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Impacts of Geopolitics and Policy on Latin American Biodiversity and Water Resources

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ABSTRACT

Latin America is a major agricultural producer with important natural resources. Efforts have been made to protect sensitive areas but are hindered by agricultural trade disruptions outside the control of individual countries due to globally integrated crop markets. This analysis assesses the effects of two trade shocks, that is, the war in Ukraine and vehicle decarbonization in the United States (US), on biodiversity and water resources in Latin America. Results show that an increase in maize and wheat exports from the region triggered by the war in Ukraine negatively affects biodiversity in Brazil and leads to cropland expansion into drought-prone areas in Argentina and Chile. For the case of reduced crop exports from Latin America due to US vehicle decarbonization and the corresponding shift away from US maize ethanol, the pressure on arable land in areas of high biodiversity and water stress is eased. As opposed to agricultural carbon emissions, which have global impacts, biodiversity and water issues have a strong local and regional significance. Regulatory frameworks aiming to protect these regions should be forward looking to detect and shield vulnerable areas from future threats. Other changes affecting global agriculture and trade, for example, sustainable aviation fuels in the US or the European Farm-to-Fork policy, need to be anticipated for effective policies in Latin America.

JEL Classification: Q13, Q25, Q34, Q56

1 | Introduction

Latin America has substantially increased its agricultural production over the last decades. The value of agricultural production in countries such as Argentina and Uruguay has outperformed the growth of the United States (US) and the European Union (EU) (Figure 1). The growth of Brazilian agriculture in terms of value is only matched by China. The high productivity and the volume of agricultural output make the region an important global food supplier. At the same time, Latin America has important biodiversity and water resources as well as biomass and soil carbon in part due to its vast

latitudinal range (OECD/FAO, 2019). Morris et al. (2020) refer to the continent as the world's largest "food net exporting region" and "producer of ecosystem services."

As in other parts of the world, the higher food production comes at the expense of losing natural resources and biodiversity as well as increased water extraction and water quality impairments (Benton et al., 2021). According to IPBES (2019), agriculture and land-use change are the main drivers of loss of biodiversity. Newbold et al. (2015) find that land-use change and land-use intensity have a significant impact on local terrestrial biodiversity, which is even more evident in biodiversity-rich but

Abbreviations: CARD, Center for Agricultural and Rural Development; EU, European Union; GHG, greenhouse gas; km, kilometer; LRLU, Long-Run Land-Use Model; RU, Russia; SAF, sustainable aviation fuel; SSP, shared socioeconomic pathway; UA, Ukraine; US, United States; WRI, World Resources Institute.

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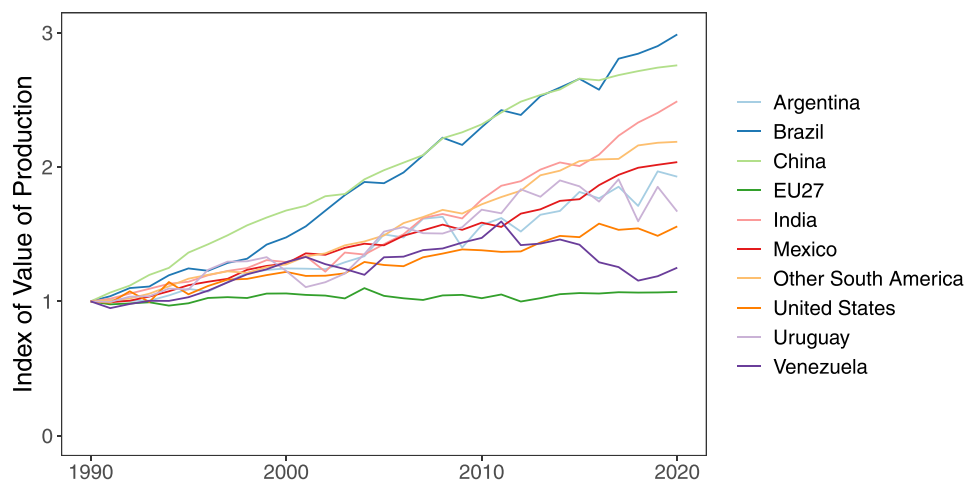


FIGURE 1 | Index of real gross production value covering crops and livestock for selected countries and regions. *Source:* FAOSTAT Gross Production Value (constant 2014–2016 US dollars).

impoverished regions. Oakley and Bicknell (2022) show that the impact of food production on biodiversity loss is dependent on the crop type and geographical region, among other factors. Crops that are harvested annually (e.g., maize, rice, and sugarcane) have a greater negative impact on biodiversity than perennial crops with longer rotation periods, such as coffee, tea, and bananas (but excluding oil palm). A significant negative impact is found in tropical regions, mainly in Asia, followed by South America.

The “cheaper food paradigm”—producing more food at lower cost—results from ignoring the negative externalities of higher food production that affect natural ecosystem and human health (Benton et al., 2021). With increasing global incomes and population, and therefore higher consumption of resource-intensive foods, agriculture will continue to drive the loss in biodiversity, water depletion, and climate change (Campbell et al., 2017). Given Latin America's large forest and arable land area, the tradeoffs between private benefits from agriculture and societal returns from natural resources are more pronounced. For example, biodiversity loss in Colombia is expected to increase by up to 52% as a result of agricultural expansion by 2033 (Guerrero-Pineda et al., 2022). Measures to combat this loss come at a cost to communities dependent on agriculture. On the other hand, while agriculture contributes to the decline in biodiversity and natural resources such as water, this reduction also affects agricultural production (FAO, 2019; IPBES, 2019; Oakley & Bicknell, 2022). That is, loss of biodiversity, and in particular, depletion of genetic diversity in plants makes agriculture less resilient to diseases, weather, and other stresses related to climate change (FAO, 2019). The decline in bird richness is more heavily impacted than mammal richness, and given that birds contribute to the disbursement of seeds and the control of pests, this also negatively impacts crop production and food security (Oakley & Bicknell, 2022).

Measuring the monetary value of biodiversity, fauna, and flora affected is difficult since it requires a mixture of market and nonmarket valuation (Bartkowski et al., 2015; Hanley & Perrings, 2019; Nijkamp et al., 2008). Market valuation would refer, for example, to the loss in agricultural productivity or

declines in touristic activities because of a reduction in biodiversity. Rucker et al. (2012) report the income of US beekeepers for honeybee pollination to be 487 million (*in* 2023). Nonmarket valuation refers to understanding the value people place on goods or services (such as ecosystem services) for which there are no market prices. This type of valuation would need to consider the cultural and recreational value of biodiversity. While important, monetary valuation of water and biodiversity is beyond the scope of this study and should be considered in future research.

