Water at Risk:
The impact of biofuels expansion on water resources and poverty

Executive Summary

Biofuels are considered to be a renewable resource because their feedstocks can be reproduced in a relatively short amount of time and they are not fossil fuel based. However, these facts alone do not capture the full impact – either environmentally or socially – or establish the sustainability of biofuels. There are many resource demands associated with the cultivation of feedstocks and the production and refining of biofuels, including that they require significantly more water than any other energy carrier. The production, trade, and consumption of biofuels and their feedstocks is happening at an ever-increasing rate, due largely to the rigorous blend mandates set by the United States' Renewable Fuel Standard (RFS) and the European Union's Renewable Energy Directive. Over 64 countries have followed this precedent and developed their own biofuels mandates, making examination of the impacts of large-scale biofuels production urgent, especially in feedstock producer countries where land use is radically shifting to meet increasing feedstock demands from developed countries.

The gravest concerns related to biofuels production are threats to food security, deforestation, biodiversity decline, and impacts on water resources. This study focuses specifically on the water consumption and pollution associated with biofuels cultivation, especially where driven by U.S. biodiesel and ethanol demand. The objective is to provide insights into the macro-scale the water implications of growing key biofuels feedstocks in countries with significant export to the U.S. market. By drawing on recent U.S. import statistics and identifying the crop origins of those imports, we are able to quantify the water footprint (WF) of cultivating key feedstock crops in major exporting countries. In applying these WF values to three different cultivation scenarios, we analyze the net water impact of displacing other land use types in the study countries. This broad-based investigation is accompanied by a spatial analysis to identify specific regions within the study countries where existing water scarcity would be further exacerbated by biofuels production. These regions are potential locations for refined study with deeper localized analysis in the future.

The key feedstock combinations supplying the U.S. biofuels market from abroad are Argentinean soybeans, Brazilian soybeans and sugarcane, Guatemalan sugarcane, Indonesian palm oil, Malaysian palm oil, Paraguayan soybeans, and Salvadoran sugarcane. Each case is unique and reflects the particular situation of the specific country and crop, but the impact of expanded biofuels production is largely detrimental in aggregate. In particular, the largest net WF increases are found in Central and South American countries where land use is shifted to sugarcane cultivation. The most critical water pollution impacts are found with cultivation of palm oil in Southeast Asia. Further investigation incorporates spatial data on the existing status of water resources in the countries of interest. Key "hot spots" have been identified including potential water scarcity impacts from sugarcane cultivation in areas of Argentina and coastal Brazil, as well as for projected water pollution effects in Indonesia and Malaysia. The next step would be more locally focused studies in these areas of risk.

1. Growing global demand for increasingly scarce — and increasingly interconnected — resources

Growing populations and shifting demographics have led to a steady increase in global demand for water, food, land, and energy resources. Barring any major changes in consumption patterns, global food production will need to be 70% greater by 2050 than it was in 2000 (Bruinsma 2003). Even with optimistic assumptions regarding productivity and technology, this will entail at least a 10% increase in cultivated land and a 20% increase in agricultural water demand (De Fraiture, Wichelns et al. 2007). Agriculture covers almost 40% of the globe (World Bank 2012) and consumes on average about 700 gallons of water *every day for every person on earth*[1] (Postel 1998). While the world is more than capable of feeding all 9 billion people in 2050, doing so will require smart policy choices.

The current and anticipated strains on our food system have necessarily focused scrutiny on biofuels, because they are at the center of the water, food, and land nexus. Biofuels compete with food production for land and water inputs, and typically require vastly more of both than any other energy source. Gerbens-Leenes, Hoekstra, et al (2009) estimated that on average, production of biofuels requires between 70 and 400 times more water than the fossil fuels they replace. For this reason, water resources have been dubbed the “Achilles heel” of biofuels production (Keeney and Muller, 2006). Decisions on biofuels will impact the availability and quality of inputs, such as land and water, for food production and other human needs, making it critical to take a closer look.

1.1 Water Scarcity Today

Many people are already living under conditions of water stress, and climate change is expected to exacerbate this significantly (IPCC, 2014). By the year 2025, the United Nations expects two thirds of all people to be experiencing some degree of water stress and 1.8 billion people to be living under conditions of absolute water scarcity (UN Water 2007). It is impossible to talk about water scarcity without considering agriculture, because agriculture accounts for nearly 70% of all water withdrawals. In some developing countries, the amount of water used for agriculture is closer to 90% (UNESCO 2009).

1 This is an average figure, and could be as much as an order of magnitude higher to support the consumption habits, particularly consumption of meat products, of many individuals in wealthier countries.

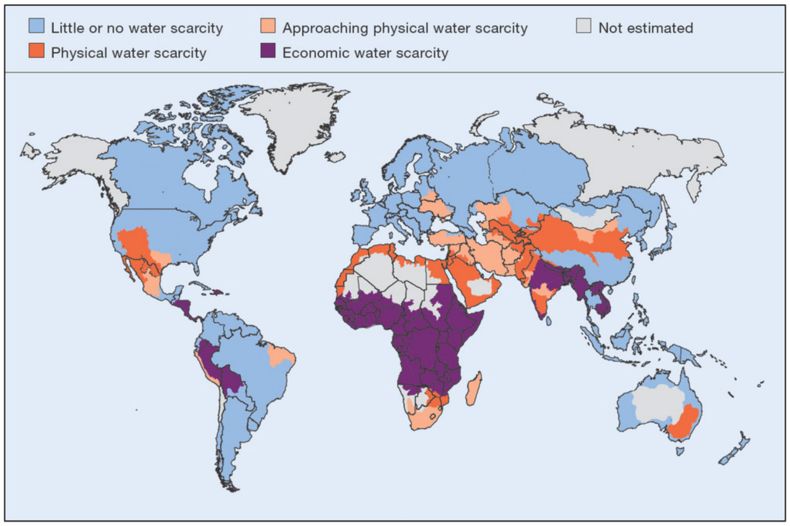


FIGURE 1: HIGH-LEVEL DISTRIBUTION OF PHYSICAL (VOLUME) AND ECONOMIC (DISTRIBUTION INFRASTRUCTURE AND GEOPOLITICAL CONSTRAINTS) WATER SCARCITY GLOBALLY. SOURCE: INTERNATIONAL WATER MANAGEMENT INSTITUTE (MOLDEN 2007)

Water is not just a critical resource; it is so fundamental to human development and wellbeing that it is a human right. Water is also critical to human survival, not just for drinking water, but for its role in food security and nutrition. There is a great deal of overlap (Hoff 2011) between the 1.2 billion people without adequate access to water (Molden 2007) and the nearly 1 billion who are undernourished (UNDP 2006). Water is necessary to cultivate crops, and also to prepare and wash food. Furthermore, water quality impacts people's ability to absorb the nutrition in their food. Waterborne diseases present a serious health threat, especially to young children. The question is not always one of quantity or quality either; access is equally important. Young girls and women disproportionately bear the burden of retrieving sufficient clean water for their families, sacrificing time that could have been spent in school and on other productive activities. Furthermore, water scarcity can intensify the significant tradeoffs that pit human needs against the integrity of ecological systems, contributing to a cycle of ecological degradation that hurts human populations, as their ecosystems can no longer provide key resources or regulate air and water contamination.

