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Land-use change and long-term socioeconomic outcomes: Studying over six decades of global data (1960–2023)

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ABSTRACT

Land Use, Land-Use Change, and Forestry (LULUCF) dynamics are often evaluated primarily through environmental and ecological perspectives, yet their long-term socioeconomic outcomes remain underexplored. This study analyses global data from 1960 to 2023 to examine how changes in key LULUCF indicators – such as forest area, agricultural land, arable land, and permanent cropland – are linked to socioeconomic indicators across fifteen thematic domains, with time lags ranging from one to ten years. Drawing on longitudinal World Bank datasets, this study uses time-series analyses to capture significant linkages and temporal dynamics. The results reveal significant correlations between past land-use changes and later socioeconomic outcomes, including unexpected links to gender equality, health outcomes, and financial and employment indicators, alongside more conventional connections with Gross Domestic Product, trade, and education. These findings underscore the complex interplay between land-use decisions and socioeconomic dynamics at the country level, emphasising the need for integrated land-use policies that weigh short-term economic gains against long-term social and economic objectives. By demonstrating land use as a strategic lever for achieving equitable, resilient, and sustainable development, this study offers actionable insights to support strategies that jointly advance environmental goals – including climate and ecological targets – and foster lasting socioeconomic progress at local, regional, national, European and global scales.

1. Introduction

Land-use changes are critical drivers of environmental, social, and economic transformation worldwide, and decisions made today can have far-reaching implications for economies and communities for decades into the future. Over the past six decades, shifts in agricultural expansion, deforestation, afforestation, and urban growth have reshaped landscapes, transformed economies and ecosystem services, and thereby influenced livelihoods and human well-being. While the environmental associations of land-use change are well documented, the long-term socioeconomic consequences have received comparatively less systematic and country-level attention. This focus on socioeconomic indicators aligns with broader international policy agendas such as the United Nations Sustainable Development Goals (Sustainable Development Goals, 2014), the New European Bauhaus principles (2024), the European Green Deal (2019), the LULUCF Regulation (2023), Directive on Soil Monitoring and Resilience by the European Council (2025), OECD (2020) and the Climate Action (2025) framework, recognising that Land Use, Land-Use Change and Forestry (LULUCF) changes present both challenges and opportunities for achieving sustainable development.

Extensive research has examined the interdependencies between land-use change and socioeconomic development. This includes the literature on the socioeconomic outcomes of deforestation (Lima et al., 2013; Dadi, 2021; Arias-Gaviria et al., 2021), urban sprawl (Pichler-Milanovic, 2007; Ewing, 2008), and desertification (Kar, 2018; Mouat et al., 2019; Al-Obidi et al., 2022). This paper adopts a meta-analytical perspective to address the broader question of the general socioeconomic outcomes of land-use change. This distinguishes it from existing literature on land-use management, which has often focused on short-term associations, specific policies, limited geographical areas, or environmental consequences, without fully integrating

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socioeconomic dimensions (e.g., Crago et al., 2025; Nambiar et al., 2025; Valbuena et al., 2025). While many studies discuss the socioeconomic consequences of LULUCF, the range of socioeconomic indicators considered remains limited. To the best of authors ́knowledge, no study has systematically and quantitatively examined the interrelations between land-use change and subsequent socioeconomic outcomes across all indicators and countries. Incorporating broader socioeconomic perspectives on land-use change enables research and policy to capture a wider range of potential LULUCF predictive relationships and implications.

This study addresses this gap by exploring whether historical changes in land use systematically precede and predict later shifts in socioeconomic indicators. This paper addresses the following research question: *To what extent have past land-use changes correlated with socioeconomic conditions such as local economies, livelihoods, and community well-being?* To answer this question, this study applies advanced statistical analyses in R to support quantitative research on the interrelation between land-use change and socioeconomic development in the long term. Drawing on World Bank data (2025) – covering more than sixteen thousand socioeconomic indicators across all countries since 1960 – approximately two thousand indicators with the most extensive time coverage were selected to explore how past and present land-use patterns have influenced societies. The hypothesis reads as follows:

Ho. *: There is no association between past land-use change and subsequent socioeconomic change.*

To test this hypothesis, the study investigates correlations between socioeconomic indicators and lagged land-use indicators over time and complement this with additional causality tests for time series. Therefore, this paper is framed as a large-scale exploratory correlation analysis. Following the fragmented evidence in existing literature, we expect to reject this hypothesis, by finding at least one significant correlation between indicators on past land-use change and subsequent socioeconomic change in global data from 1960 to 2023.

This paper is a descriptive and hypothesis-generating study structured as follows. 2 provides a concise review of existing evidence on how historical LULUCF changes have shaped socioeconomic outcomes, highlighting both the methodological gaps and conceptual blind spots this study addresses. 3 introduces the World Bank datasets and complementary sources used in this research, covering land-use, economic, and social indicators from 1960 to 2023. 4 explains data processing steps, the lagged correlation approach, and the causality testing procedures applied. 5 presents empirical findings, organised by socioeconomic domains such as demographics, health, employment, finance, education, and equality. Finally, 6 discusses the implications for policy design and long-term sustainable land management, providing concrete recommendations for integrating historical land-use considerations into socioeconomic planning.