Recent geopolitical events, such as the war in Ukraine and the trade conflict between the US and China, have disrupted and altered international agricultural trade flows (Carriquiry et al., 2022; Elobeid et al., 2021). Because there are differences in agricultural productivity, carbon pools, biodiversity, and water quantity and quality across countries, a shift in production can have adverse or beneficial effects on these resources. The direction and magnitude of these effects depend on the countries' relative ecosystem richness and the location of agricultural land. For example, Beyer et al. (2022) show that a hypothetical reallocation of cropland to North America, Russia, and Ukraine can reduce the negative impacts of food production on carbon emissions, biodiversity, and irrigation water use. The effects of the US–China trade conflict suggest a potential decline in global carbon emissions (Elobeid et al., 2021). The trade conflict reduces commodity prices, resulting in lower feed costs and, hence, an expansion of US livestock. Since Brazilian livestock production is not competitive compared with the US, pasture area in Brazil contracts leading to overall lower carbon emissions.

Whereas previous research has shown the impact of both cases on carbon emissions from land-use change, this paper specifically focuses on the impact on biodiversity and water resources. Carbon emissions have global climate change effects independent of where the release occurs, whereas biodiversity and water issues are relatively localized. Decarbonization policies change energy use and can impact land use, commodity production, and trade flows. For example, Dumortier et al. (2022) show that efforts to accelerate the electrification of the light

vehicle fleet in the US affect global commodity markets by significantly altering the demand for liquid fuels in general and maize ethanol in particular. This, in turn, impacts the demand for maize in the US, which has spillovers on global supply and demand for that commodity as well as for other products that use maize, are a substitute for maize, and/or compete with maize for resources, such as land. There are also subnational impacts on land allocation and net returns as shown in Dumortier (2024).

This paper assesses the effects of (1) the war in Ukraine as a current geopolitical event and (2) likely decarbonization of the US road transportation sector on biodiversity and water in Latin America. We extend the work presented in Carriquiry et al. (2022) and Dumortier et al. (2022), who simulate trade effects from the war in Ukraine and reduced US ethanol demand due to vehicle electrification on carbon emissions. Their land-use results are applied to (1) biodiversity data on the species richness of mammals and birds and (2) water data assessing water stress, water depletion, drought risk, and overall water risk.

Although our analysis focuses specifically on Latin America, it could easily be expanded to other regions and countries. The scenarios analyzed in this paper serve as case studies since there are other long-term trends such as climate change, demographic shifts, rising income in developing countries, changes in relative productivity across regions, and efforts to reduce greenhouse gas (GHG) emissions that impact the global food system in the long-run. The Biden administration in the US is also focused on expanding the use of sustainable aviation fuels. The EU's Farm-to-Fork policy may alter international agricultural trade as well (USDA, 2020). As opposed to slow-moving shifts in biofuel use, the war in Ukraine presents a shock with short- and potentially long-run implications. After the war ends and/or if production and exports resume, land area could revert to prewar levels. However, biodiversity and water dynamics, depending on the length of the shock, are both more difficult to assess and beyond the scope of this paper.

The paper highlights how external factors outside the control of individual governments could make meeting environmental benchmarks difficult. Not only do demographic shifts and climate change put pressure on food security, biodiversity, and access to water, but also so do global politics and policy. OECD/FAO (2019) states that several "governments in the region also face the need to invest in improving the environmental performance of the sector and reduce soil erosion, deforestation and emissions from agricultural production." There is the need for policy makers to detect potential future issues early to protect natural resources. Although this may be difficult to achieve in the case of sudden disruptions such as the war in Ukraine, establishing a forward looking view on areas potentially threatened by external factors can provide a basis for regulatory frameworks protecting sensitive areas.

2 | Modeling Approach

To assess the impact of the scenarios considered in this paper on biodiversity and water, we combine the land-use change results from Carriquiry et al. (2022) (war in Ukraine scenario)

and Dumortier et al. (2022) (US vehicle decarbonization scenario) with data on biodiversity and water. This section outlines the data and model linking land-use change to biodiversity and water data as well as the scenarios analyzed.

2.1 | Biodiversity

The gridded data on global biodiversity differentiates between mammal and bird richness at a resolution of 10×10 km (Jenkins et al., 2013).¹ The biodiversity data covers species richness, that is, the number of species per 100 km^2 (Figure 2). The richness range for birds is 19–648 species (median of 354) and 1–200 species (median of 119) for mammals.

As expected, the number of bird and mammal species is highest in the Amazon river basin with mammal species being also high in the northern part of South America (Figure 2). Especially in Colombia and Venezuela, mammal biodiversity is collocated with crop production. In the analysis that follows, we implicitly assign equal importance to each individual species and assume that cropland expansion into areas of high species richness is associated with more negative environmental outcomes as opposed to expansion into areas of lower richness (Gotelli & Colwell, 2001). An alternative approach could assess, for example, the number of species classified as threatened in a particular area or differentiate between subtypes of birds and mammals. These alternative specifications require knowledge about the distribution of species over space. For example, if two adjacent grid cells each count 100 species, then it is not clear, based on the data, how many species are overlapping. That is, there could be a total of 200 different species in the two grid cells or only 100 total species. These questions are beyond the scope of the paper, and hence, we focus on the species richness in general. We assume that the disturbance or displacement of more species has a higher impact on ecosystems by affecting, for example, pollination, seed dispersal, or nutrient cycling (Jordano et al., 2011).

2.2 | Water Resources

We use the AQUEDUCT 3.0 database from the World Resources Institute (WRI) to assess how changes in Latin American production may affect water resources (Hofste et al., 2019).² The database includes physical risk quantities (i.e., baseline water stress and depletion, interannual and seasonal variability, groundwater table decline, riverine and coastal flood risk, and drought risk), physical risk qualities (i.e., untreated connected wastewater and coastal eutrophication potential), and regulatory and reputational risk (i.e., unimproved/no drinking water and sanitation as well as an environmental, social, and governance risk indicator). For this analysis, we use the core index of overall water risk as well as baseline water stress, baseline water depletion, and drought risk since those are most closely related to agricultural production (Figure 3).

