covering waves of industrial reorganization, such as the cessation of international garment quotas, might require defining multiple geographic or time scopes to capture the shifts in global production. For studies of complex products or countries with many importing and exporting relationships, prioritizing one or two countries at each stage of the supply chain can keep project scope manageable. The outcome of this step is a list of the countries and regions where the supply chain operates. This, alongside the temporal scope, will guide your data needs.

3.2. Step 2: collect data

This step involves identifying data sources, and then gathering, validating the data, and cleaning the data.

3.2.1. Identify appropriate data sources

Each study will have distinct requirements. However, there are several ex-situ data sources that are likely to apply to most TRACAST analyses (see Tables A.1-A.4 for a non-comprehensive list). Concession maps can reveal corporate actors at the resource extraction stage. Numerous data repositories specialize in documenting social and environmental challenges. Company websites and reports often publicize high-profile buyers, retailers, or distributors. Corporate financial disclosure documents (e.g. U.S. Securities and Exchange Commission '10-K' forms) list relevant downstream subsidiaries and locations of physical assets.

Customs data are particularly useful for building linkages between companies that trade internationally.[2] For example, *Export Genius* (www.exportgenius.in) can help build internal linkages upstream and downstream from Chinese shirt manufacturers in Fig. 2. Customs data types include: public, semi-public, private and confidential. Governments collect public customs data and make them freely available to the public or make semi-public data available via third-party resellers. Private companies produce and sell private customs data. Public, semi-public and private customs data cover much of the international trade (see Table A.4). Lastly, NGOs have occasionally surreptitiously obtained confidential customs data or lists of company suppliers.

In-situ approaches can address remaining data gaps after using ex-situ approaches. Common data gaps include building supply linkages within a country and documenting environmental and social impacts at a specific geographical site. If both in-situ and ex-situ approaches fail to generate the require data, then consider amending the study aim (Step 1).

Ensure that both the in-situ and ex-situ approaches you select can support the chosen temporal scope. Customs and remotely sensed data, for example, are often only available for select years. This may limit the ability to capture supply chain linkages or environmental change. Similarly, interviewees may not be knowledgeable of production practices in previous years. In such instances, others TRACAST approaches can help address these gaps. Or you may need to revise the study scope.

3.2.2. Validate the data

Tests must be performed to ensure data validity. As with many data sources, customs data present completeness and accuracy challenges. Completeness issues arise when data providers redact company names in the data, either at company request or as standard protocol (e.g. Canadian Importers Database). Inaccuracies appear through numerous processes, including misalignment (purposeful or accidental) between HS codes and shipment contents, and transshipping through a third country that obscures shipment origins. High levels of redaction hinder the ability to build linkages, potentially thwarting study aims. Data also often list shipping companies instead of importer or exporter. Although these companies are corporate actors, they are not usually the relevant linkages functioning as key nodes, except in rare instances (see Global Witness and Environmental Investigation Agency, 2009). To validate the quality of the customs data, a basic mass balance check can be done using authoritative, official trade data from national statistics agencies or UN-Comtrade. Deviations greater than a factor of 2 suggest accuracy issues (Higgs, 2017).

3.2.3. Clean the data

Cleaning the data maximizes the chances of making linkages. Firm names need to be standardized within and between datasets using a many-to-one concordance matrix that captures the aliases arising from transcription errors, acronym and abbreviation usage, and subjective choices. 'Jones Co.,' 'Jonse Co.,' and 'Jones Company' may all appear, yet they refer to a single corporate actor that should be represented by one name. With customs data, temporal misalignments may occur due to lengthy transit times. For instance, transoceanic shipments can be at sea for a month or more, so separate import and export datasets might log 1/12 of annual shipments in different years. Researchers can overcome this by matching shipments using mass, vessel name, and good descriptions or by excluding shipments within a defined buffer period.

3.3. Step 3: identify and verify corporate actor linkages

With data in hand, it is time to construct corporate actor linkages. The linkages will always include those internal to the supply chain, but may also include external corporate actors that influence the dynamics, structure and impacts of the supply chain. Whether external corporate actors are included depends on the purpose of the study.

3.3.1. Build linkages between corporate actors

If using customs data, it is useful to organize datasets so that you list trading partners for each company in a unidirectional manner. List the downstream customers for each upstream producer or vice-versa, depending whether there a more customers than producers or more producers than customers, respectively. Comparing datasets enables the identification of purchasers in datasets of stages 'upstream' in the supply chain datasets that appear as sellers in datasets of stages 'downstream' in the supply chain. Using the example from Fig. 2, the same corporate actor might be a purchaser of yarn in an Indian-Chinese customs dataset and a seller of shirts in a Chinese-U.S. customs dataset, linking the Indian yarn producer to the U.S. retailer through the Chinese trading partner. Repeating this process across the supply chain will identify additional linkages. The company name need not be the matching element that reveals a link. Sometimes, shipping details, such as a vessel name, arrival date and cargo volume can build linkages between datasets, even those containing only one corporate actor each.

The mechanics of concatenating supply chain processes varies depending on the form and volume data. If document review or interviews reveals only a few buyers and suppliers, then the supply chain and linkages between corporate actors can be generated using short tables. Pivot tables are useful for small to medium datasets ($<$10,000 data points). With large datasets, custom algorithms that match names, vessels, volumes, and other information can accelerate the process of building corporate actor linkages. It may be necessary to collect additional data or even re-scope the study if important linkages remain elusive.

