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Disaggregating the role of international and domestic trade in the global land system

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Abstract

A fundamental question in land system science is the extent to which impacts are driven by international trade. Here, we review the studies which attribute land-related impacts (land use, land-use change, biodiversity loss, and land-use emissions) to international markets, finding a wide range of results, with 13-94% of impacts driven by exports. We discuss the methodological choices and assumptions that explain this variation and reflect that 'attributional' approaches, which allocate impacts according to the total share of consumption, consistently find that international trade makes up less than 25% of impacts in the land system. Conversely, three-quarters of impacts are allocated to domestic markets, which receive comparatively less attention in the land systems literature. We encourage the land system community to develop the data and methods necessary to unpack domestic markets, outline four approaches to do so, and reflect on what such analyses can tell us about the responsibility of different actors, value chain governance, and resilience within domestic markets.

1. Introduction

Humans have a huge impact on the land system. We occupy more than 70% of the Earth's ice-free land surface and the expansion of human activities (particularly agriculture) into remaining areas of nature is the leading cause of biodiversity loss globally (Maxwell et al., 2016), and the source almost one quarter of anthropogenic greenhouse gas emissions (IPCC, 2019). A key question in land system science is therefore 'who is responsible for these impacts?'

Notably, over the last half-century the global economy has experienced rapid globalization, with a growing distance between producers and consumers. The distant telecoupling of the production-consumption system leads to legitimate concerns over equity and unequal exchange, where wealthy regions (in the Global North or 'core') benefit from environmental harms that fall disproportionately on the shoulders of less wealthy communities (in the Global South or 'periphery') (Hickel et al., 2021). It also raises questions of environmental governance and accountability for environmental harms. Often, these questions get reduced to 'which consumers drive these impacts?', or more specifically 'how much is driven by international trade?' (DeFries et al., 2013, 2010; Hong et al., 2022; Pendrill et al., 2019).

These questions have always been important but come to the surface again today as trade and trade-dependency is used as a geopolitical weapon, and trade is posited as a tool to smooth the adverse impacts of climate change (Bajaj et al., 2025).

Here, we review the literature estimating the footprint of international trade on the land system: specifically, the importance of export markets in terms of land use, land use change, biodiversity loss, and land use emissions. We find that there is a huge variation in the allocation of impacts to international trade – from 13-94% – and we explore why the variation is so large. Specifically, the approach used to attribute impacts - whether based on market share, market growth, the ownership of capital, or welfare gains - leads to a wide divergence in results. Next, we reflect on the normative positioning of this branch of land system science, and consider how these different framings match to the question of 'who is responsible for these impacts?', and their implications for policy. Notably, we call for more attention to the role of domestic markets in the land system.

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We summarise different approaches to disaggregate domestic markets, and reflect on what these subnational analyses can tell us about the responsibility of different populations within domestic markets, about value chain governance in domestic markets, and resilience of domestic economies.

2. Who is responsible for impacts in the land system?

To answer the question of how much of the environmental impacts in the land system are driven by international trade, we extracted estimates from studies which (i) are conducted at global scale, (ii) quantify environmental impacts linked to land: whether land use, land use change (such as deforestation), biodiversity loss, or land use emissions, and (iii) report the total share of impacts attributed to international trade. To disaggregate the role of international trade, these studies all used bilateral trade data and some variant of the Leontief method to trace impacts via global value chains, from producers through to consumer countries, in the spirit of so called 'consumption-based accounting' (Supplementary Table S1). We therefore excluded studies which focus on a subset of countries (such as G20 nations, the EU, or report results for groups such as the Global South/North), and do not include studies which compute greenhouse gas emissions related to non-land use sectors or produce hybrid footprints (such as the 'ecological footprint', which mixes land use and total emissions), though we expect that our insights and argument will similarly apply in these cases. The studies were identified from the authors' knowledge of the literature and a snowball approach, reviewing studies cited in each identified paper. As such, this is not intended as a formal systematic review of the literature. Rather, our sample is designed to capture the diversity of approaches used in the literature and explore how methodological heterogeneity shapes reported estimates.

This literature is summarised in Figure 1. Notably, we find that the share of impacts attributed to international markets (i.e. exports) varies widely, from 13-94%. What explains all the variation? There are many methodological choices involved in the allocation of impacts within the global economy (Bruckner et al., 2015), and prime candidates to explain the variation include choices about metrics, accounting methods, land use types, time windows, and the approach to attribution, discussed below and shown in Figure 2. Other methodological choices such as amortization time, canopy cover threshold, and net vs. gross expansion are not discussed further, because previous work has found this changes the export share by only 1-2% (Pendrill et al., 2019).