1.2 Biofuels

Historically, biomass was the central source of energy, however since the expansion of modern energy sources, the demand for energy has outgrown the realistic supply of biomass. To put the implications of any significant shift into perspective, total global energy demand today – about 500EJ per year – is an order of magnitude larger than the energy content of all food and feed crops produced annually (Gerten, Heinke et al. 2011).

Modern bioenergy[2] (liquid biofuels and bioelectricity) currently plays a relatively small role

2 "Bioenergy," as used in this report, connotes energy derived from recently living organic material. While fossil energy sources such as petroleum, coal, and natural gas are also biogenic, they are the remnants of ancient biological material and energy from these fossil sources is not typically considered "bioenergy."

in the global energy system. Liquid biofuels met an estimated 2.3% of global liquid fuel demand, and bioelectricity accounted for 1.8% of global power generation in 2013 (REN21, 2014)[3]. However, both the proportion of biogenic sources in the energy mix and the absolute amount of bioenergy produced are growing rapidly. Global ethanol production has grown at a rate of 5.7% per year since 2008, and biodiesel production has grown at a rate of 11% per year (REN21, 2014). Figures 2 and 3 depict the overall trends in consumption and trade of biofuels in the recent past.

Most of the biofuels expansion that has occurred over the past decades has been driven by policy mechanisms intended to increase the share of renewable fuels in transportation. The Renewable Fuel Standard (RFS) in the United States currently mandates 16.3 billion gallons of total biofuels this year (although this level has routinely been reduced to allow for a lack of cellulosic ethanol production), rising to 36 billion gallons in 2022. Europe has taken a proportional approach, with its Renewable Energy Directive (RED) targeting a 10% share of renewables in the liquid fuel mix by 2020, but has recently enacted a 7% cap for food-based biofuels.

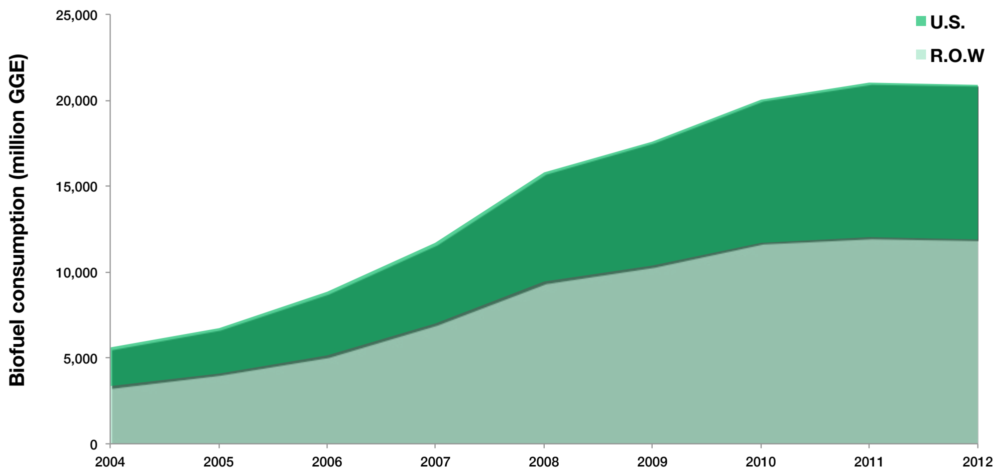


FIGURE 2: UNITED STATES BIOFUELS CONSUMPTION (BIODIESEL AND ETHANOL) COMPARED TO THE REST OF THE WORLD OVER THE LAST DECADE (DATA: EIA, 2015).

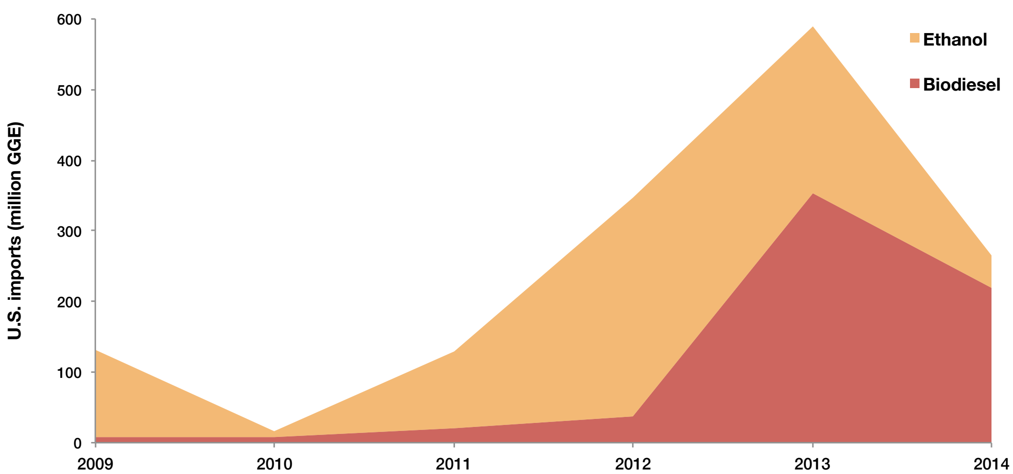


FIGURE 3: ANNUAL U.S. IMPORT OF BIODIESEL AND ETHANOL SINCE 2009 (DATA: EIA, 2015).