The baseline water stress is the ratio of water withdrawals to available supplies (i.e., renewable and groundwater). Related to baseline water stress is baseline water depletion. Whereas water stress includes consumptive and nonconsumptive withdrawals,

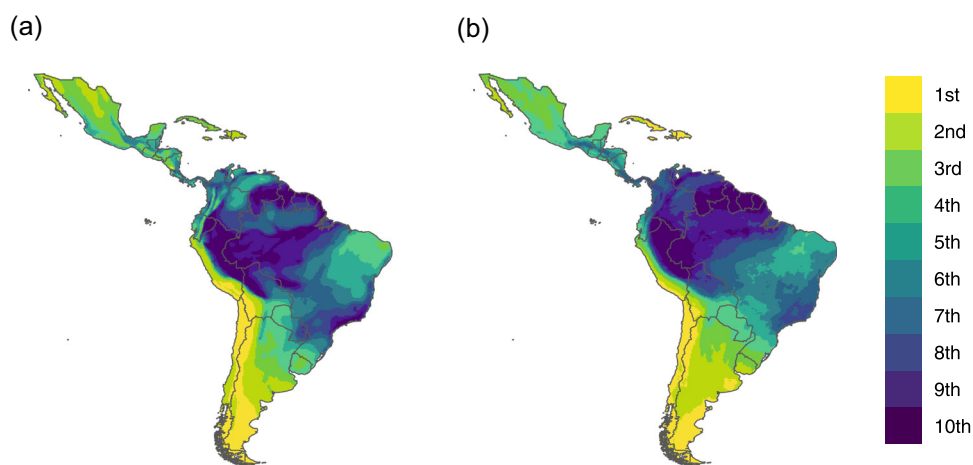


FIGURE 2 | Deciles of bird and mammal richness based on Jenkins et al. (2013). The data have been grouped into deciles to allow for comparison because bird richness is, on average, about 2–4 times that of mammals. (a) Deciles of bird richness and (b) deciles of mammal richness.

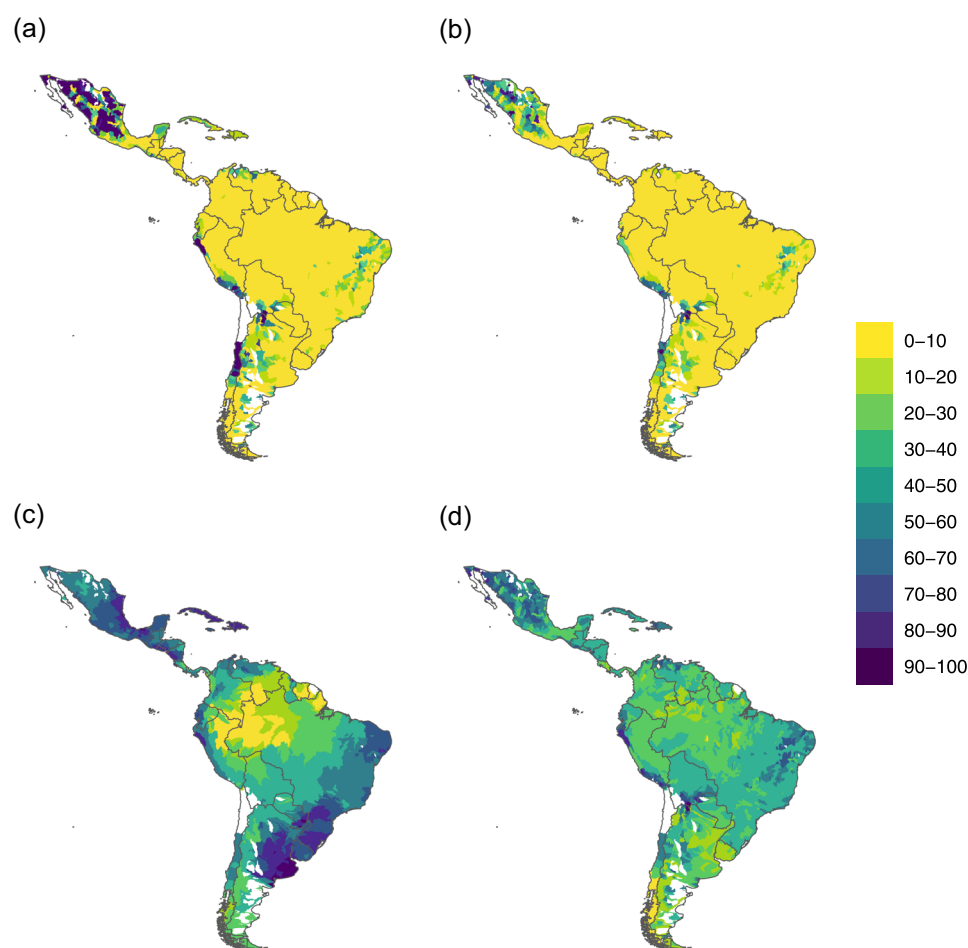


FIGURE 3 | Score of water indicators from the AQUEDUCT 3.0 database. Baseline water stress and depletion, as well as drought risk, are associated with the physical risk quantity, whereas overall water stress is a composite index including physical risk quantity, physical risk quality, and regulatory and reputational risk. (a) Baseline water stress, (b) baseline water depletion, (c) drought risk, and (d) overall water risk.

water depletion only focuses on consumptive use. Non-consumptive withdrawals refers to water diversion without evaporation or loss (in terms of use) into the atmosphere. The drought risk is calculated as a combination of hazard, exposure, and vulnerability of assets and people (Hofste et al., 2019). The overall water risk index is a composite index across all 13 indicators used in the WRI AQUEDUCT database.

The AQUEDUCT 3.0 database contains future projections of water issues until 2040 under various climate change scenarios. Although beyond the scope of this paper, which does not include climate change effects on agriculture, the projections could help evaluate long-term issues with respect to water quantity and quality issues in Latin America (and globally) due to long-term socioeconomic trends and climate change.

2.3 | Global Agricultural Production Model

The model assessing the agricultural trade scenarios is the Center for Agricultural and Rural Development Long-Run Land-Use (CARD LRLU) Model, which has been used in previous publications addressing issues, such as climate change, vehicle electrification, and the war in Ukraine (Carriquiry et al., 2022; Dumortier et al., 2021a, 2023, 2022).³ The partial equilibrium model quantifies the consumption and production of agricultural commodities at the global level for 22 countries and regions until 2050. In this paper, we focus on maize, rice, soybeans, and wheat, which are the common commodities in all the scenarios. In the US vehicle decarbonization scenario, the baseline in terms of population and economic growth is centered around the quantitative components of the shared socioeconomic pathways (SSPs) (O'Neill et al., 2014). The solution to the model is a time series of commodity prices that equalizes supply and demand. The prices determine the land allocation in each country and region, as well as the crop yields. That is, the model includes price-yield elasticities since higher commodity prices are expected to result not only in extensification (i.e., expansion of cropland) but also in intensification of farming. The model has a single export market and does not quantify bilateral trade between individual countries or regions. The results are presented for the baselines and scenarios representing the long-run equilibria. For the scenarios surrounding the war in Ukraine, these long-run equilibria are assumed to be 2 years into the projection whereas, for the electrification scenarios, the equilibrium occurs in 2050.

