Evaluating Alternative Designs of the 30×30 Land-Based Conservation Targets in a Spatially Explicit Global Economic Model

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Abstract

The global 30×30 conservation target introduces a new class of land-based policies with inherently spatial and economy-wide implications. Standard computable general equilibrium (CGE) models typically represent such policies using aggregate land shocks, abstracting from spatial heterogeneity in land quality, ecosystem value, and conversion costs. This paper evaluates how alternative spatial designs of market-based conservation policies affect land use, trade, and economic outcomes within a high-resolution gridded equilibrium framework. We implement a set of land-use tax instruments in the SIMPLE-G model, which represents global production, consumption, and trade with spatially explicit land allocation across cropland, pasture, managed forest, and natural land. All policy scenarios achieve a consistent 30% conservation target at the biome-region level but differ in the spatial structure of taxation: (1) uniform taxes applied across all locations, (2) taxes targeting high-value grid cells, and (3) differentiated taxes based on conservation rankings. The results highlight the importance of spatial targeting in determining both efficiency and system-wide adjustments. Uniform taxes distribute land-use constraints broadly, generating relatively smooth adjustments in production and trade. In contrast, targeted and differentiated taxes concentrate conservation in high-value locations, improving allocation efficiency but inducing stronger spatial reallocation of land use and associated trade responses. These patterns reflect the interaction between local land constraints and global market feedbacks. The analysis demonstrates that incorporating spatial heterogeneity into equilibrium modeling is critical for evaluating land-based conservation policies. It also shows that intermediate policy designs, such as biome-region differentiation, can capture key efficiency gains while remaining tractable for implementation.

JEL: C68, H23, Q15, Q24, Q57

Keywords: land, conservation, gridded modeling, targeted tax, spatial equilibrium

Introduction

The global commitment to protect 30 percent of terrestrial ecosystems by 2030 ("30×30"), represents a major shift in the scale and ambition of global conservation policy. Unlike earlier conservation efforts, the 30×30 target is inherently spatial: it requires decisions about *which* lands to protect, not simply how much. These decisions have direct implications for agricultural production, land markets, and international trade, as protecting land in one location can displace economic activity to others through market adjustments. As a result, the effectiveness and cost of achieving 30×30 depend critically on how conservation policies are designed and where they are implemented.

Despite this, much of the existing economic literature evaluates land-based conservation policies using highly aggregated representations of land supply, often modeling protection as a uniform land withdrawal or productivity shock. Such approaches ignore the spatial heterogeneity in land quality, ecosystem value, and opportunity costs that fundamentally shape conservation outcomes. They also limit the ability to capture spillover effects, including the relocation of production and associated environmental pressures across regions. As global conservation targets become more binding, these limitations pose a significant challenge for policy-relevant analysis.

This paper addresses this gap by examining how alternative spatial designs of market-based conservation policies affect land-use outcomes and economic adjustments in a spatially explicit equilibrium framework. We focus on land-use taxes as a flexible policy instrument that can be differentiated across locations to reflect variation in ecological value and economic opportunity costs. Using the SIMPLE-G model, a global gridded framework that represents land-use decisions at high spatial resolution (Haqiqi & Hertel, 2025), we compare a range of policy designs, from uniform taxes applied broadly across regions to targeted interventions that prioritize high-value locations.

Our analysis highlights three key contributions. First, we show that market-based instruments can operationalize the 30×30 target in a way that endogenizes land-use spillovers and opportunity costs, rather than imposing fixed area-based constraints. Second, we demonstrate that a biome-region-specific tax schedule can capture many of the efficiency gains associated with fully location-specific targeting, while remaining more practical to implement. Third, we illustrate the importance of spatial resolution in economic modeling, as high-resolution representations of land heterogeneity reveal trade-offs and spillovers that are not observable in aggregated frameworks.

By integrating spatial heterogeneity, economic behavior, and global market linkages, this paper contributes to a growing literature on the design of conservation policies under real-world constraints. It provides a framework for evaluating how the spatial targeting of conservation affects both local land-use outcomes and global economic adjustments, offering insights that are directly relevant to the implementation of ambitious targets.