3.3.2. Verify accuracy of linkages

Linkages made on paper require verification. Mathematical approaches exist to test the validity of linkages. Discrete analysis of modeling choices or Monte-Carlo analysis of continuous data can test the sensitivity of model outcomes to uncertainty (Saltelli et al., 2008). An example of discrete analysis for the supply chain in Fig. 2 would be to see if the choice of truck or train transport changes where Chinese factories source their cotton. Monte Carlo analysis could simulate how

[2] Goods that enter or exit countries at seaports, airports, and land crossings generate customs data. Shipping-related documents, such as vessel manifests and bills of lading, comprise the sources of most of these data, which include the names and addresses of trading companies, trade amounts (mass, value and volume), vessel identification numbers or designations, descriptions of goods (either as an HS code or a qualitative description). Database generators, including government agencies and third-party companies, organize and collate these documents into structured datasets. For instance, the U.S. Customs and Border Protection collects digital data on all imports through its Automated Commercial Environment (U.S. Customs and Border Protection, 2017). Data distributors, who may be different from the database generators, publish the data. IHS Markit (www.ihsmarkit.com) is one of many data distributors of U.S. import data generated by the U.S. government, and this company also generates and distributes a dataset of U.S. exports.

the distribution of domestic cotton consumption in India might influence which provinces export their cotton. If these analyses generate inconclusive results, researchers may ultimately have to resort to in-situ approaches to validate linkages.

In-situ methods can identify whether process inputs from different upstream sources are blended or segregated, and these practices can validate or invalidate connections between upstream and downstream nodes. Using the supply chain from Fig. 2, visiting a Chinese yarn factory would reveal if the cotton from different farms was kept segmented during the spinning process, and hence, whether a shirt producer is linked to specific farms. If studying a previous time period, interviewing employees familiar with past production practices may be necessary. When discussing unconfirmed linkages, the supply chain may not be invalid, but use caution when making claims or identifying key nodes.

3.4. Step 4: evaluate environmental and socioeconomic impacts

With a supply chain constructed, including verified, internal corporate actor linkages, it is possible to analyze it for hotspots and key nodes. Techniques from LCA and geography are useful to capture supply chain hotspots, whereas approaches used in political ecology, network science, and GPN, GVC, and GCC theories provide means to identify key nodes.

3.4.1. Identify hotspots

Hotspots can arise at any supply chain stage. Using the example from Fig. 2, an environmental hotspot in the t-shirt supply chain might be a cotton-producing Indian province, and a social hotspot might be a Chinese garment factory complex. Existing datasets are one way to identify locations and the degree of impact (see Table A.4 for a partial list), although in-situ approaches are often needed to relate hotspots to corporate actors. An example of ex-situ hotspot identification is analyzing municipal-level deforestation data to link corporations to changes in land use for soy farming (Godar et al., 2016). In-situ hotspot identification approaches include site visits to Laotian logging sites to document destructive logging (Environmental Investigation Agency, 2011b), and interviews with laborers to capture human trafficking on fishing vessels (Greenpeace, 2015). LCA can help move from identifying hotspots to providing quantitative estimates of ecosystem damage, resource depletion and social impacts (Hellweg and Milà i Canals, 2014). Hotspots might shift within or between countries as supply chains reorganize, necessitating analysis of multiple time periods.

Deleterious environmental and social changes do not arise immediately or spontaneously. Supply chains become embedded in places and social networks over time (Hess, 2004). Knowledge of the history and geography of a location is necessary to understand how the hotspots emerged and why they persist. Political ecology provides a means to gain insights through analysis of the broader social, political and historical drivers behind environmental change and how nature and humans simultaneously influence each other (Robbins, 2012). This understanding then provides the foundation to develop strategies that address environmental and socioeconomic pressures and imbalances associated with the hotspots (Bush et al., 2015).

3.4.2. Identify key nodes

In TRACAST, a key node is a specific corporate actor who exerts significant power along portions or throughout the entire supply chain. Multiple analytical tools can identify them. Social Network Analysis is one approach that uses connectivity as a metric to pinpoint important nodes in a supply chain based on the number of incoming and outgoing connections to other corporate actors (Kim et al., 2011; Pinheiro, 2011). Another idea is to rank corporate actors on volume produced or sold, severity of social or environmental impacts, or other metric of influence. When study scope permits, analysis over time will reveal key nodes and their linkages are durable (i.e. they embed spatially or socially). Studies indicate that stability influences the ability to address sustainability challenges in supply chains (Bartley, 2018). It is possible to use less quantitative approaches. Knowledge of inter-firm governance from GVC/GCC theory can help identify key nodes in the supply chain, particularly in finding corporate actors with power over upstream suppliers. Expanding this analysis to include external supply chain linkages (as in GPN theory) is also worthwhile, because these can reveal drivers behind the emergence of a key node. Such drivers may be regulatory capture, nepotism, financial pressure, or lobbying. In-situ approaches, especially interviews, are critical in articulating these nuanced aspects of supply chain formation and governance, which can be particularly important for developing intervention strategies.

4. Using TRACAST to link russian forests to U.S. big-box retailers

To illustrate the TRACAST process, we applied the framework to answer the question: Is there evidence that big-box retailers, specifically Walmart, The Home Depot, and Lowe's, profit from unsustainable logging practices of their suppliers? This example demonstrates how TRACAST can uncover linkages between these transnational corporations and companies involved in ecologically destructive logging practices. We focused on the southern Russian Far East (RFE) – a sensitive biodiversity refuge beset by continued forest degradation (Liang et al., 2016), chiefly from illegal logging (Actman, 2015, Newell and Simeone, 2014). From the logging sector in the RFE, we construct a supply chain with corporate actor linkages connecting Russian logging firms to U.S. big-box retailers. Although we applied TRACAST to the years 2007 and 2013, we focus on 2013 for brevity.

4.1. Scope study

4.1.1. State study goals

Our goal was to understand the role of U.S. transnationals in problematic logging in the RFE. Answering this helps us understand if powerful transnationals act as key nodes that can mitigate environmental and social impacts in complex global supply chains. It also provides insights into the limitations of well-intentioned sustainability policies designed to 'green' supply chains. We selected the RFE region because it is an important source of wood for U.S. retailers (WWF, 2013), and because one of the authors has experience studying supply chains in the region (Newell and Simeone, 2014). This regional expertise was highly valuable in terms of understanding local context, gaining access to data, and interpreting results.

4.1.2. Identify product

We focused on products made from Mongolian Oak (*Quercus mongolicus*) and Manchurian Ash (*Fraxinus mandschurica*), since these trees play a vital role in supplying food to keystone species in the region (Newell, 2004). Both tree species are used to make flooring and other hardwood products. The specific product in this case was hardwood flooring, as this supply chain has previously contributed to problematic logging in the region (Vandergert and Newell, 2003). These are HS 440391 (oak) and 440399 (ash) and both are defined as variants of, 'Wood; in the rough, whether or not stripped of bark or sapwood, or roughly squared, untreated.'