The US vehicle electrification scenarios are framed around the global socioeconomic pathways (SSPs) 1–3. The SSPs consist of quantitative and qualitative storylines to allow for comparison of climate change research. Specifically, the SSPs quantify economic and population growth, which are the two components used in the CARD LRLU Model. The third quantitative storyline represents urbanization rates. The SSP1 (“Sustainability”) has high economic growth and relatively low population growth. The qualitative storylines are comprised of low mitigation and adaptation challenges in SSP1. This is different from SSP3 (“Regional Rivalry”), which includes low economic growth combined with high population growth. SSP3 storylines represent high mitigation and adaptation challenges. The “middle of the road” (SSP2) lies in between SSP1 and SSP3 both in terms of economic and population growth as well as mitigation and adaptation challenges.

2.4 | Subnational Land-Use Allocation

The output of the CARD LRLU Model is at the national level and, thus, needs to be broken down to the subnational level to assess impacts on biodiversity and water. The five Latin American countries explicitly modeled in the CARD LRLU Model are Argentina, Brazil, Chile, Mexico, and Peru. All other countries in the region are grouped into *Rest of the World*. To assess biodiversity and water effects, we need to (1) distribute cropland to the subnational level and (2) link land-use change

to biodiversity and water indicators. The distribution of cropland to the subnational level and its linkage to carbon emissions has been described in previous publications such as Dumortier et al. (2012), and a similar approach is used here for biodiversity and water.

In the first step, the area allocated to each crop modeled in the CARD LRLU Model is broken down to the subnational level based on a 5-min harvested area raster presented in Monfreda et al. (2008). For example, if a particular grid cell represents 0.1% of the harvested area for a particular crop in country A, then 0.1% of the harvested area by country/region is allocated to that grid cell. This assumes that the share (as a fraction of the total area allocated to a crop in a country) in a particular grid cell is fixed over time. The assumption is rationalized given that the location of future agricultural production is likely adjacent to the current area. Given the subnational allocation of area, we can calculate the change in cropland for the countries of interest. For each crop, we can calculate the area necessary in each grid cell. Area impacts are calculated by taking the area difference between the baseline and the scenario. Note that the relative change in area for the countries not explicitly modeled in the CARD LRLU Model is identical to the *Rest of the World* region (Figure 4), but the absolute change is different by country (Figures 5 and 6).

In the second step, we calculate the average biodiversity and water indicators presented in the previous sections weighted by crop area for each country in Latin America. That is, the total area across all crops in each grid cell is multiplied by the various biodiversity and water indicators and then divided by the total crop area in a country. The resulting values reflect, for example, the average bird richness or water stress from agricultural production in that country. Combining the average biodiversity and water score associated with the location of crop area in a particular country with the change in crop area from our scenarios leads to an assessment of the likely impact on natural resources.

Allocating cropland proportional to the current area may have some implications for our results. If shifts in crop production are not allocated based on historical areas but on land with the highest yields, then there may be shifts across space, which are not captured in our model. This could lead to a change in which biodiversity (including the types of species) and water are affected. However, these changes are likely small since historic land allocation probably follows the highest yields. It is also possible that cropland expansion into native vegetation has different effects depending on the current share of cropland in a particular grid cell. That is, when the crop share increases from an already high fraction, the impacts on biodiversity may be different than when the same rate of change occurs from a grid cell with a low crop fraction. The impact of a change in area on biodiversity and water indicators is also assumed to be symmetrical regardless of whether it is a positive or a negative change. While we do not anticipate a change in the direction of the results, this assumption may have some implications in terms of the magnitude of the results given that the impacts are not necessarily symmetrical.

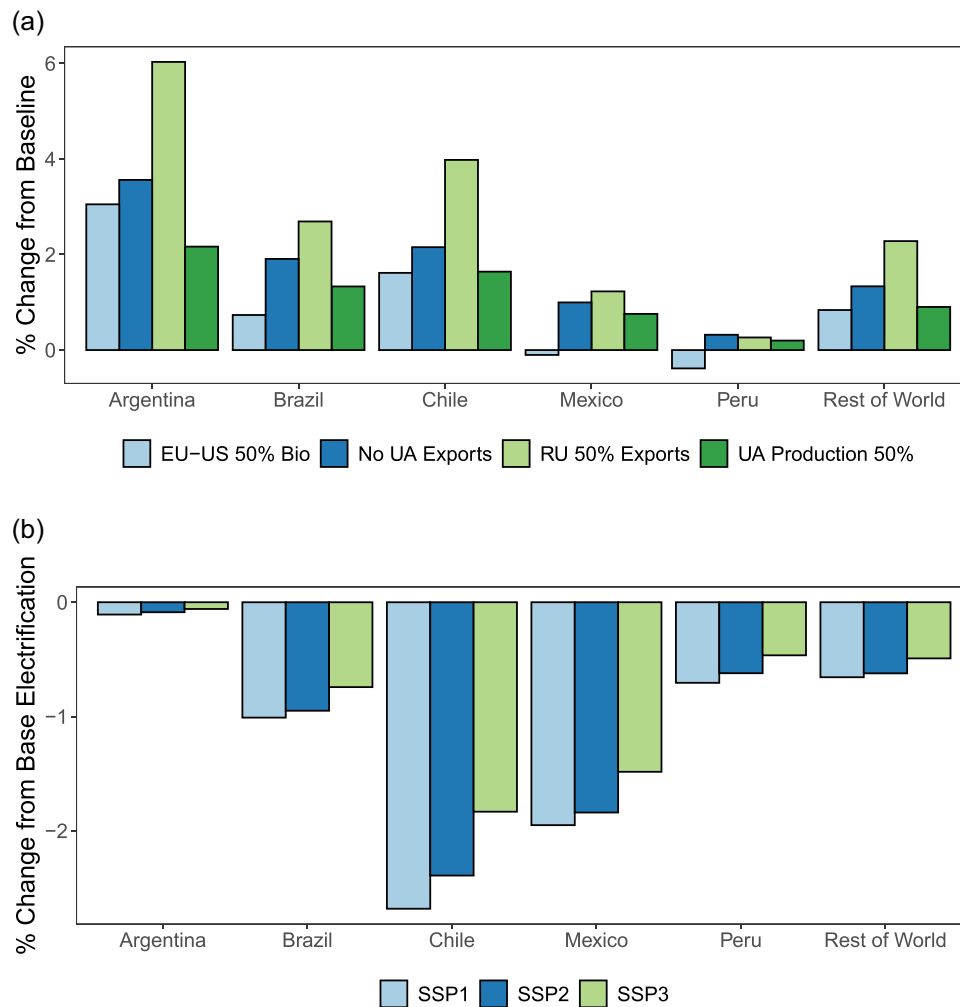


FIGURE 4 | Percentage change in crop area from scenarios surrounding the war in Ukraine and United States (US) vehicle electrification. The vehicle electrification scenario assessed is a sales market share of 100% electric vehicles by 2050 in the US. SSP1–3 refers to the shared socioeconomic pathways. (a) War in Ukraine and (b) vehicle electrification. SSP, shared socioeconomic pathway.