Literature Review

Land conservation has been analyzed in general equilibrium (GE) and partial equilibrium (PE) models primarily through land withdrawal, land-use taxes, or productivity adjustments at regional or sub-regional aggregates (Hertel et al., 2009; Golub & Hertel, 2012). However, most studies impose conservation at an aggregate regional or sub-regional level. Land is withdrawn proportionally across uses or Agro-Ecological Zones (AEZs), implicitly assuming homogeneous or uniform distribution and opportunity cost. The conservation science literature demonstrates that spatial targeting can dramatically improve outcomes for a given land area or cost (Wilson et al., 2007). Priority-setting frameworks show that protecting high-value locations yields greater species preservation than uniform protection (Margules & Pressey, 2000). However, these studies typically abstract from market feedbacks and economic displacement. Recent integrated assessments highlight that ignoring market-mediated leakage can overstate conservation benefits (Meyfroidt et al., 2013). When protection is concentrated in high-yield areas, production shifts elsewhere, potentially offsetting ecological gains. Efforts to integrate spatial land-use detail into economic models have expanded in recent years. Frameworks linking CGE models to gridded land-use allocation or ecosystem-service models demonstrate that spatial heterogeneity matters for both economic and environmental outcomes (Popp et al., 2017; Johnson et al., 2025).

In general equilibrium framework, land is typically represented through AEZs and allocated across uses via constant elasticity of transformation (CET) functions (Golub & Hertel, 2012; Hertel, 2011, 2017; Hertel et al., 2009, 2019). Extensions such as GTAP-BIO and MAGNET have improved land-use representation by distinguishing managed and unmanaged land, incorporating bioenergy competition, and introducing dynamic land supply responses (Marquardt et al., 2021; Van Der Hilst et al., 2018; Verstegen et al., 2016). In parallel, the land-use science community has made substantial progress in monitoring land cover and land-use change using satellite observations. Global products such as ESA CCI Land Cover, MODIS land cover, and more recent high-resolution time series provide consistent observations of cropland expansion, abandonment, and intensification (Li et al., 2016, 2018; X. Liu et al., 2018). Several studies demonstrate that historical land-use change is highly persistent and influenced by local biophysical suitability and accessibility (Akpoti et al., 2019; Jafari & Zaredar, 2010). Efforts to bridge land-use science and economic modeling have gained momentum in recent years. Integrated frameworks couple economic models with spatial land-use allocation models. Where, SIMPLE-G, GTAP-SIMPLE-G, and GTAP-InVEST represent a notable step by linking global economic models with gridded land-use outcomes (Haqiqi & Hertel, 2025; Johnson et al., 2025; Wang, 2024).

Contribution

The interaction between spatial targeting, economic efficiency, and leakage remains insufficiently understood in equilibrium analyses of conservation policy. While conservation science emphasizes the importance of prioritizing high-value areas, and economic models capture market-mediated spillovers, few studies integrate these perspectives within a unified, spatially explicit framework. As a result, the trade-offs inherent in alternative policy designs for achieving the 30×30 target are not well characterized.

This paper addresses this gap by combining high-resolution spatial data with a global economic equilibrium model to evaluate how different targeting strategies shape both local land-use outcomes and global market responses. We make three primary contributions.

First, we provide a systematic evaluation of policy-relevant 30×30 implementation strategies, spanning a range from uniform land-use taxes to biome-region differentiation and grid-cell-level targeting. This structured comparison allows us to isolate how increasing spatial precision in policy design affects land allocation within a consistent equilibrium setting.

Second, we demonstrate that spatial targeting fundamentally alters the balance between economic efficiency and leakage. More precise targeting improves the allocation of conservation effort toward high-value areas but can amplify spatial displacement of production through market adjustments. By contrast, less targeted policies distribute costs more evenly, moderating spillovers but reducing efficiency. This analysis offers a transparent framework for understanding these trade-offs within global models.

Third, we advance the empirical foundations of land-use modeling by integrating observed land-use and land-cover data into both the construction of the model database and the parameterization of land supply behavior. We develop a globally consistent land-use dataset that reconciles remote-sensing products and high-resolution time series data to infer spatial variation in land conversion likelihood. These empirical patterns are then used to inform spatially explicit land supply and transformation parameters, improving the representation of heterogeneity in land-use responses.

