Clean Fuels
ALLIANCE AMERICA

CALIFORNIA
ADVANCED BIOFUELS
ALLIANCE

June 16, 2023

Cheryl Laskowski, Chief
Transportation Fuels Branch
California Air Resources Board
1001 I Street
Sacramento, CA 95814

Dear Dr. Laskowski:

The Clean Fuels Alliance America (Clean Fuels)[1] and California Advanced Biofuels Alliance (CABA)[2] appreciate the opportunity to provide comments on the May 23rd Low Carbon Fuel Standard (LCFS) workshop focused on a stepdown and auto-acceleration mechanism for the LCFS. Clean Fuels and CABA have been longtime supporters of the state's overall climate and air quality improvement goals and have collaborated frequently with CARB staff toward achieving those goals. We continue to support California's efforts to decarbonize its economy, especially in the transportation sector, with a comprehensive all-of-the-above suite of measures.

Our California member producers and marketers support over 3,900 well-paying jobs in the state and about $960 million in economic activity each year. Further, the biodiesel, renewable diesel, and sustainable aviation fuel supplied to the state by our California and national members are collectively the single largest source of GHG reductions in the LCFS, providing nearly half[3] (about 45%) of the carbon reductions since 2017, more than any other fuel including electricity, and 42% since the start of the LCFS. Our fuels have grown to the point where nearly half (46%) of each gallon on average of diesel fuel consumed in the state in 2022 consisted of our industry's low-carbon fossil diesel replacement fuels.[4] Our sustainable replacements for petroleum diesel have been a major factor in driving California's continuing

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[1] Clean Fuels (formerly the National Biodiesel Board) is the U.S. trade association representing the entire supply chain for biodiesel, renewable diesel, and sustainable aviation fuel. The name change reflects our embrace of all the products Clean Fuels members and the U.S. industry are producing, which include biodiesel, renewable diesel, sustainable aviation fuel, and Bioheat® fuel for thermal space heating. Our membership includes over 100 farmers, producers, marketers, distributors, and technology providers, and many are members of environmental organizations supportive of state and local initiatives to achieve a sustainable energy future.

[2] California Advanced Biofuels Alliance is a not-for-profit trade association promoting the increased use and production of advanced biofuels in California. CABA represents biomass-based diesel (BMBD) feedstock suppliers, producers, distributors, retailers, and fleets on state and federal legislative and regulatory issues.

[3] Biodiesel and Renewable Diesel provided 45% of the LCFS credits in Q1-Q4 2022. See LCFS Quarterly Data Spreadsheet (dated April 28, 2023).

[4] Ibid.

large-scale transformation of transportation from petroleum based diesel toward a carbon neutral system. In short, the LCFS would not be the success it is today, and one the state is looking to export to other jurisdictions, without the key role our diesel replacements have played. More to the point, our liquid petroleum replacement fuels remain the only viable, large-scale alternatives for the next several decades to decarbonizing the most difficult-to-electrify sectors: heavy duty on- and off-road, marine, rail, and aviation.

We appreciate the opportunity that CARB provided for local environmental justice (EJ) community residents and advocates to voice their questions about the LCFS and the ongoing rulemaking. CARB invited only one external presentation at the first community meeting, Dr. Michael Wara of Stanford University, who presented the results of his team's analysis of an "EJ Scenario" for CARB's consideration. The EJ Scenario incorporated two main recommendations for CARB's consideration: (1) ending avoided methane crediting in 2024, and (2) imposing a cap on biofuel crop feedstocks (hereinafter referred to as "plant-based feedstocks"). Unfortunately, Mr. Wara's presentation lacked transparency and details, making it difficult to see how he arrived at a number of conclusions presented. More importantly, his analysis presented nothing new to CARB's deliberations. In fact, the analysis provided a disservice to the EJ communities by: (1) obscuring the benefits plant-based feedstocks already provide to these communities, and (2) not presenting the disbenefits a cap on plant-based feedstocks would have on such communities.

Our remaining comments will focus on Mr. Wara's presentation to highlight deficiencies which, in the aggregate, show that the analysis and its results do not support a conclusion that a cap on plant-based feedstocks is in neither California's nor local EJ communities' interests.

1. Need to Update Underlying Science, Data, and Assumptions

In both presentations, Wara says, "CARB's assumptions used for scenario development are <u>out of date</u> in ways that drive model results"[5] [emphasis in the original] and "CI values haven't been updated by ARB and if the CI is incorrect it could lead to incorrect results from the CATS model." On this point, Clean Fuels and CABA agrees. As we have commented numerous times, CARB uses Purdue University's GTAP-BIO model to estimate Indirect Land Use Change (ILUC) impacts from plant-based biofuels (a critical part of the overall CI score of plant-based fuels in CARB's view). But the underlying dataset in the version of GTAP embedded in the LCFS is woefully outdated (much of the data is well over a decade old), which results in a gross overestimation of the ILUC impacts. This has resulted in an historic and ongoing exaggeration of the ILUC impacts from plant-based biofuels, as noted below.

To illustrate, CARB's 2015 LCFS rulemaking established the current soybean ILUC score of 29.1 gCO2/MJ based on a shock of about 800 million additional gallons of biomass-based diesel. However, Purdue used current (at the time) data and a 2-billion-gallon shock in 2020 to show the ILUC penalty was closer to 17.5, a 40% reduction in the ILUC penalty based on an assumed

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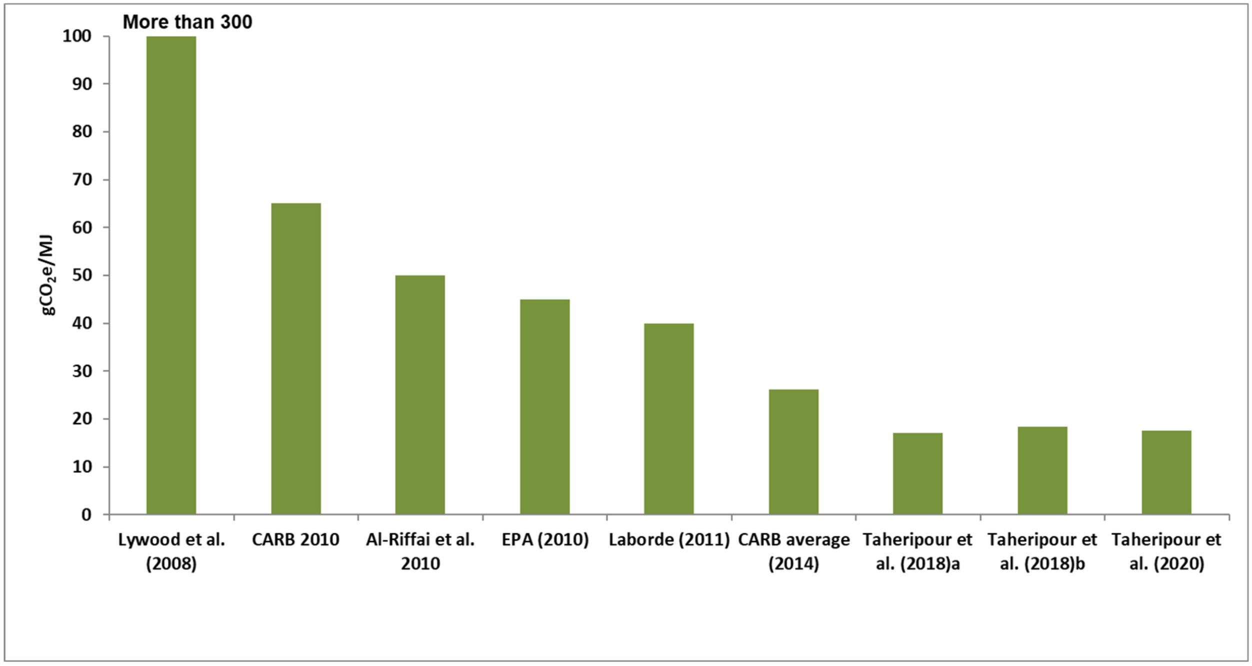
[5] Wara Presentation at slide 4

biodiesel shock volume 2.5 times the 800 million gallons CARB used to establish the 29.1 value. Indeed, studies in this field have shown an ongoing and substantial decline in estimates of the ILUC penalty (e.g., Purdue's 2020 ILUC estimate is at least 94% less than Lywood's 2008 estimate, 74% less than CARB's 2010 estimate, and 40% less than CARB's 2014 estimate now embedded into the LCFS; see Fig. 1).

Fig. 1. Some Estimated ILUC Values for Soybean Biodiesel



Source: Taheripour, et al., June 2023.

Further, the latest estimate from Purdue shows soybean's impacts on ILUC are likely substantially lower than even the 2020 Purdue estimate (Attachment 1). Purdue's latest 2023 work – using the same GTAP-BIO model CARB uses but updated with 2014 datasets – results in an estimated ILUC penalty for soy of 9.78 gCO2e/MJ based on a shock of 3.22 billion gallons (i.e., an ILUC penalty that is one-third CARB's current value using a shock volume that is 4 times the original shock volume used by CARB).[6] This work clearly shows that CARB's current ILUC penalty continues to grossly overestimate the ILUC impacts from plant-based biofuels.