2.5 | Scenarios

We use two broad situations that affect Latin American agriculture and that are outside the control of individual countries: (1) war in Ukraine and (2) US vehicle electrification. For both events, we use the scenarios presented in Carriquiry et al. (2022) and Dumortier et al. (2022).

The war in Ukraine has raised major concerns about global food security because Russia and Ukraine are major exporters of maize and wheat. Carriquiry et al. (2022) have analyzed various scenarios to determine the impact of the war on commodity prices, trade, and land allocation. Specifically, they have quantified scenarios regarding (1) no grain exports from Ukraine and a reduction of biofuel use in the EU and the US by 50% (*EU–US 50% Bio*), (2) no grain exports from Ukraine (*No UA Exports*), (3) no grain exports from Ukraine and a 50% export reduction from Russia (*RU 50% Exports*), and (4) no restriction on exports but a reduction in Ukrainian grain production by 50% (*UA Production 50%*). The scenarios reflect the uncertainty that was present at the beginning of the war with regard to Ukraine's production and export

capacity, Russia's ability to export, and policy solutions in the US and the EU. The first scenario was included as a policy, which was suggested at the beginning of the war, to ease the pressure on food prices. Scenarios (2) and (3) were executed to simulate a significant reduction in the exports from two major maize- and wheat-producing nations. The question about what would potentially cause the reduction in exports from Ukraine was modeled with the last scenario, that is, the inability to plant associated with 50% of the total production capacity.

The results by Carriquiry et al. (2022) show a relatively moderate increase in global food prices (except for sunflower) as other countries increase their production to compensate for the shortfall of Ukrainian and/or Russian exports (Panel (a), Figure 4). While Brazil experiences smaller percentage changes in area compared with Argentina and Chile, the increase in absolute terms is very large for Brazil (Figure 5). Although easing the negative effects on food security, the expansion of production in other regions (e.g., Latin America) comes at the expense of significant carbon emissions from land-use change. This study expands on those results by addressing biodiversity and water attributes.

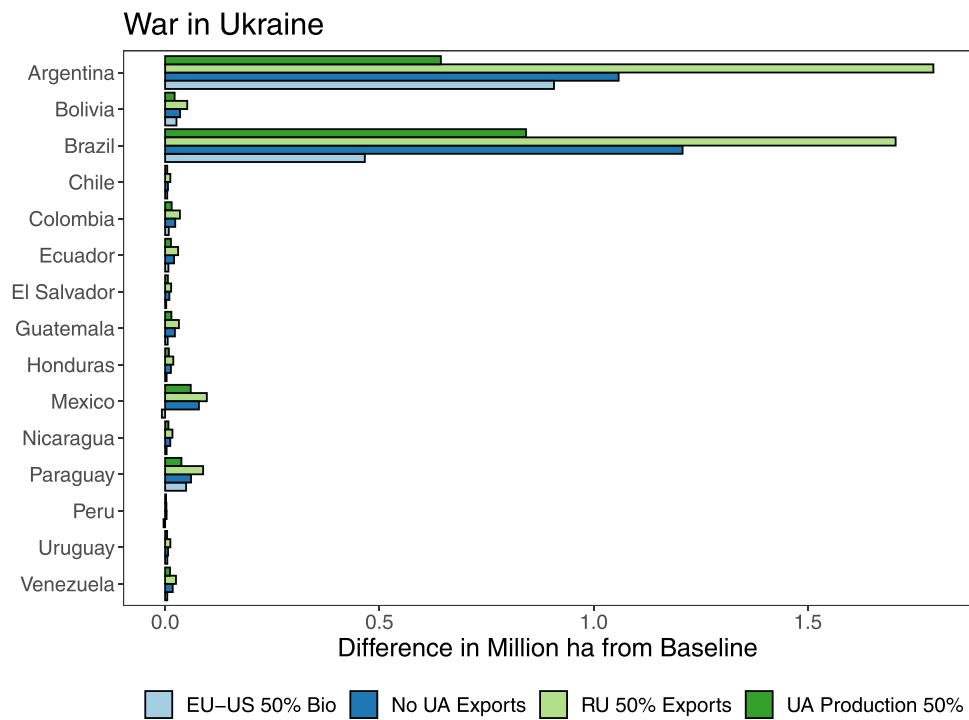


FIGURE 5 | Absolute changes area compared with the baseline for the war in Ukraine scenarios.

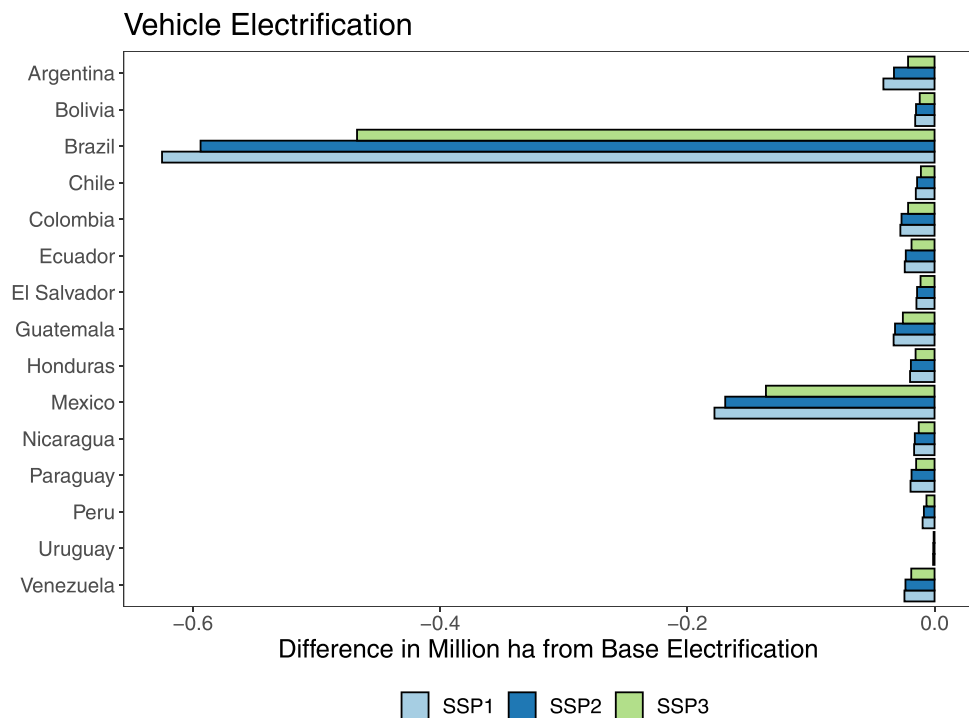


FIGURE 6 | Absolute changes in the area compared with the baseline for US electrification scenarios. SSP, shared socioeconomic pathway.

