Assessing Effects of U.S. Corn Ethanol Production on Land Cover and Management

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Introduction

Research at Oak Ridge National Laboratory (ORNL) improves understanding of social, economic, and environmental effects of renewable energy options. Issues underlying controversies about costs and benefits of corn ethanol and approaches to overcoming barriers to scientific consensus are discussed, focusing on land cover and management. References are provided for further research.

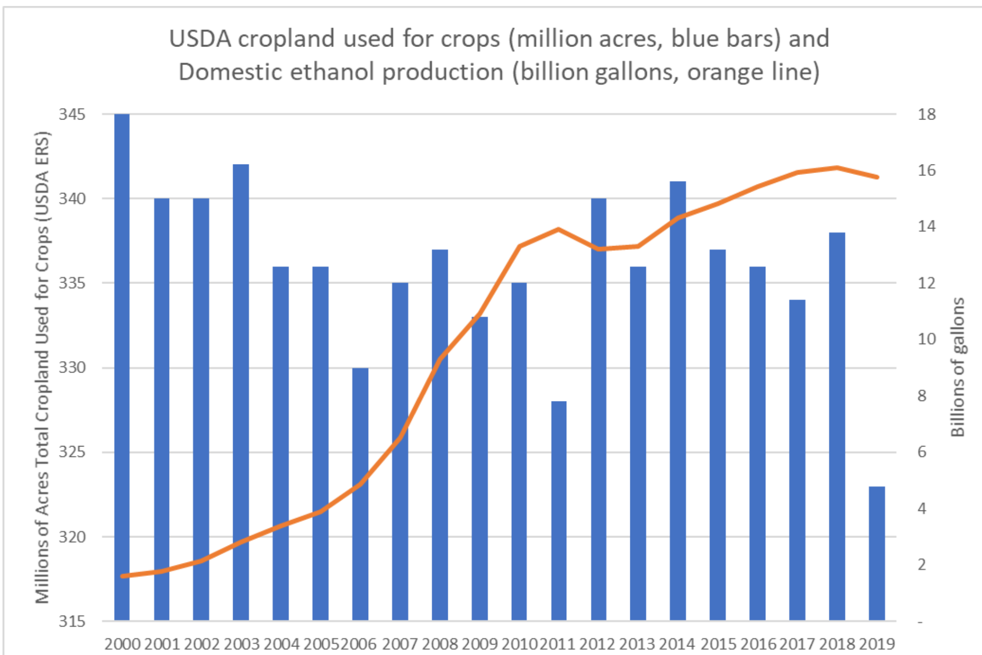

Figure 1 illustrates US trends for total cropland used for crops (millions of acres) and domestic ethanol production (billions of gallons) since 2000 [USDA 2021]. Ethanol output rose quickly 2003-2010 in response to state bans on the use of MTBE, high oil prices, and other factors. Total cropland area each year is determined by a variety of factors, including weather, global markets, crop subsidies, and the acreage authorized and funded for Conservation Reserve Program (cropland set-asides), among other factors.[1]

International organizations recognize that public concerns about food security, land-use change, and other market-induced effects or 'leakage' of impacts to other locations represent major obstacles for renewable energy pathways that require biomass feedstocks [IEA 2017; Marazza et al 2018]. Science-based approaches are required to assess observed changes in land cover and management and attribute them to various drivers.[1] Analyses of land change are facilitated by high-quality, geospatially resolved, time-series data with consistently defined classes of land cover, management, and other attributes that can be evaluated and verified with acceptable confidence levels [Dale and Kline 2013]. Lacking reliable data, estimates of climate and environmental effects of biofuels, including corn ethanol, often rely on models with significant uncertainties [Dunn et al. 2017; Lewandrowski et al. 2019]. Modeling indirect effects or leakage creates special challenges; these effects may not be measurable or verifiable.

Sources of disparate estimates of the effects of US corn ethanol

The impacts of corn ethanol remain controversial largely due to distinct approaches for:

- Defining reference scenarios (what would have happened if corn ethanol had not been produced) [Koponen et al. 2018; Kline and Dale 2008; Dale et al. 2010]
- Estimating indirect effects (leakage) and externalities [Birur et al 2013; Kline et al. 2017a]
- Modeling and classifying land cover and management [Kline et al 2011; Hertel et al. 2019].

To illustrate the effect of choice of land management reference scenarios, consider possible approaches to measure effects of U.S. corn ethanol. Case 1 measures effects without a reference scenario, implicitly assuming land-related effects would not otherwise exist e.g., [Hill et el. 2006; Hertel et al. 2010]. Case 2 measures impacts compared to a reference scenario where crops are grown regardless of whether ethanol is produced or not, based on historical trends. Case 3 assumes ethanol production expands low-till corn-soy rotations in lieu of more intensive crop management. The same quantity of ethanol produced would have apparent net effects ranging from highly detrimental in Case 1 to highly beneficial in Case 3. This comparison is related to changes caused by land management which some studies describe as “direct” or “domestic” LUC, as discussed in Skully et al [2021].