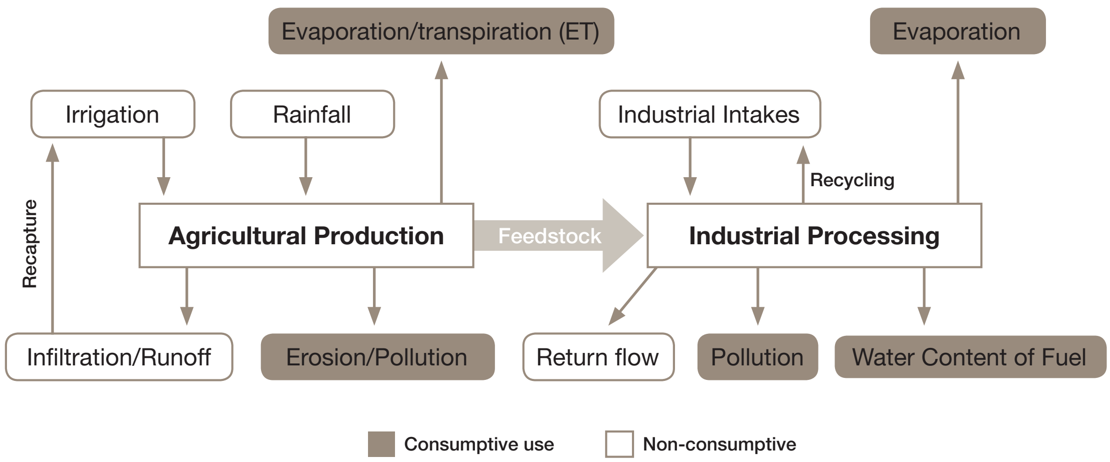
3 These figures only include “modern” bioenergy. Traditional bioenergy (mainly wood, charcoal, and dung burned directly for heating and cooking needs) comprises an estimated 9% of *total* human energy use (REN21, 2014).

1.3 This report

Biofuels are by far the most water intensive of all major energy carriers, as long as these fuels are derived from purpose-grown agricultural feedstocks (Gerbens-Leenes, 2008, Fingerman, 2012). Biofuels production could exacerbate conditions of water scarcity or degraded water quality in some regions to the detriment of local ecological systems and human populations. Biofuels are still a small part of the current energy mix and represent only about 1% of all total consumptive water use in agriculture (De Fraiture, Giordano et al. 2008). However, their impact on water is still worth scrutiny, considering both the importance of water and the tremendous growth of biofuels. Global water figures often hide challenges or problems in specific geographic locations, making close study necessary. Consumption or degradation of freshwater resources can disrupt ecosystem functioning and can harm local communities by reducing water quality, quantity, or access (Milà i Canals, Chenoweth et al. 2009). Biofuels production has already begun to exacerbate water scarcity in some locations, and with it local food security risks, and these challenges stand to spread and intensify with projected increases in global biofuels use.

This report investigates the link between biofuels imported to the United States and impacts on water resources in some less developed nations. We identify potential hot spots where increased production of biofuels could place a strain on water resources, and potentially on the food security of local communities. We then investigate the existing water, bioenergy, and food security circumstances in key regions in order to better understand the risks biofuels expansion might pose, and how to mitigate those risks.

The flow-chart below lays out the major flows of water in the biofuels life cycle. The agricultural production phase typically represents over 99% of life cycle water use for most biofuels (Fingerman, Torn, et al. 2010) making it the key driver of most risks stemming from the biofuels/water nexus. This report, therefore, focuses primarily on feedstock cultivation. While feedstock cultivation is by far the most important biofuels production activity from a water footprint standpoint, in some cases water consumption or pollution may occur on a local level due to processing rather than cultivation. This consideration should be evaluated more closely where risks have been identified; it is not considered here because the dynamics are not scale-appropriate to a global study.



SCHEMATIC OF WATER USES IN THE BIOFUELS LIFE CYCLE. FLOWS OF WATER BOTH INTO AND OUT OF THE BIOENERGY PRODUCTION AND PROCESSING SYSTEM ARE REPRESENTED. SOURCE: (FINGERMAN ET AL., 2010)

2. Types of water use

2.1 Withdrawal

Withdrawal is the removal of water from a natural system or a managed resource base. About 70% of all water withdrawn globally is used for irrigation (Hoff, 2011). Recent decades have seen rapid global growth in irrigation water use to increase agricultural productivity. Almost half of all agricultural production today comes from the approximately 15% of cultivated land that is irrigated (Molden 2007).

When water is removed from the resource base, it is considered withdrawn regardless of its eventual fate. For example, water withdrawn for irrigation may be consumed in the process through evapotranspiration[4], or it may infiltrate or run off of the soil surface, later rejoining the usable resource base. These are all water withdrawals, but with different outcomes that have very different implications for the state of the water resource base. For this reason, this paper focuses on water consumption rather than withdrawal.

2.2 Consumption

As discussed above, not all of the water that is withdrawn for use by humans is consumed in the process[5]. Furthermore, much of the water that is consumed by human activities has not been applied. Agriculture is a good example of this; about 80% of all crop water requirement globally is met by rainfall, including for some important biofuels feedstocks such as most Brazilian sugarcane and U.S. corn as

4 Cropping systems consume water in two ways: through evaporation from the soil surface and through transpiration, which is essentially the productive evaporation of water through plant tissues. These two processes are collectively referred to as evapotranspiration (ET).

5 Use of the term "consumption" is complicated by the fact that most of the processes being considered do not actually destroy water molecules. We rely here on a commonly used definition of water consumption; water is considered consumed when it is removed from the usable resource base for the remainder of one hydrologic cycle. Evaporation, therefore, is considered a form of consumption. Although the water has simply changed phases, we do not control where evaporated water will fall next, so the water is functionally lost to the system.

well as the majority of global oil palm and rapeseed production (De Fraiture and Berndes 2009). If not used to produce biofuels feedstock, rainwater could provide environmental services, recharge groundwater, or could be used in cultivation of a different crop. However, while rainwater is a valuable resource, its use has fundamentally different implications than the use of irrigation water. For this reason, this analysis distinguishes between water consumed from different sources.

One common convention in water footprint analysis is to break up water consumption of different types into categories known as green, blue, and grey water. **Green water** refers to rainwater and soil moisture that is naturally available *in situ* to the plant. **Blue water** is applied through human intervention; in the case of agriculture, it would describe water applied as irrigation. **Grey water** is used to describe water consumed through pollution, and is discussed in more detail in the following section.

2.3 Pollution

Pollution is another important anthropogenic impact on water resources. It can be considered a form of consumption, as it makes water unavailable for some other productive uses. It is difficult, however, to quantify a volume of water pollution in the same way that most consumption is quantified, since there is no objective basis for determining how much water is lost to pollution through the addition of a given mass of a pollutant. In approaching this issue, many researchers define the amount of water consumed as the volume that would be required to dilute a pollutant discharge to below a defined water quality standard.

Nutrient pollution is the most important water quality impact of biofuels production systems, since the production of feedstock frequently requires application of chemical fertilizers. In the United States, for example, Donner and Kucharik (2008) found that the increase in corn ethanol production required to meet U.S. Renewable Fuel Standard targets would lead to a 10–34% increase in the export of dissolved inorganic nitrogen (DIN) from the Mississippi River into the Gulf of Mexico. This flow of agricultural nutrients into surface waters can make those waters toxic to surrounding communities and can lead to eutrophication, with potentially devastating effects to aquatic ecosystems and the human populations that rely on them.