4.1.3. Map supply chain structure

We limited the scope of the study to the supply chain stages of extraction, manufacturing, and retail, shown in a product-system diagram (Fig. 4). Using ex-situ (document review) and in-situ (tradeshow visits, interviews) approaches, Newell (2008) identified six nodes in the typical hardwood supply chain over these three stages. First, are the logging concession holders (node 1) in the RFE, who may subcontract other logging firms (node 2) to log the ash and oak trees on their leased land. These logging firms either export the logs or sell them to a Russian exporting firm (node 3), who in turn may sell them directly to flooring manufacturers (node 4). The wholesalers (node 5) broker between

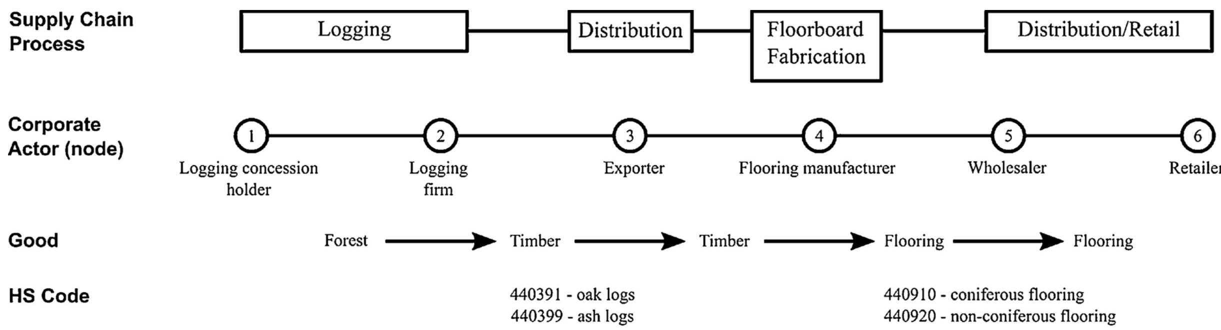

Fig. 4. Production-system diagram of a logging supply chain initiating in Russia.

flooring manufacturers and final retailers (node 6). However, Newell (2008) uncovered alternative supply chain configurations. For instance, Russian concession holders may log and export themselves, effectively collapsing nodes 1–3 into one node. Similarly, some Russian lease-holders may log, but lack the foreign contacts or knowledge of customs procedures to export. There can also be additional nodes such as Russian mills that process logs into sawed wood or Chinese import firms.

4.1.4. *Define scope of supply chain, relevant geographies, and time period*

Our research objective was to evaluate if U.S. transnationals have internal supply chain linkages to illegal and/or unsustainable logging in the RFE. Thus, we needed to capture all nodes in Fig. 4 in order to rebuild the supply chain from retailers and sites of timber harvest. The large number of international trade partners who purchase Russian logs hindered a complete tracking of this supply chain that includes all international and domestic purchasers. To make the study manageable, we prioritized wood exports, as this is the fate of most Russian wood (Simeone and Eastin, 2012). We consulted bilateral trade statistics from UN-Comtrade to identify major importing and exporting countries along the supply chain. By doing so, we capture the major markets for Russian logs and hardwood flooring made using Russian wood. Focusing on oak logs (HS 440391), we found that China accounts for 67% of Russian oak log exports between 2007 and 2016 (Fig. 5A). Exploring Chinese exports of hardwood floors using HS 4409 [‘Wood (including strips, friezes for parquet flooring, not assembled), continuously shaped…’] showed that the U.S. dominated consumption over the past decade (Fig. 5B). Our supply chain geography is thus: Russia (raw material extraction), China (manufacturing), and U.S. (retail). We focused on three retailers, The Home Depot, Lowe’s and Walmart, due to their longstanding commitments to transparent wood sourcing (Lowe’s, 2019; The Home Depot, 2019; Walmart, 2019) and because these transnational corporations are ostensibly key nodes that can influence the environmental actions of their suppliers. We selected 2013 as the year for the assessment, since this follows an NGO exposé linking U.S. hardwood flooring giant, Lumber Liquidators, to illegal logging in the RFE (Environmental Investigation Agency, 2013).

4.2. *Collect data*

4.2.1. *Identify appropriate data sources*

Given the transnational nature of our supply chain geography, we initially focused on customs data. We obtained information about Russian exports of HS 440391 (oak logs) and 440399 (ash logs) to China from IHS Global Trade Atlas (https://www.gtis.com/gta/) and information about U.S. imports of HS 440910 (non-coniferous flooring) and 440920 (coniferous flooring) from China from IHS PIERS (www.ihs.com/products/piers.html). Global Trade Atlas covers all modes of freight transport and should include the totality of Russian timber exports. IHS Piers only covers seaborne imports. Since sea is more cost effective than air transport, the only alternative mode to the U.S., these data should adequately capture most imports of wood flooring. Both datasets include shipment mass, arrival date, origin country, HS code, and names of both importing and exporting companies.

4.2.2. *Validate the data*

We validated these data by comparing them with official trade statistics from UN-Comtrade. Here, we focus on oak. We compared the 5-year average U.S. imports of non-coniferous flooring (HS 440910) from China (2009–2013) in UN-Comtrade with those we obtained from PIERS. UN-Comtrade covers 73% of the non-coniferous flooring data by