Methods

Model

The analysis employs the SIMPLE-G spatially explicit equilibrium model (Haqiqi & Hertel, 2025). SIMPLE-G stands for Simplified International Model of agricultural Prices, Land use, and the Environment- gridded version. SIMPLE focuses on four commodities: crops, livestock, processed food, and non-food (Baldos & Hertel, 2013; Hertel & Baldos, 2016). The gridded version includes total cropland (J. Liu et al., 2017), water and irrigation (Haqiqi et al., 2022; Haqiqi, Hertel, et al., 2025), labor markets (Ray, 2025; Ray et al., 2023), and fertilizer (Haqiqi, Breier, et al., 2025).

Here, land supply and production decisions are resolved at the grid-cell level and responses are aggregated consistently to regions and sectors. We implement the 30×30 target at the region×biome level, ensuring that at least 30 percent of land in each targeted combination is either protected or in natural form (not commercial use). Policy instruments take the form of land taxes that raise the marginal cost of using land for all agricultural production. Gridded tax rates are the same for cropland, pastureland, or managed forest.

The land allocation structure is summarized in Figure 1, which presents the nested quantity-preserving constant elasticity of transformation (CET) land allocation structure. Total suitable land is first divided between protected and non-protected uses. Within non-protected land, allocation occurs across natural land and commercial uses, including cropland, pasture, and managed forest. Crop production is further modeled through a constant elasticity of substitution (CES) structure combining land with non-land inputs, and crop commodities are treated as imperfect substitutes across grid cells under a Sub-regional Armington specification.

We evaluate three equivalent scenarios that achieve the same 30% natural plus protected land target at the biome-region level. These scenarios differ only in the spatial targeting of the tax instrument, allowing comparison of outcomes under alternative allocation rules.

- Scenario 1 applies a uniform tax across all grid cells within each biome-region.
- Scenario 2 restricts the tax to high-biodiversity-value grid cells.
- Scenario 3 applies differentiated taxes across all grid cells based on biodiversity rankings.

These scenarios span the policy-relevant range from coarse to highly targeted interventions. Market clearing ensures that land withdrawal affects production, prices, and trade endogenously. Assumptions regarding land mobility, substitution elasticities, and price transmission are consistent with standard SIMPLE-G

(Haqiqi & Hertel, 2025). This extended version includes more than 2.2 million grid cells at 5 arc-min resolution (roughly 10 km x 10 km grids at the equator).