3. Methods

3.1 Characterizing U.S. Biofuels Demand

In order to evaluate the international water scarcity and poverty implications of U.S. biofuels demand, the first step is to quantify U.S. biofuels imports, including feedstock and country of origin. The following section describes the process by which we characterize these biofuels flows.

3.1.1 Determining biofuels import volumes

The primary sources of biofuels trade flow data for this study are the U.S. DOE Energy

Information Administration (EIA) and the USDA Global Agriculture Information Network (GAIN). The EIA database provides time series for annual flows of ethanol and biodiesel from each country into the United States since 2004. The EIA does not distinguish between types of ethanol and biodiesel; for example, it does not differentiate between corn ethanol and sugarcane ethanol. However, in order to evaluate the implication of these flows from a water and food availability perspective, it is necessary to determine the feedstock from which the fuel in question is produced and the source of that feedstock. The GAIN reports provide the information on feedstocks, in most cases offering the feedstock ratios in the domestic biofuels markets for countries from which the U.S. imports.

This analysis assumes that the fuel imported to the U.S. is representative of the bulk of fuel produced in the exporting country. For example, where Canadian ethanol is produced 75% from maize, and 25% from wheat, we assume these ratios to apply to U.S. imports as well, unless there is evidence to the contrary[6]. However, especially in relation to palm oil, these feedstock pairs should be viewed as more of a measure of U.S. biofuels demand impact rather than exact nature of U.S. biofuels imports.

In some cases, the above approach fails to accurately capture the realities of biofuels trade and particularly the origins of biofuels feedstocks. The following sections describe two such situations and the approach taken to manage each.

The Caribbean basin ethanol "illusion"

The Caribbean Basin Initiative (CBI) and the Central American Free Trade Agreement (CAFTA-DR) are two U.S. trade programs that took effect in 1984 and 2006 respectively, with the stated aim of furthering U.S. economic and diplomatic agendas while encouraging economic growth in the Caribbean and Central America[7]. The preferential tariff and trade structures under the CBI and CAFTA distorted ethanol markets until 2011 because they exempted ethanol imports from the $0.54/gallon tariff applied at the time to other imports, including most notably those from Brazil. However, significant amounts of the exported fuels could be produced from non-locally grown feedstock, provided that some value-adding process took place in the trade partner nation.

These trade deals led to a large quantity of Brazilian sugarcane ethanol being exported from Brazil to CBI and CAFTA-DR countries in hydrous form, to be dehydrated and then re-exported as tax-exempt fuel ethanol to the United States. In 2009, for example, the EIA trade data show 27% of U.S. ethanol imports coming from Brazil, while 34% came from Jamaica and 17% from Trinidad and Tobago. This is clearly not representative of the actual sources of the feedstock for these fuels. However, the $0.54 tariff on ethanol imports was allowed to expire on December 31, 2011, removing the distortion from the

6 Biofuels are traded as a commodity, making it impractical to determine the feedstock of each specific shipment of fuel being exported to the US. Moreover, this work aims to evaluate the impact of US biofuels demand on international agricultural activities. US demand for Canadian ethanol drives up demand for ethanol in Canada overall. This, in turn, causes cultivation of feedstocks according to their share of the Canadian ethanol market, regardless of the characteristics of the specific fuels exported to the U.S.

7 The CBI in particular was created to further a geopolitical goal - to solidify U.S. influence in the Caribbean and Central America in the face of Cold War era leftist movements in the region

CBI and CAFTA ethanol markets. In the years since, an average of 86% of U.S. ethanol imports have originated in Brazil, with 4.7% coming from Jamaica, and none from Trinidad and Tobago; this is a better representation of the actual sources of these fuels. In the interest of capturing the feedstock cultivation element of biofuels production, only 2012-2014 trade flow data are considered for the CBI and CAFTA-DR member nations.

Post 2011, the CBI/CAFTA-DR countries that exported ethanol to the U.S. were Costa Rica, El Salvador, Guatemala, and Jamaica. However, some of this fuel may still be ethanol that originated in Brazil due to existing supply chains and facility sunk costs. In order to determine the actual amount of domestically produced ethanol coming from these countries, we used the United Nations Comtrade Database to compare each country's ethanol imports from Brazil with its export to the United States. Ethanol is not typically cost-competitive with gasoline (which is why support policies such as the RFS are in place), so we assume that there is negligible domestic consumption of ethanol in the CBI/CAFTA countries. The difference between each country's ethanol import and its ethanol export provides an approximate amount of domestically produced ethanol. This domestic fuel is attributed to the US import market proportional to its share of the exporting country's total.

Through this process, we conclude that Guatemala and El Salvador have sufficient domestic biofuels feedstock production to warrant their inclusion. Guatemala produces over 44% of Central America's sugarcane ethanol (Tay, 2012). While there is still some dehydration of Brazilian ethanol in El Salvador, these activities are slated to close soon due to "lack of profit…[and] competitiveness" (Herrera, 2012) and our calculated volume of domestically produced ethanol exported to the U.S. is sufficient to warrant its inclusion here. Costa Rica and Jamaica, however, appear to still be primarily exporting dehydrated Brazilian ethanol rather than producing feedstock domestically. In Costa Rica, for example, Rutz and Jannsen (2014) note: "ethanol production has not started yet on an important and regular basis, because relative prices of sugar and ethanol do not provide adequate incentives" (p. 216). It is also notable that Costa Rican law specifically prioritizes food production over biofuels (IRENA, 2015).

Biodiesel supply from the European Union, Korea, and Singapore

For some countries exporting biofuels to the U.S. market, a significant fraction of that fuel is derived from feedstocks that are not of domestic origin. For example, Germany and the Netherlands both produce significant quantities of biofuels, some of which is exported to the U.S. market. Much of this fuel has historically been produced primarily from domestic rapeseed (a.k.a. canola), but international production increases in the past decade have led to the increased use of imported feedstocks. The same is true for Korea and Singapore, where biodiesel is made in large part from palm oil imported from major regional producers such as Indonesia and Malaysia. Since this analysis is primarily concerned with the impact of feedstock cultivation, we characterize the domestic biofuels industries in exporting countries, using national trade statistics and the UN Comtrade Database. In this way, we attribute fuel production to the country of feedstock origin, and are able to aggregate multiple trade pathways for a given feedstock into the U.S. biofuels market.