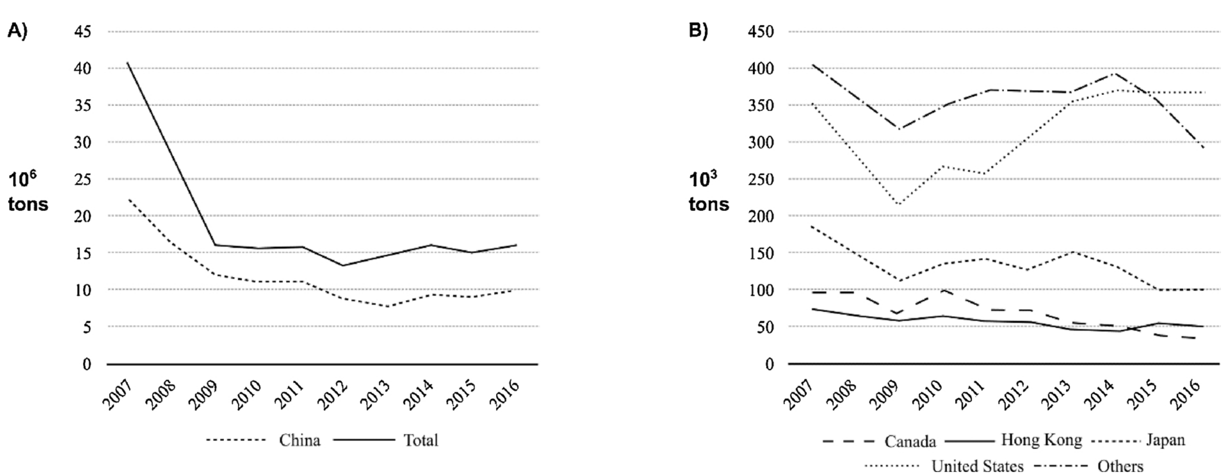

Fig. 5. Russian exports of oak logs and Chinese exports of wood flooring. (A) Russian exports of ‘oak logs’ (HS 440310) (B) Chinese exports of ‘wood for flooring’ (HS 4409), with major trade partners (>5% of total trade) shown.
Source: UN-Comtrade (2017)

mass from PIERS (2.5 vs 1.8 kiloton). UN-Comtrade also covers 51% of oak log (HS 440391) data in Global Trade Atlas for 2013, the single year for which we had data. Although not nearly 100% correspondence, an error below a factor 2 between customs and official datasets was sufficient for us to proceed based on experience.

4.2.3. Clean the data

We manually constructed concordance tables mapping multiple company aliases to unique Russian, Chinese, and U.S. company names. We removed data points containing blatant errors (e.g. address in company name field), redacted company names, or freight carriers. Temporal coverage of our data was not adjusted for transit or production lags, because the error is negligible (~5%) given a 20-day transit between Chinese ports and the U.S. West Coast.

4.3. Identify and verify corporate actor linkages

4.3.1. Build linkages between corporate actors

The aim is to connect the Russia-China and China-U.S. customs datasets that contain a combined 40,000 unique shipments. To aid the process, we used computer algorithms to sift through each shipment and reconstruct internal linkages for the year 2013 by matching Chinese companies present on both datasets. Consequently, common Chinese firms become a bridge between Russian timber exports and U.S. flooring imports. By connecting the datasets, we identified 22 Chinese companies with linkages both to Russian firms and U.S. firms. The Russia-China customs data has the benefit of listing both the Russian exporting and logging firms. Thus, the two customs sets cover nodes two through five in Fig. 6: Russian logging firms (114 corporate actors), Russian exporters (68 corporate actors), Chinese manufacturers (22 corporate actors), and U.S. importer (62 corporate actors).

We procured additional data to expand our findings to include nodes one and six (Fig. 6) and build linkages across the entire extraction, manufacturing, and retail supply chain. We started with spatial data on forestry concessions in the RFE. These maps contain the names of Russian landowners that we cross-referenced with the 114 Russian logging firms with links to U.S. importers. Cross-referencing revealed 14 concession owners that appear on the customs data, identifying them as both landowners and logging firms. These 14 corporate actors served as sources of wood for 62 U.S. importers. We used the websites of the 62 U.S. importers to classify them into small retailers, small construction firms or distributors to major U.S. big-box retailers. We determined that 9 of the 62 U.S. importers distribute to major U.S. big-box retailers, thereby building linkages to node six. Using the corporate actor linkages and the quantitative data from the customs databases, we constructed the hardwood flooring supply chains of U.S. big-box retailers Walmart, The Home Depot, and Lowe's to RFE landowners selling timber through one of their Chinese suppliers. Fig. 7 shows simplified supply chains from retailer to forest with only one inbound connection and outbound connection for each node.

4.3.2. Verify accuracy of linkages

So far, this analysis provides evidence of linkages between RFE forests and U.S. big-box retailers. However, linkages derived from these ex-situ approaches cannot conclusively confirm the presence of wood from any particular RFE logging concession on a U.S. retailer's shelves. Russian exporters can source their wood from many logging firms. Likewise, Chinese manufacturers can have many suppliers from Russia and other countries. Validation of the supply chain linkages is required, because we do not know whether wood from different sources is kept segmented or mixed together at different stages along the supply chain.

When Newell (2008) and EIA (2013) attempted to validate linkages between Russian loggers and U.S. retailers using interviews and site visits, they found that wood from different sources was mixed at two locations: Russian consolidation lots prior to export and at Chinese factories. The mixing of wood from multiple sources means that we cannot confirm linkages between U.S. retailers and specific RFE loggers. Further work using in-situ approaches is needed to track the flows of wood from logging site to factory and validate the linkages across the entire supply chain in Fig. 7.

4.4. Evaluate environmental and socioeconomic impacts

4.4.1. Identify hotspots

To identify supply chain hotspots, we used GIS to overlay forest conservation data in the Primorsky region of the RFE with the concession maps for the Russian logging firms (Fig. 8). Both Taiga and Leseksport LLC operate logging concessions that intersect with High Conservation Value Forests in the region. This GIS overlay illustrates the potential to identify environmental hotspots in the hardwood supply chains of these retailers by ex-situ means. Field work by NGOs (WWF, 2013), has documented how Russian timber companies log commercially under the guise of sanitary logging permits that are intended to improve forest health by removing diseased or dying trees. For example, Les Eksport LLC has used this tactic to harvest healthy ash and oak (Newell, 2008). Consequently, the lack of source segmentation at Russian timber lots and Chinese factories makes it impossible to deem the supply chains of U.S. big-box retailers as free of wood from destructive logging in High Value Conservation Forests in 2013. Sourcing from these forests would contravene longstanding wood sourcing policies of both The Home Depot (The Home Depot, 2019) and Lowe's (Lowe's, 2019). More detailed TRACAST analysis could explore other impacts associated with this logging, including its effects on biodiversity (Miquelle et al., 2015), ecosystem health (Mishina, 2015), and indigenous livelihoods (Vandergert and Newell, 2003).