2. Literature review

Understanding how land-use and socioeconomic systems interact has been a persistent theme across geography, economics, and environmental science. The discussion traces back to Johann von Thünen's model (1826), which conceptualised land use as concentric zones determined by transportation costs and market proximity. This classic model sparked a long line of market-centred models explaining LULUCF, inspiring later approaches such as Concentric Zone Theory (Park et al., 1925), Sectoral Theory (Hoyt, 1939), Subcentre Model (Harris and Ullman, 1945), and Bid-Rent Theory (Alonso, 1964). All share the principle that most socioeconomic activity occurs nearest to a market core. Barlowe (1958, 1978) further demonstrated that Thünen's spatial patterns also emerge along coastlines or near industrial hubs, emphasising the evolving interplay between societal development and land-use structures and changes.

While this earlier research focused more on spatial patterns, later work explored how geography, agroecology, demography, socioeconomics, history, policy, and technology shape land use over time (see the overview in Loginova and Mann, 2024). For example, land abandonment (Pointereau et al., 2008; Fayet et al., 2022; Muscat et al., 2022; Ojha et al., 2022) and deforestation (Geist and Lambin, 2002) have been linked to socioeconomic factors. Moreover, over the long term, agri-food producers tend to yield land to urban expansion or protected areas while intensifying production on remaining parcels (Foley et al., 2005).

Agriculture represents a prime sector for studying the LULUCF-socioeconomic interaction, since farming strategies can affect and advance sustainable agricultural, land-use, and food practices (e.g., IPCC et al., 2000; Jónsdóttir and Gísladóttir, 2023). The prevailing perspective is that socioeconomic change drives land-use change, consistent with LULUCF's inclusion of factors such as quality, usage, height, and slopes of lands and water pools, biodiversity, habitat welfare, climate, and human-made barriers (e.g., roads, railways, city blocks, industrial territories, and protected zones).

However, the reverse relationship – land-use change influencing socioeconomic outcomes – is equally relevant. As the IPCC et al. (2000) report, primarily focused on climate change, points out:

> *"LULUCF activities may generate socioeconomic impacts through changes in producer and consumer welfare, employment, poverty, and equity. […] There are Parties other than the landowner, however, for whom the change in land use or management may affect their welfare either positively or negatively. For instance, modification of land-use or management practices may change employment opportunities or affect environmental quality either positively or negatively. Therefore, important indirect effects of LULUCF activities on the environment and socioeconomic welfare are likely to remain; the Parties may want to consider these effects in planning and implementing strategies for fostering LULUCF activities."*
>
> (IPCC et al., 2000)

The same report identifies potential contributions to sustainable development such as the provision of wood products and biofuels, agricultural output, rural poverty alleviation, and aesthetic, spiritual, and recreational values. Later studies (Climate Chance, 2018) submit a similar view:

> *"The LULUCF sector has strong socio-economic influence, as it depends on one of the country's primary natural resources: its forests."*
>
> (Climate Chance, 2018)

Both sources emphasise the reciprocal links between land use and societal outcomes, albeit lack robust statistical backing.

In August 2025, Google Scholar indexed approximately 15,300 and about 78,100 recorded works, containing both terms "land use" and "socioeconomic", since the beginning of 2025 and early 2020, respectively. These represent only a small and recent portion of studies that have discussed LULUCF in connection with socioeconomics. Similar Google Scholar queries for "land use" and "socioeconomic drivers" return approximately 543 and 3170 works, respectively. By contrast, the query for "land use" and "socioeconomic outcomes" yields only about half as many results –237 works since 2025 and 1480 since 2020. From these, Google Scholar identified 144 review articles since 2020, of which only 63 had DOI and contained the phrase "socioeconomic outcomes" in the text. One particularly relevant review by Appelt et al. (2022) analysed cases of agricultural land-use change in Southeast Asia and reported positive outcomes for income and employment, mixed outcomes for health, and negative outcomes for food security, gender equality, and economic equality. Murage et al., (2025) analysed the contributions of nature-based solutions on human health and recommended intervention policies targeting livelihood improvement, rather than carbon mitigation or biodiversity. However, as discussed in 1, most of the literature continues to focus on individual land-use changes in small regions or local settings, while the broader correlation between past land-use change and later societal outcomes remains underexplored and difficult to quantify.

Nevertheless, it is overdue to exploring such broader associations. After it has often been shown how forests recreate individuals (e.g. Pintilii, 2022) or how beautiful landscapes generate amenities among individuals (e.g. Aziz et al., 2023), it is a necessary next step to broaden this picture and test for possible predictive relationships of forests and agricultural areas to a major set of socioeconomic indicators. Fig. 1 demonstrates such connections of LULUCF and groups of indicators. The connected indicators fall into categories such as geography, agroecology, land cover and ecosystems, demography, technology, socioeconomics, policy and governance, economic drivers, historical factors, and environmental and climate influences. Each category is split into "farm level" and "general level" factors, listing specific elements like soil infertility, population shifts, mechanisation, market pressures, land tenure policies, and climate change.