Despite the continued evolution and refinement of ILUC science, CARB has declined to update the ILUC data and assumptions in the several rulemakings it has conducted since 2015. This lack of a serious effort to update the science underpinning a critical part of biofuels' ILUC penalty (ILUC is more than half of the total CI score for soy biodiesel and renewable diesel) has served as a barrier to additional deployment of low-carbon, drop-in fossil diesel replacements that can achieve immediate carbon reductions of 74% on average. As a reminder, biodiesel and

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[6] F. Taheripour, O. Karami, E. Sajendinia, "Biodiesel Induced Land Use Changes: An Assessment Using GTAP-BIO 2014 Data Base," Purdue University, June 2023.

renewable diesel provide more carbon reductions than all other fuels combined under the LCFS except for ethanol,[7] serving a key role in the success of the LCFS.

As Wara notes, an incorrect CI estimate can lead to incorrect results from the CATS model, which CARB is using in support of its current LCFS rulemaking. This is a key and accurate observation. When CARB's current ILUC penalty for soybean biofuels continues to overestimate by a large margin the likely impacts, the inevitable result is that it calls into question the results of Wara's analysis, which are premised on misinformed and outdated estimates of ILUC impacts. In short, Wara's conclusions are incorrect since they assume a much greater ILUC impact from plant-based biofuels than current science shows.

2. The Use of Outdated Science Obscures the Benefits Biofuels Provide to EJ Communities

Because Wara's analysis is premised on flawed and outdated estimates of the ILUC impacts from plant-based biofuels, it inevitably provides a disservice to EJ communities by masking the immediate benefits that such fuels provide to residents in those communities. The literature is replete with studies that document the ability of drop-in biomass-based diesel fuels to reduce diesel particulate matter (diesel PM), particularly in legacy vehicles which continue to operate in large numbers. CARB's own biodiesel characterization study in 2011, along with numerous other studies, showed that biodiesel can reduce diesel PM by up to 80% or more in older engines,[8] many of which remain in operation and will be doing so for many years. Since EJ and disadvantaged communities are often located at or near high diesel use sites (e.g., ports, railyards, logistics centers, freight corridors), the ability of biomass-based diesel to reduce residents' exposure to diesel PM now is a missed opportunity for CARB, particularly given the years or decades it will take for electrified heavy duty vehicles to make a material dent in the overall HDV population. And Wara's analysis fails to recognize the benefits to the health of EJ residents by simply assuming, without rigorous proof, that capping plant-based feedstocks will necessarily benefit EJ communities.

To illustrate this point, we note the results of the Trinity study, which we have shared with CARB staff on several occasions. Trinity Consulting conducted air dispersion modeling in 2021 and 2022 using standard USEPA modeling tools for 28 high-diesel use sites around the country (23 for transportation sources), including four in California (Port of LA/Long Beach, Port of West Oakland, South Fresno, and San Bernardino).[9] The Trinity analysis modeled the impacts and benefits of substituting biodiesel for the petroleum diesel used in the study sites. This study quantified the benefits from switching to biodiesel as preventing over 900 premature deaths per year, hundreds of thousands of asthma cases reduced or avoided per year, and reducing

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[7] Biodiesel and renewable diesel have generated 44-45% of the GHG reductions in the LCFS program since 2017 and over 42% since the start of the program, more than renewable natural gas, electricity, and hydrogen combined. LCFS Dashboard, April 28, 2023.

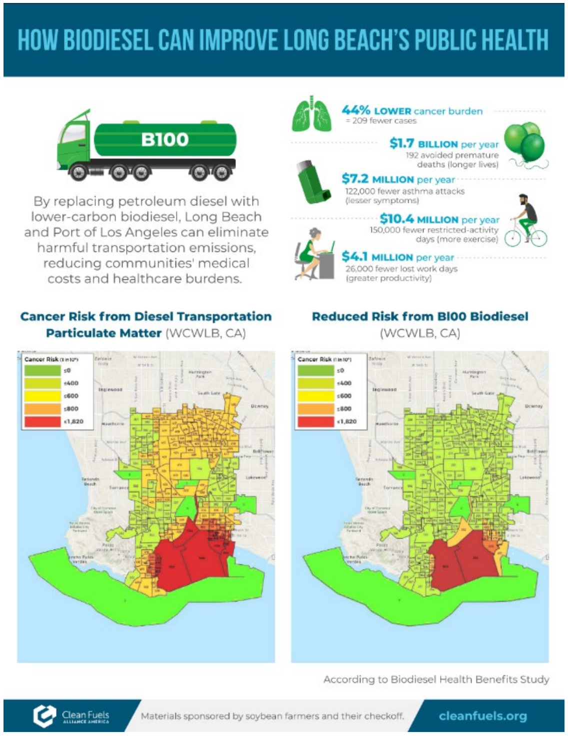
[8] Durbin et al., CARB Assessment of the Emissions from the Use of Biodiesel as a Motor Vehicle Fuel in California "Biodiesel Characterization and NOx Mitigation Study", October 2011.

[9] Health Benefits Study, Clean Fuels Alliance America, 2021-2022.

over 100,000 work loss days per year, totaling $7 billion dollars per year in avoided health costs. In the 19 transportation-focused sites outside of California, the biodiesel used in the analysis is presumed to be plant-based (given that virtually all waste oil-derived feedstocks are expected to be consumed in California, which historically has been the case).

Thus, Wara's conclusion that capping plant-based feedstocks has no apparent basis in the real world – biodiesel and renewable diesel reduce diesel PM substantially, which benefits EJ communities located near high-diesel use sites, and that is the case <u>irrespective of the feedstock</u> used to produce those fuels. The diesel PM reduction benefit is a function solely of the fuel (biodiesel, renewable diesel), and not the feedstock used to make that fuel, so capping a particular feedstock would effectively have no benefit to EJ communities. In fact, to the extent such a cap reduces the supply of biodiesel and renewable diesel, a cap could actually harm EJ communities by making biodiesel and renewable diesel more expensive and less attractive for fleets to use, resulting in greater use of petroleum diesel (see Fig. 2 and 3).

Fig. 2 and 3. Trinity Study Results for Port of L.A./Long Beach and Port Elizabeth.



HOW BIODIESEL CAN IMPROVE LONG BEACH'S PUBLIC HEALTH

By replacing petroleum diesel with lower-carbon biodiesel, Long Beach and Port of Los Angeles can eliminate harmful transportation emissions, reducing communities' medical costs and healthcare burdens.

44% LOWER cancer burden = 209 fewer cases

$1.7 BILLION per year 192 avoided premature deaths (longer lives)

$7.2 MILLION per year 122,000 fewer asthma attacks (lesser symptoms)

$10.4 MILLION per year 150,000 fewer restricted-activity days (more exercise)

$4.1 MILLION per year 26,000 fewer lost work days (greater productivity)

Cancer Risk from Diesel Transportation Particulate Matter (WCWLB, CA)

Reduced Risk from B100 Biodiesel (WCWLB, CA)

According to Biodiesel Health Benefits Study

Clean Fuels Alliance America

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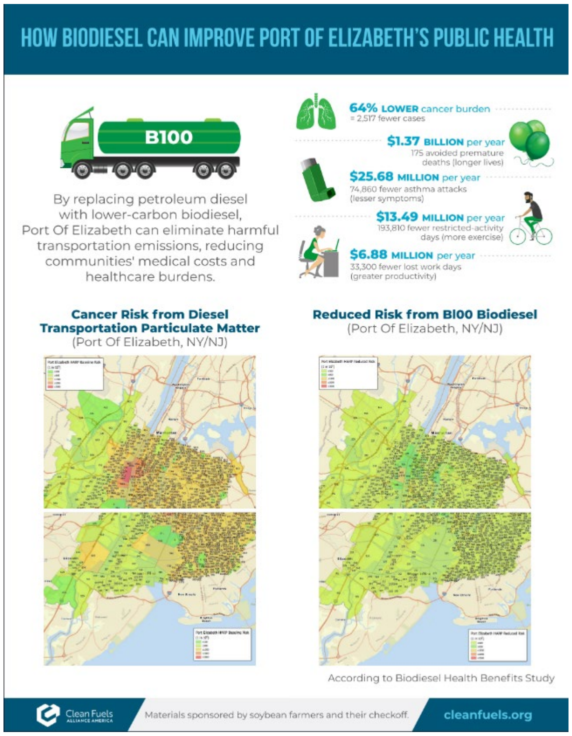

HOW BIODIESEL CAN IMPROVE PORT OF ELIZABETH'S PUBLIC HEALTH

By replacing petroleum diesel with lower-carbon biodiesel, Port Of Elizabeth can eliminate harmful transportation emissions, reducing communities' medical costs and healthcare burdens.

64% LOWER cancer burden = 2,517 fewer cases

$1.37 BILLION per year 175 avoided premature deaths (longer lives)

$25.68 MILLION per year 74,860 fewer asthma attacks (lesser symptoms)

$13.49 MILLION per year 193,810 fewer restricted-activity days (more exercise)

$6.88 MILLION per year 33,300 fewer lost work days (greater productivity)

Cancer Risk from Diesel Transportation Particulate Matter (Port Of Elizabeth, NY/NJ)

Reduced Risk from B100 Biodiesel (Port Of Elizabeth, NY/NJ)

According to Biodiesel Health Benefits Study

Clean Fuels Alliance America

Materials sponsored by soybean farmers and their checkoff.