4.4.2. Identify key nodes

From the corporate linkages in the logging supply chains shown in Fig. 7, one might predict that Walmart, Lowe's, and The Home Depot are key nodes in the supply chains, because they are the classic 'chain drivers' in GVC literature with clout over suppliers. However, in-situ work reveals that the keys nodes are also the Russian exporters and loggers (Environmental Investigation Agency, 2013; Newell, 2008; WWF, 2013). Despite their purchasing power and ability to dictate prices and quality standards of first-tier suppliers, large retailers are too far removed from the nodes that blend legally and illegally harvested timber, both physically and in terms of governance, to stop this practice. For instance, IKEA attempted to control timber sourcing at its Chinese sub-contractors, but were thwarted by the ready availability of forged Russian logging permits, the inability (or unwillingness) of Chinese suppliers to identify such

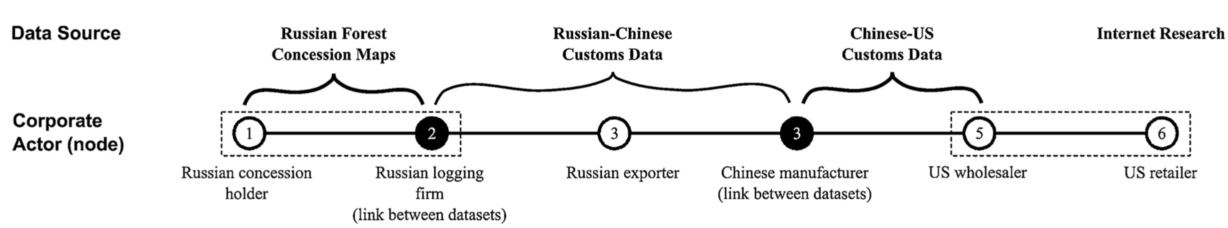

Fig. 6. Linking corporate actors in the Russian-U.S. hardwood flooring supply chain outlined in Fig. 4. Black dots are corporate actors that connect two datasets. Nodes within dashed box can be a single corporate actor.

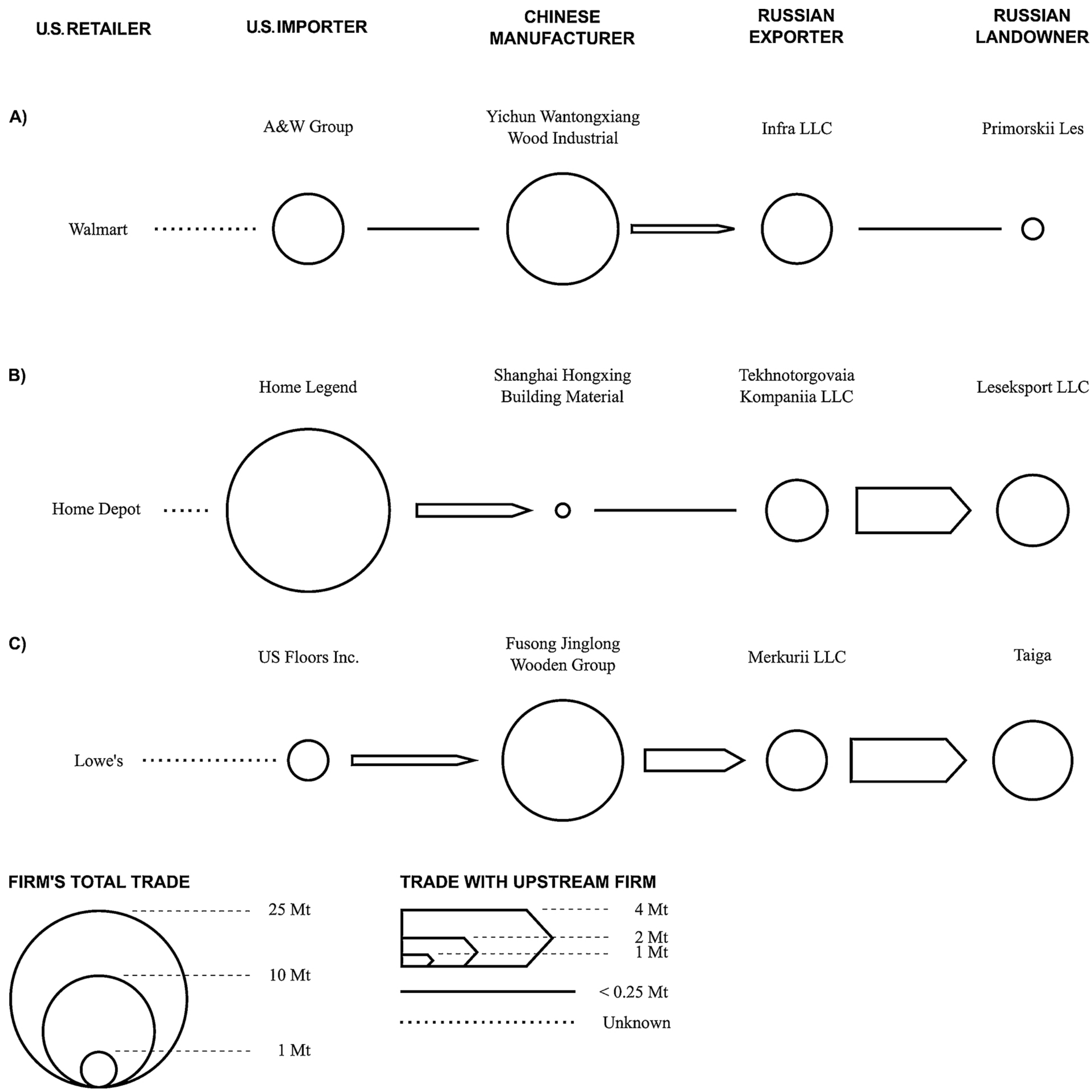

Fig. 7. Select wood flooring supply chain from major U.S. retailers (A) Walmart, (B) The Home Depot, and (C) Lowe's to the Russian landowner and logger through Chinese factories for the year 2013 in megatons (Mt).

documents, and the absence of a tracking system to link wood to a specific logging permit (Newell, 2008). Moreover, investments in training at Chinese firms by foreign retailers deters them from ending relationships with Chinese suppliers. Thus, geographic distance, the multiple nodes between retailer and logger, and economic priorities can undermine commitments to nondestructive wood sourcing by transnationals like The Home Depot, Lowe's, and Walmart.