3. Data and preprocessing for lulucf-socioeconomic analysis

To test the hypothesis of this study, extensive analysis of land-use and socioeconomic indicators was conducted. The analysis covered the period from 1960 to the present across all countries for which data were available. Therefore, this study is both data- and outcome-intensive, relying on more than 16,000 indicators measured since 1960. The primary data source is the World Bank (2025), one of the most comprehensive openly available repositories for socioeconomic data, which provides consistent data coverage for 213 countries (Fig. 2).

World Bank database was selected for this analysis because it offers global data and supports bulk data downloads via the R-package "wbstats" (2025), which allowed efficient handle of large datasets. Alternative data sources – FAOSTAT, Eurostat, UN, and OECD databases – were reviewed and ultimately excluded because they focus on agriculture and European countries, limiting their applicability for a global scope. In comparison, World Bank data offers the broadest and most reliable set of indicators to explore possible interrelations between LULUCF and socioeconomic indicators.

To reduce issues with stationarity, a common approach in time series analysis was used, that is converting all level values $(\acute{c})$ into growth rates as many studies do (e.g. Loginova and Mann, 2022; Mink et al., 2023). After the growth rate values within each indicator were calculated, the resulting time series were filtered for further analysis to be stationary according to Augmented Dickey-Fuller Unit Root test. Formally, growth rates (c) for each indicator of interest (id) in levels, country (i) and year (t) were calculated as shown in Eq. (1):

$$c_{i,id,t} = \frac{\acute{c}_{\,i,id,t} - \acute{c}_{\,i,id,t-1}}{\acute{c}_{\,i,id,t-1}} \tag{1}$$

Furthermore, socioeconomic indicators ($y = c_{i,idy,t} = y_{i,idy,t}$) were distinguished from LULUCF indicators ($x = c_{i,idx,t}$), and the lagged values for land indicators ($x_{i,idx,t-l}$) were calculated, where $l \in (1\ldots10)$ are time lags. The paper considered the maximum lag (l_{max}) to be 10, because 10 years is a minimum number of years to consider the study period as a long-term. Being restricted in computational power and time, the authors assumed that this maximum lag will not shorten the range of indicators with significant contribution much. However, data allowed for analysis with more lagging years, albeit for a smaller number of indicators. This way, this paper considers that the earlier potential correlations are more interesting for decision-makers.

LULUCF indicators were identified based on the presence of the word "land" in their name description. While this rule occasionally included indicators unrelated to land (e.g. transport services, gross capital formation), these indicators were retained to maintain a simple, reproducible selection criterion. *Socioeconomic indicators* were defined broadly to include all non-LULUCF World Bank indicators, including economic, environmental and sustainability indicators. For computational efficiency, LULUCF indicators were excluded from the socioeconomic set. In broader research contexts and for other research purposes,

Fig. 1. Indicators connected to LULUCF.
Source: visualised based on Loginova and Mann (2024, p. 26), Pointereau et al. (2008), Geist and Lambin (2002).

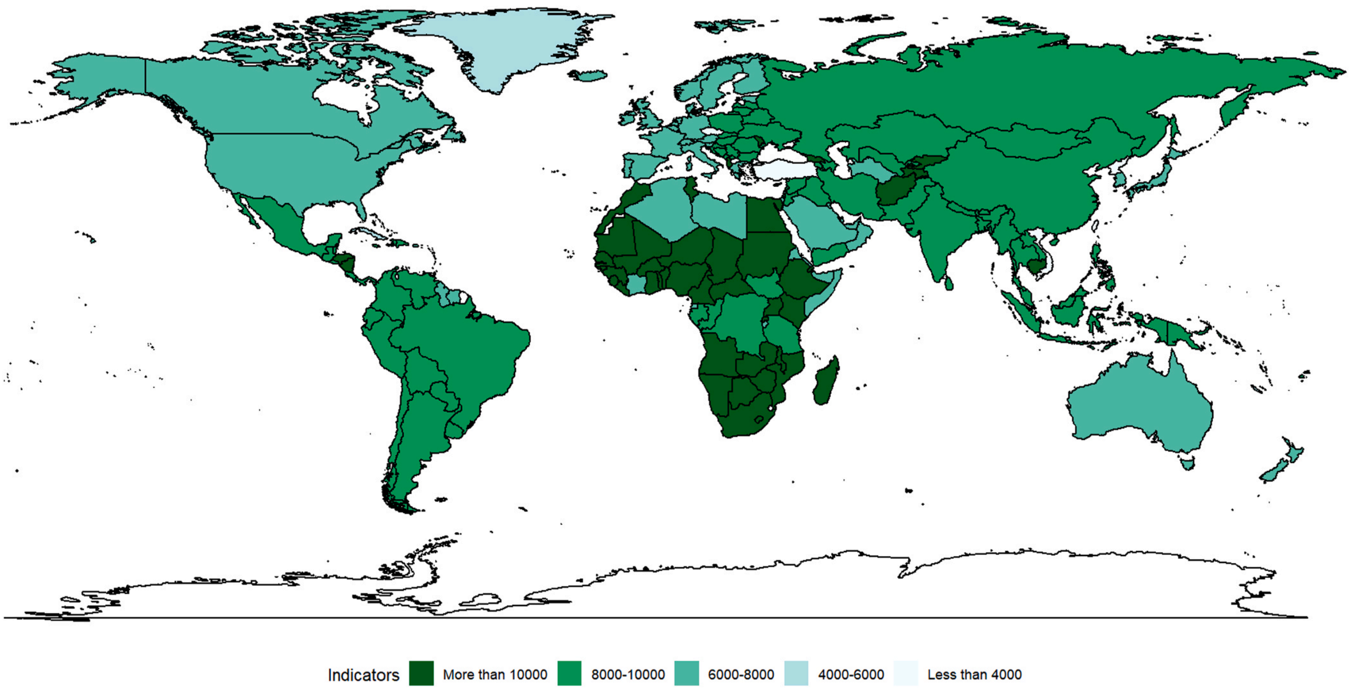

Fig. 2. Countries and number of indicators analysed in this study.

however, LULUCF indicators could be treated as economic indicators, because land is a fundamental economic resource.