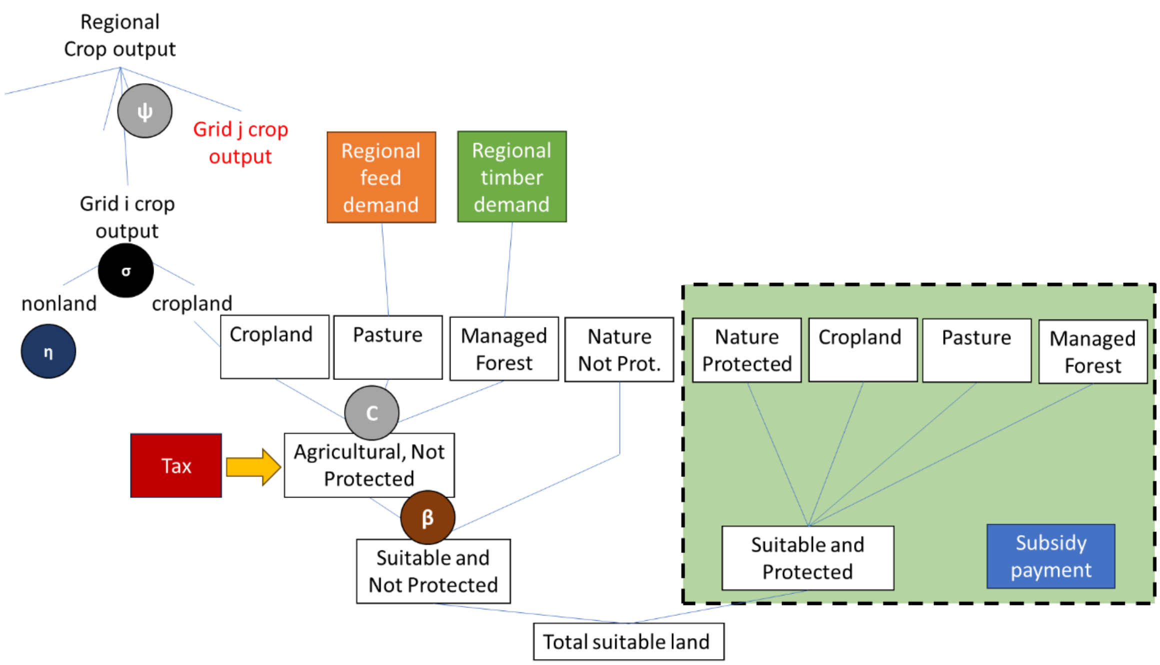

Figure 1. Nested land allocation structure in SIMPLE-G.
Schematic representation of the quantity-preserving constant elasticity of transformation (CET) structure for land allocation. Total suitable land is allocated between protected and non-protected land. Non-protected land is further allocated among natural land, cropland, pasture, and managed forest. Crop production is a CES function combining land and non-land inputs. Outputs are traded across regions under a sub-regional Armington assumption.

Data

Figure 2 reports the land use and land cover areas in the dataset underpinning the SIMPLE-G model. These data establish the baseline distribution of land across categories used in subsequent simulations. Global land-use and land-cover database is constructed by processing remote-sensing products. Observed land-use change is derived from high-resolution remote-sensing time series of ESA, which capture transitions among cropland, pasture, forest, and other land uses. The outputs of LPJmL crop model (Schaphoff et al., 2018; Von Bloh et al., 2018) are used to calculate the expected revenue of each land use practice. Then transitions and gaps are analyzed to estimate the suitability and relative likelihood of conversion for all grid cells, conditional on historical land use and biophysical characteristics. We identify the locations suitable for each agricultural activity (crop, pasture, managed forest). Within the SIMPLE-G model, these spatial indicators are used to parameterize land supply and transformation elasticities that vary across space rather than being uniform at the regional level. This approach includes more local features compared to universal conversion matrix approach. Economic demand for land is generated by a partial equilibrium system consistent with gridded modeling with added grazing and timber demand, while spatial allocation reflects suitability.

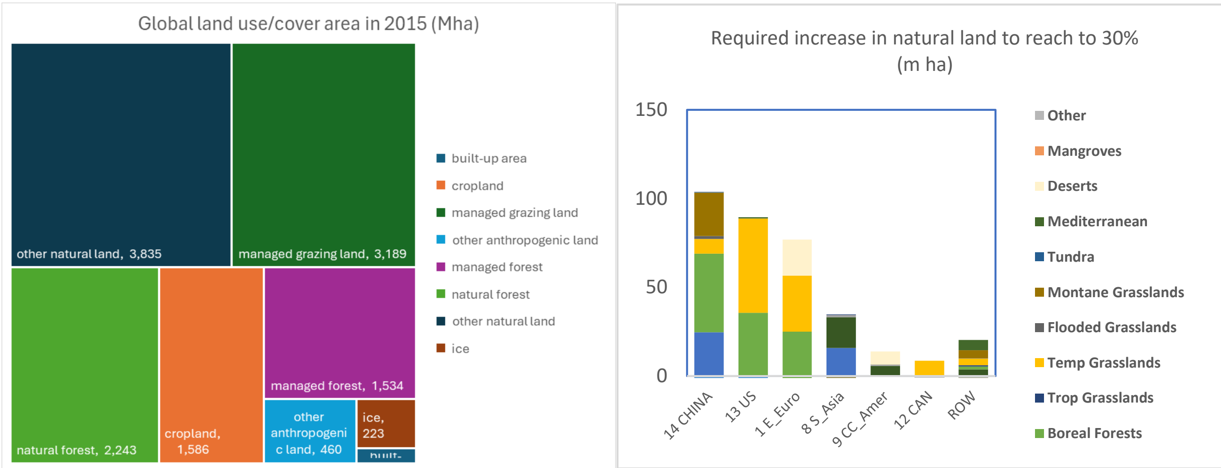

Figure 2. Baseline land use and land cover dataset and required increase in natural land.
Land use and land cover areas underlying the SIMPLE-G model. The left figure reports the distribution of land across categories used in the model baseline. Spatial resolution and regional aggregation follow the model dataset. The right panel shows the required change in each biome in each region to reach to the 30% target.