By combining, for example, figures for the annual U.S. biodiesel imports from Germany with data on the fraction of German biodiesel derived from soybean oil, as well as the fraction of German soybean oil imported from Paraguay, we are able to determine the volume of U.S. biofuels imports from Germany that is ultimately derived from Paraguayan soy.[8] Fuels with a given country and feedstock of origin enter the U.S. through a variety of intermediary countries, so this value would be summed with similar values from other trading partners, including direct imports, to determine the total amount of Paraguayan soybean oil biodiesel in the U.S. market.

3.1.2 Country/feedstock pairs of interest

After developing a database of U.S. biofuels imports by country of origin and associated feedstock, we then apply a significance threshold, eliminating sources representing less than 0.5% of total biodiesel or ethanol imports to the U.S. during the study period. This approach allows us to focus attention on significant biofuels trade flows, excluding marginal or one-time sources of biofuels from the study, while still capturing approximately 91% of all U.S. biofuels imports. Table 1 reports the ultimate list of crop/country pairs considered for the water footprint analysis, as well as the average volume of biofuels supplied by each. Since this analysis is primarily concerned with issues of extreme poverty and development challenges, we focused on developing countries and eliminated Canada and Germany from further analysis. However, as with the United States, production of biofuels in both of these countries still has the potential to negatively impact water quantity and quality in those countries.

TABLE 1: LIST OF IMPORTED BIOFUELS FEEDSTOCKS BY COUNTRY OF ORIGIN, INCLUDING THOSE INDIRECTLY IMPORTED VIA NON-DOMESTIC FEEDSTOCKS. HIGHLIGHTED COUNTRY/CROP PAIRS ARE INVESTIGATED FURTHER IN THIS STUDY, DUE TO INTERSECTING POVERTY/WATER SCARCITY ISSUES. BRAZILIAN SOY AND MALAYSIAN PALM ARE IMPORTED EXCLUSIVELY VIA OTHER COUNTRIES.

Country	Crop	Imported Via	Annual Import (1000s barrels)
		BIODIESEL	
Argentina[i]	Soybean		875
Brazil[ii]	Soybean	Belgium, Finland, Germany, Netherlands, Portugal, Spain	64
Canada[iii]	Rapeseed		353
Germany[iv]	Rapeseed	Netherlands, Norway	334
Indonesia[v]	Oil, palm	Belgium, Finland, Germany, Korea, Netherlands, Portugal, Spain, Singapore	547
Malaysia[vi]	Oil, palm	Belgium, Finland, Germany, Korea, Netherlands, Portugal, Spain, Singapore	83
Paraguay[vii]	Soybean	Belgium, Finland, Germany, Netherlands, Portugal, Spain	24
		ETHANOL	
Brazil[ii]	Sugarcane	Costa Rica, El Salvador, Jamaica	8,733
Canada[iii]	Maize		86
El Salvador[viii]	Sugarcane		42
Guatemala[ix]	Sugarcane		120

UNDERLYING TRADE DATA SOURCES: I) JOSEPH (2015); II) BARROS (2014), SECEX (2014); III) DESSUREAULT (2014); IV) COMTRADE (2015), ZHOU & KOJIMA (2011), UFOP (2013); V) WIYONO & WRIGHT (2014), COMTRADE (2015); VI) WAHAB (2014), COMTRADE (2015), GRAPHENE (2014); VII) JOSEPH (2015), COMTRADE (2015); VIII) HERRERA (2012), USITC (2015); IX) TAY (2012)

8 We assume that the sources of a country's biofuels reflect the sources of the feedstock in question overall. For example, if Germany sources 14% of its total soybean oil from Paraguay, we assume the same to be true of German soy oil biodiesel.

Palm oil biodiesel presents a unique case. Unlike the other fuels listed, palm oil biofuels do not meet RFS requirements. The EPA life cycle analysis found that palm oil biodiesel production systems generate on average a 17% GHG emission reduction below the petroleum baseline, failing to meet the threshold for inclusion (USEPA, 2012). However, we include it in this analysis for several reasons. First, despite its not being incentivized under the RFS, palm oil biodiesel *is* being imported to the U.S. in significant volumes (Wiyono and Wright, 2014 - USDA GAIN report). Further, palm oil is a major source for the biodiesel industries in many countries in Europe and East Asia that export biodiesel to the U.S. (see table 1). We assume a country's exports to be reflective of that country's production overall, because even where actual fuel shipments are shifted in order to meet U.S. regulations prioritizing different types of biofuels, the U.S. drives up demand for bulk biofuels in exporting countries, impelling their import of feedstocks proportional to their share of the domestic industry (see footnote 6). Finally, there is strong evidence that the production and import of biodiesel from non-palm fuels for the U.S. market also has the effect of spurring palm oil production for fuel and food markets in producer nations (UCS et al, 2012, Qui, 2014). The purpose of this study is to examine the impact of U.S. biofuels demand on water in feedstock producing developing countries. U.S. demand is clearly having an impact on palm oil biodiesel production in several ways, warranting its inclusion in the study.

3.2 Country Cultivation Profiles

To quantify the water impacts of growing various biofuels feedstocks, it is necessary to characterize the business-as-usual cultivation pattern in each country of interest. The crop profile of average cultivated land provides the basis from which different water footprint scenarios can be evaluated. The Food & Agriculture Organization Statistics Division provides key metrics in this process, including commodity production, area harvested, and producer price[9]. From these, yield and value per area are easily calculated. A larger time period is utilized for these statistics than for the biofuels data sample, in order to capture a wider array of agricultural outcomes, and to dilute the anomalous effects of short-term economic fluctuations. Over the ten-year period of 2004-2013, the database of annual average values for all crops in each country of interest is reduced to comprise only the crops that make up 1% or more of the average cultivated area in each country. The top cultivar lists range by country from 5 to 15 crops and cover 86% to 96% of the land area within each country.

3.3 Quantifying water use

The standard approach to estimating total crop water footprint is to calculate evapotranspiration (ET) using one of several models, which typically draw on mathematical characterizations of key crop physiological traits as well as climatic factors such as solar radiation, wind speed, humidity, and temperature (Allen, Pereira et al. 1998). Calculated ET can then be combined with estimates of effective (usable) rainfall to

9 FAOSTAT lacks producer price values for some of the top cultivars in specific countries, as well as prices for all Guatemalan crops. These data points are substituted with existing price values for the same crops in adjacent countries.

estimate blue and green water footprint.