The second broad scenario used in our analysis is the case of US vehicle fleet electrification. Currently, close to 30% of US maize production is used for the production of ethanol, which is blended with gasoline. A shift toward more electric vehicles reduces maize demand in the absence of any alternative uses. Electrification scenarios are analyzed in Dumortier et al. (2021b, 2023, 2022), and we use the land-use change results from Dumortier et al. (2022).

Specifically, we focus on the scenario assuming an electric vehicle market share in 2050 of 100% of light-duty vehicles sold. This results in a decrease in maize consumption used for ethanol by between 62.2%–70.1% depending on the SSP. The decline in domestic US maize demand lowers prices and leads to an increase in US maize exports to the rest of the world. The decline in maize prices also affects other commodities (e.g., soybeans), which

become relatively more profitable compared with maize, leading to an expansion of these crops and a subsequent decline in prices. The increase in exports from the US lowers the export demand for crops grown in Latin American countries resulting in a decline in crop area (Panel (b), Figure 4). The largest decrease in absolute terms is observed in Brazil and Mexico (Figure 6).

3 | Results

The results are presented along two dimensions: (1) Effects on biodiversity and water and (2) the scenarios (i.e., the war in Ukraine and US vehicle fleet decarbonization). For some combinations of countries and scenarios (e.g., Argentina and Brazil in the case of the war in Ukraine as depicted in Figure 5), the results are very large and hence, for ease of readability, are presented in table format rather than included in the plots.

3.1 | Impact on Biodiversity

3.1.1 | War in Ukraine

The war in Ukraine puts pressure on Latin American agriculture to compensate for the export and/or production shortfalls from Ukraine. In Brazil, the area increases by 0.8 or 1.2 million hectares (ha) in the case of a Ukrainian production shortfall of 50% or export stop, respectively (Table 1). Given Brazil's high bird richness of about 400 species per 10 km² and

the large increase in crop area, the war is very detrimental to bird biodiversity on the Latin American continent. Although Argentina sees similar effects in terms of area change (Table 1), the bird and the mammal diversity are much smaller compared with Brazil. Despite this, climate change and land-use change have been shown to be significant predictors of bird species in central Argentina's provinces of Cordoba, Santa Fe, and Entre Rios (Schrag et al., 2009). The war in Ukraine has much smaller effects on the area in Mexico compared with Argentina and Brazil. Other countries of concern both in terms of bird and mammal biodiversity are Paraguay—which has a higher bird biodiversity than Brazil—Colombia, Ecuador, and Venezuela (Figure 7). Especially the decline in terms of agricultural output observed in Venezuela (Figure 1) combined with high bird and mammal biodiversity (378 and 159 per 10 km², respectively) could make the region more vulnerable to biodiversity loss.

As aforementioned, the northern part of the South American continent is particularly rich in terms of birds and mammals and even small area increases from an event such as the war in Ukraine can lead to important biodiversity loss in countries, like, Colombia, Ecuador, and Venezuela. These findings echo the results of Zabel et al. (2019), who indicate that the biodiversity most threatened by cropland expansion is found mainly in the tropics, in particular, in Central America, the Western part of the Amazon Basin, and the Atlantic forest. The adverse results in terms of crop area increases are driven by the scenarios limiting the exportability of Ukraine and/or Russia and less by a reduction in Ukrainian production or EU-US biofuel policy.

TABLE 1 | Biodiversity and water indicators as well as area change for Argentina, Brazil, and Mexico.

	Argentina	Brazil	Mexico
<i>Biodiversity indicators (number of species per 10 km²)</i>			
Birds	232.3	404.4	270.5
Mammals	39.1	112.9	91.1
<i>Water indicators (0–100 range, with 100 being the highest risk)</i>			
Baseline water depletion	7.1	2.0	22.4
Baseline water stress	11.2	3.3	50.0
Drought risk	65.3	49.9	55.4
Overall water risk	26.1	33.0	39.9
<i>Area change (in million ha): War in Ukraine</i>			
EU–US 50% Bio	0.9	0.5	<0.1
No UA exports	1.1	1.2	0.1
RU 50% exports	1.8	1.7	0.1
UA production 50%	0.6	0.8	0.1
<i>Area change (in million ha): Vehicle electrification</i>			
SSP1	<0.1	−0.6	−0.2
SSP2	<0.1	−0.6	−0.2
SSP3	<0.1	−0.5	−0.1

Note: These indicator/country combinations are excluded in Figure 7–10 due to the large area changes compared with the other countries. The water indicators are measured from 0 to 100 on the global scale (Hofste et al., 2019). For Baseline Water Depletion, values between 5 and 25 are in the low–medium risk category. For the Baseline Water Stress, the risk category of “high” is associated with values of 40–80. The risk category “medium–high” for drought risk covers the value of 60–80. The Overall Water Risk is a weighted score based on all the indicators including but not limited to the three indicators previously mentioned. Abbreviation: SSP, shared socioeconomic pathway.