Moving up the supply chain from retailers to U.S. importers does little to address governance challenges. Even large Chinese importers (Fusong Jinglong Wood Group, Yichun Wantongxiang Wood Industrial) are relatively powerless, in part because they lack fundamental knowledge of the Russian language and business landscape. Consequently, the Chinese importers are often reliant on Chinese buyers based in Russia for their imported wood. Evidence from multiple studies reveals that Russian exporters that purchase and blend wood from different sources and Russian logging firms that label and fell trees are key nodes, because they present the best opportunities to build a legitimate chain of custody for wood provenance from the RFE (Environmental Investigation Agency, 2013; Newell, 2008; WWF, 2013). Newell and Simeone (2014) also found that the cash-strapped, local forest service increased its output of sanitary logging permits and road construction permits in conservation forests after lobbying by Primorskii Les. This external linkage with corrupt local authorities underscores RFE logging firms as critical control points in the supply chain.

5. Discussion

TRACAST enables a researcher to tell the story of a supply chain; where it is located, who is involved, and how it affects people and planet. In this discussion, we reflect on the implications of the case study for the TRACAST methodological framework, followed by a discussion on how it can inform and advance research on supply chains.

5.1. Data and methodological challenges with TRACAST

As the Russian logging case illustrates, uncovering linkages within a particular country is perhaps the most challenging task. Many Chinese

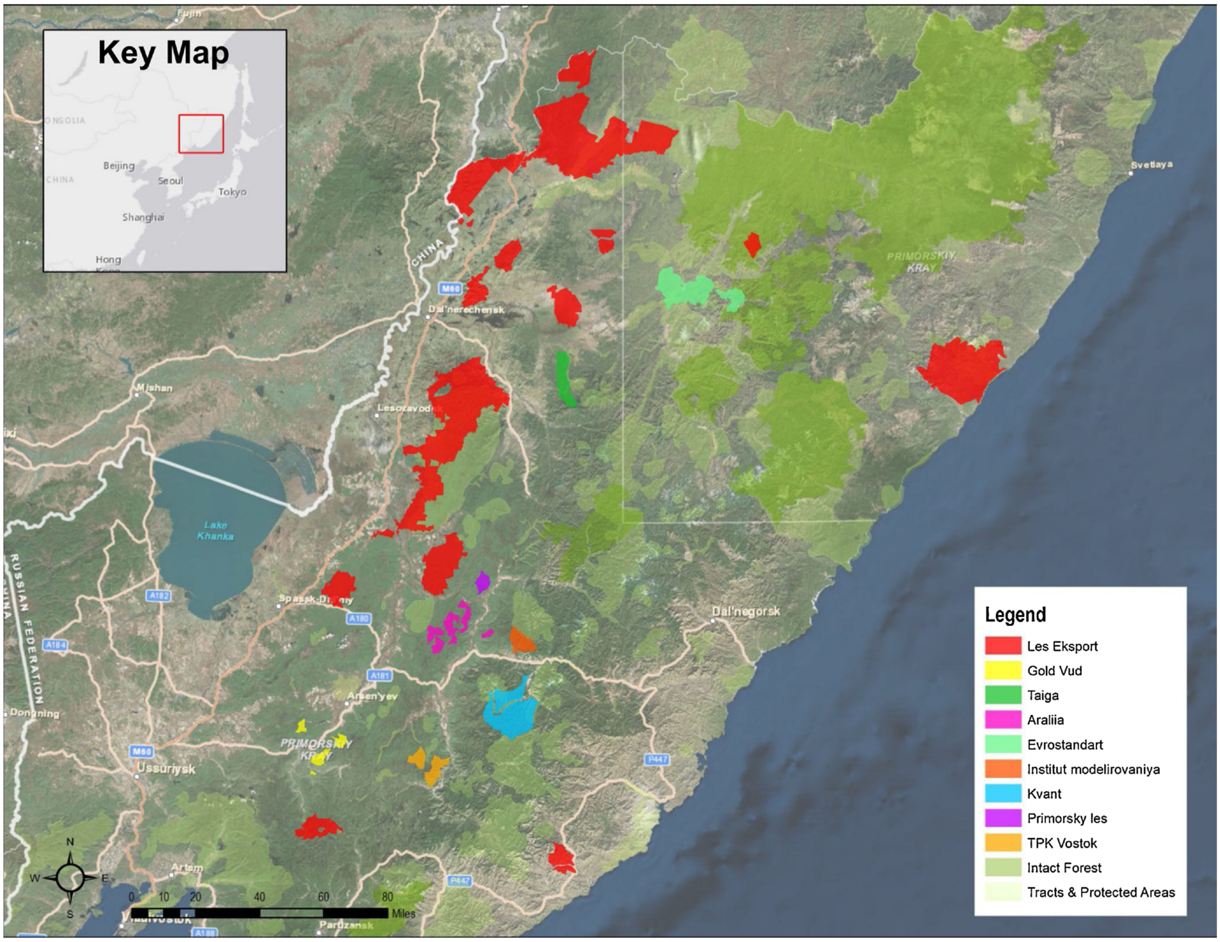

Fig. 8. Map of logging concessions and co-location of logging and High Conservation Value Forests.

importers of Russian wood sell to Chinese manufacturers, but lacking data on trade within China, we were not able reconstruct these supply chains. We worked around this by focusing Chinese companies that both imported wood from Russian companies and exported wood to U.S. companies, at the cost of excluding imported Russian Ash and Oak that did not take this route to U.S. retailers. Even when we can make linkages, in many cases, the customs data provides a physical address far from sites of production and manufacturing. For example, the corporate headquarters might use the address of the distribution center rather than the factory or a paper mill rather than timber harvest site. Thus, identification of these linkages and supply chain locations typically involves in-situ methods. Companies may be willing to provide these details, especially those who view supply chain transparency as a key aspect of doing business in a globalized world and a means to differentiate their products (Kashmanian, 2017; Mol, 2015). In other cases, companies may not be willing due to so for reasons of risk or competitive advantage. Gaining access to sites and interviewees is difficult when corporate actors view transparency as against their best interests. NGOs can falsely pose as buyers (EIA, 2011a), but academics cannot due to ethical standards in research.