The water footprint calculations for this work draw on the methods and published "WaterStat" databases from Mekonnen and Hoekstra (2011). In combining these values with the FAOSTAT production and yield data, we determine the blue, green, and grey water footprints on a per-acre basis for each of our target crop/country biofuels feedstock pairs as well as for other crops grown in each country. Where we evaluate water consumption per unit of biofuels, upstream consumption in the supply chain must be allocated among the various products being produced. For example, soy cultivation consumes a significant amount of water, and it takes about 40 pounds of soybeans to make a gallon of fuel, implying an *extremely* high WF per gallon of fuel. However, the bulk of that 40 pounds of soy is still very valuable as animal feed – and was also grown for that market. Assigning all of the water intensity of the soy cultivation to the biodiesel would imply that the cultivation of animal feed incurs no water footprint, which is clearly not the case. Assigning the water footprint to both products separately would be double-counting the impact. There are many ways to allocate among co-products, and this is an active area of research in the field of life cycle assessment (Wang et al, 2011). For this study, we allocate the upstream consumption among co-products on the basis of their relative energy content (i.e. if 50% of the energy content of a bushel of soy is in the oil used for biodiesel production, then that portion would be allocated 50% of the water footprint of its cultivation).

3.4 Biofuels Cultivation Scenarios

Having calculated the water footprints of the key biofuels feedstocks as well as the average cultivated acre in our focus countries, we are able to determine the water footprint associated with three basic scenarios for expanding biofuels production. The three scenarios evaluated by this study are extensification (expansion) onto previously uncultivated lands, displacement of average business as usual (BAU) cultivation, and displacement of low-economic value cultivation.

In the extensification scenario, the impact on water resources is the entire gross water footprint of biofuels crop cultivation. While the natural vegetation being displaced by biofuels feedstock cultivation would itself have consumed some green water, this water would not have been appropriated for human use, and is therefore not a 'footprint' in the conventional sense.

For the BAU displacement scenario, we make the first-order assumption that biofuels feedstock cultivation displaces other crops on average proportional to their share of cultivated land in the country of interest. Thus, the WF of the average cultivated acre in each country is characterized by the average of every cultivar's WF, weighted by its respective percentage of cultivated land. The displacement of this average acre is quantified as the difference between the specific biofuels crop's WF values per acre and those of BAU cultivation.

In practice, it is unlikely that expanded biofuels cultivation will displace crops indiscriminately regardless of their value or local agronomic conditions. Thus, the third scenario reflects overall water footprint change with the conversion of low-value crops, such as sorghum and wheat, to biofuels feedstock cultivation. Value is assessed on a dollar-per-area basis to reflect crop yields as well as price, and the quantity displaced is enough to meet the annual U.S. biofuels demand reported in Table 1. However, this scenario still doesn't necessarily project a precise representation of selective displacement, which would require detailed characterization of economic, political, and environmental drivers at the local level, including agricultural sector structure, land use policies, and local soil and climatic conditions. This level of detail would not be suitable to the first-order global analysis conducted here, which aims to identify cases in which higher resolution investigation is warranted.

3.5 Characterizing water stress and identifying "hot spots"

Most assessments of the water footprint of biofuels (King and Webber, Gerbens-Leenes, Hoekstra et al 2009, Fingerman, Torn et al 2010) aim solely to quantify water consumption per unit of biofuels produced. Such quantified water demand can be useful in developing a high-level understanding of impacts or trends, but is of limited utility absent some characterization of the resource base being drawn upon (Fingerman, 2011). While water is an essential resource everywhere, some areas have a more limited water resource base, making any increase in consumption due to biofuels feedstock cultivation a more acute stressor. In order to identify hot spots for water resource risks from biofuels production, our estimated water footprint values have to be placed into a quantitative context of water scarcity and pollution.

For this study, we evaluate water scarcity on the basis of the Water Stress Indicator (WSI) developed by the International Water Management Institute (Smakhtin et al. 2004). This metric is based on the fraction of the total renewable resource base that is being withdrawn for all human uses. In quantifying the renewable resource base, the WSI also takes into account the fact that some volume of flow (termed 'environmental flow' or 'environmental water requirement') must be left in-stream for the maintenance of ecological integrity and ecosystem services[10].

$$\mathbf{WSI} = \frac{\mathbf{U}}{\mathbf{(R\text{-}EWR)}}$$

where:

WSI = *Water stress indicator (Smakhtin, 2004)*
U = *Withdrawal for human use in the area of interest [m^3 $year^{-1}$]*
R = *Renewable water resource in the area of interest [m^3 $year^{-1}$]*
EWR = *Environmental Water Requirement in the area of interest [m^3 $year^{-1}$]*

10 Examples of the services provided to human populations by aquatic ecosystems include water purification, food production, flood and drought mitigation, and groundwater recharge.

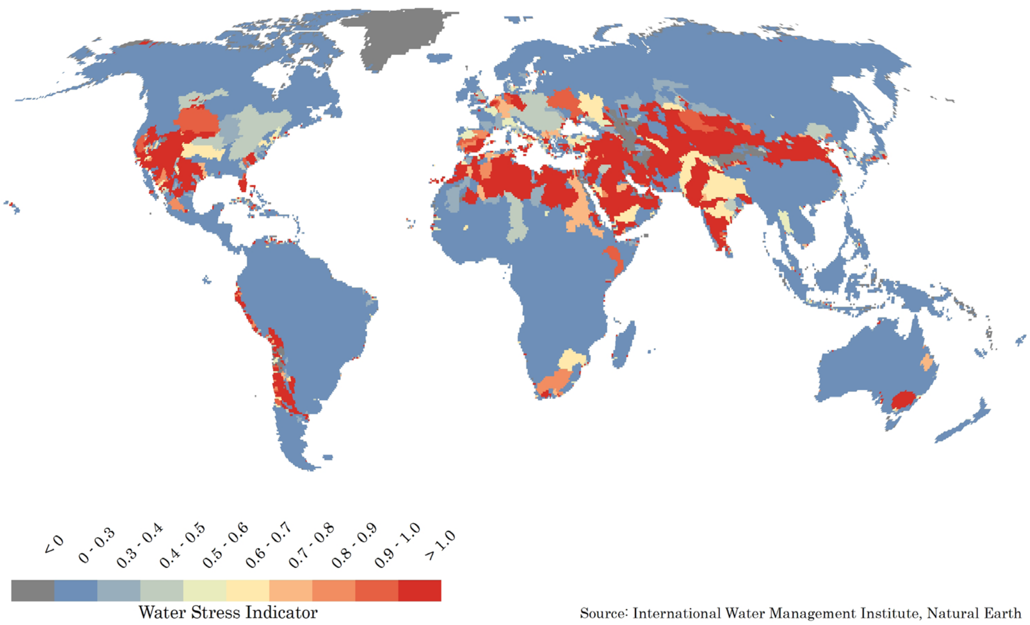


FIGURE 4: GLOBAL WATER STRESS AS CHARACTERIZED USING THE WSI.