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3. Assumption That “Spending Down” the Credit Bank Benefits EJ Communities

In Wara’s remarks, it is unclear what mechanism he assumes for eliminating the credit bank; regardless, there are a number of concerns with this assumption. First, CARB staff has already concluded the credit bank serves an important role,[10] but Wara assumes eliminating the surplus in the bank provides a benefit to EJ communities without exploring whether there are potential downsides to such an action. For example, the bank provides a buffer to reduce compliance costs for regulated parties and for accommodating potential market disruptions; without a reasonable surplus, LCFS participants can quickly face a large deficit situation under certain market conditions, which can rapidly increase credit prices; reduce availability of biodiesel, renewable diesel, and other low carbon fuels; and have negative consequences such as increasing the use of petroleum diesel, all of which are disbenefits to EJ communities.

4. Fuel Demand Assumptions and Other Changes Make Wara’s Comparisons to CARB’s CATS Modeling Apples-to-Oranges

Wara stated his modeling included changes to the fuel demand assumptions for the CATS model. However, such changes effectively render the results of his modeling to be non-comparable to the outputs of CARB’s CATS modeling. Moreover, it remains an open question on whether CATS is a robust model for these purposes; there are significant shortcomings to that modeling that stakeholders have raised in comments to various CARB workshops. Further, Wara noted his team “relaxed the electricity supply assumptions.” Because of the lack of transparency in the Stanford analysis, it’s unclear what the implications of that “relaxation” are. Was this done to minimize the cost of shifting to EV technology? Also, would the costs of an additional $19 billion (cited in his presentation) be even higher without revising the CATS model assumptions?

With regard to the $19 billion extra cost for compliance Wara cites, he makes no attempt to put the figure, assuming *arguendo* that it is valid, into appropriate context. His analysis concludes, with no justification, that an extra $19 billion in compliance costs is reasonable. Is it reasonable compared to what alternative strategy?

5. Deforestation and Food Price Impacts Are Already Accounted for in the LCFS’ ILUC Provisions

With respect to Wara’s claims that not having a plant oil cap will result in an additional 500,000 acres of soybeans and that it will result in the destruction of the Amazon, there are a number of important issues with such claims:

- The federal Renewable Fuel Standard has built-in protections which avoid RIN generation from feedstock grown on acres not in production in 2007.[11] Thus, the use of new acres that

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[10] CARB Presentation, LCFS Workshop, May 2023.

[11] Stakeholder meeting with CARB staff, June 14, 2023 (Attachment 2)

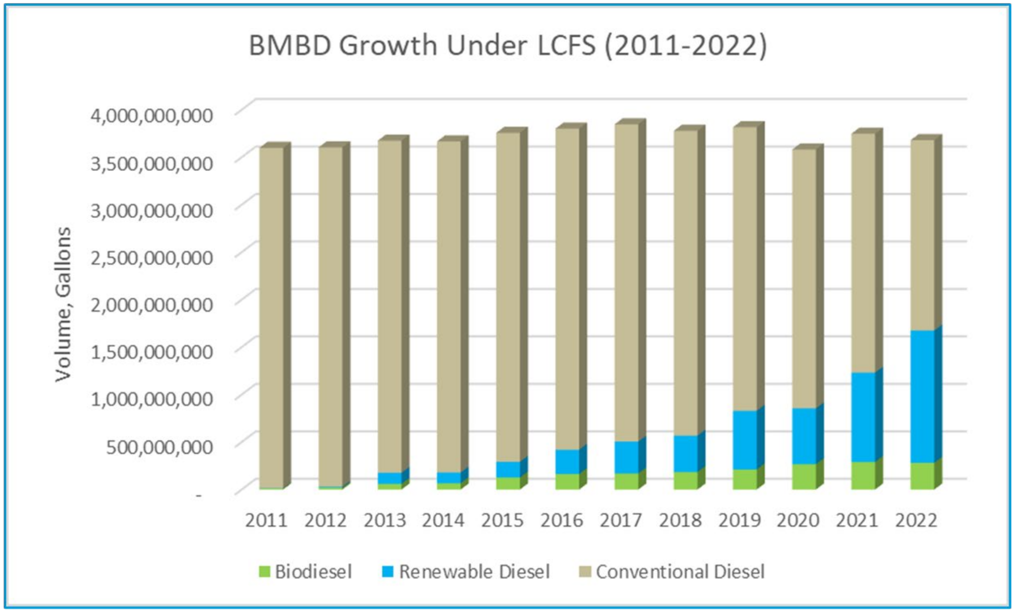
were not already in production in 2007 would prevent that fuel from getting a RIN under the RFS.

- As we noted above (and as Wara highlights), CARB has yet to update the underlying science and datasets for its GTAP-BIO modeling for ILUC assessments. If CARB were to update those dataset to the latest GTAP-BIO datasets, the results would clearly be different.
- And as we have noted to CARB in previous comments,[12] there is no attempt at all to account for expected increases in yield technology, biotechnology, crush capacity, acreage shifting, and winter oilseeds, to name a few, which are expected to minimize any increase in acreage to meet future fuel, feed, and fuel demands. If properly accounted for, the assumed increase in acreage would be much smaller, if any.

6. Capping Plant-Based Feedstocks Disbenefits EJ Communities

Wara's assumption that capping plant-based feedstocks will reduce petroleum refinery utilization is nonsensical and unjustified. Without such a cap, biodiesel and renewable diesel have led the way in providing more carbon reductions under the LCFS than any other fuel combined (excluding ethanol), generating 44-45% of the LCFS credits in 2017-2022.[13] Further, biodiesel and renewable diesel (BMBD) now comprise nearly half (46%) of the entire diesel fuel pool in California,[14] and there's no indication of that fossil diesel displacement trend going away anytime soon. Indeed, we are seeing increasing numbers of refueling stations offering completely sustainable 100% blends of biodiesel and renewable diesel (e.g., 80% renewable diesel, 20% biodiesel or R80/B20).

Fig. 3. Biodiesel and Renewable Diesel Displacement of Fossil Diesel, 2011-2022



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[12] Clean Fuels and CABA Joint Comments on Feb. 2023 workshop, incorporated herein by reference.

[13] CARB LCFS Dashboard, op cit.

[14] Ibid

To the extent EJ communities are located around the biodiesel or renewable diesel producers in California, the production of these fossil diesel replacements generates much lower toxic air contaminant emissions relative to their petroleum refinery counterparts. For example, Figure 4 shows a comparison of air pollutants between California's four biodiesel producers and two petroleum refineries in California. As shown in Figure 4, not only do the biodiesel producers release a much smaller set of chemical species, but the chemical species they do share with petroleum refineries are released at much lower rates than the refineries, ranging from several times to hundreds of thousands of times smaller than petroleum refineries. Thus, communities surrounding producers of biomass-based diesel would actually benefit disproportionately from a switch to use and production of biomass-based diesel fuel, rather than be adversely harmed by them (relative to a petroleum refinery's emissions).