Researchers also need scalable and efficient methods to connect corporate actors to specific sites, but these are nascent. In trying building supply chain linkages in the trade of Brazilian soy, an early version of Godar et al.'s (2016) model used algorithms to identify Brazilian municipalities likely supplying transnational soy distributors. However, models like this are controlled conjectures that require field verification. Some countries and trading-blocs specify goods at 8-, 10- and 12-digit levels (e.g. Russian HTS 4403999501 – Manchurian Ash), which helps focus on the limited locations that produce very specific products. However, much model outputs, findings still require verification using maps, land registries, or in-situ work.

Emerging technologies may help overcome these data gaps. Blockchain, the technology behind cryptocurrencies, records transactions on a non-corruptible ledger (Casey and Wong, 2017). If applied to supply chains it would generate near real-time, accurate data on trading companies, trade volume, segmentation and locations. However, widespread proliferation of blockchain is decades away and requires buy-in from all parties (Iansiti and Lkhani, 2017), and there are no guarantees that researchers will get access to these data. Similar data might be available from the electronic tracking systems, such as the radio-frequency ID tags used to track supply chains in numerous industries (Sarac et al., 2010).

A software developer, Sourcemap (2018), achieved success in mapping supply chains using participatory digital surveys sent to cellphones and computers. Starting at the bottom of the chain, a survey is sent to all suppliers one tier upstream. The survey propagates to the top of the supply chain, and information on the upper tiers trickles down to the bottom, eventually leading to the mapping of the chain. The Sourcemap database provides successful applications of this method for internal supply chain tracking by prominent names in food (Hershey's), apparel (Vivienne Westwood) and telecommunications (Fairphone) (Sourcemap, 2018). Though powerful, like blockchain, this method needs cooperation from all actors in the supply chain.

Supply chains are fluid as locations and suppliers shift based on price, availability, and stability of supply (O'Rourke, 2014). Such fluidity can make identifying actor linkages, nodes, and hotspots in a supply chain more difficult. Alternatively, because of advantageous local conditions, a phase of a supply chain can become 'embedded' (Coe et al., 2008) and certain corporate practices dominant (Manning et al., 2012). Local labor laws, wages, environmental regulations, taxes, trade agreements, consumer preferences, human capital, local institutions, and other factors attract specific economic activities and corporate actors to particular sites and promote linkages between corporate actors (Hess, 2004). There are situations in which a supply chain configuration embeds at one scale, but stays fluid at another. In our case study of Russian wood DIY retailers, China has remained dependent on Russian wood to manufacture flooring and the U.S. has remained dependent on China for finished supply (Fig. 5). However, the specific companies within these supply chains can change between years and even months. For example, in the customs data, the number of Chinese firms importing Russian timber dropped from 179 to 119 between 2007 and 2013, with only 22 companies exporting in both years. Bartley (2018) found similar fluidity in the Indonesian garment industry. Capturing this tension between embeddedness and fluidity in supply chains necessitates that data be collected in short intervals and at subnational geographic specificity.

The TRACAST process comes with other important considerations. For example, successful in-situ work rests on knowing key local actors, being aware of problematic sites or companies, and having an understanding of local political economy and history. Language barriers may pose a significant challenge. It can take years for a research to accumulate this knowledge or know where to find it. Partnering with local actors (e.g. NGOs, scholars, media) can help overcome this. When studying the garment and timber industries in China and Indonesia, Bartley (2018) drew on both to gain access to factory audits and identify workers to interview. This speaks to the collaborative and interdisciplinary nature of TRACAST. It may be necessary to form a research team with expertise in the mining and processing large amounts of disparate data, understanding local conditions, and the ability to draw on a wide range of conceptual frameworks to interpret and contextualize findings.

A final consideration is the ethics of studying and publishing research on individual corporations. There are instances when companies have punished workers who provided information to NGOs, even those who provided this information through anonymous interviews (Bartley, 2018). The impact of publishing such research on the broader welfare of potentially affected communities needs to be weighed. For example, Nike dropped a Pakistani sub-supplier that used child labor. Leading to near-term poverty for 20,000 local residents who relied on income from the jobs at that factory (Montero, 2006). However, it should be noted that Nike terminated this sub-contractor after multiple attempts to address child labor concerns. Nevertheless, researchers who publish such research need to carefully consider potential negative impacts on local livelihoods.

5.2. How TRACAST contributes to research on supply chain dynamics

Existing academic and NGO literature on supply chains form the building blocks of TRACAST, in particular the different strands of supply chain studies (GCC, GVC and GPN), land change science, and industrial ecology. By incorporating knowledge and methods from these literatures, TRACAST provide a recognizable approach that scholars in these communities can use to advance their work.

Our literature review found limited work by GVC, GCC and GPN scholars on individual corporations and, in particular, their supply chain linkages. This is crucial as Dicken identifies transnational corporations as the 'movers and shapers' of the global economy, intimating that because of this power, these linkages need particular attention. NGOs and civil society have made this inquiry a focus of their corporate advocacy. A methodological framework like TRACAST lets researchers do the same by enabling them to reconstruct supply chains and critically analyze the activities of the corporate actors that constitute those supply chains.