In evaluating water quality, nitrogen contamination is used as a key indicator of overall basin-scale pollution level. Spatial data obtained from the World Water Assessment Program (WWAP) (Figure 5) include nitrogen flux values for riverine systems on a water basin scale.

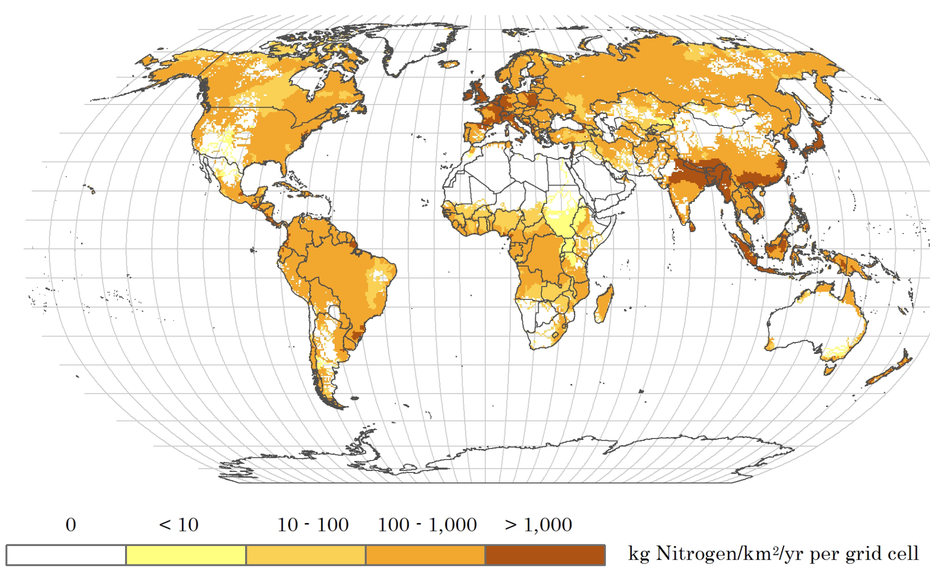


FIGURE 5: GLOBAL NITROGEN FLUX BY RIVER BASIN (DATA: WORLD WATER ASSESSMENT PROGRAM).

By combining calculated blue water consumption on gross and net basis with this characterization of water stress, we are able to identify areas and conditions in which water stress stands to be potentially exacerbated by bioenergy crop cultivation. A similar approach is taken for water quality concerns; spatial data describing nitrogen pollution levels at a river basin scale are combined with grey water footprint values to identify nutrient pollution hot spots attributable to biofuels feedstock cultivation.

To identify regions of water quantity concern, we select areas of overlap between water scarcity and blue water consumption of the biofuels crops in select countries. Following Smakhtin et al (2004) we consider a WSI value above 0.3 to significant, and highlight those areas where this level of scarcity or greater overlaps with blue water consumption via irrigation for biofuels feedstock cultivation.

Identifying regions of water quality concern follows a similar process, in which areas of overlap are identified between nitrogen pollution and the grey water footprints of the biofuels crops. Following the U.S. EPA's average standard for U.S. surface flows, we consider water quality to be degraded in areas where nitrogen contamination exceeds 1395 kg per km^2. These regions are then combined with grey water footprints for the crop/country combinations in question to identify regions where water contamination from bioenergy feedstock cultivation occurs in already degraded watersheds.

4. Background on Countries of Interest

All bioenergy information in this section is sourced from each country's referenced Biofuels Annual GAIN report, unless cited otherwise.

Argentina

Argentina presents a particularly interesting case since, as can be seen in Figure 6, its current agriculture cultivation patterns already contains huge amounts of biofuels feedstock. Argentina does consume some biofuels domestically, with 10% blend mandates for both biodiesel and ethanol. There is some momentum to increase the ethanol mandate to 12% in the coming years. However, 70% of Argentina's biofuels are exported, with increased domestic consumption expected to decrease exports to 55% by 2016. Over half of Argentina's cultivated area is devoted to soybean production, with an average annual production of 45 million kilograms (FAOSTAT, 2013). During the last decade, the average cultivated area has been 30.7 million hectares, for which the other major cultivars and their proportions can be seen in Figure 6. Argentine ethanol feedstocks are a combination of sugarcane and grain, making up about 55% and 45%, respectively.

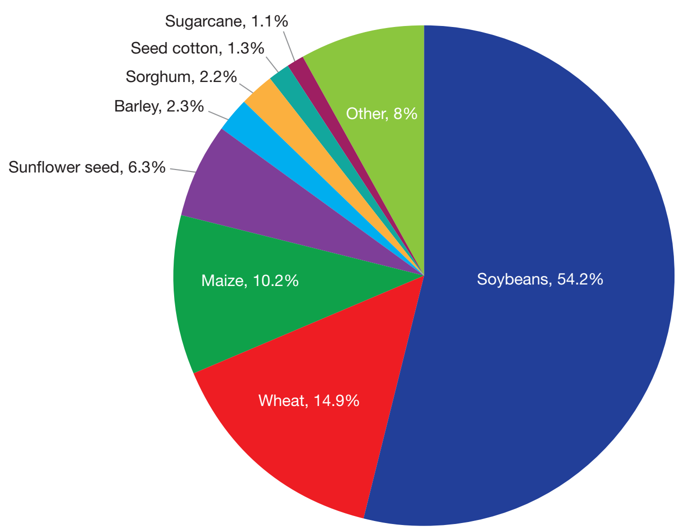


FIGURE 6: ARGENTINEAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (DATA: FAOSTAT, 2015).

Even in countries like Argentina, there are opportunity costs to water consumption for bioenergy, as they still face notable challenges for food and water security. Over 8% of Argentinean children are stunted or severely underweight. While improvements have been made, nearly 11% still lack access to piped water and only 35% of the population does not have access to sanitation facilities.

Brazil

With one of the world's most active biofuels industries, Brazil has alternated with the United States several times in recent years as the world's largest ethanol producer and exporter. Brazil mandates a 27.5% ethanol blend in its gasoline as well as 5% for biodiesel, although the government has been known to adjust this mandate. Brazil's domestic consumption is far higher than most developing countries, particularly in the Americas. Operating at 65% capacity, Brazil's 400 refineries process over 300 million MT of sugarcane feedstock and produce about 27 billion liters of ethanol annually, over 90% of which is consumed domestically. Brazil also produces almost 1 billion gallons of biodiesel annually, with 70% from soybeans and 20% from animal tallow. Considering the level of biofuels production, it is not surprising to see soybeans, corn and sugarcane as the top three crops in Brazil. São Paulo, Goias, Minas Gerais and Mato Grosso do Sul are the top sugarcane producing states in Brazil. In the senario where low-dollar value cultivation is converted for biofuels, wheat would be displaced.