Computation

The model is written in TABLO and solved with GEMPACK (Horridge et al., 2013, 2018). We used condensation and linearization to speed-up the solution time (Haqiqi & Baldos, 2025). We employed Purdue University's Anvil high-performance computing resources to run the simulations and process data (Song et al., 2022).

Results

All scenarios are designed to meet the same conservation constraint (i.e., 30 percent nature at the region×biome level) but economic outcomes differ. Uniform global taxes are expected to produce the largest increase in global food prices, reflecting widespread production constraints and limited scope for reallocation. More targeted policies are expected to achieve conservation goals at lower aggregate cost. By concentrating land withdrawal in high-value locations, scenarios 3 reduces the total amount of productive land affected, improving economic efficiency. However, it suggests stronger spatial displacement: production shifts toward non-target regions and lower-cost areas, increasing leakage. Uniform policies distribute marginal impacts more evenly, leading to lower spatial concentration and reduced leakage, but at higher overall economic cost.

Regional land-use responses under Scenario 1

As in Figure 2, China, South Asia, East Europe, and US are expected higher increase in nature and protected area. Figure 3 reports percentage changes in land use across 17 global regions under Scenario 1. The results indicate heterogeneous responses across land categories and regions. Managed forest area exhibits the largest declines in China by 24.48%, the United States by 15.34%, and South Asia by 24.03% (Figure 3, left panel). Grazing land changes are shown in the middle panel with larges change in China by -6.27%. Cropland changes (Figure 3, right panel) are also largest in China by -14.78% and the US by -18.76%. The biggest changes simulated in managed forest areas are partly due to more inelastic crop demand compared to timber demand in the SIMPLE-G model.

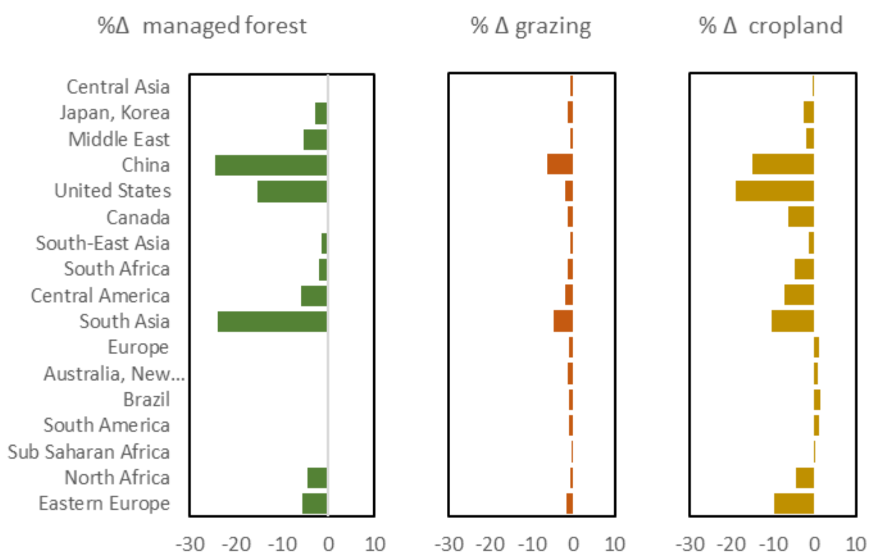

Figure 3. Regional land-use changes under Scenario 1.
Percentage change in land use across 17 global regions under Scenario 1: (left) managed forest area, (middle) grazing land, and (right) cropland. Results are reported relative to baseline of 2017.

Trade adjustments

Figure 4 presents regional trade responses under Scenario 1. The left panel shows that percentage changes in regional crop supply are small across regions with the biggest % change in China by -2.47%. The middle panel reports percentage changes in exports with China's exports decline by 15.04% and in South Asia by 11.17%. The right panel shows changes in imports, indicating that China and South Asia increase imports relative to baseline. These results reflect adjustments in trade flows across regions under the imposed land-use constraints. While the impact on regional production is moderate, the change in trade in China and South Asia are substantial.