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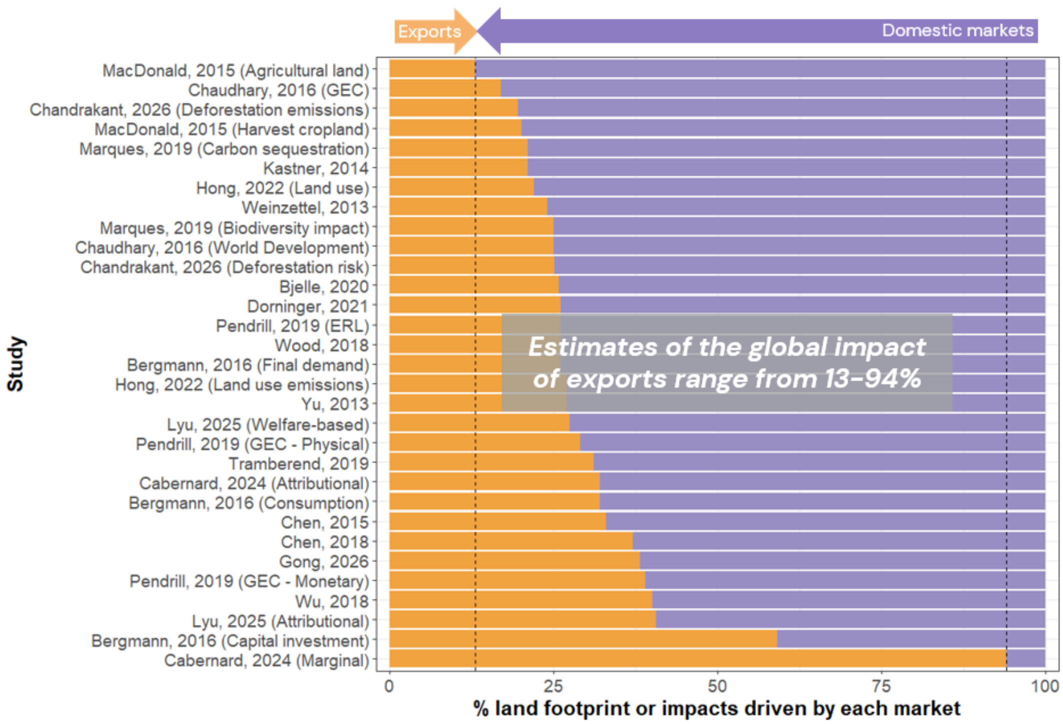

Figure 1 - The share (%) of the land use footprints or impacts (land use change, biodiversity loss, or land use emissions) which are driven by exports or domestic markets. *Studies are listed by the first author and year of publication. Where studies included multiple scenarios (e.g. different metrics or allocation methods), we include in brackets the distinguishing methodological choice. Chaudhary and Pendrill both published multiple studies on this topic within the same year (2016 and 2019, respectively), and so the journal title is added to differentiate these results. Where a study included a time series, the value from the end year is shown here, and where studies included multiple land uses, we focus on 'total land use', though these are disaggregated in Figure 2C and 2E. The full list of studies is detailed in Supplementary Table S1.*

The reviewed studies include a range of metrics of impacts in the land system, including land use, land use change, biodiversity loss, and land use emissions, and the variation in answers could therefore simply stem from different studies measuring different outcomes. In Figure 2A we compare results within studies who calculated multiple metrics - thus holding other methodological choices constant. Whether comparing deforestation risk or deforestation emissions, or impacts on biodiversity and foregone carbon sequestration, the variation between metrics is small: 4-7%.