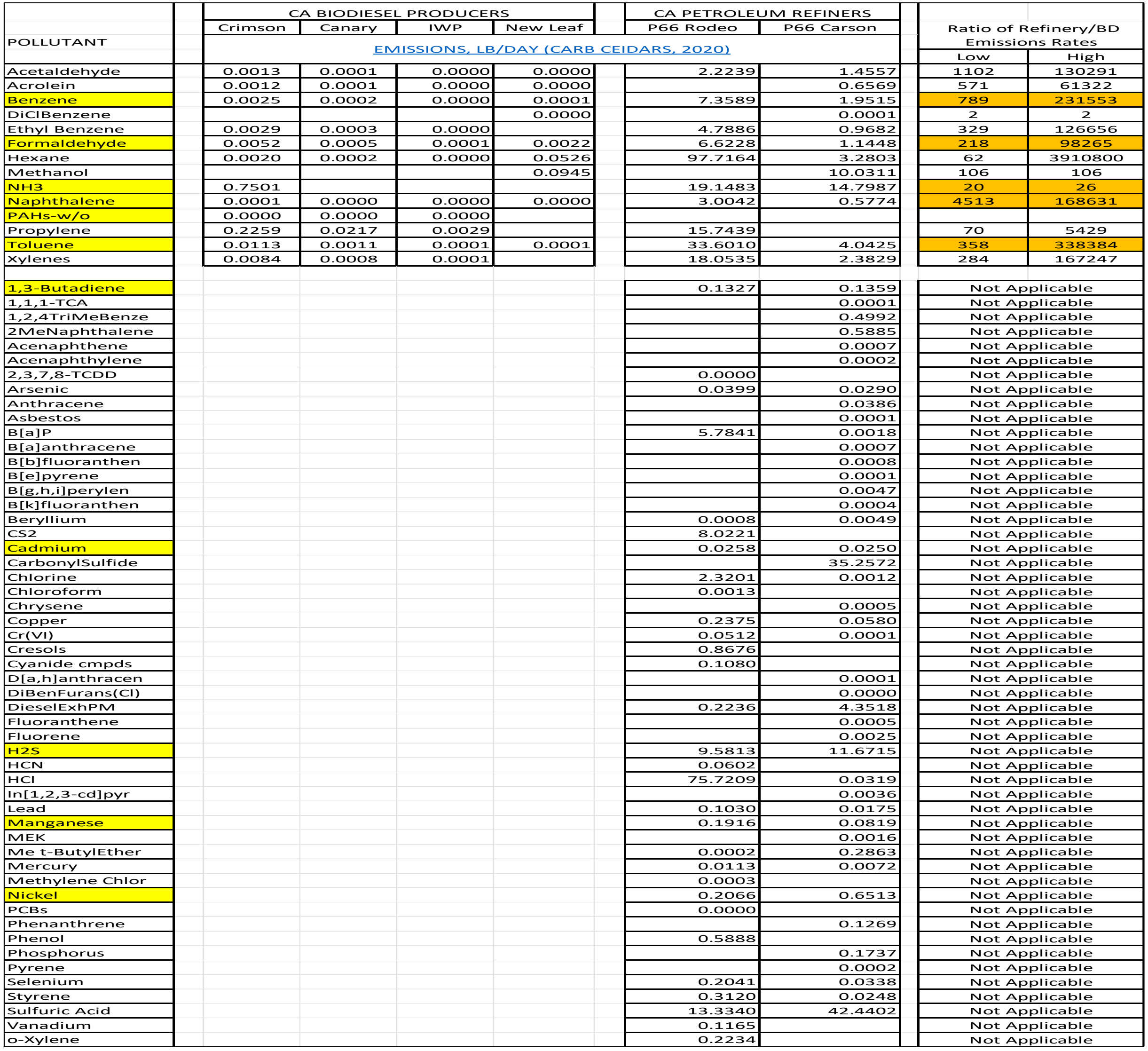

Fig. 4. Comparison of Production Emissions, Biodiesel vs. Petroleum Diesel[15]

POLLUTANT	CA BIODIESEL PRODUCERS				CA PETROLEUM REFINERS		Ratio of Refinery/BD Emissions Rates	
	Crimson	Canary	IWP	New Leaf	P66 Rodeo	P66 Carson	Low	High
	EMISSIONS, LB/DAY (CARB CEIDARS, 2020)							
Acetaldehyde	0.0013	0.0001	0.0000	0.0000	2.2239	1.4557	1102	130291
Acrolein	0.0012	0.0001	0.0000	0.0000		0.6569	571	61322
Benzene	0.0025	0.0002	0.0000	0.0001	7.3589	1.9515	789	231553
DiClBenzene				0.0000		0.0001	2	2
Ethyl Benzene	0.0029	0.0003	0.0000		4.7886	0.9682	329	126656
Formaldehyde	0.0052	0.0005	0.0001	0.0022	6.6228	1.1448	218	98265
Hexane	0.0020	0.0002	0.0000	0.0526	97.7164	3.2803	62	3910800
Methanol				0.0945		10.0311	106	106
NH3	0.7501				19.1483	14.7987	20	26
Naphthalene	0.0001	0.0000	0.0000	0.0000	3.0042	0.5774	4513	168631
PAHs-w/o	0.0000	0.0000	0.0000					
Propylene	0.2259	0.0217	0.0029		15.7439		70	5429
Toluene	0.0113	0.0011	0.0001	0.0001	33.6010	4.0425	358	338384
Xylenes	0.0084	0.0008	0.0001		18.0535	2.3829	284	167247
1,3-Butadiene					0.1327	0.1359	Not Applicable	
1,1,1-TCA						0.0001	Not Applicable	
1,2,4TriMeBenze						0.4992	Not Applicable	
2MeNaphthalene						0.5885	Not Applicable	
Acenaphthene						0.0007	Not Applicable	
Acenaphthylene						0.0002	Not Applicable	
2,3,7,8-TCDD					0.0000		Not Applicable	
Arsenic					0.0399	0.0290	Not Applicable	
Anthracene						0.0386	Not Applicable	
Asbestos						0.0001	Not Applicable	
B[a]P					5.7841	0.0018	Not Applicable	
B[a]anthracene						0.0007	Not Applicable	
B[b]fluoranthen						0.0008	Not Applicable	
B[e]pyrene						0.0001	Not Applicable	
B[g,h,i]perylen						0.0047	Not Applicable	
B[k]fluoranthen						0.0004	Not Applicable	
Beryllium					0.0008	0.0049	Not Applicable	
CS2					8.0221		Not Applicable	
Cadmium					0.0258	0.0250	Not Applicable	
CarbonylSulfide						35.2572	Not Applicable	
Chlorine					2.3201	0.0012	Not Applicable	
Chloroform					0.0013		Not Applicable	
Chrysene						0.0005	Not Applicable	
Copper					0.2375	0.0580	Not Applicable	
Cr(VI)					0.0512	0.0001	Not Applicable	
Cresols					0.8676		Not Applicable	
Cyanide cmpds					0.1080		Not Applicable	
D[a,h]anthracen						0.0001	Not Applicable	
DiBenFurans(Cl)						0.0000	Not Applicable	
DieselExhPM					0.2236	4.3518	Not Applicable	
Fluoranthene						0.0005	Not Applicable	
Fluorene						0.0025	Not Applicable	
H2S					9.5813	11.6715	Not Applicable	
HCN					0.0602		Not Applicable	
HCl					75.7209	0.0319	Not Applicable	
In[1,2,3-cd]pyr						0.0036	Not Applicable	
Lead					0.1030	0.0175	Not Applicable	
Manganese					0.1916	0.0819	Not Applicable	
MEK						0.0016	Not Applicable	
Me t-ButylEther					0.0002	0.2863	Not Applicable	
Mercury					0.0113	0.0072	Not Applicable	
Methylene Chlor					0.0003		Not Applicable	
Nickel					0.2066	0.6513	Not Applicable	
PCBs					0.0000		Not Applicable	
Phenanthrene						0.1269	Not Applicable	
Phenol					0.5888		Not Applicable	
Phosphorus						0.1737	Not Applicable	
Pyrene						0.0002	Not Applicable	
Selenium					0.2041	0.0338	Not Applicable	
Styrene					0.3120	0.0248	Not Applicable	
Sulfuric Acid					13.3340	42.4402	Not Applicable	
Vanadium					0.1165		Not Applicable	
o-Xylene					0.2234		Not Applicable	

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[15] The yellow highlighted cells represented the priority chemical species recommended by OEHHA for fenceline monitoring of petroleum refineries.

On a final note, we find it somewhat disingenuous for Dr. Wara to state the opinions and conclusions he presented are his and his team's alone and not attributable to Stanford University. Yet, in every single slide in his presentation, his affiliation with Stanford University and its Climate and Energy Policy Program is clearly noted in the margins, strongly implying that this analysis is, indeed, supported by and reflects the gravitas of Stanford University. At best, it is misleading, and at worst, it provides a significant disservice to the EJ communities on behalf of which this analysis was purportedly conducted. Such communities would clearly benefit through the increased deployment of biomass-based diesel, irrespective of the feedstock used, while the state is pursuing electrification everywhere it can over the many years or even decades it will take to achieve.

Conclusion

As noted in our prior comments, we remain deeply concerned with and are strongly opposed to any CI reduction targets premised on a cap on plant-based oil feedstocks. We see such action as unwarranted, not based in sound science, chilling of ongoing and future investments, and counterproductive to California's climate and carbon neutrality objectives. After reviewing Dr. Wara's presentation, we conclude his analysis does not add anything scientifically meaningful to the debate that would warrant such a cap since the analysis makes a number of flawed assumptions, which in turn result in erroneous conclusions.

Thank you for your consideration of these comments. We look forward to continuing our strong collaboration with CARB and staff.

Sincerely,

Floyd Vergara, Esq., P.E. Director of State Governmental Affairs Clean Fuels Alliance America	Carlos Gutierrez Executive Director California Advanced Biofuels Alliance

Attachment 1

Biodiesel induced land use changes: An assessment using GTAP-BIO 2014 data base

By

Farzad Taheripour, Omid Karami, and Ehsanreza Sajedinia

Purdue University

Department of Agricultural Economics
Report: June 2023

This research was funded by Clean Fuels Alliance America

Biodiesel induced land use changes: An assessment using GTAP-BIO 2014 data base

Farzad Taheripour, Omid Karami, and Ehsanreza Sajedinia

1. Introduction

Biofuel production and policy may Induce Land Use Change (ILUC) emissions. However, the extent to which these emissions may occur needs more attention. Biofuel production started to grow in the early 2000s for several reasons, including but not limited to: major surpluses in crop markets leading to low crop prices, high crude oil prices, and environmental concerns about the expansion in consumption of fossil fuels (Taheripour et al., 2022). In the late 2000s, in the absence of actual observations, some papers argued that biofuel production will largely increase demand for new cropland, generate major deforestation, and cause large GHG emissions (Tilman et al., 2006; Fargione et al., 2008, Searchinger et al., 2008; Plevin et al., 2010). Since then, major efforts have been made to re-evaluate these early assessments. These efforts have concluded that the early research in this area had significantly overstated the land use implications of biofuels (Zilberman et al., 2018). Some of these efforts are highlighted in the following.