After calculating lagged variables, country-specific pairs from lagged land-use change indicators and socioeconomic change indicators ($y_{i,idy}$, $x_{i,idx,l}$) were created. Only observations with valid matches were retained, resulting in unique pair lists for each country based on data availability. Cross-country correlations were not studied due to computational limitations.

To ensure sufficient observations and variation for correlation analysis, the following were excluded:

– indicators with: (a) fewer than 30 annual observations or (b) zero mean over the study period, as well as
– indicator pairs with: (i) fewer than 10 years of paired data, (ii) correlations > 0.9 or (iii) fewer than 3 unique values in either series over the study period.

These steps provided sufficient data quality for correlation analysis and reduced the dataset from over 16,000 indicators to approximately 1453 socioeconomic indicators and 400 lagged land indicators, depending on the country. The number of countries under study dropped from 213 to 197, and the volume of the data fell from over 100 million to roughly 10 million observations. Despite this reduction, the dataset still allowed for testing more than 200 million correlations to explore the potential predictive relationship of lagged land-use change with subsequent socioeconomic developments. This curated and pre-processed dataset lays the groundwork for the subsequent quantitative analysis.

4. Methods

This study employs regression analysis, Granger causality testing, scaling, filtering, and grouping of the dataset and indicators. Fig. 3 is a depiction of the analytical workflow applied and the conceptual framework behind the hypothesis logic/methods applied so that the steps taken in this analysis are transparent and replicable.

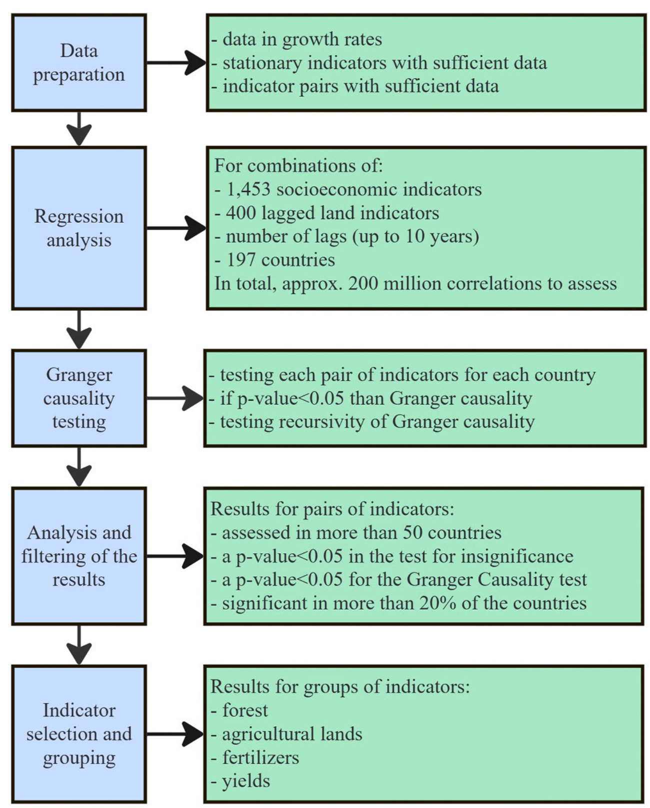

Fig. 3. Analytical workflow and the conceptual framework applied in this study.

4.1. Regression analysis

To test the hypothesis – that LULUCF can be associated to local economies and community well-being, i.e. that there is a statistically significant correlation between past land-use change and subsequent socioeconomic change – regression analysis was applied as a primary quantitative method. All tested regressions followed the general structure of Eq. (2):

$$y_{i,idy,t} = \alpha_{i,idy} + \beta_{i,idy} x_{i,idx,t-l} + \varepsilon_{i,idy,t}, \quad l \in (1\ldots10) \tag{2}$$

where $\alpha_{i,idy}$ are constants, $\beta_{i,idy}$ are the coefficients measuring the predictive relationship of LULUCF to socioeconomic indicators, $\varepsilon_{i,idy,t}$ are error terms, and l denotes time lags (1–10 years). Significance of $\beta_{i,idy}$ indicates a correlation between lagged land-use change indicator $x_{i,idx,t-l}$ and later socioeconomic change $y_{i,idy,t}$. Following our specification, it is not possible to include time and country fixed effects, because we regress one time series on another for each country separately. All bulk calculations were performed in R, utilising high-performance computing resources and regression functions with robust estimates.