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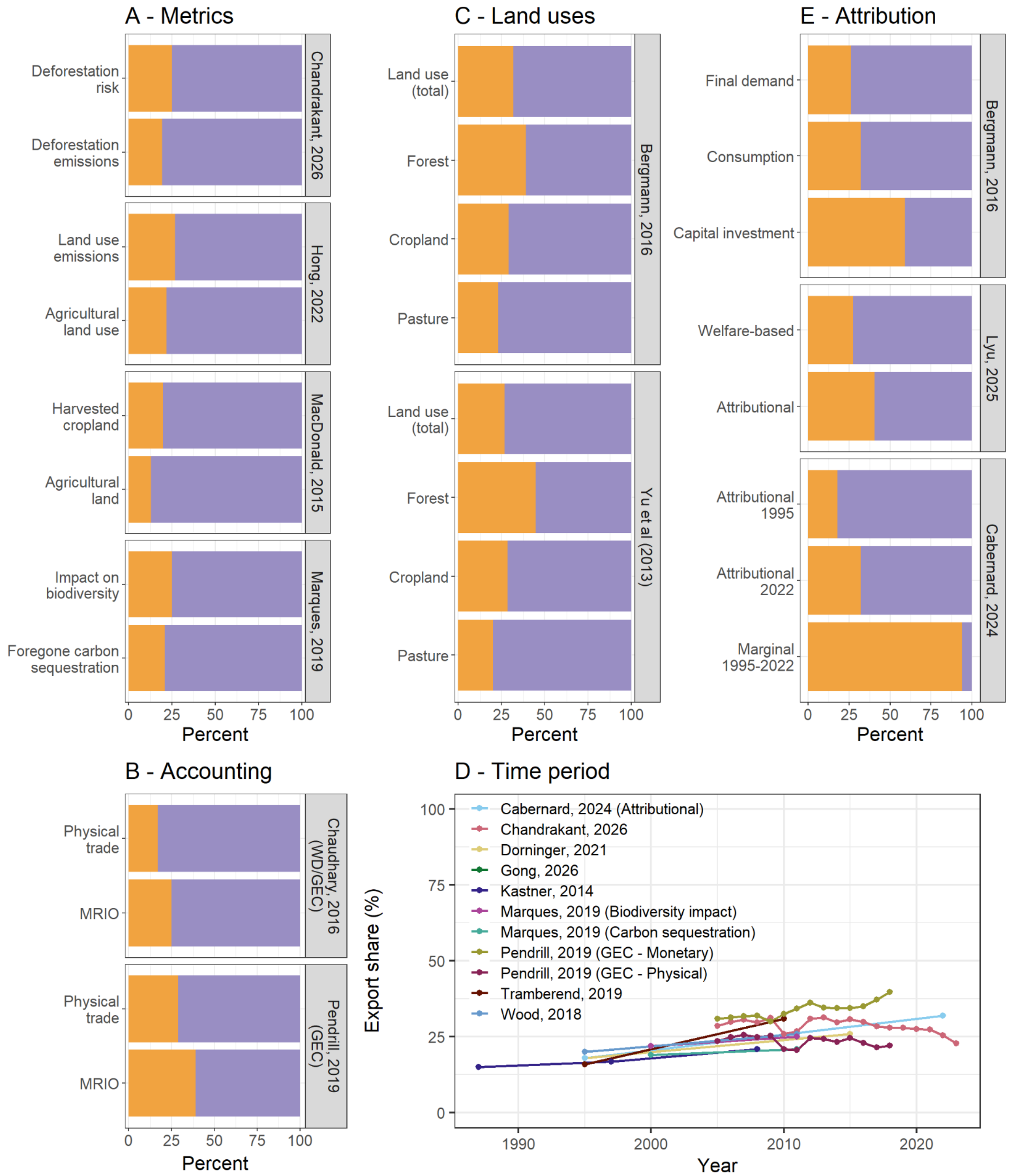

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86
87 ***Figure 2 - Variation in the allocation of impacts to exports and domestic markets****, depending on the (a) metrics*
88 *selected, (b) accounting method (physical trade models or input-output models), (c) land uses modelled, (d) time*
89 *period analysed, or (e) assumptions about how impacts are attributed to actors. In Panel (e), the lines capture the*
90 *change between values reported in the start and end years of each analysis, except where annual time series were*
91 *published by the authors. MRIO = multi-regional input output models.*
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The accounting method is known to be important in global trade studies, with Bruckner and colleagues distinguishing between ‘environmental-economic accounting’, based on monetary values, and ‘physical accounting’, based on tonnes of commodities traded (Bruckner et al., 2015). Here, we compare estimates by Pendrill and Chaudhary where the authors used both physical trade models and multi-regional input output models (MRIO models). The studies using physical trade flows report 8-10% lower estimates of the footprint of international trade than the MRIO studies using monetary values. This variation reflects that exports are typically high-value products (and so exports are greater when measured in dollars than in physical volumes), and also the fact that MRIO models better capture product processing and the embedding of commodities in downstream sectors. In contrast, models based on physical trade flows typically capture fewer upstream and downstream linkages across sectors, resulting in a more truncated representation of supply chains (Bruckner et al., 2015).

Few studies directly compare the international trade share for a variety of land uses - notably Bergmann and Yu differentiate globally traded pasture, cropland, forestry, and total land use (Figure 2C) (Bergmann and Holmberg, 2016; Yu et al., 2013). The authors find that the degree of globalization varies by 16-25%, with pasture notably less tied to international markets (20-23% export share) than cropland (29% export share in both studies) or forestry (39-45%). Pendrill and colleagues also note that pasture is relatively less globalized than other land use types (Pendrill et al., 2019). Since pasture is one of the most expansive land uses (in terms of total land occupation) and the expansion of pasture the main proximate driver of vegetation loss in the tropics, this means that studies attributing land footprints or deforestation to trade converge toward the pasture trade share (Figure 2C).

The reviewed studies cover a range of time periods, and so the range of values of impacts attributed to trade could also vary as a function of time. Indeed, global trade has increased since the 1980s, though the share of impacts attributed to international trade has been relatively stable since the turn of the century (Figure 2D).