More than a decade ago, Searchinger et al. (2008) used the CARD/FAPRI model and argued that producing corn ethanol in the U.S. will generate more than 100 grams of CO_2 emissions equivalent per megajoule (gCO_2e/MJ). Over time, this model has been modified and improved by various authors. As an example, in a more recent paper, Carriquiry et al. (2019), using an improved version of this model, have estimated that the land use emissions associated with U.S. corn ethanol could vary between 9.7 gCO_2e /MJ and 23.9 gCO_2e/MJ. These values are substantially lower than the estimated ILUC value by Searchinger et al. (2008).

In the late 2000s, the GTAP-BIO model was developed at Purdue University to assess the economic and environmental impacts of biofuels production and policy. Since then, this model has been frequently improved and used to evaluate the land use emissions due to biofuels. In the earlier stages of this process, the California Air Resources Board (CARB) adopted and used this model to assess ILUC emission values for various biofuel pathways. The early improvements in this model were made based on a set of recommendations suggested by an expert group assembled by CARB. Using the improved model, CARB (2015) has assessed that corn ethanol and soybean biodiesel generate about 19.8 gCO_2e/MJ and 29.1 gCO_2e/MJ emissions, respectively. Those assessments were made using the GTAP-BIO model and its 2004 benchmark data base.

In addition to the improvements mentioned above, several new efforts have been made to further improve the GTAP-BIO model since 2015. Taheripour et al. (2017) made two lines of modifications in this model. They first used an updated benchmark data base. Unlike the CARB assessment that was based on benchmark data for 2004, Taheripour et al. (2017) used a newer GTAP-BIO data base to represent the global economy in 2011. In addition, they improved the model to take into account intensification due to multiple cropping and/or conversion of idled land to crop production. They also made it possible to take into account the fact that yield to price response varies by region. With these modifications, Taheripour et al. (2017) have shown that induced land use emissions due to corn ethanol and soybean biodiesel would be about 12 gCO_2e /MJ and 18.3 gCO_2e /MJ emissions, respectively.

The estimated ILUC values for corn ethanol and soybean biodiesel have generally followed declining trends over time. For example, Figure 1 provides an overview of several estimated ILUC emissions for soybean biodiesel obtained from various modeling approaches.

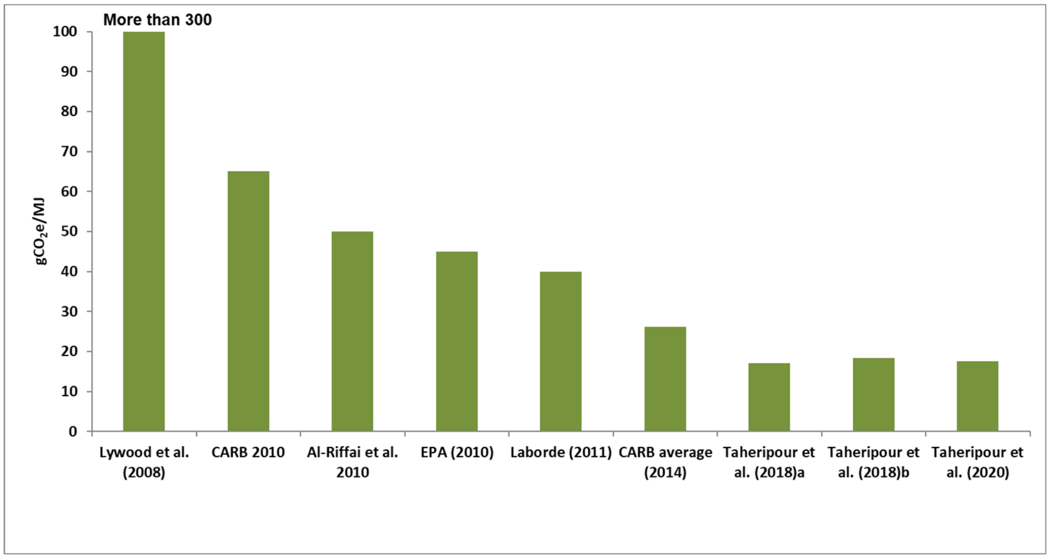


Figure 1. Some estimated ILUC values for soybean biodiesel.

As shown in Figure 1, the estimated ILUC values for soybean biodiesel has declined over time from more than 300 gCO_2e/MJ (estimated by Lywood et al., 2008) to 17.5 gCO_2e/MJ (estimated by Taheripour et al., 2020). Various factors, including model and data improvements, productivity increases, intensifications, and tuning modeling practice to actual observations, explain the observed declining trend in ILUC emissions for soybean biodiesel.

In a recent effort, a new data base has been developed for use in the GTAP-BIO data base. This new data base represents the global economy in 2014. This research uses this new data base and provides new assessments for ILUC emissions values for the U.S. soybean biodiesel and rapeseed biodiesel pathways. This report uses the modeling framework developed and reported by Taheripour et al. (2017) to provide these assessments. The rest of this research report provides the following sections. First, the 2014 GTAP-BIO data base is introduced. Then a brief summary of the GTAP-BIO model used in this study is provided. The examined scenarios are outlined in the next section. The last section provides the results.

2. 2014 GTAP-BIO data base

The standard GTAP data bases which trace production, consumption and trade of all goods and services by country at the global scale do not explicitly represent biofuels and their by-products. In a pioneer practice and for the first time, Taheripour et al. (2007) introduced biofuels into the 2001 GTAP data base and generated the first GTAP-BIO data base. In 2001, only a few countries (mainly Brazil, U.S., and some EU members) were producing limited amounts of biofuels. The global biofuel production was about 5 billion gallons in 2001. Since then, major efforts have been made to provide GTAP-BIO data bases for 2004 (Taheripour and Tyner, 2011) and 2011 (Taheripour et al., 2016). However, as the number of biofuel-producing countries and quantities of biofuels produced in each country grew over time, introducing biofuels into GTAP data bases turned to a challenging and time-consuming task. For example, it took a long time to introduce about 23 billion gallons of ethanol and 6 billion gallons of biodiesel produced from different feedstock across the world into the 2011 GTAP-BIO data base.

While introducing biofuels into a new version of GTAP-BIO data bases is an important task to accomplish, more steps are required to develop one of these data bases. In addition to biofuels, these data bases trace land cover, land use, harvested area, and crop production across the world. Furthermore, compared to the standard GTAP data bases, the GTAP-BIO data bases split various original GTAP sectors to better understand and establish the links between biofuels, agricultural, non-agricultural, and energy sectors. For additional steps needed to generate a new GTAP-BIO database, see Taheripour et al. (2016).

During the past three years, major efforts have been made to update the GTAP-BIO data base to represent the global economy in 2014. This data base is developed based on the standard GTAP data base for this year (Aguiar et al. 2022). To accomplish this task, data on biofuels produced and consumed around the world by feedstock were collected and introduced into the Input-Output table of each biofuel-producing country. The monetary values for crops and food products for each country are matched with the corresponding data provided by the Food and Agricultural Organization (FAO). Following Taheripour et al. (2016), the following standard GTAP sectors are divided into new sectors:

- Coarse grains (gro) is divided into: corn and other coarse grains,
- Oilseeds (osd) is divided into: Soybeans, rapeseed, palm, and other oilseeds,
- Vegetable oil (vol) is divided into: vegetable oil soy, vegetable oil palm, vegetable oil rapeseed, vegetable oil other, and their corresponding meals,
- Food (ofd) is divided into: Food and feed,
- A dummy sector is introduced for cropland pasture (this version includes cropland pasture for all countries around the world).

In addition to the above changes, a new sector is added to blend biofuels with conventional transportation fuels. Furthermore, following Baldoset al. (2020), land cover, land use, and crop production by Agro Ecological Zones are added to the data base for 2014.

In what follows, we compare a few key differences between the 2011 and 2014 GTAP-BIO data bases. Figure 2 compares ethanol and biodiesel produced across the world in these two data bases. The global supplies of ethanol and biodiesel were about 22.8 billion gallons and 6.1 billion gallons in 2011, respectively. The corresponding figures in 2014 were about 24 billion gallons for ethanol and 5.6 billion gallons for biodiesel. The largest ethanol producers in these two years are the U.S. and Brazil at the global scale. The EU region is the largest biodiesel producer in both years. In general, ethanol production has increased in most regions across the world in 2014 compared to 2011. However, in the case of biodiesel, the global supply has declined in 2014 compared to 2011 with some fluctuations across the world.