4.2. Granger causality testing

To complement and strengthen the findings, Granger Causality tests were performed. The Granger Causality examines whether one time series can be used to forecast another. The null hypothesis of a Granger test states that the first time series A does not Granger-cause time series B. Therefore, if a p-value for this test is below 0.05, time series X at a given lag is valuable for forecasting the value of time series Y in a later period.

In this study, Granger tests used only one lag to maximise the number of indicator pairs assessed. In over 90% of cases, Granger-causes were rejected, suggesting that changes in lagged land-use indicators generally have predictive value for a small range of socioeconomic changes and lags. Although the Granger Causality offers weaker causal inference compared to difference-in-difference tests (e.g., Loginova et al., 2021; Mink et al., 2023), it is particularly suited for long time series (as is the case for this study, having over 60 years of scope), avoiding challenges with defining fair control groups, common trends or single-treatment periods. In this study, the Granger causality test was therefore used as a screening tool to reduce the large number of tested relationships to a smaller subset with potential predictive relevance. Additional Granger Causality tests were performed for pairs of $x_{i,idx,t}$ and $y_{i,idy,t}$ that had significant connections ($\hat{\beta}_{i,idy}$). The latter were expected to reveal recursive correlations between socioeconomic and land indicators and are available from the corresponding author on request.

4.3. Analysis and filtering of the results

In total, 39.2 million correlations were computed for 71.1 thousand pairs of indicators, of which 2.1 million results were statistically significant. At this stage, it became clear that further processing was necessary to account for occasional significances that could arise, given the large number of trials. To address this, the frequency of statistically significant results relative to the total number of results for each pair of indicators was counted. The maximum possible number of results per pair was 197, corresponding to the number of countries under study. To reduce the likelihood of random significance, only the results for pairs of indicators that met all the following criteria were retained:

- assessed in more than 50 countries,
- demonstrated a p-value <0.05 in the test for insignificance,
- demonstrated a p-value <0.05 for the Granger Causality test,
- were significant in more than 20% of the countries where estimation was possible.

These criteria enabled us to select the most robust and significant correlations, while also considering less widely available indicators if they showed frequent significance. For example, the pair Forest area (sq. km) and Age dependency ratio, old (% of working-age population) could be estimated in 151 countries and was significant in 51 countries. The pair Forest area (sq. km) and Gross national expenditure deflator (base year varies by country) could be estimated in 82 countries and was significant in 28 countries. Both pairs were significant in approximately 34% of the countries examined and are reported in the results section.

4.4. Indicator selection and grouping

An important feature of this study is that it reports all significant and recurring results obtained through the procedures described in this section. Even when no clear socioeconomic explanation exists in the current literature for the discovered tendencies, the study documents these patterns as potentially valuable connections in the data, providing a basis for awareness and for guiding the logic of future studies.

To facilitate interpretation of the results, *land use indicators* were grouped following the classification of Foley et al. (2005), where possible:

a) Forest: lagged change in forest area (% of land area) and forest area (sq. km)
b) Agricultural lands: lagged change in agricultural and arable lands in percent of land area, hectares, and hectares per person
c) Fertilisers: fertiliser consumption (kilograms per hectare of arable land)
d) Yields: cereal yield (kg per hectare)

Forest indicators were used to represent natural ecosystems and frontier clearings, while indicators on agricultural lands, yields, and fertilisers captured subsistence and intensive agriculture. No results were obtained for urban areas and protected lands because data for these indicators were either unavailable or not enough to pass filtering for the selected timeframe.

Socioeconomic indicators were grouped according to thematic areas. Significant results were found for 478 socioeconomic indicators, categorised into the following themes: aid, banking, communication, education, employment, equality, expenditures, gross domestic product (GDP), grants, health, population density and pyramid, price, production, trade, and water.

4.5. Limitations

The main limitations of this research are:

- the absence of a credible identification strategy. The empirical approach relies on lagged regressions and Granger causality tests, which do not establish causal relationships. This is particularly problematic given: strong potential for omitted variable bias, global common shocks (e.g., technological change, globalisation), reverse causality between socioeconomic development and land use.
- the absence of control groups and treatments. The relations are studied in the period over 10 years and over 50 years for most advanced data. Causal interpretation is not possible in such setting because it will be wrong to assume that there were no contributions from other variables during this long period. This was the main reason why this study takes the best from Granger causality tests for time series (e.g. Loginova and Irek, 2022) rather than causal inference (e.g. Loginova et al., 2021; Mink et al., 2023). This restriction limits discussions to associations, correlations, or predictive relationships, that are candidates, but not pure causal effects;
- the scale of hypothesis testing: this study reports tens of millions of estimated relationships, with millions of statistically significant results. However, no formal correction for multiple hypothesis testing is applied. The current filtering rules (e.g., significance in a share of countries) do not substitute for established methods such as false discovery rate control. As a result, a substantial fraction of the reported findings may be spurious. At the same time,