Environmental effects of corn ethanol can also be expressed in comparison to those from the fossil gasoline replaced, finding more extensive and persistent negative impacts on biodiversity and ecosystem services from gasoline than from ethanol [Parish et al. 2013; Dale et al. 2014; Lewandrowski et al. 2019]. The calculated carbon intensity (CI) of US corn ethanol production depends on many factors including local agricultural practices, coproduct treatment, and energy sources for processing corn to ethanol. Data from the certified mills documented by the California LCFS range from 53.5 to 85.6 for US corn starch ethanol, and the volume-weighted average CI for ethanol consumed in California under LCFS in 2020 was 62.1, a 38% reduction in emissions relative to fossil gasoline (CI = 100.1). Recent analyses by GREET (2020) and Skully et al. (2021) find that corn ethanol produced using best practices provides a 46% reduction in emission relative to fossil gasoline, while other studies and older data sets find poorer performance (e.g., 25% reduction per Hill et al. 2006).

Indirect effects

More complicated challenges in estimating effects of corn ethanol production arise when indirect effects, including indirect land-use change (ILUC), and other market-induced or cross-boundary (leakage) effects are estimated, particularly at global scales.[2] Issues with indirect effects include:

- Indirect land-use change (ILUC) hypotheses, wherein U.S. land for corn ethanol causes land displacement elsewhere, lack empirical support [Babcock 2009; Oladosu et al. 2011; Kline et al. 2011; Dale and Kline 2013; Woods et al. 2015; Kline et al. 2017; Shrestha et al. 2019; Oladosu et al. 2021].
- ILUC estimates are products of model simulations that cannot be verified or validated e.g., [Babcock 2009; NRC 2011; Valin et al. 2015; Kline et al. 2017a&b; Marazza et al. 2018].
- Modeled LUC estimates are sensitive to data source, parameterization, and questionable assumptions [Kline et al. 2011; Oladosu et al. 2021].
- Datasets used for modeling land effects, especially in global models and for land classes at the margins (pasture, grassland), are unreliable [Oliviera et al. 2020; Babcock and Iqbal 2014].[2]

- Disparate LUC estimates for US ethanol abound ranging from various degrees of expansion as reviewed in [Skully et al. 2021]. to contraction of global agricultural area e.g., [Popp et al. 2014; Dunn et al. 2017; Hertel et al. 2019; Oladosu 2013].
- Models that attribute changes in land cover or management to corn ethanol tend to use simplified economic relationships and assumed elasticity factors (modeled responses to relative prices) while omitting other important parameters.[3]

Resolving controversies

An interdisciplinary approach that considers other social and political factors and local heterogeneity of drivers is required for more accurate LUC projections[1] [Hertel et al. 2019; Kline et al. 2017a; Eigenbrod et al. 2020]. Attribution of land management and environmental effects to corn ethanol must be analyzed with more scientific rigor to improve accuracy and confidence for the public and decision makers [Efroymson et al. 2016; Kline et al. 2009; Kline et al. 2011; Katrakilidis et al 2015; Kline et al. 2017; Marazza et al. 2018].

Debate over land effects of corn ethanol will not be resolved until interdisciplinary and interagency research teams collect the necessary data to build consensus in three areas.

1) *Empirical observations of land cover, management, productivity, and changes over time and space.* Remotely sensed data for clearly specified land cover types and management regimens at high geospatial and temporal resolutions are required for analysis.
2) *Reference scenarios.* Science-based methods and data sets need to provide more consistency and transparency for assumed conditions in the absence of corn ethanol production. A common reference data set would provide a starting point to facilitate inter-model comparisons.
3) *Causation.* Causal analysis is a set of rigorous methods to attribute and allocate observed effects among potential causes based on strength of evidence for defined causal pathways.

The first step of causal analysis will help reduce controversies over indirect effects of corn ethanol: determine when and where effect(s) of concern in fact occur (or are absent). Analyses can then proceed to evaluate cause-effect relationships among defined variables [Kline et al 2011; Efroymson et al 2016]. With adequate data, causal analysis can determine whether the timing and persistence of observed effect(s) are linked with the presence or absence of potential change agents, signals, or policies.