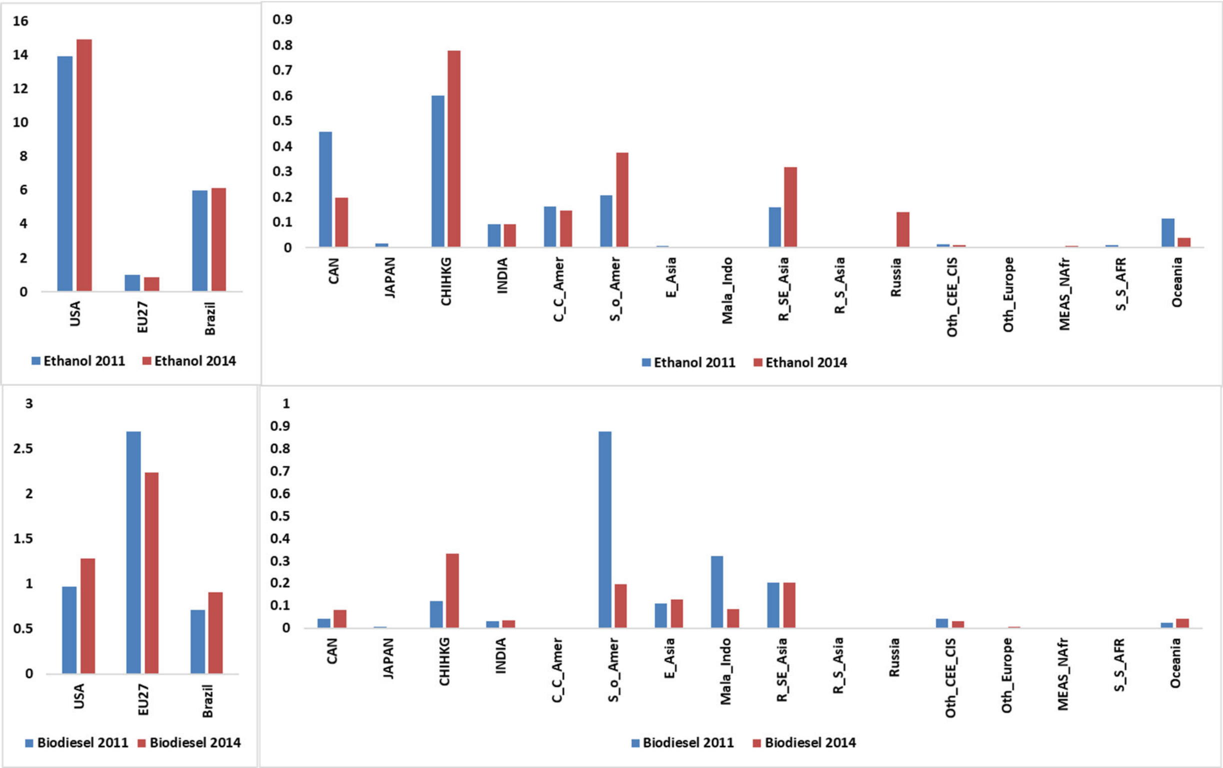
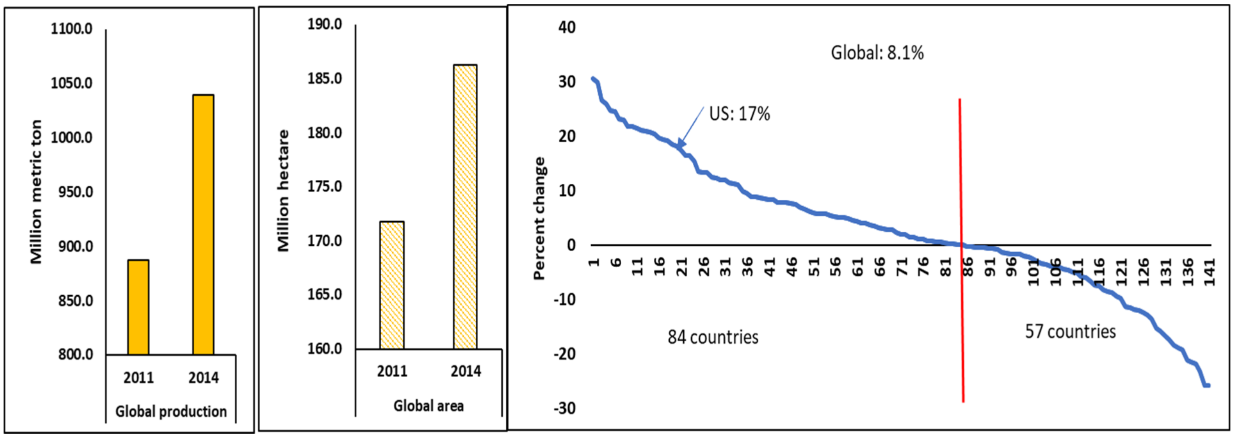


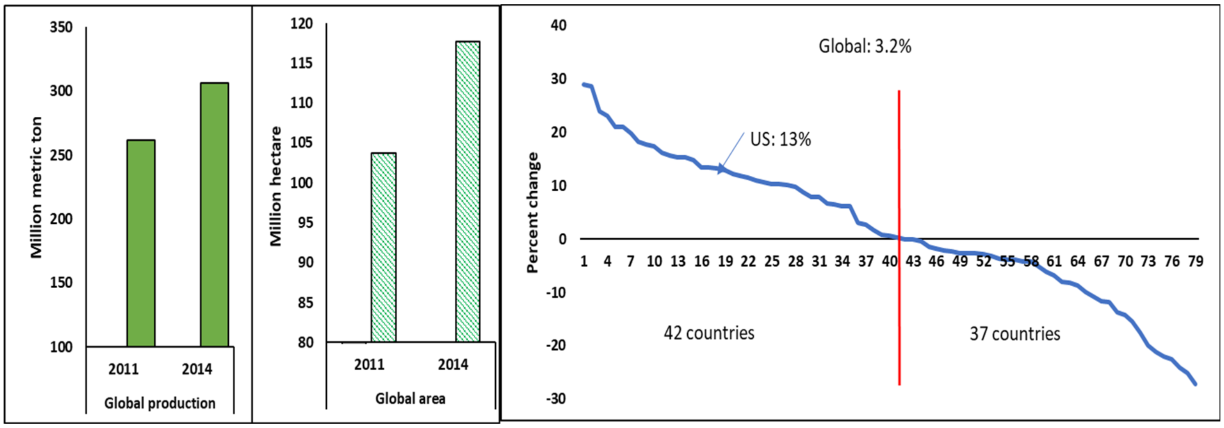
Figure 2. Biofuels produced across the world: 2011 and 2014 GTAP-BIO data bases

Figures 3 and 4 highlight a key difference between the 2011 and 2014 data bases. These figures mainly compare changes in corn and soybean yields by country between 2011 and 2014. For example, Figure 3 shows that between 2011 and 2014 the area of corn and its production have increased at the global scale. In addition, this figure shows that between 2011 and 2014 corn yield has increased in 84 countries and decreased in 57 other countries with an average increase of 8.1% at the global scale. The corresponding yield increase for U.S. corn was about 17%. Figure 4 provides a similar pattern for the case of soybeans between 2011 and 2014. For the case of soybean, yield has increased in 42 countries and declined in 37 countries, with an average increase of 3.2% at the global scale. Between 2011 and 2014, the U.S. soybean yield has increased by 13%. In general, crop yields were higher in 2014 compared to 2011 in many countries because in this year drought conditions occurred in many countries.



Panel A: Area Panel B: Production Panel C: Yield

Figure 3. Global corn area and production in 2011 and 2014 and regional percentage changes in corn yield between these years



Panel A: Area Panel B: Production Panel C: Yield

Figure 4. Global soybean area and production in 2011 and 2014 and regional percentages change in soybean yield between these years

The differences between the 2011 and 2014 data bases go beyond the differences just between the biofuel and agricultural sectors. Rather, they cover a wide range of changes across many economic activities that could directly or indirectly affect the biofuel analyses. While any element of the new data base is different from its older version, reflecting the state of the global economy in that year, the extent to which any of these differences could affect the ILUC results could be insignificant.

3. Implemented GTAP-BIO model

We use the GTAP-BIO model developed and reported by Taheripour et al. (2017). Compared to the earlier version of this model used by CARB, this version takes into account multiple cropping and conversion of unused cropland to active cropland. This model has been adopted by the Carbon Offset and Reduction Scheme for International Aviation (CORSIA) of the International Civil Aviation Organization (ICAO) of the United Nations (Zhao et al., 2021) as well. However, this is the first research that uses the 2014 GTAP-BIO data base in combination with this model.

In summary, this model includes and carries all properties and developments made in the GTAP-BIO model to date. The implemented modifications are augmented in this model to take into account market-mediated responses that occur in real world due to biofuels. Among these market-mediated responses are interactions between agricultural (crops and livestock), forestry, biofuel, and energy sectors with other industries and services. For example, it takes into account land transition among land cover items considering opportunity costs of land conversions. It also allows crop switching among alternative crops due to changes in relative crop prices. Endogenous yield improvements due to higher crop prices are included as well. It also considers yield differences between the new and existing croplands. In addition, it allows conversion of cropland pasture (a sub-category of cropland used by livestock) to cropland. The model also takes into account multiple cropping and the use of unused cropland for crop production. Lastly, the model considers substitution among animal feed rations and allows substitution between conventional transportation fuels and biofuels. As noted in the data base section, unlike the earlier versions, the model now incorporates land classified as cropland pasture for all regions.