Finally, attribution studies have several options for how to attribute impacts to actors. Most studies follow an ‘attributional’ approach, where responsibility is allocated according to each actor’s market share of total consumption. Hence, domestic markets are >70% of the food system and responsible for >70% of the impacts. Bergmann, on the other hand, distinguished attribution based on household consumption, capital investment, and final demand (the sum of household consumption, capital investment, and government expenditure). They find that the capital investment perspective, attributing land use to investors and owners of capital rather than to end consumers of goods, leads to a greater share of impacts attributed to international actors (Figure 2D). Lyu compared an attributional consumption-based allocation with one where welfare gains associated with consumption are shared among producers and consumers - the logic being that trade is a win-win transaction, with both exporters and importers gaining, and so the environmental impacts should be allocated according to welfare gains. Under this approach, the share allocated to international trade is reduced by 13%, as part of the responsibility for impacts associated with international consumption is allocated back to exporters. Finally, Carbernard and colleagues used a marginal allocation approach to look at biodiversity loss from 1995-2022, which leads to a 62-76% shift in the allocation between exports and domestic markets (Figure 2C) (Cabernard et al., 2024). Marginal approaches allocate responsibility according to who is driving change ‘at the margin’. In purist economic terms, marginal analyses are a derivative — the effect of one *additional, infinitesimal* unit, while in consequential life-cycle assessment ‘marginal allocation’ refers to the substitution with the most-competitive supplier, though Cabernard use the the term slightly differently, comparing biodiversity footprints in 1995 and 2022, and assigning the difference to who increased or decreased biodiversity impacts over this time period. Here, the logic being that exports have grown since 1995, and it is this change which drives production decisions at the margin - i.e. "change is allocated to change", rather than the attributional "total impact is allocated to total consumption".

3. A normative question of where to focus research attention

Evidently, the choice of how to allocate responsibility is an important one, and so we ask, ‘why do we, the land system community, calculate these numbers in the first instance?’. We agree with Nielsen and colleagues' framing of

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land systems science as a normative science (Nielsen et al., 2019), where researchers, conscious of multiple converging environmental crises within the land system, conduct analyses motivated at least in part by assigning responsibility, holding actors accountable, identifying who has leverage, whose behaviour 'needs to change', ultimately with the intention of informing policy responses to improve socio-environmental outcomes. Marginal, attributional, welfare-based, or capital-investment-based attributions are all legitimate perspectives on which actors have responsibility, understood as the 'obligation and a duty to address certain sustainability impacts that are associated with supply chain activities and products' (Meyfroidt et al., 2026), though we caution against an overemphasis on international trade, and call for more research into the workings of domestic markets, given their dominant market share and importance for the implementation of sustainability policies.

Even where studies find a modest impact of trade, for example, they tend to develop strong narrative framings about the importance of international trade (Hong et al., 2022; Pendrill et al., 2019). Ultimately, only 12-26% of agricultural products are internationally traded (D'Odorico et al., 2014; Geyik et al., 2021; Li et al., 2022). The remaining 74-88% are produced and sold within domestic markets, and the attributional estimates reviewed here (based on market share of consumption) associate 74% of land system impacts, on average, to domestic markets (median 72%, range 59-87%). Sustainable supply chain initiatives - such as certification schemes, company standards, and zero deforestation commitments - emerged principally as a governance tool for international companies in the Global North to mitigate the overseas impacts of international trade (Sikor et al., 2013). Though these initiatives can influence domestic markets by promoting international harmonization, by incentivizing improvements with the threat of losing market access, by the changing of norms, or by influencing domestic policy processes (Bernstein and Cashore, 2012), international trade remains a limited lever, and similar uptake in domestic markets is essential to avoid leakage undermining any benefits. Subnational analyses suggest, for example, that the domestic markets for Brazilian beef and soy have disproportionately high deforestation footprints (zu Ermgassen et al., 2020; da Silva et al., 2023), and half of the deforestation avoided by the Amazon Soy Moratorium was undermined by leakage of deforestation-linked products into the domestic market (Villoria et al., 2022).

4. Which are the main domestic markets?

Step one of a research agenda on sustainability within domestic markets is to identify who are the major players. For studies which provided data disaggregated per consumer country (Cabernard et al., 2024; Pendrill et al., 2019; Singh and Persson, 2026; Yu et al., 2013), we therefore identified the top-8 domestic markets in each case, 19 countries in total (Figure 3, with an alternative figure highlighting the top-5 and top-10 domestic markets in Supplementary Figure S1). Across these different studies, which include analyses of land use footprints, deforestation, and biodiversity loss, Brazil and India were featured among the top-8 most impactful domestic markets in all studies, Colombia and Indonesia were identified among the top-8 in three of the four datasets, and China, Nigeria, and the United States of America appeared among the top-8 in two studies each.