- some discovered relationships may lack an immediately self-explanatory theoretical background at the current state of research, though they remain valuable for guiding further research. The study would benefit from a more explicit discussion of endogeneity concerns and possible strategies to address them (e.g., lag structures, instrumental variables, or robustness checks). Clarifying the direction of causality would substantially improve the interpretability and credibility of the empirical findings;
- the paper uses Granger causality tests to strengthen the results. However, Granger causality reflects predictive ability (which is the scope of this paper and projects like LandShift), not causal effects. Moreover, the use of a single lag in the Granger tests raises concerns about model specification and robustness, but was the strongest possible setting for keeping the variety of tested indicators;
- stringent data quality requirement, which reduced the initial data set volume by more than a factor of ten;
- high demands on computing power, with associated potential environmental footprints;
- no cross-country correlations included, as such analysis would require substantially more computational resources. While future studies using advanced computing infrastructure could address this issue, one can expect fewer but potentially more insightful significant results between neighboring countries;
- the study does not cover such cases when stable LULUCF may be associated with socioeconomic change. Even though such evidence is difficult to derive quantitatively this study may be a good starting point for further research in this direction;
- the methodology of this study, similar to many other methodologies, does not consider things like global shocks, spillovers or global common trends. Even though common trends and sudden shocks are partially cleaned while using stationary series of growth rates and robust functions for estimations, this is an important methodological, not just computational limitation;
- this study did not use AI/ChatGPT5 and other available AI-powered computing infrastructure to validate the findings of this study and reprocessing the data with an AI agent. These opportunities may be used in future research.

5. Results

A change in land-use indicators with a lag of up to 10 years was significant in a regression with changes in socioeconomic indicators as specified in Eq. (2). The results, including the magnitude of the significant estimates for agricultural and arable lands, yields, fertiliser consumption, and forests are presented in Appendix A. Appendix A presents the number of countries where the correlation was assessed, found to be significant, significantly positive, or significantly negative (these are separated by "/" in the Appendix file). The squared brackets include the minimal and maximal significant estimate. Changes in LULUCF contribute to a wide variety of indicators, and these predictive relationships (meaning the significant estimates) can be positive or negative depending on the country, sign of correlation, and the nature of the indicator. The following subsections present part of the results and highlight the dominant sign of correlation (in brackets) among countries.

5.1. Changes in forest land use indicators

Forest indicators from previous years correlated with more socioeconomic areas than any other land use indicator examined. For example, forest indicators correlated with consumption, communication, employment, GDP, health, and price indicators, unlike other indicators. Health and employment indicators were important for both genders and for males and females separately. The socioeconomic outcomes that changed after a positive change in forest coverage (and regressions assessed these predictive relationships as significant) included:

i. *Consumption and communication*, e.g., final consumption expenditures of general government (+), households and non-profit institutions serving households (NPISHs) (+), mobile cellular and fixed telephone subscriptions (+).
ii. *Employment*, e.g. age dependency ratio (% of working-age population, "+"), Women Business And The Law Index Score (-), employment in agriculture (+), employment to population ratio (-), indicators on employers (+) and self-employed (+), vulnerable employment (+), wage and salaried workers (-), contributing family workers (+), employment in industry (-) and services (-), labor force participation rates (-), ratio of female to male labor force participation rate (-), labor force (+) and gross enrolment ratio (primary and secondary, female, "+").
iii. *GDP*, e.g. value added at basic prices (+) and that of services (+), public and publicly guaranteed debt outstanding from the International Development Association (PPG, IDA, "+"), revenues (+), taxes on goods and services (+), gross national expenditure (+) and its deflator (+), GDP (+) and its deflator (+), GDP per capita (+), gross national income (GNI) (+) and GNI per capita (+).
iv. *Health*, e.g. mortality rates and numbers of infant (+), under-five (+) and neonatal deaths (-), women's share of population ages 15+ living with human immunodeficiency virus (HIV) (%, "+"), prevalence of overweight (+) and obesity (+), population groups newly infected and living with HIV (+), death rates (+) and number of deaths (+), prevalence and incidence of HIV (+), probability of dying among all age groups (+), acquired immunodeficiency syndrome (AIDS) estimated deaths (+), children orphaned by HIV/AIDS (+), incidence of HIV in any age (+), maternal mortality ratio (+), newborns protected against tetanus (+), adolescent fertility rate (-), birth rate (+), life expectancy at birth (-), survival to age 65 (females "-", males "+").
v. *Prices*, e.g. official exchange rate (-), consumer price index (CPI, "+") and CPI Prices (+), purchasing power parity (PPP) conversion factor for GDP (+) and private consumption (+).
vi. *Population*, e.g. number and share of people of any age-gender group ("+", except age over 60), population in urban agglomerations of more than 1 million (-), population in largest city (-), etc.
vii. *Water*, e.g. water productivity ("-" for forests in sq.km, "+" for forests in % of land area), annual freshwater withdrawals from agriculture (-), industry (+) and domestic (+), level of water stress (freshwater withdrawal as a proportion of available freshwater resources, "+"), renewable internal freshwater resources per capita (-).

5.2. Changes in agricultural land use

Changes in agricultural land use and arable land correlated with fewer socioeconomic indicators than changes in forest cover did. Nevertheless, many of these indicators are highly important for society. For example, predictive relationships observed for agricultural land use and arable lands – but not for forests – are:

i. *Consumption*: interest payments (+), and
ii. *Aid*: net official flows from the United Nations (UN) agencies (+).