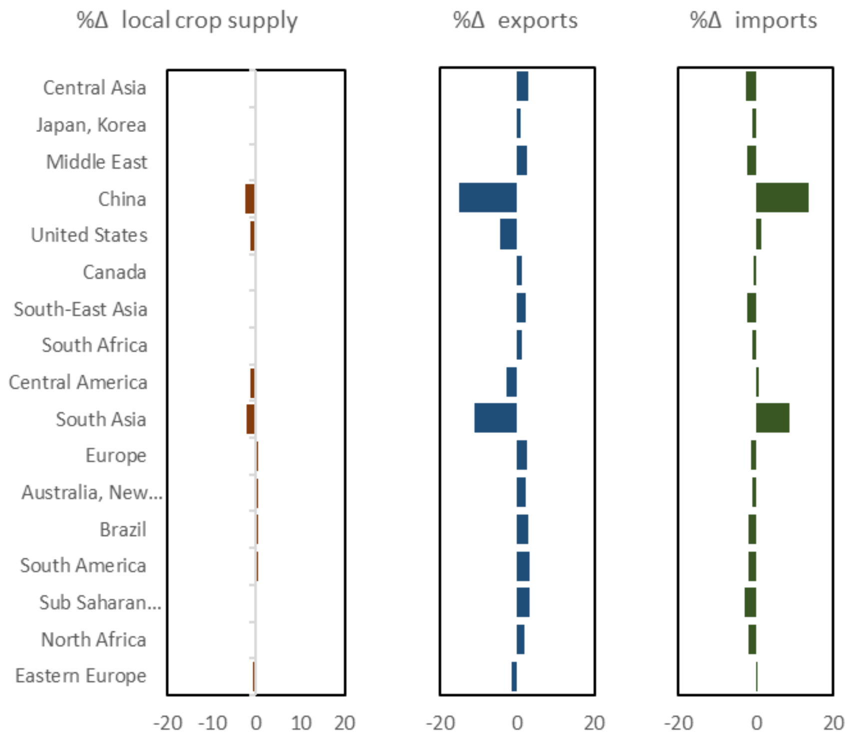

Figure 4. Trade responses under Scenario 1.
Percentage change in trade-related variables across 17 global regions under Scenario 1: (left) regional crop supply, (middle) exports, and (right) imports. Results are reported relative to baseline of 2017.

Consumption responses

Figure 5 reports percentage changes in consumption across 17 global regions under Scenario 1. The left panel shows changes in direct crop consumption, the middle panel shows changes in livestock consumption, and the right panel shows changes in processed food consumption. The results indicate that consumption adjustments occur across multiple food categories. However, China and South Asia are more affected with small reduction (around 1%) in crop consumption and smaller reductions in livestock and processed food demand.