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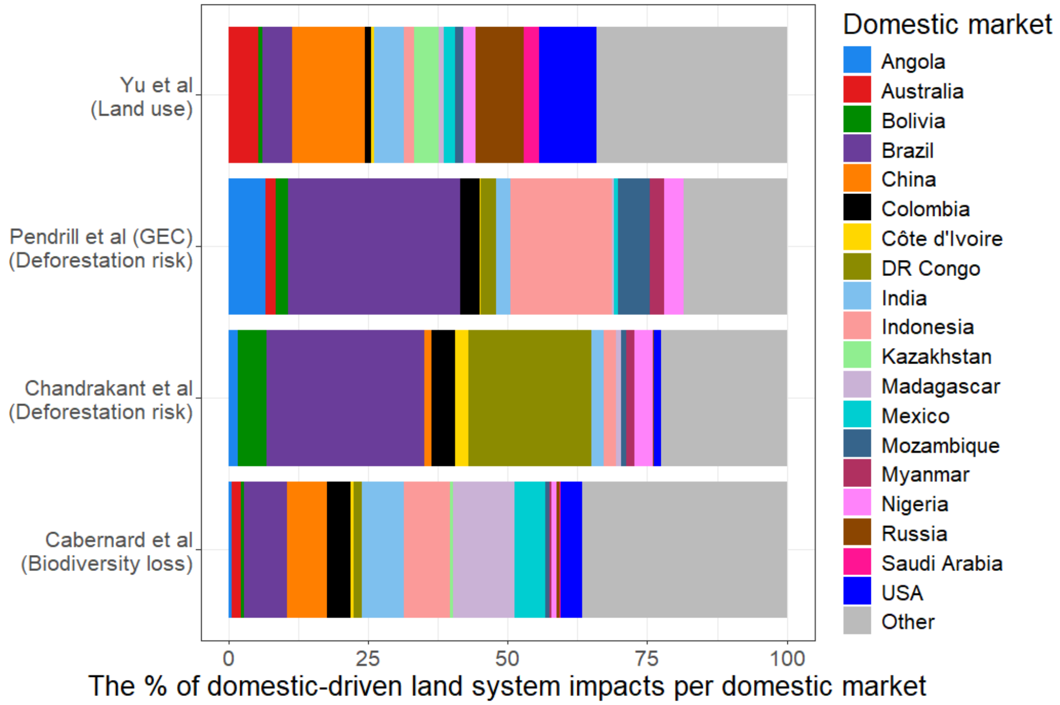

Figure 3 *- For four studies which provided results disaggregated per consumer market, the share of domestic-driven impacts which are linked to each domestic market. The top-8 countries in all contexts are highlighted (19 countries in total). Where a study reported data from multiple years, we use data from the most recent year, and the data from Cabernard refers to the attributional allocation approach.*

5. How can domestic markets be mapped?

Since no globally consistent data exist for subnational trade flows (in contrast to national-level data from FAO or Comtrade, for example), disaggregating domestic markets requires new data and methods to identify where products consumed within a country originate from, at scales that are informative for decision making. In practice, we support a middle-ground approach (Godar et al., 2016), for example mapping flows at state, regional, municipal, or district scales depending on the policy question (Supplementary information).

There are four broad, partly overlapping approaches to mapping subnational product flows: leveraging logistics surveys, subnational input-output analyses, gravity models, and product traceability data. For example, studies based on the FoodS3 model and the Food Flow Model have reconstructed food flows in the United States by combining information on production, consumption, freight movements, and transport costs within mass-balance frameworks (Goldstein et al., 2025; Lin et al., 2019; Smith et al., 2017). Where freight data are not systematically collected, researchers have used surveys at key logistical nodes, such as major roads entering and leaving cities, to reconstruct domestic food flows (Karg et al., 2023).

Alternatively, studies have used subnational input-output models to map the land embedded in inter-regional trade within China and Brazil (Afonso et al., 2025; Fan et al., 2022; Haddad et al., 2024; Wang and Wang, 2023). Where official subnational input-output tables are unavailable, gravity assumptions can be used to estimate trade between regions as a function of transport frictions and economic activity (Jain, 2026). Finally, tax invoices, supermarket barcodes, and sanitary information offer new opportunities to trace products through domestic supply chains. One

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such example is the "do Pasto ao Prato" initiative in Brazil (www.dopastoaoprato.com.br), which traces beef products using sanitary inspection codes.

6. What can subnational analyses of domestic markets tell us?

Subnational analyses are important to reveal the differentiated responsibility of different actors within domestic markets, inform value-chain governance, and support analyses of supply-chain resilience.

Not all populations within countries have the same impacts, and efforts to map domestic trade reveal subnational patterns of ecologically unequal exchange, where natural resources are systematically transferred from poorer regions to wealthier and more industrialised ones. While ecologically unequal exchange is more commonly framed as a Global North-South phenomenon (Hickel et al., 2021), it can also be observed within countries. In Brazil, for example, states with high GDP tend to have higher imports of vegetation conversion to meet their consumption, with more than 90% of the conversion linked to the economies of Rio de Janeiro and São Paulo occurring elsewhere – notably in the Cerrado and Amazônia (Afonso et al., 2025). Similar patterns have been observed in China, where major urban centres rely heavily on land embodied in inter-regional trade (Wang and Wang, 2023). In many cases, these represent important urban-rural telecouplings that can only be understood when using subnational data on domestic value chains (Seto et al., 2012).

Subnational analyses can also inform sustainability governance in domestic markets. While value-chain governance emerged principally as an approach to tackle transboundary environmental challenges (Sikor et al., 2013), there are increasing calls for these approaches to complement traditional state-led governance within domestic markets(Marx et al., 2024; van der Ven et al., 2021). Consumer surveys in Brazil, for example, suggest high demand for information on product origins and sustainability impacts (Supplementary Information), while public procurement is increasingly recognised as an important lever for improving supply-chain sustainability (Reeve et al., 2026).