Statistical tests can determine the strength of causal relationships among corn ethanol production, market prices, and land cover change, when adequate data are available. Studies based on historical data have not found evidence to support relationships assumed in most models that estimate indirect effects. For example, corn ethanol production is not identified as a causal driver for changes in U.S. commodity exports or a significant mechanism for market-induced effects through global commodity prices [Oladosu et al. 2011; Katrakilidis et al 2015; Oladosu et al. 2021]. Yet, these are two primary mechanisms assumed in conceptual causal chains for ILUC. Combinations of statistical tests, natural experiments, and weight-of-evidence approaches to examine each link in conceptualized causal chains can help clarify whether a relationship is causal (versus other relationships, such as non-causal correlations or instances where agents serve as a catalyst or buffer for the observed effect [Efroymson et al. 2016; Kline et al. 2017a].

Conclusions

Fundamental challenges for modeling LUC include a lack of agreement on (i) a clear and consistent definition of what constitutes LUC, (ii) what causes observed changes, (iii) relevant and verifiable time-series data, and (iv) standard reference scenarios. LUC assessments results improve when

a) Unambiguous land cover and land management categories are consistently applied,

b) Criteria determine when and where each transition occurs among the defined categories in (a), including timing and extent of each transition, and

c) What is measured is distinguished from what is inferred or modeled, and the net and gross changes measured in each time step are clearly documented and communicated.

Given the size of the U.S. ethanol industry, reliable analyses of current effects carry significant implications for guiding decisions that improve climate outcomes while reducing negative impacts. Collaborations across agencies and disciplines should expand to build consensus on science-based approaches, focusing on effects of high priority for development. Research can help stakeholders identify preferable options for advancing to a more equitable, circular economy based on sustainably sourced, renewable biomass.

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End Notes

1. For further discussion, see Kline et al. 2017a. Factors that determine or influence total US cropland acreage but are often omitted from studies that estimate effects of biofuel production on cropland include:

- Investment and equipment lock-ins (precision corn planting and harvesting equipment)
- Prior year performance and other psychological factors
- Crop rotation plans (often approved in advance by USDA and linked to subsidies)
- Concentrated animal feeding operations (CAFOs), intensive dairy operations and other sources of manure, which are spreading across the landscape and use corn acres preferentially for manure disposal
- Government set-asides and the Conservation Reserve Program (CRP)
- Other state and federal farm subsidies
- State and local regulations, tax schemes, and subsidies
- Ownership changes and securitization of farmland
- New seed varieties
- New pests or difficult-to-control weeds (impacting some crops, not others)
- Farmers' gut feelings
- Established long-term growth trend for corn and soy acreage in rotation – a trend with momentum prior to establishing U.S. Renewable Fuel Standards
- Foreign markets
- Technology advances
- Variable crop rotations and management practices (Kline et al. 2013)

[2] Uncertainty in global LUC estimates is compounded by the need to aggregate, average, and simplify categories for heterogeneous land cover and management attributes. For example, global land cover data sets report total current pasture areas for Brazil that differ by a factor of four, from 43 million to over 170 million hectares (Oliveira et al., 2020). Depending on which input value is used in a model, one may conclude either that hundreds of millions of acres were deforested due to sugarcane expansion, or that hundreds of millions of acres of degraded pasture fell under improved management. The range of classification error in land cover datasets typically eclipses the magnitude of change simulated for biofuel production.

[3] Skully et al. 2021 find that modeled estimates of ILUC depend largely on the underlying model and data sets used for input values that parameterize the model, definition of variables, assumed yield response to price or other factors, and land intensification. Factors relevant to drivers of deforestation and LUC, such as land tenure, productivity, yield response, etc., Global models simplify or use average values globally, omitting important drivers. Dale and Kline (2013) and Kline

et al. (2011 & 2017a) describe common factors omitted from most LUC models. Among variables critical for understanding observed changes in land cover are the following.

- Policies and social variables impacting land tenure, land claims, and frontier colonization (Eigenbrod et al. 2020). Federal and state subsidies in frontier regions around the globe aim to “open new lands to development” – at times, literally paying large firms to clear forests and “develop” the hinterland.
- Governance and administration of justice and the degree of active/effective enforcement of laws protecting public forests and “legal reserves”.
- Roads, ports, and infrastructure that provide or improve access to otherwise remote lands with natural cover. The access is often built with government support for oil and gas concessions, large hydropower, mining and logging industries.
- Farm subsidies and credit programs to farmers for land clearing, typically facilitated via government banks and related programs for “agricultural development”
- Unemployment and poverty (poor people will turn to public lands and clearing “unclaimed” (forest) when they have no other options for making a living).

To the degree biofuel policies interact with the factors above, they may influence deforestation. For example, due to the requirements for certification and pressures to legalize operations, the sugarcane industry in Brazil, which had been running with little oversight for 500 years, began to implement a series of compliance regulations to protect riparian zones, manage waste water, retain private forest reserves, and end indiscriminate burning. The industry organized around efforts to develop ethanol fuels that could meet international standards and to avoid being labeled as a cause of deforestation. This transformation impacted the broader sugar industry with beneficial effects for the environment and biodiversity