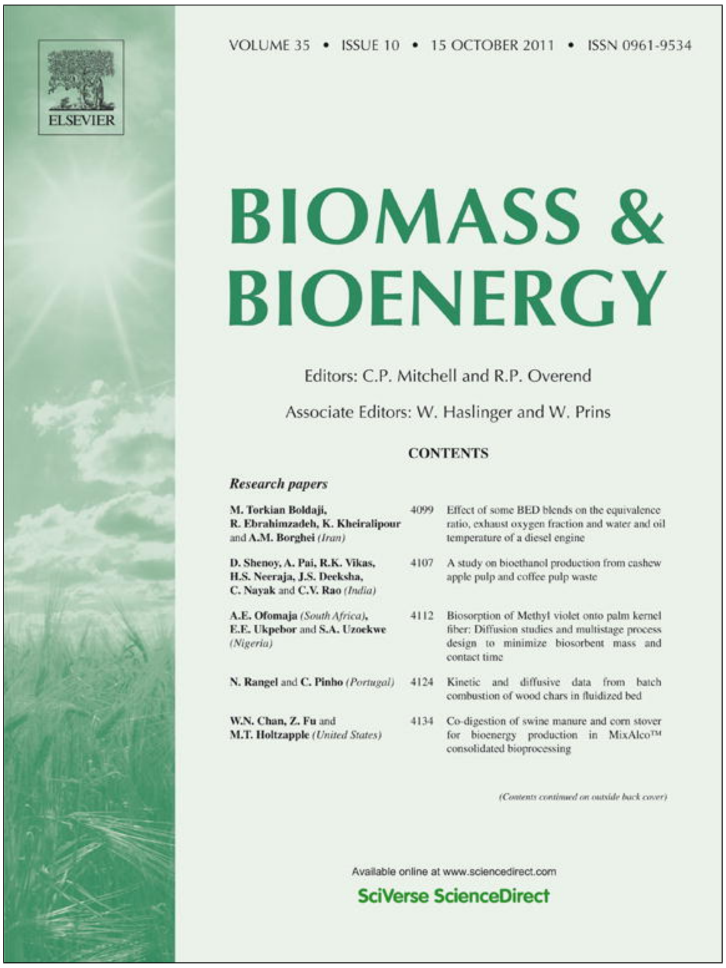
ELSEVIER
VOLUME 35 • ISSUE 10 • 15 OCTOBER 2011 • ISSN 0961-9534
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Scientific analysis is essential to assess biofuel policy effects: In response to the paper by Kim and Dale on "Indirect land-use change for biofuels: Testing predictions and improving analytical methodologies"

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ARTICLE INFO

Article history:
Received 12 August 2011
Accepted 17 August 2011
Available online 10 September 2011

Keywords:
Bioenergy
Land-use change
Policy
Causation
Economic
Models

ABSTRACT

Land-use change (LUC) estimated by economic models has sparked intense international debate. Models estimate how much LUC might be induced under prescribed scenarios and rely on assumptions to generate LUC values. It is critical to test and validate underlying assumptions with empirical evidence. Furthermore, this modeling approach cannot answer if any specific indirect effects are actually caused by biofuel policy. The best way to resolve questions of causation is via scientific methods. Kim and Dale attempt to address the question of if, rather than how much, market-induced land-use change is currently detectable based on the analysis of historic evidence, and in doing so, explore some modeling assumptions behind the drivers of change. Given that there is no accepted approach to estimate the global effects of biofuel policy on land-use change, it is critical to assess the actual effects of policies through careful analysis and interpretation of empirical data. Decision makers need a valid scientific basis for policy decisions on energy choices.