There is a growing literature about the role of international trade in conferring supply stability and resilience in the face of shocks - for example, geopolitically motivated changes in tariffs, logistic shocks from the COVID19 pandemic response, or climate-related crop failures (Bajaj et al., 2025; Janssens et al., 2020; Li et al., 2024; Puma et al., 2015). There remains, however, limited literature on the resilience of domestic trade patterns. Gomez and colleagues, for example, have shown that cities with a higher diversity of suppliers have more stable supply during droughts in the US (Gomez et al., 2021). Such subnational analyses can also identify critical infrastructure and help navigate trade-offs between efficiency, resilience, and sustainability (Karakoc et al., 2023; Karakoc and Konar, 2025; Rose and Wei, 2013).

7. Conclusions

The role of international trade has become a hot topic of land systems research because of concerns over telecoupling, unequal exchange, and the governance of transboundary environmental impacts. Here we show that estimates of the contribution of international trade to land-system impacts vary widely, ranging from 13% to 94%, in large part because studies adopt different assumptions about how impacts and responsibilities should be attributed across actors and supply chains. Methods based on market share consistently find, however, that domestic markets account for around three-quarters of land use, land use change, biodiversity loss, and land use emissions. Continued efforts to improve transparency and governance in international supply chains remain essential, but they should be complemented by greater attention to the domestic markets into which most products linked to land system impacts are sold. Emerging advances in logistics data and methods, subnational input-output modelling, gravity-based approaches, and product traceability create new opportunities to map domestic supply chains and identify differentiated responsibilities within countries, support sustainability governance, and improve resilience within the land system.

Code and data availability

Data are provided in the supplementary material. Code to reproduce the figures from the paper are available upon request.

Author contributions

Conceptualization: EzE; Investigation**:** FM, EzE; Writing (original draft preparation): EzE; Writing (review and editing): FM, BGN, DLA, JTdS; Funding acquisition: EzE.

Competing interests

At least one of the (co-)authors is a member of the editorial board of Land Systems.

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References

Afonso, D. L., Perobelli, F. S., Faria, W. R., and zu Ermgassen, E. K. H. J.: The role of domestic and international markets in the loss of nature across Brazil, https://doi.org/10.21203/rs.3.rs-8308196/v1, 9 December 2025.

Bajaj, K., Mehrabi, Z., Kastner, T., Jägermeyr, J., Müller, C., Schwarzmüller, F., Hertel, T. W., and Ramankutty, N.: Current food trade helps mitigate future climate change impacts in lower-income nations, PLOS ONE, 20, e0314722, https://doi.org/10.1371/journal.pone.0314722, 2025.

Bergmann, L. and Holmberg, M.: Land in Motion, Ann. Am. Assoc. Geogr., 106, 932–956, https://doi.org/10.1080/24694452.2016.1145537, 2016.

Bernstein, S. and Cashore, B.: Complex global governance and domestic policies: four pathways of influence, Int. Aff. R. Inst. Int. Aff. 1944-, 88, 585–604, 2012.

Bruckner, M., Fischer, G., Tramberend, S., and Giljum, S.: Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods, Ecol. Econ., 114, 11–21, https://doi.org/10.1016/j.ecolecon.2015.03.008, 2015.

Cabernard, L., Pfister, S., and Hellweg, S.: Biodiversity impacts of recent land-use change driven by increases in agri-food imports, Nat. Sustain., 1–13, https://doi.org/10.1038/s41893-024-01433-4, 2024.

DeFries, R., Herold, M., Verchot, L., Macedo, M. N., and Shimabukuro, Y.: Export-oriented deforestation in Mato Grosso: harbinger or exception for other tropical forests?, Philos. Trans. R. Soc. B Biol. Sci., 368, 20120173, https://doi.org/10.1098/rstb.2012.0173, 2013.

DeFries, R. S., Rudel, T., Uriarte, M., and Hansen, M.: Deforestation driven by urban population growth and agricultural trade in the twenty-first century, Nat. Geosci., 3, 178–181, https://doi.org/10.1038/ngeo756, 2010.

D'Odorico, P., Carr, J. A., Laio, F., Ridolfi, L., and Vandoni, S.: Feeding humanity through global food trade, Earths Future, 2, 458–469, https://doi.org/10.1002/2014EF000250, 2014.

zu Ermgassen, E. K. H. J., Godar, J., Lathuillière, M. J., Löfgren, P., Gardner, T., Vasconcelos, A., and Meyfroidt, P.: The origin, supply chain, and deforestation risk of Brazil's beef exports, Proc. Natl. Acad. Sci., 117, 31770–31779, https://doi.org/10.1073/pnas.2003270117, 2020.