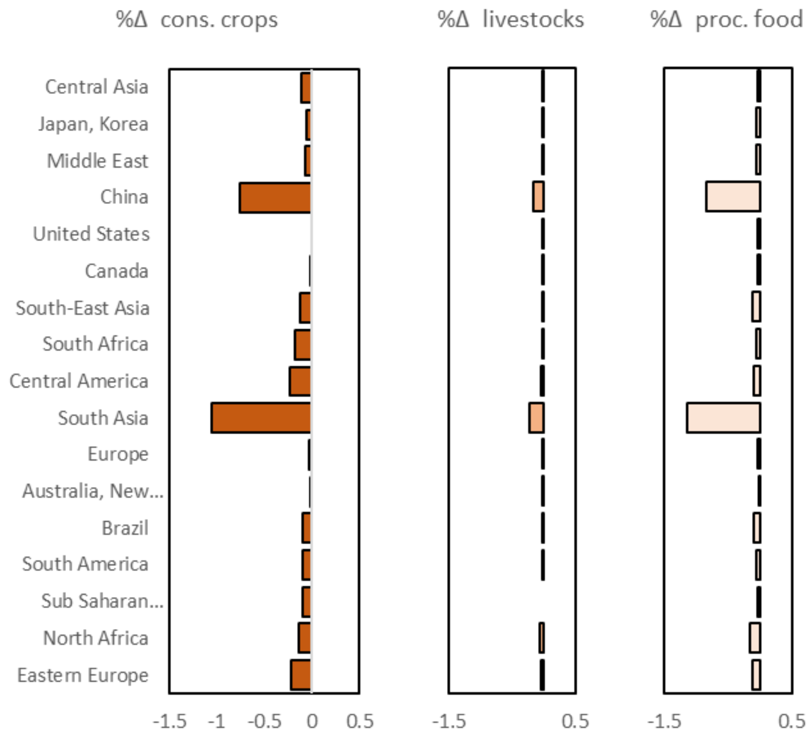

Figure 5. Consumption responses under Scenario 1.
Percentage change in consumption across 17 global regions under Scenario 1: (left) direct crop consumption, (middle) livestock consumption, and (right) processed food consumption. Results are reported relative to baseline of 2017.

Gridded land-use responses

Figure 6 provides spatially explicit maps of land-use impacts under Scenario 1. The results show declines in cropland, pasture, and managed forest in targeted locations, consistent with the imposition of land-use constraints. However, natural land shows decline in the Western United States combined with increase in grazing areas indicating conversion to pasture.

Comparison of tax structures across scenarios

Figure 7 compares the tax rates required under the three scenarios. The horizontal axis represents the uniform tax in Scenario 1, while the vertical axes represent tax rates in Scenarios 2 and 3. This comparison illustrates differences in tax levels associated with alternative spatial targeting strategies. For example, while in uniform tax may call for 50% tax on all grid cells a targeted tax may call for 150% tax only on selected locations.

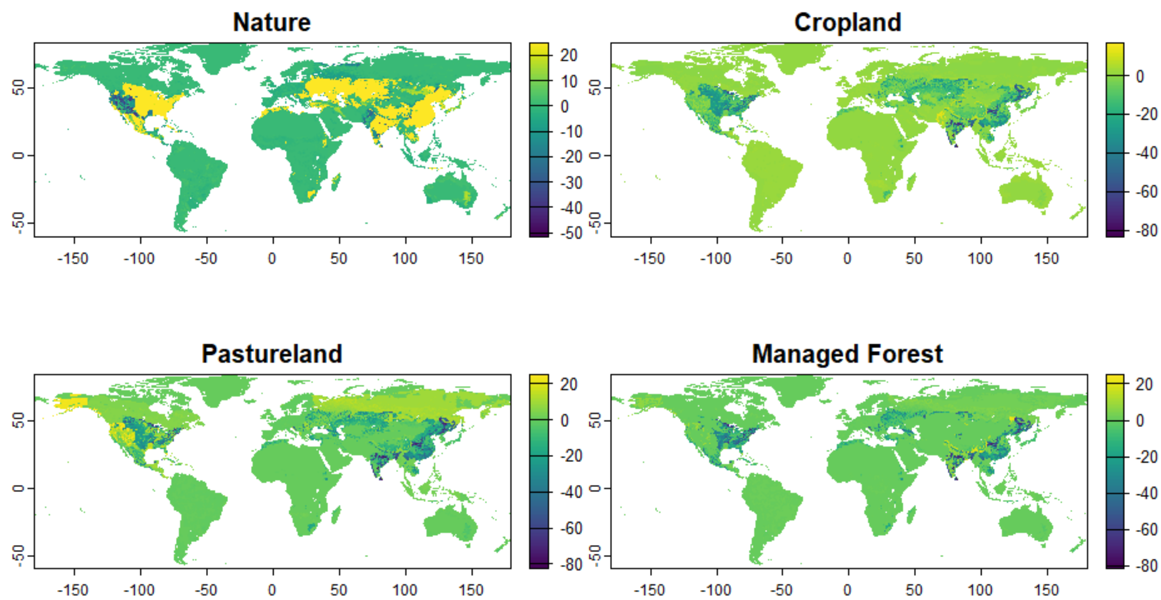

Figure 6. Spatial land-use impacts under Scenario 1.
Maps of land-use changes under Scenario 1, showing impacts on natural land, cropland, pasture, and managed forest. Changes are reported relative to baseline at grid-cell resolution.