We use the AEZ-EF emission module Plevin et al. (2014) to convert the estimated GTAP-BIO land conversions to land use emissions. Note that currently the AEZ-EF module follows the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. An update in this module according to the new IPCC 2019 refinement could alter the ILUC results provided in this report.,

4. Examined scenarios

In this research, we assess ILUC emission values for the following various soybean biodiesel demand shocks to evaluate the extent to which ILUC values may respond to shock sizes:

i) An expansion in soybean oil biodiesel by 1.05 billion gallons off of 2014
ii) An expansion in soybean oil biodiesel by 1.35 billion gallons off of 2014
iii) An expansion in soybean oil biodiesel by 1.81 billion gallons off of 2014
iv) An expansion in soybean oil biodiesel by 2.22 billion gallons off of 2014
v) An expansion in soybean oil biodiesel by 2.51 billion gallons off of 2014
vi) An expansion in soybean oil biodiesel by 3.22 billion gallons off of 2014

In addition, we calculate ILUC emission values for the following shocks in rapeseed biodiesel:

i) An expansion in rapeseed oil biodiesel by 0.06 billion gallons off of 2014
ii) An expansion in rapeseed oil biodiesel by 0.47 billion gallons off of 2014
iii) An expansion in rapeseed oil biodiesel by 0.03 billion gallons off of 2014

5. Results

5.1. ILUC values

Figure 5 shows the ILUC emission values for the implemented soybean biodiesel shock sizes. This figure shows an ILUC value of 9.11 gCO_2e/MJ for an increase in soybean biodiesel by 1.05 billion gallons. The ILUC value slightly increases to 9.78 gCO_2e/MJ for the largest implemented shock size of 3.22 billion gallons. The results presented in Figure 5 suggest that the soybean ILUC values do not significantly change with shock size. That basically shows that the model results are linear and are not sensitive to the shock size of soybean biodiesel.

As noted in the introduction section, using the 2011 GTAP-BIO data base, Taheripour et al. (2017) estimated an ILUC value of 18.3 gCO_2e/MJ for soybean biodiesel. However, the results provided in Figure 5 indicate that the 2014 data base provides a significantly smaller ILUC value than using the 2011 data base for this type of biodiesel, even with the largest implemented shock size (9.78 gCO_2e/MJ for 3.22 billion gallons). Three factors mainly contribute to this result: (1) Higher soybean yields in 2014 than 2011; (2) including cropland pasture in all regions of the model, and (3) a larger crop production base in 2014 compared to 2011. Regarding the first factor, ceteris paribus, the higher the yield, the lower the ILUC value. The second factor helps to use cropland pasture across the world instead of higher demand for conversions of pasture and forest to cropland, leading to lower land use emissions. Finally, the last item refers to saving in the existing uses of various related items due to biofuel demand. For a given change in demand for soybean biodiesel, a portion of the additional demand will come from the savings in current consumptions of oilseeds, vegetable oils, tallow, and animal fats. Hence, ceteris paribus, the larger uses of oilseeds and vegetable oils in the 2014 data base (compared to 2011)provides more savings in the existing uses of oilseeds, vegetable oils, tallow, and animal fats, leading to less demand for land conversions and hence a lower ILUC value. Also, it is important to note that the 2014 area of soybeans provides more feedstock due to yield improvements, which leads to lower demand for land conversion.

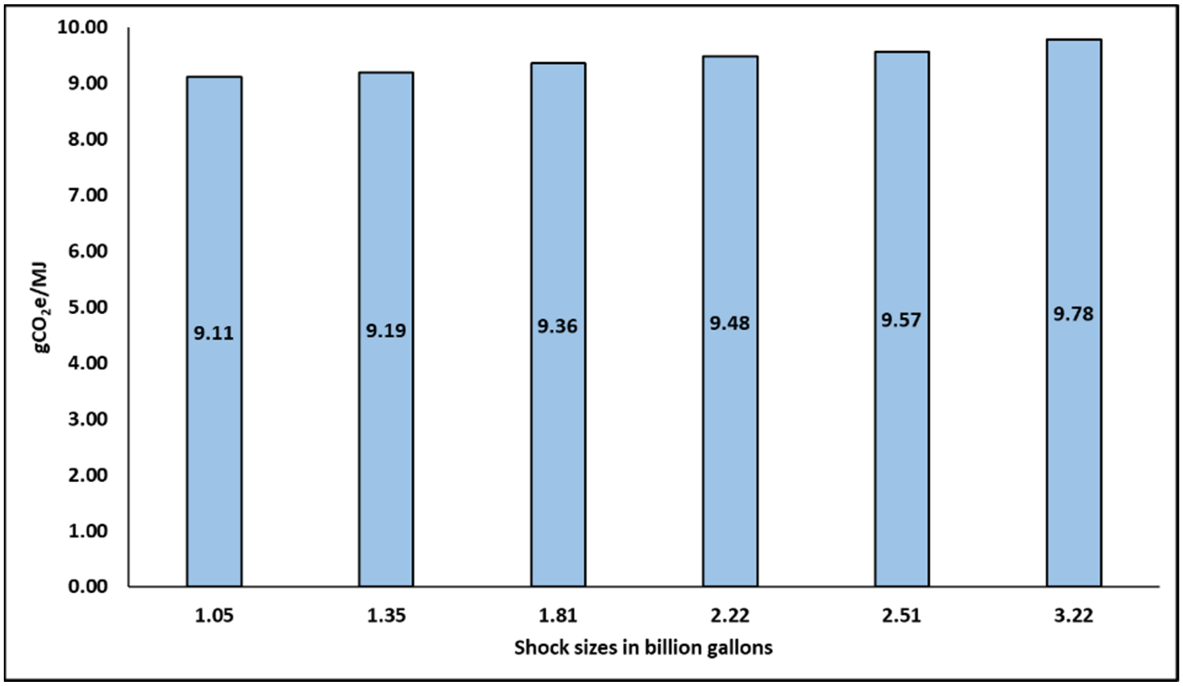


Figure 5. Soybean biodiesel ILUC emission values for various levels of shock sizes using the GTAP-BIO 2014 data base.

Figure 6 shows the ILUC values for the three examined small levels of increased rapeseed biodiesel demand. This figure shows that an increase in this type of biodiesel by 0.03 billion gallons generates an ILUC emission value of 14.07 gCO_2e/MJ. The ILUC emission value for this biodiesel increases to 14.22 gCO_2e/MJ for a shock size of 0.06 billion gallons and to 15.06 gCO_2e/MJ for a shock size of 0.47 billion gallons. These results suggest that the size of ILUC grows slightly as the shock size grows for this type of biodiesel. That is because the U.S. rapeseed and rapeseed oil sectors are small, so yield increases result in relatively less increased supply of rapeseed oil than would occur in the case of soy. Increases in demand for this biofuel necessitate either domestic land conversion or increased imports of imported feedstock which can trigger land conversion in other rapeseed-producing countries.

Note that, regardless of the shock size, the rapeseed ILUC value is larger than the soy ILUC value. Several factors explain this observation. Unlike soybean biodiesel, a big portion of feedstock for rapeseed biodiesel comes from other countries. The nature of land use and land cover and their corresponding emissions factors in countries that produce rapeseed are different from the U.S. The markets and uses of rapeseed and rapeseed oil are different from soybeans and soybean oil markets. As an example, implementing a similar shock in soybean biodiesel and rapeseed biodiesel will generate different responses in the oilseeds and oil market at the global scale. Compared to the cases of soybean biodiesel, since a big portion of feedstock for rapeseed biodiesel comes from other countries, a shock in this biofuel will generate more effects (e.g., substitutions among oilseeds and oils) outside the U.S. Substitutions among oils in many countries are significantly higher than the U.S. Yield responses are different across the two crops. It is also important to note that the links between rapeseed and palm markets are different than the links between soybeans and palm markets. An expansion in rapeseed demand could relatively induce more land use changes (adjusted to the shock size) in Malaysia and Indonesia than an expansion in soybeans demand.

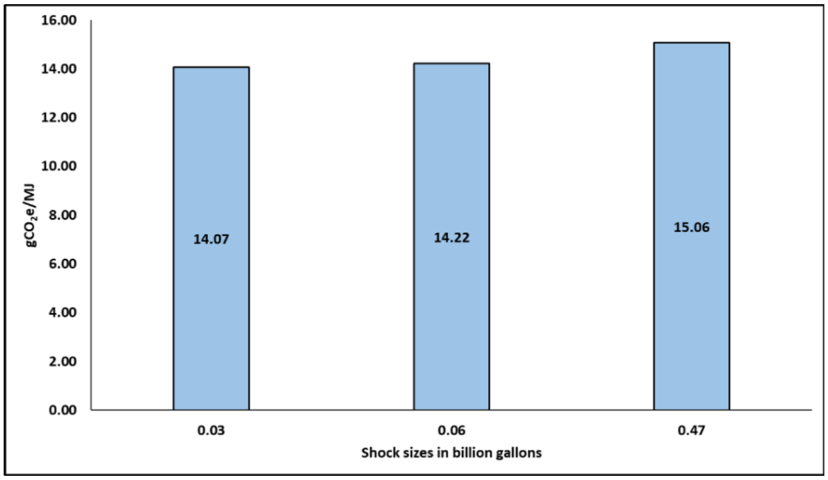
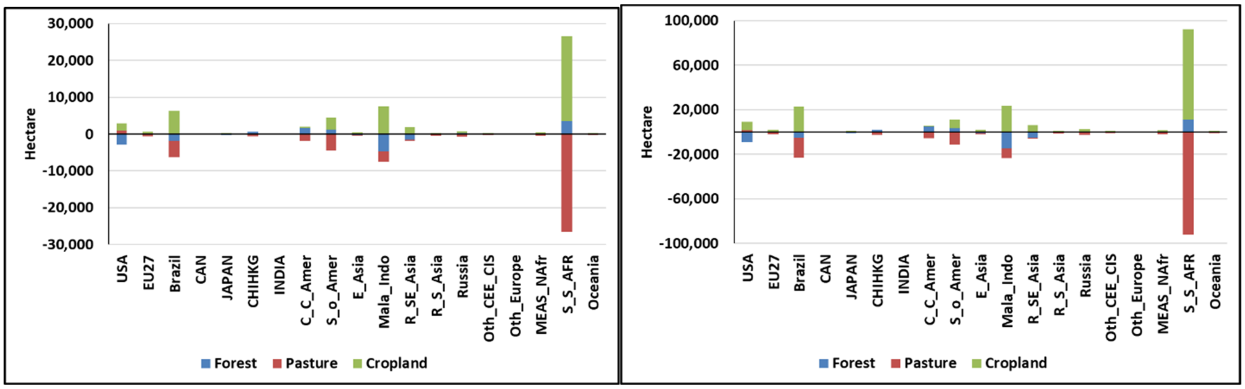


Figure 6. Rapeseed biodiesel ILUC emission values for various levels of shock sizes using the GTAP-BIO 2014 data base.