Fan, X., Liu, H., and Wang, M.: Study on the Agricultural Land Transfer Embodied in Inter-Provincial Trade in China, Land, 11, 656, https://doi.org/10.3390/land11050656, 2022.

https://doi.org/10.5194/ls-2026-3
Preprint. Discussion started: 16 September 2026

Geyik, O., Hadjikakou, M., Karapinar, B., and Bryan, B. A.: Does global food trade close the dietary nutrient gap for the world's poorest nations?, Glob. Food Secur., 28, 100490, https://doi.org/10.1016/j.gfs.2021.100490, 2021.

Godar, J., Suavet, C., Gardner, T. A., Dawkins, E., and Meyfroidt, P.: Balancing detail and scale in assessing transparency to improve the governance of agricultural commodity supply chains, Environ. Res. Lett., 11, 035015, https://doi.org/10.1088/1748-9326/11/3/035015, 2016.

Goldstein, B. P., Pelton, R. E. O., Gounaridis, D., Schmitt, J., Springer, N., and Newell, J. P.: The carbon hoofprint of cities is shaped by geography and production in the livestock supply chain, Nat. Clim. Change, 15, 1190–1197, https://doi.org/10.1038/s41558-025-02450-7, 2025.

Gomez, M., Mejia, A., Ruddell, B. L., and Rushforth, R. R.: Supply chain diversity buffers cities against food shocks, Nature, 595, 250–254, https://doi.org/10.1038/s41586-021-03621-0, 2021.

Haddad, E. A., Araújo, I. F., Feltran-Barbieri, R., Perobelli, F. S., Rocha, A., Sass, K. S., and Nobre, C. A.: Economic drivers of deforestation in the Brazilian Legal Amazon, Nat. Sustain., 7, 1141–1148, https://doi.org/10.1038/s41893-024-01387-7, 2024.

Hickel, J., Sullivan, D., and Zoomkawala, H.: Plunder in the Post-Colonial Era: Quantifying Drain from the Global South Through Unequal Exchange, 1960–2018, New Polit. Econ., 26, 1030–1047, https://doi.org/10.1080/13563467.2021.1899153, 2021.

Hong, C., Zhao, H., Qin, Y., Burney, J. A., Pongratz, J., Hartung, K., Liu, Y., Moore, F. C., Jackson, R. B., Zhang, Q., and Davis, S. J.: Land-use emissions embodied in international trade, Science, 376, 597–603, https://doi.org/10.1126/science.abj1572, 2022.

IPCC: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, 2019.

Jain, S.: Mapping global cereal flows at subnational scales uncovers heterogeneities in sourcing dependencies, Environ. Res. Food Syst., 3, 021002, https://doi.org/10.1088/2976-601X/ae69e9, 2026.

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., Leclère, D., Ohrel, S., Ragnauth, S., Schmid, E., Valin, H., Van Lipzig, N., and Maertens, M.: Global hunger and climate change adaptation through international trade, Nat. Clim. Change, 10, 829–835, https://doi.org/10.1038/s41558-020-0847-4, 2020.

Karakoc, D. B. and Konar, M.: Trade-offs between resilience, sustainability and cost in the US agri-food transportation infrastructure, Nat. Food, 1–9, https://doi.org/10.1038/s43016-025-01128-9, 2025.

Karakoc, D. B., Konar, M., Puma, M. J., and Varshney, L. R.: Structural chokepoints determine the resilience of agri-food supply chains in the United States, Nat. Food, 4, 607–615, https://doi.org/10.1038/s43016-023-00793-y, 2023.

Karg, H., Akoto-Danso, E. K., Amprako, L., Drechsel, P., Nyarko, G., Lompo, D. J.-P., Ndzerem, S., Sidibé, S., Hoschek, M., and Buerkert, A.: A spatio-temporal dataset on food flows for four West African cities, Sci. Data, 10, 263, https://doi.org/10.1038/s41597-023-02163-6, 2023.

Li, M., Jia, N., Lenzen, M., Malik, A., Wei, L., Jin, Y., and Raubenheimer, D.: Global food-miles account for nearly 20% of total food-systems emissions, Nat. Food, 1–9, https://doi.org/10.1038/s43016-022-00531-w, 2022.

Li, X., Wang, H., Kharrazi, A., Fath, B. D., Liu, G., Liu, G., Xiao, Y., and Lai, X.: A network analysis of external shocks on the dynamics and resilience of the global staple food trade, Food Secur., https://doi.org/10.1007/s12571-024-01462-z, 2024.

https://doi.org/10.5194/ls-2026-3
Preprint. Discussion started: 16 September 2026

Lin, X., Ruess, P. J., Marston, L., and Konar, M.: Food flows between counties in the United States, Environ. Res. Lett., 14, 084011, https://doi.org/10.1088/1748-9326/ab29ae, 2019.

Marx, A., Depoorter, C., Fernandez de Cordoba, S., Verma, R., Araoz, M., Auld, G., Bemelmans, J., Bennett, E. A., Boonaert, E., Brandi, C., Dietz, T., Fouilleux, E., Grabs, J., Gulbrandsen, L. H., Harrison, J., Heilmayr, R., Hernandez, A., Hoekman, B., Lambert, S. R., Lambin, E., Li, L., Maertens, M., Mortara Batistic, P., Michida, E., Nakagawa, J., Negi, A., Pérez-Pineda, J. A., Ponte, S., Rueda, X., Schleifer, P., Thorstensen, V., and van der Ven, H.: Global governance through voluntary sustainability standards: Developments, trends and challenges, Glob. Policy, https://doi.org/10.1111/1758-5899.13401, 2024.