Like forests, agricultural land correlates with many socioeconomic areas, but fewer socioeconomic indicators:

iii. *Population*, almost all indicators of population pyramid ("+" for agricultural lands in sq. km and % of area, "+" for arable lands in ha and in % of area, "-" for arable lands in ha per person, "+" for permanent cropland),
iv. *Education*, namely, school age population (alike to population indicators),

v. *Employment*, namely, age dependency ratio for all (+), old ("-", except one "+" for arable land in % of land area) and young ("+", except one "-" for arable land in ha per person),
vi. *GDP*, namely, value added from services (-),
vii. *Banking*, namely, PPG, IDA (+),
viii. *Prices*, namely, exchange rates (+),
ix. *Health*, e.g. numbers of infant ("+", except crop land, where "-"), under-five ("+", except arable land, where "-") and neonatal ("+", except arable land, where "-") deaths, mortality rate (diverse, mainly "-") and prevalence of overweight in female ("+", except arable land in ha per person, where "-"),
x. *Water*, e.g. annual freshwater withdrawals from agriculture, industry and domestic (for all three sectors separately: "-" for agricultural lands, "+" for arable lands, "+" for permanent cropland), level of water stress ("+" for agricultural lands, "-" for arable lands), renewable internal freshwater resources per capita (-).

5.3. Summarising changes in LULUCF

The socioeconomic indicators correlated with past LULUCF include production, health, education, employment, equality, and population (demographics) in general. Table 1 presents the indicators most frequently and significantly associated with changes in LULUCF across countries, along with the frequency of significant outcomes (in brackets). In addition to the predictive relations of forests and agricultural land, Table 1 also summarises the outcomes associated to using fertilisers and of changing yield levels (with signs).

The empirical results indicate that changes in land-use indicators exert statistically significant predictive relationships on socioeconomic outcomes with lags of up to ten years, suggesting the presence of temporally mediated transmission mechanisms. Across specifications, the direction and magnitude of these predictive relationships vary by land-use category, country context, and indicator type, pointing to heterogeneous adjustment pathways rather than uniform causal relationships. From a theoretical perspective, this reinforces the view that land-use change may operate as a structural driver of economic, demographic, and institutional changes. From a policy standpoint, the findings imply that land-use interventions should be evaluated within a medium-term horizon and in conjunction with complementary sectoral policies, given the delayed and context-dependent nature of their socioeconomic associations.

Forest-related changes emerge as the most systemically important, displaying associations with a broad set of socioeconomic domains, including consumption, labor markets, macroeconomic performance, health, prices, and resource use. However, the coexistence of positive and negative correlations across countries underscores the conditionality of these predictive relationships, which may depend on institutional quality, economic structure, and demographic pressures. In policy terms, this implies that forest expansion or conservation strategies cannot be assumed to yield uniformly beneficial socioeconomic outcomes; instead, their effectiveness is likely contingent on alignment with labor market policies, public health systems, and fiscal frameworks.

In contrast, changes in agricultural land, yields, and input use exhibit more selective and domain-specific associations, reflecting narrower transmission channels. Agricultural expansion and intensification are linked primarily to demographic structure, employment composition, and selected macroeconomic and financial indicators, while yield improvements and fertiliser use show targeted connections to trade, aid, and financial flows. This pattern is consistent with theories of sectoral transformation, where agricultural dynamics influence development through productivity and surplus generation. For policymakers, these findings highlight the importance of targeted interventions: productivity-enhancing measures (e.g., yield improvements) may be

Table 1
Examples of the most frequently significant predictive relationships.

Group of indicators	*Indicator (percentage of countries where predictive relationships were significant in total number of countries)*			
	Forest	*Agri-land*	*Fertilisers*	*Yields*
Aid		Net official flows from UN agencies (30)		Net bilateral aid flows from DAC donors (28, Austria (-), Denmark (draw), Finland (-), Norway (+), Sweden (-))
Banking			Commercial banks and other lending (27; -)	Public and publicly guaranteed bank loans (PPG) of other private creditors (20; +)
Communication	Fixed telephone subscriptions (37)			
Education	School age population, primary education, male (35)	School age population, lower secondary education (25)		
Employment	Contributing family workers, female (30)	Economically active population in agriculture (27)		
Equality	Rural population (43), Women Business and the Law Index Score (21)	Urban population (34)		
Expenditures	Households and NPISHs Final consumption expenditure (32)			Households and NPISHs Final consumption expenditure (21; +)
GDP	Gross national expenditure deflator (34)	PPG, IDA (22)	PPG of commercial banks (+) and other private creditors (-), (23)	Foreign direct investment net inflows, Short-term debt (25; -)
Grants			Technical cooperation grants (23; -)	
Health	Mortality rate, under−5, male (44),	Prevalence of overweight, female (27)		
Population	Population in urban agglomerations of more than 1 million (48)	Population in largest city (34)	Population in urban agglomerations of more than 1 million (24; +)	
Price	Consumer price index (2010 = 100) (26)			
Production				Cereal production (21, -)
Trade			Arms imports (20, +)	Exports of goods and services (24, +)
Water	Renewable internal freshwater resources per capita (43)	Renewable internal freshwater resources per capita (30)		

more effective when integrated with trade and investment policies, whereas land expansion and input intensification require careful management of demographic pressures, resource constraints, and financial exposure to avoid adverse or unintended consequences.