Vigorous debate on the effects of biofuels derives largely from the changes in land use estimated using economic models designed mainly for the analysis of agricultural trade and markets. The models referenced for land-use change (LUC) analysis in the U.S. Environmental Protection Agency Final Rule on the Renewable Fuel Standard include GTAP, FAPRI-CARD, and FASOM [1]. To address bioenergy impacts, these models were expanded and modified to facilitate simulations of hypothesized LUC. However, even when models use similar basic assumptions and data, the uncertainty surrounding the LUC results can vary by ten-fold or more [2,3]. While the market dynamics simulated in these models include processes that are important in estimating effects of biofuel policies, the models have not been validated for estimating land-use changes [4,5] and employ crucial assumptions and simplifications that contradict empirical evidence. For example, these models typically assume that:

(a) all land is privately owned and managed to maximize profit, but in reality, the forest lands that the models estimate to be converted by indirect LUC are nearly all public property [6,7] and farmers in the neighboring agricultural frontiers often lack secure land titles [8,9];
(b) elasticity factors and mathematical functions driven by relative global commodity prices determine land-use change including new forest conversion, but in reality, forest conversion is driven primarily by complex interactions among many factors at local scales including

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0961-9534/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2011.08.011

governance, policies, poverty and land speculation or clearing to stake land claims [8,10];

(c) U.S. biofuel policy creates a "shock" in corn ethanol demand, and production and land-use systems are stable, but in reality, ethanol policies in the U.S. have been implemented over more than twenty years and provided advance notice to producers [11], while production and land-use remain highly dynamic independent of ethanol policies; and

(d) land is either fully utilized or in a stable, natural state. This assumption facilitates modeling but predetermines indirect LUC outcomes by forcing biofuels to displace a current productive use or augment land conversion. In reality, less than one quarter of global, non-forest, arable land is cultivated [12], leaving ample opportunity to improve management on the majority of previously cleared land. In the absence of management, rather than natural forest regrowth as assumed in models, these underutilized arable lands suffer persistent disturbance and contribute to an average global burned area of 380 million hectares each year [10,13]. The distribution and effects of fire and other disturbances are not considered in economic modeling of LUC.

By including some mechanisms that are assumed to cause deforestation (e.g., increase in crop prices) while omitting other mechanisms known to induce deforestation (e.g., local policies and governance), model assumptions drive the simulated LUC results. Thus the necessity and value of validating assumptions with empirical evidence.

More importantly, the economic models are incapable of addressing whether biofuel policies actually cause any of the indirect effects being simulated [10,14]. The models estimate *how much* indirect change might be induced under prescribed scenarios that start with the assumption that indirect effects occur. This approach cannot answer *if* any specific indirect effects are actually caused by the policy. The best way to resolve the question of causation is to apply scientific methods to test alternative hypotheses based on the analysis of extensive observations. Kim and Dale [15] take advantage of historic data to attempt to address the question of *if*, rather than how much, market-induced land-use change is currently detectable, and in doing so, explore some modeling assumptions about the drivers of market-induced land-use change.

Based on the analysis of global data, Kim and Dale conclude that there is no empirical evidence to support the hypothesis that biofuel production in the United States (U.S.) has induced significant indirect changes in land use. They also note that additional data and analyses are required to understand better the relationships between U.S. bioenergy policies and global land-use change dynamics. We reached similar conclusions using a very different method. Applying a systematic analysis to trace the sources of corn used for ethanol production in the U.S. between 2001 and 2010, we found that ethanol production had little effect on corn and other crop exports from the U.S. and, consequently, little if any global land conversion implications [16]. Our analysis of U.S. data suggested that reallocation of domestic corn uses (efficient substitutions among feed sources) and increases in production accounted for nearly all ethanol, with production changes mainly due to increases in yields rather than land expansion or displacement. Linear regressions of U.S. land-use and total production [17] indicate that, as ethanol output increased over five-fold from 2000 to 2010, total output of major crops increased by 24% and total planted area declined by 1.5%. Net expansion in corn acreage over the past decade was largely offset by reductions in acreage for lower yielding coarse grains, pasture, and cotton; while wheat and soy acreage grew [17]. These data complement Kim and Dale's analysis by offering sharp contrasts to model results that consistently projected U.S. cropland expanding into forests and grasslands and corn displacing large areas of soy and wheat, thereby driving significant LUC effects [1]. The increase in fuel ethanol production since 2005, when the U.S. established a Renewable Fuel Standard, represents about 5.5 million hectares, or about 6% of total cropland area planted (calculated assuming 100% of ethanol production came from corn, a 35% adjustment for co-products, and industry biorefinery yields) [17,18]. Plausible hypotheses could be tested to estimate what portions of this land, in the absence of biofuel policies, might have remained in prior agricultural uses (e.g., cotton, hay, corn, and lower yielding coarse grains), gone fallow, or been converted to non-agricultural/developed uses.