Maxwell, S. L., Fuller, R. A., Brooks, T. M., and Watson, J. E. M.: Biodiversity: The ravages of guns, nets and bulldozers, Nature, 536, 143–145, https://doi.org/10.1038/536143a, 2016.

Meyfroidt, P., Heilmayr, R., zu Ermgassen, E. K. H. J., Persson, U. M., Bastos Lima, M., Gardner, T., Guye, V., and Lathuilliere, M.: A theory of change of supply chain transparency for sustainability, https://doi.org/10.5281/zenodo.21290522, 2026.

Nielsen, J. Ø., de Bremond, A., Roy Chowdhury, R., Friis, C., Metternicht, G., Meyfroidt, P., Munroe, D., Pascual, U., and Thomson, A.: Toward a normative land systems science, Curr. Opin. Environ. Sustain., 38, 1–6, https://doi.org/10.1016/j.cosust.2019.02.003, 2019.

Pendrill, F., Persson, U. M., Godar, J., Kastner, T., Moran, D., Schmidt, S., and Wood, R.: Agricultural and forestry trade drives large share of tropical deforestation emissions, Glob. Environ. Change, 56, 1–10, https://doi.org/10.1016/j.gloenvcha.2019.03.002, 2019.

Puma, M. J., Bose, S., Chon, S. Y., and Cook, B. I.: Assessing the evolving fragility of the global food system, Environ. Res. Lett., 10, 024007, https://doi.org/10.1088/1748-9326/10/2/024007, 2015.

Reeve, E., Venegas Hargous, C., Farrell, P., Patay, D., Rippin, H., Roesler, A., Peeters, A., and Thow, A. M.: Strategic Design of Public Food Procurement to Leverage Positive Food Systems Outcomes: A Framework of Actions, Sustain. Dev., 34, 3880–3898, https://doi.org/10.1002/sd.70508, 2026.

Rose, A. and Wei, D.: Estimating the Economic Consequences of a Port Shutdown: The Special Role of Resilience, Econ. Syst. Res., 25, 212–232, https://doi.org/10.1080/09535314.2012.731379, 2013.

Seto, K. C., Reenberg, A., Boone, C. G., Fragkias, M., Haase, D., Langanke, T., Marcotullio, P., Munroe, D. K., Olah, B., and Simon, D.: Urban land teleconnections and sustainability, Proc. Natl. Acad. Sci., 109, 7687–7692, https://doi.org/10.1073/pnas.1117622109, 2012.

Sikor, T., Auld, G., Bebbington, A. J., Benjaminsen, T. A., Gentry, B. S., Hunsberger, C., Izac, A.-M., Margulis, M. E., Plieninger, T., Schroeder, H., and Upton, C.: Global land governance: from territory to flow?, Curr. Opin. Environ. Sustain., 5, 522–527, https://doi.org/10.1016/j.cosust.2013.06.006, 2013.

da Silva, R. F. B., Moran, E. F., Millington, J. D. A., Viña, A., and Liu, J.: Complex relationships between soybean trade destination and tropical deforestation, Sci. Rep., 13, 11254, https://doi.org/10.1038/s41598-023-38405-1, 2023.

Singh, C. and Persson, U. M.: Global patterns of commodity-driven deforestation and associated carbon emissions, Nat. Food, 7, 138–151, https://doi.org/10.1038/s43016-026-01305-4, 2026.

Smith, T. M., Goodkind, A. L., Kim, T., Pelton, R. E. O., Suh, K., and Schmitt, J.: Subnational mobility and consumption-based environmental accounting of US corn in animal protein and ethanol supply chains, Proc. Natl. Acad. Sci., 114, E7891–E7899, https://doi.org/10.1073/pnas.1703793114, 2017.

https://doi.org/10.5194/ls-2026-3
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van der Ven, H., Sun, Y., and Cashore, B.: Sustainable commodity governance and the global south, Ecol. Econ., 186, 107062, https://doi.org/10.1016/j.ecolecon.2021.107062, 2021.

Villoria, N., Garrett, R., Gollnow, F., and Carlson, K.: Leakage does not fully offset soy supply-chain efforts to reduce deforestation in Brazil, Nat. Commun., 13, 5476, https://doi.org/10.1038/s41467-022-33213-z, 2022.

Wang, S. and Wang, J.: Embodied land in China's provinces from the perspective of regional trade, J. Geogr. Sci., 33, 59–75, https://doi.org/10.1007/s11442-023-2074-1, 2023.

Yu, Y., Feng, K., and Hubacek, K.: Tele-connecting local consumption to global land use, Glob. Environ. Change, 23, 1178–1186, https://doi.org/10.1016/j.gloenvcha.2013.04.006, 2013.