6. Discussion and conclusion

The lists of indicators obtained in this study confirm the presence of significant correlations between past changes in LULUCF indicators and *socioeconomic indicators* observed with lags of 1–10 years. The study expands the set of socioeconomic indicators that show correlations with LULUCF and demonstrates that variables such as aid, banking, communication, education, employment, equality, expenditures, GDP, grants, health, population density, population pyramid, price, production, trade, and water can be modeled alongside LULUCF indicators. These socioeconomic indicators can be forecasted using lagged LULUCF indicators, and in many countries, they produce statistically significant estimates.

The results of this study broaden the range of socioeconomic indicators (e.g. in IPCC et al., 2000; Appelt et al., 2022) that respond to LULUCF and merit greater attention. In fact, the correlation between past LULUCF and later socioeconomic indicators may be comparable to those in the opposite direction reported in now classic influential studies such as Barlowe (1978), Geist and Lambin (2002), Foley et al. (2005), and Pointereau et al. (2008). However, the main added value of the present work lies in its breadth and data-driven screening approach. This aspect contributes to the novelty of the present study, while not diminishing the importance of previous research, which have examined territorial features in greater detail.

The authors acknowledge that it is difficult to draw clear-cut conclusions from the vast body of results. At the same time, this study provides an important complement to the many works addressing the non-market value of agriculture (e.g. Ahlheim and Frör, 2003; Obeng et al., 2020; Alcon et al., 2024) and forestry (Riera et al., 2012; Upton et al., 2012; Yao, 2012). Whereas the cited studies focus on the subjective perception of amenities, this paper, to authorś knowledge, is among the first to demonstrate objective changes resulting from land-use change. Some of these changes (e.g., the association between forestry and the labor force) are likely market-driven, while others (e.g., the association between agriculture and freshwater resources) are more closely related to ecosystem services. Regarding the latter, it must also be acknowledged that forestry and agriculture appear to generate predictive relationships with negative externalities: in 27 countries, women's obesity rates are positively correlated with agricultural land, and in 44 countries forestry shows a significant positive predictive relationship with infant mortality.

Compared with previous studies that mainly anticipated associations between LULUCF and dimensions such as income, emissions, and health, this study also identified correlations between land-use indicators and *equality indicators*. This highlights a social dimension of land use, namely gender equality, which warrants explicit consideration in future social science research. In addition, the analysis expands the set of *economic indicators* linked to past land use. Variables such as industry, manufacturing and service value added, total employment, exchange rates, foreign direct investment, inflation and GDP – few of which were previously associated with LULUCF – were found to correlate with land-use dynamics. These socioeconomic associations are highly relevant for policymakers and land managers, given that both LULUCF and economic development are shaped by human decisions, as are agricultural and social sustainability for future generations.

Overall, the results of this study are relevant for local, international and global socioeconomic policymaking, including in countries engaged in projects such as Nostradamus (2024), LandShift (2024) and AfroGrow (2025), see Varvaris et al. (2025a, 2025b, 2025c). Understanding the dynamics between LULUCF and socioeconomic outcomes can help refine strategies that not only align with environmental objectives but also foster socioeconomic development at both local and regional levels. The key recommendation emerging from this research is that policymakers should anticipate socioeconomic changes following LULUCF policies and recognise that these predictive relationships will vary by country and encompass a far broader range of indicators than suggested in previous theory. Land-use policies should adopt a medium- to long-term perspective, as their socioeconomic linkages may appear with significant time lags and vary across national contexts. Forest-related interventions require integrated, cross-sectoral policy design, as their linkages span multiple domains (e.g., economic performance, health, and labor markets) and can produce both beneficial and adverse outcomes depending on institutional and economic conditions. In contrast, agricultural and input-focused policies should be more targeted, aligning productivity measures with trade, financial, and demographic strategies to maximise benefits while mitigating resource and socioeconomic risks.

Understanding the interplay of LULUCF and socioeconomic indicators is crucial for refining strategies that align environmental objectives with socioeconomic development at both local and regional scales. Future activities will therefore anticipate socioeconomic changes associated with LULUCF policies and recognise that these predictive relationships differ across countries and extend beyond the narrower indicator sets considered in earlier research. This study explores the contribution of LULUCF to socioeconomic indicators on available data pairs that exhibit sufficient variation. The key limitation of this approach is that the analysis relies on correlations rather than causal identification, and that stable LULUCF may still be associated with socioeconomic change, even though this is difficult to derive quantitatively. If there are indicators that benefit/lose from stable land-use, they may also be interrelated with other non-numeric, socioeconomic, environmental, and institutional indicators. This study does not cover such cases and may be a good starting point for further research. A similar quantitative and qualitative assessment, as conducted in this study, may be performed for industrial LULUCF types, such as water cover, urban, and infrastructural land-use.

Further research should focus on disentangling country-specific differences and regional patterns in both established and newly identified indicator pairs, alternative lags, subsamples, specifications, including a more explicit discussion of endogeneity concerns and possible strategies to address them. Clarifying the direction and recursivity of relationships would substantially improve the interpretability and credibility of the empirical findings in this paper and can serve as a main avenue for further research.

CRediT authorship contribution statement

Daria Loginova: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stefan Mann:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Sabine Hoidn:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **Ioannis Varvaris:** Writing – review & editing, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2026.108155.

Data availability

Data will be made available on request.

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