There is no accepted approach to estimate the global effects of biofuel policy on land-use change, and it is unlikely that a single model or method will be suitable to every situation [19]. The research community, therefore, needs to apply scientific methods and use best available data to explore the issue from several perspectives. Science is defined as a pursuit of knowledge and understanding of the world following a systematic methodology based on evidence [20]. The scientific process involves objective observation, measurement of verifiable data, and analysis based on evidence, observations and experiments as benchmarks for testing hypotheses. Applying the scientific process permits repetition, critical analysis and, over time, verification or refutation. Scientific methods are transparent and can be replicated and tested based on evidence to insure *consistent* results – an important distinction between an empirical approach and the economic modeling used for most current LUC estimates, which are highly sensitive to uncertain inputs and assumed parameters.

Kim and Dale offer an analytical approach that can be tested. However, any global analysis of land-use change requires choices to be made about how to organize and assess information. Decisions about data sets, aggregation, averaging, threshold values and other variables can influence results of any study. And results will never be more reliable than the input data utilized. Unfortunately, high-quality land cover and land-use data are not available across the relevant temporal and spatial scales for understanding changes in land management [21], the effects of changes in land cover [22], or the causal attributions for change [8,10,23]. Alternative modeling approaches need to be tested using a growing body of empirical evidence in order to clarify the effects of biofuel policy options. High-resolution, geospatially and temporally explicit data sets on global land cover and corresponding biophysical characteristics (carbon stock and fluxes, for example) are needed to facilitate more consistent and objective analysis of global change. Complex issues such as deforestation and food security may require different approaches to characterize the dynamic interactions between policies and land-use at different scales [14]. Causal analysis [24,25] is one approach that has yet to be adequately applied to improve understanding of LUC effects of bioenergy policy, in part because it is highly data-intensive and requires significant investments in long-term research [26,27].

New opportunities to test and verify LUC hypotheses using scientific methods are emerging as the quality and availability of data improve. Observations based on recent land-use trends suggest that probable indirect effects of biofuel policy on deforestation and greenhouse gas emissions may be the opposite of those assumed by current economic models [9,19,28]. For example, biofuel policies could create incentives that reduce the rate of loss of productive farmland to urban sprawl and development in nations such as the U.S. [29] and to manage land more productively, without the chronic use of fire, in tropical nations where more land has been previously cleared than is fully utilized [12,19,30].

Empirical data on corn supply, distribution, and use in the U.S., combined with data on corn-ethanol production, other crop production, exports, and land use changes over past decades, should be carefully assessed when trying to understand the effects of U.S. biofuel production on global markets and land-use. Kim and Dale make contributions by examining specific parameters affecting global drivers for land-use change. Their work along with other recent analyses [16,31,32] underscore the importance of testing underlying model assumptions. With the benefit of hindsight, we may discover that indirect LUC penalties not only lack scientific basis, but also undermine their intended purpose by creating market uncertainty for cleaner alternatives to fossil fuels and by displacing direct performance incentives to improve land management with a complex and costly regulatory framework based on “double guessing” [33] that cannot be verified, measured or managed. Actual effects of policies need to be assessed to verify that environmental and social objectives are being achieved. Careful analysis and interpretation of empirical data are essential to provide a valid scientific basis for policy decisions on energy choices.

Acknowledgements

The authors’ research is supported by the U.S. Department of Energy (DOE) under the Office of the Biomass Program. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for DOE under contract DE-AC05-00OR22725.

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