5.2. Land use changes

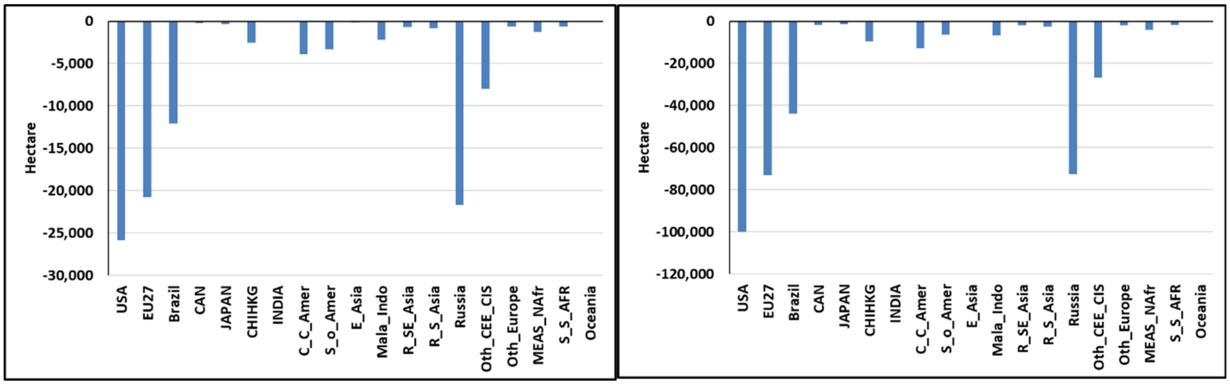
Figure 7 shows the global changes in land cover items (forest pasture and cropland for the smallest (1.05 billion gallons in panel A) and largest (3.22 billion gallons in panel B) shock sizes in the soybean biodiesel examined in this research. The largest shock size represents larger land conversion in panel B, following in a linear scale. Regardless of the shock size, Figure 7 shows that the examined expansion in soybean biodiesel generates the largest land conversions in Sub Saharan Africa. This region is a large producer of various grains, oilseeds, and many other crops at the global scale. It is also a U.S. trade partner in several agriculture markets. Cropland has historically increased in this region due deforestation as well. According to these actual observations, which are embedded in the model data base, the model projects that this region provides land conversion to satisfy the increased feedstock demand and/or demand for soy oil substitutes in other markets. After that, more land conversions occur in the main oilseed producers' regions, such as Malaysia-Indonesia, Brazil, and Central and South America.



Panel A Panel B

Figure 7. Land conversion due to soybean biodiesel shocks: Panel A for 1.05 billion gallons shock and Panel B for 3.22 billion gallons

In addition to the land conversion among land cover items, expansion in soybean biodiesel provides incentives to convert cropland pasture from livestock use to crop production across the world, as shown in Figure 8. The conversion of cropland pasture for the smallest and largest shocks are presented in panels A and B of Figure 8.



Panel A

Panel B

Figure 8. Conversion of cropland pasture from the use by livestock to crop production due to soybean biodiesel shocks: Panel A for 1.05 billion gallons shock and Panel B for 3.22 billion gallons

Finally, Figure 9 illustrates land conversions due to the largest shock (0.34 billion gallons) in rapeseed biodiesel. As shown in this figure, expansion in this type of biodiesel (as for the case of soybean biodiesel) causes larger land conversions in Sub-Saharan Africa relative to other regions. However, for this pathway, land conversion occurs in more regions than in the cases of soybean biodiesel. That said, given the implanted small shocks in rapeseed biodiesel, the scale of land conversion for this pathway is relatively small compared to all soybean biodiesel shocks which are significantly larger. As shown in Figure 10, the expansion in rapeseed biodiesel triggers the conversion of cropland pasture from livestock to crop production as well.

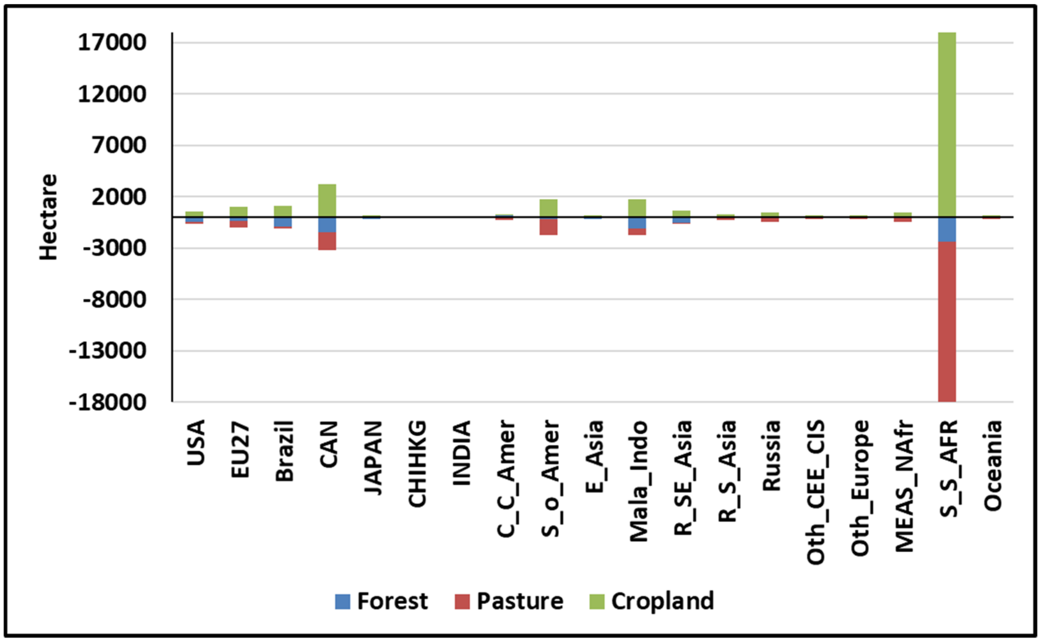


Figure 9. Land conversion due to rapeseed biodiesel shock by 0.47 billion gallons shock

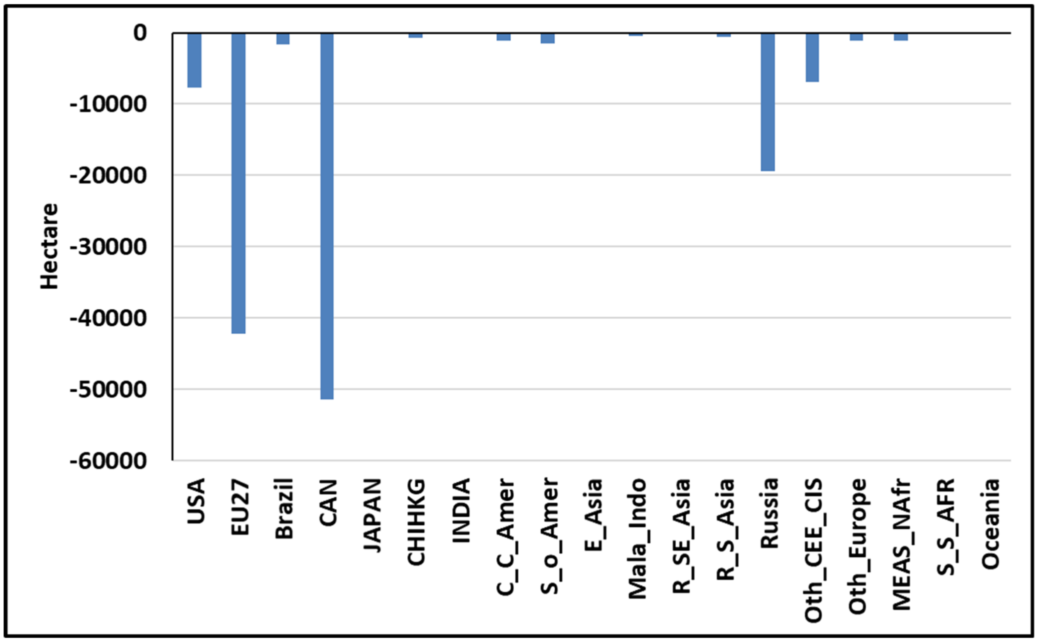


Figure 10. Conversion of cropland pasture from the use by livestock to crop production due to rapeseed biodiesel shock by 0.47 billion gallons shock

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