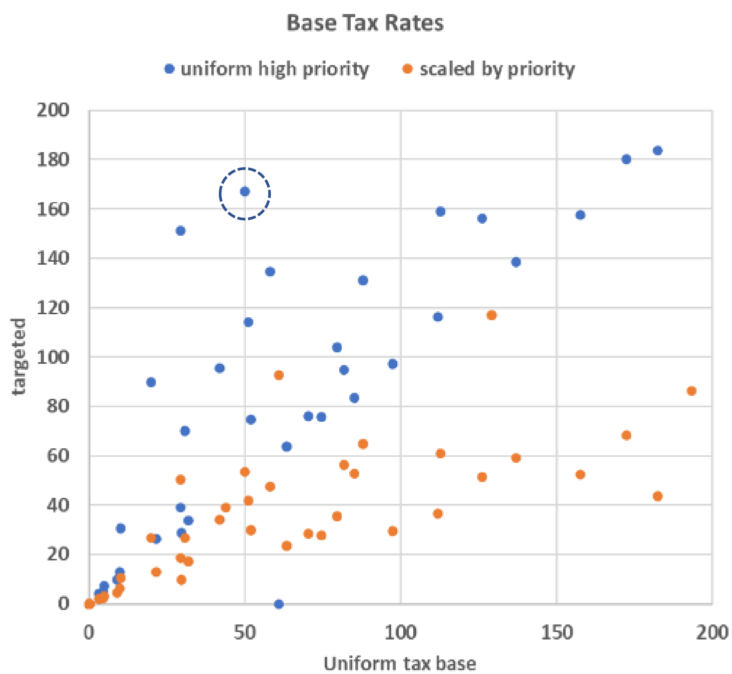

Figure 7. Comparison of tax rates across scenarios.
Scatter plot comparing tax rates across scenarios. The horizontal axis shows uniform tax rates from Scenario 1, while the vertical axes show corresponding tax rates in Scenarios 2 and 3. Each point represents a biome-region.

Targeted Tax Scenarios

[To be completed]

Discussion

The results highlight the importance of spatial design in determining the economic and environmental consequences of large-scale conservation policies. When land-use decisions are modeled with spatial heterogeneity, the location of conservation, not just its aggregate extent, emerges as a central determinant of outcomes. This has direct implications for how conservation targets such as 30×30 are evaluated and implemented.

A key insight is that market-based instruments, particularly land-use taxes, provide a flexible mechanism for incorporating spatial variation in both ecological value and economic opportunity cost. By influencing land-use decisions through prices rather than fixed constraints, these instruments allow conservation outcomes to emerge endogenously within the broader economic system. This feature is particularly important in a global context, where land-use changes in one region can induce adjustments elsewhere through trade and price responses.

At the same time, the results highlight a trade-off between policy precision and systemic effects. More spatially targeted taxes prioritize high-value areas and improve cost-effectiveness by concentrating conservation where it yields the greatest ecological benefit. However, this concentration can also intensify displacement effects, as production shifts toward non-targeted areas. In contrast, more uniform policies distribute the pressure more evenly across space, which can dampen spillovers but at the cost of higher aggregate economic impacts. These findings suggest that the design of conservation policy involves balancing efficiency gains from targeting against the risks of spatial leakage and uneven regional impacts.

Importantly, the analysis shows that intermediate policy designs, such as biome-region-differentiated taxes applied uniformly within each category, can achieve a substantial share of the gains from fully location-specific targeting. This result has practical significance. Fully granular, grid-cell-specific policies may be difficult to implement due to informational, administrative, and political constraints. By contrast, policies defined at the biome-region level offer a tractable compromise, capturing key dimensions of ecological heterogeneity while remaining aligned with existing governance structures.

More broadly, the findings illustrate the value of high-resolution spatial modeling in the analysis of land-use policy. Aggregated representations of land obscure critical variation in land suitability, and conversion costs, leading to incomplete or potentially misleading assessments of policy impacts. As spatial data and computational tools continue to improve, incorporating such detail is increasingly necessary for credible policy analysis.

Finally, the results point to the importance of considering conservation policy within a broader economic and institutional context. Because land-use changes propagate through markets, the effectiveness of conservation efforts depends not only on local policy design but also on global interactions, including trade linkages and regional differences in land-use regulation. Future work can build on this framework by incorporating additional dimensions, such as dynamic adjustment processes, evolving conservation priorities, and interactions with other environmental objectives.

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