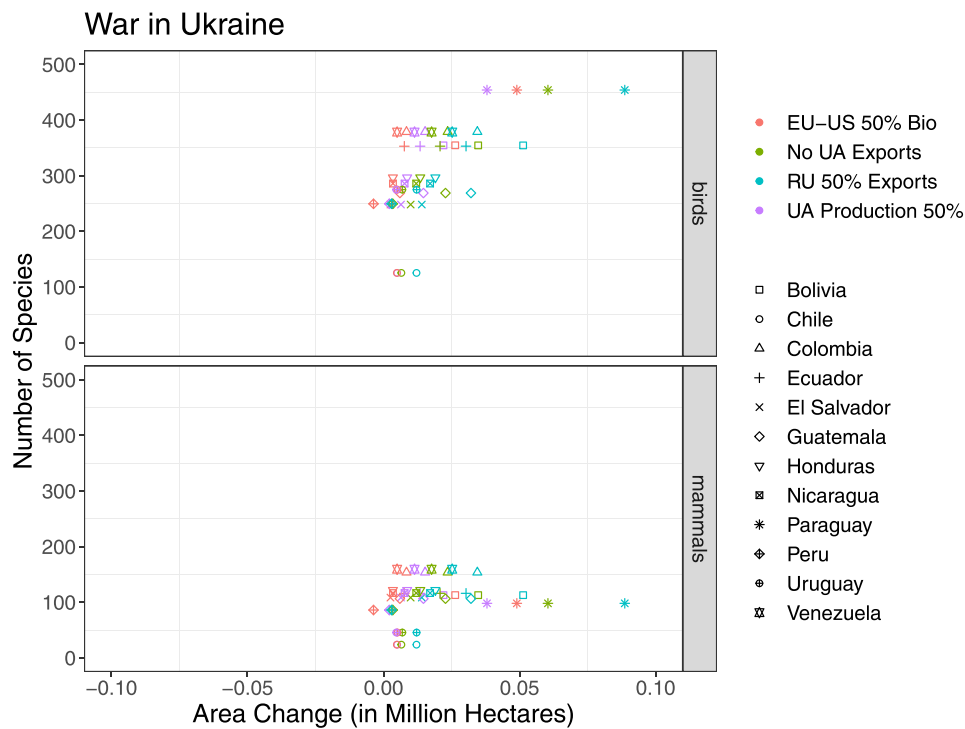


FIGURE 7 | Area change and average number of species of birds and mammals for the scenarios regarding the war in Ukraine.

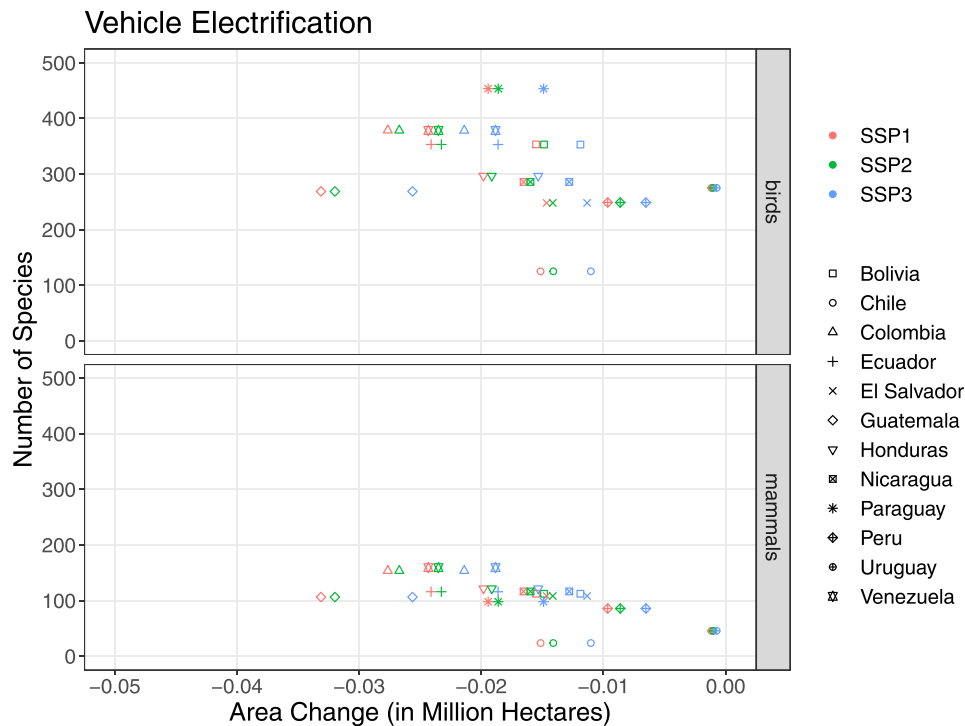


FIGURE 8 | Area change and average number of species of birds and mammals for the scenarios regarding decarbonization of the US vehicle fleet. SSP, shared socioeconomic pathway.

3.1.2 | Vehicle Electrification

The impact on biodiversity of US vehicle electrification is differentiated by SSP. The results in terms of area decline from 100% US sales share of electric vehicles are more pronounced for SSP1 than for SSP3 (Figure 6). The two Latin American

countries with the highest decline in area are Brazil and Mexico. This is different from the case of the war in Ukraine case in which Argentina was also strongly affected due to its sizeable production of wheat. Whereas the war in Ukraine affects the maize and wheat markets, the US vehicle decarbonization mostly affects global maize markets. The country benefiting

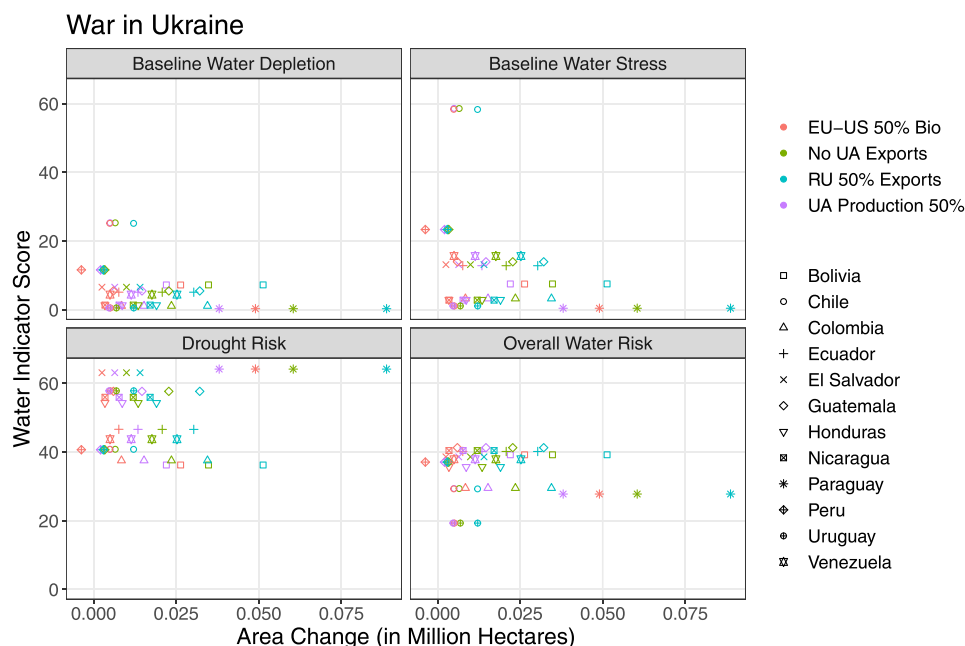


FIGURE 9 | Area change and average water scores for the scenarios regarding the war in Ukraine.

most from US vehicle electrification in terms of biodiversity is Brazil due to its large area decline and high bird/mammal density (Table 1). Similar to the case of the war in Ukraine, Paraguay is high with respect to species count but experiences a very small area decline (Figure 6).