TRACAST could help address topical gaps in the important work on GVCs, GCCs, and GPNs. GPN research, for example, has focused primarily on topics of economic upgrading and inter-firm governance, with relatively limited attention to the environmental, equity, cultural and poverty impacts of supply chains (Bridge, 2008; Kelly, 2013; McGrath, 2018; Werner, 2018). Similar concerns have been raised by GVC scholars (Bolwig et al., 2010; Fearne et al., 2012). Exciting work by GPN (Gibson and Warren, 2016; Kelly, 2013) and GVC (Ferrando, 2017; Loconto and Simbua, 2012) researchers has made strides in addressing these research gaps. TRACAST could facilitate further inquiry into these issues, for instance, by identifying hotspots (environmental or social) along the supply chain. TRACAST could also help these communities add quantitative aspects, such as the analysis of trade volumes between companies using customs data, to what have up until now primarily qualitative studies of individual corporate supply chains (Goldstein and Newell, 2019).

Through the concepts of teleconnections and telecoupling, land change scientists have provided powerful lenses to understand the co-evolution of distal spaces. But empirical research has centered on national level assessments (see Sun et al., 2017). There has also been increasing work linking specific companies to land use change (Garrett and Rausch, 2016; Gibbs et al., 2016), but not their linkages to other companies through international trade. TRASE (www.trase.earth) is one empirical example of research that links corporate actors and their land change impacts to the global economy. As with TRACAST, TRASE uses customs and related data to map bilateral trade of agricultural products at the corporate-to-corporate level. Through remote sensing and cadastral maps, companies are then linked to forest degradation. TRASE visually communicates teleconnections induced by production and consumption, with a focus on soy and beef. To date, TRASE makes internal supply chain linkages between two nodes, such as a Brazilian soy exporter and its customer abroad. Our case study shows how TRACAST could help extend the number of supply chain stages covered and companies included by building linkages across multiple customs datasets. Moreover, by wedding supply chain mapping and assessment of environmental and social impacts with theory from GCC, GVC and GPN, TRACAST is well-suited to understand the processes and actors that facilitate and govern the teleconnections revealed by projects like TRASE. Through its hybrid of in-situ and ex-situ approaches, TRACAST also complements supply chain mapping with rich analysis of the sociopolitical and economic contexts where supply chains embed.

From the field of industrial ecology, TRACAST adopts life cycle thinking and product-system diagrams. Although this field has developed methods to identify environmental impact hotspots in supply chains, these have rarely been applied to individual corporations (Goldstein and Newell, 2019). TRACAST can address this gap and provide opportunities for industrial ecologists to critically consider issues of equity and justice in supply chains. This move towards a 'political-industrial ecology' that questions the broader socio-economic and political structures that produce and reify uneven environmental impacts (Newell et al., 2017). With its focus on geographic specificity, TRACAST might also encourage LCA researchers to address the spatial limitations of the national- and regional-level data that predominate in both environmental LCA modeling (Goldstein and Newell, 2019) and the emergent field of 'social' LCA (Jørgensen, 2013).

5.3. How TRACAST can improve supply chain governance

The number of schemes certifying the conditions under which a product was made have proliferated alongside public awareness of environmental and social challenges related to production (Bartley, 2018; Rueda et al., 2017). But these schemes have been susceptible to corruption and lax reporting (Dauvergne and Lister, 2012; Gallemore et al., 2018). For instance, the Forest Stewardship Council (FSC) can certify that a factory sources wood from a responsibly managed forest, yet factories have been caught blending FSC certified wood with wood from other sources, undermining the validity of FSC labelling on final products (Bartley, 2018). Bartley also suggests that compliance with certification more often entails better documentation than meaningful improvements in production practices, especially with respect to labor conditions. TRACAST provides an alternative means to audit sites of production independent of the information voluntary provided by companies and helps identify problematic and key nodes in supply chains where audits would be most effective. Moreover, voluntary environmental and labor certification schemes only cover a small proportion of global trade. TRACAST provides a means to investigate the majority of global trade that is neither transparent nor certified. Relatedly, TRACAST can augment work by NGOs to notify enforcement agencies about corporate infractions of environmental laws (e.g. U.S. Lacey Act) (Gibson and Warren, 2016).

Corporations themselves, even large ones, often do not know the identities of the companies in their supply chain beyond their immediate suppliers (O'Rourke, 2014). By providing a deeper understanding of their supply chain configurations, TRACAST can assist corporate actors committed to transparency and shifting toward more environmentally and socially responsible sourcing.

6. Conclusion

Numerous actors have a stake in knowing the story behind a product. Companies want to reduce risk from upstream suppliers. Governments want to enforce environmental and labor laws. Consumers want safe products that align with their personal values. Academics want to test theories, develop concepts and methods, and, ultimately, build an understanding of the global economy and its impacts. Uncovering these stories is a formidable challenge in an interdependent economy in which vast, opaque supply chains stretch across the planet. Consequently, consumers and companies often lack knowledge about the social and environmental conditions at the mines, forests, farms and factories from which these products originate.

Our case study of the flooring supply chains of Walmart, The Home Depot, and Lowe's illustrates that it is possible to uncover the story behind a product, even those that cross oceans and involve many corporate actors. By combining customs data, GIS data and document review, we were able to reconstruct these supply chain linkages, from forest to the store. We identified potential environmental hotspots and key nodes, where destructive logging in the Russian Far East is taking place.

TRACAST provides a structured methodical approach to identify and connect corporations to environmental, socioeconomic change in production-consumption systems. A hybrid combination of in-situ and ex-situ approaches, TRACAST is informed by a range of concepts and ideas from other academic fields, especially economic geography, sociology, and industrial ecology. As such, TRACAST is complementary to these literature streams, namely, (i) by helping address topical omissions in GCC, GVC, and GPN research, (ii) by bridging supply chain transparency methods and theoretical constructs from social science, and (iii) by enabling researchers to track entire supply chains using a combination of data sources and methods. Importantly, TRACAST provides a springboard for more structured empirical case work on the supply chains of individual companies. As outlined earlier, we believe that this has implications for researchers in a number of fields. TRACAST enables us to more deeply understand why and how supply chains take the forms that they do and their corresponding impacts on people and the planet.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ecolecon.2019.106492.

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