3.2 | Impact on Water Quantity and Quality

3.2.1 | War in Ukraine

The results in terms of water quality and quantity are different compared with biodiversity. Brazil is rich in biodiversity as well as in water resources. However, area changes in Brazil from the scenarios analyzed have a lower impact on water resources than biodiversity. Baseline water depletion and stress are low in Brazil (Table 1). The drought risk is highest in Argentina and Mexico. In the scenario pertaining to the war in Ukraine, the drought risk is a more significant problem for Argentina than for Mexico. The compensation for the lack of exports from Ukraine and/or Russia occurs in drought-prone areas in Argentina. The same is true for Paraguay (Figure 9). Chile also has a high-risk score for baseline water stress with lower area expansion compared with other countries. Similar to biodiversity, Paraguay is an extreme example of having very low-risk scores in terms of baseline water depletion and stress but having a high risk of drought.

3.2.2 | Vehicle Electrification

For the US electrification scenarios, the area decline in Brazil occurs in areas of low water depletion and stress. Although Chile has a high-risk score in terms of baseline water stress (Figure 10), the area decline is relatively small. In terms of drought risk, Argentina and Guatemala stand out as both having higher area declines—compared with the majority of other Latin American countries—and also a high drought risk.

4 | Conclusion

Our analysis highlights that external factors outside the control of individual governments could adversely impact the achievement of important environmental benchmarks. General results indicate that there are beneficial effects in terms of biodiversity in Latin American countries from vehicle electrification in the US. This is due to a significant increase in maize exports from the US as a result of reduced biofuel demand, which reduces the crop area in countries with high biodiversity. The effects echo the findings by Dumortier et al. (2022), who calculate lower GHG emissions from land conversion associated with vehicle electrification. The results regarding the trade disruption from the war in Ukraine indicate a significant loss of biodiversity in Latin America due to a shift of maize and wheat exports away from Ukraine and Russia and toward Latin American countries, especially Brazil. The impacts on water quality from the two cases are small, although an increase in crop production in Chile and Mexico could potentially increase water stress since both countries have large areas of high baseline water stress.

These results underline the importance of integrated and comprehensive analysis of global agricultural markets and policies to detect potential issues early. This is especially critical since agricultural production will continue to grow to meet the increasing demand for food and is likely to occur in countries that are economically poor and are home to biodiverse ecosystems, such as Latin America (Oakley & Bicknell, 2022). Additionally, policies addressing the broader issue of how food is grown, dietary changes as incomes rise, crop productivity, diversification in food production, and management practices that integrate conservation efforts with food production all play an important role in addressing the challenges faced by trying to achieve food security for a growing population. Investments in conservation have to take into account the livelihood of agricultural producers by

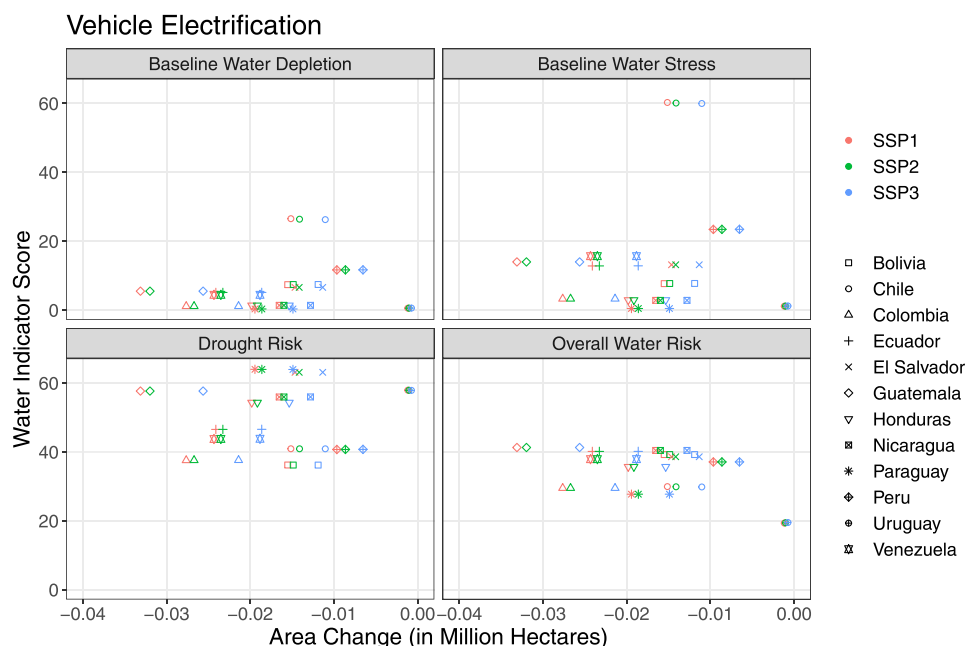


FIGURE 10 | Area change and average water scores for the scenarios regarding decarbonization of the US vehicle fleet. SSP, shared socioeconomic pathway.

targeting the areas that provide the potential for the highest returns on investment by balancing the cost of conservation (opportunity cost for agriculture) and the expected impacts on biodiversity (Guerrero-Pineda et al., 2022). Sustainable systems are better able to withstand unanticipated “shocks,” such as the war in Ukraine.

Previous research has expressed concerns that trade disruptions due to political decisions have a larger impact on food security than climate change itself. It should be highlighted that these factors coexist, with the potential of compounding, or partially offsetting each other. In this study, we add the dimension of biodiversity and water to the issues associated with food security and carbon emissions.

While some factors represent long-term trends or gradual changes that can be anticipated (e.g., electrification of a fleet), others occur with little time to react, such as the war in Ukraine. Future research should disentangle the biodiversity and water dynamics given shocks and policies that differ in time length. Although the war in Ukraine has a short-run effect on the area, the effects on biodiversity and potentially water indicators may have long-run and irreversible implications, given how long it takes species to adjust to change. Moreover, even though crop area could revert to the prewar levels, biodiversity will likely not recover at the same pace. In the case of the EV scenario, the equilibrium—for both cropland, biodiversity, and water indicators—is achieved in the long run, and the model captures those effects. Hence, the reported impacts on biodiversity and water are assumed to be realized immediately in the case of the war in Ukraine. Those different time horizons have important consequences for agricultural and environmental regulators, and for the achievement of country-specific environmental objectives. Regulatory frameworks, as well as food systems, should be designed considering the interconnectedness of these factors.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Endnotes

¹The data can be downloaded from Mapping the World's Biodiversity. Here, we extract data for Latin America from the gridded data at the global level but region-specific data for Brazil and the US are available as well.

²The data can be downloaded from the WRI's AQUEDUCT Global Maps 3.0 Data web page.

³The CARD LRLU Model is maintained at Iowa State University and the University of the Republic in Uruguay.

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