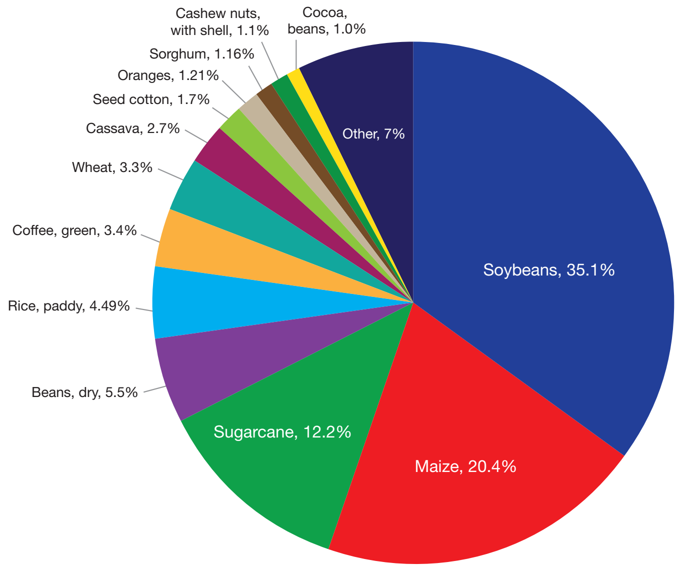


FIGURE 7: BRAZILIAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (DATA: FAOSTAT, 2015).

Brazil has made important strides on hunger, but this progress is potentially fragile. In 2015, São Paulo, Brazil has struggled as an ongoing drought has all but drained the water reserve systems that serve the city and surrounding areas (Whately and Lerer).

El Salvador

While there have been several domestic and international efforts to stimulate biofuels production in El Salvador, the industry has not grown significantly. CAFTA provides

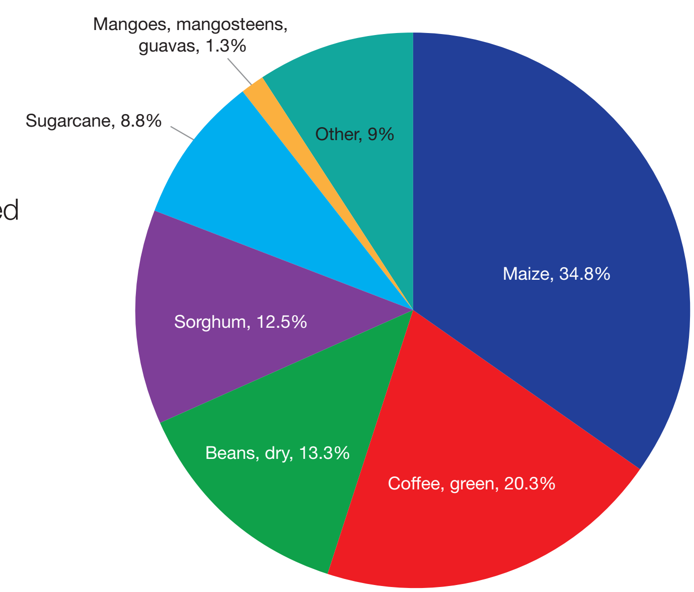


FIGURE 8: SALVADORAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (DATA: FAOSTAT, 2015).

El Salvador with a sizeable ethanol quota for duty-free export to the U.S., of which 5.2 million gallons can be produced from non-domestic feedstocks. Some of El Salvador's current ethanol production is from domestic feedstock, and the intent is to realize its capacity for increased local production in the future. While the 2012 GAIN report is optimistic about future production potential, it is unclear where the authors anticipate such expansion. El Salvador's land area is slightly over 2.1 million hectares, and between current agriculture occupying 1.5 million hectares plus forests at 270,000 hectares, before considering urban areas, there is little unused land. The crop breakdown of El Salvador's cultivated area can be seen in Figure 8. El Salvador grows a significant amount of corn, which could be used for biofuels but also obviously for food, but otherwise grows far fewer feedstocks than either Brazil or Argentina. In a low dollar cultivation scenario, sorghum would be displaced.

Considering the limited available land, it is quite likely that an expansion of biofuels in the country would displace cultivation for other purposes, putting food rights at risk. Over 19% of El Salvador's children are stunted and 12% of people are undernourished, while many of those living in rural areas do not have access to sanitation.

Guatemala

Food security remains a challenge in Guatemala, where over 30% of the population is undernourished. This level of food insecurity has remained fixed since 2000, despite GDP increases. Of particular concern, according to UNICEF, 48% of children suffered from stunting between 2008 and 2012.

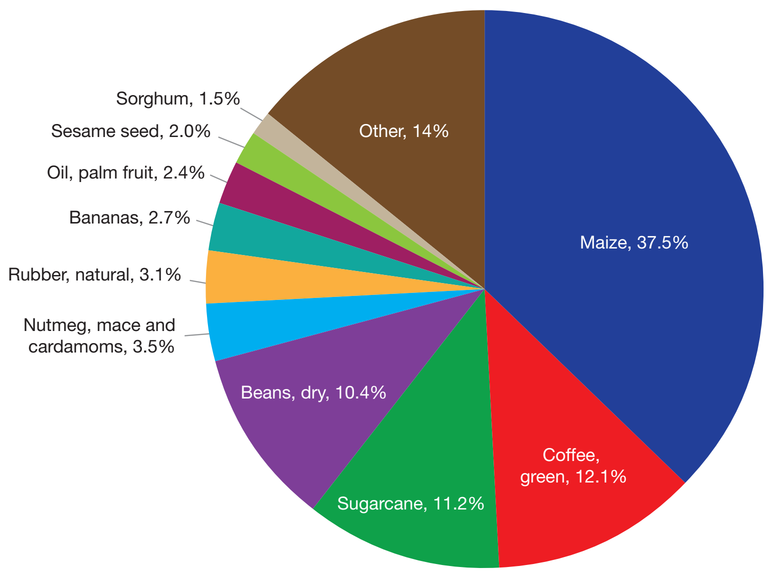


FIGURE 9: GUATEMALAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (DATA: FAOSTAT, 2015).

The remaining food security challenges have not prevented the growth of biofuels production in Guatemala. However, there is essentially no domestic market for ethanol consumption, due to political and economic barriers that prevent enactment of a blend mandate. Despite this, global demand has driven expansion of feedstock cultivation in Guatemala.

The structure of Guatemala's bioenergy industry is concisely captured in the title of the 2012 Guatemala GAIN Report, "A big splash of ethanol and a drop of biodiesel." The robust sugarcane industry has made it the most prolific ethanol producer in Central America. It is one of the top five sugar exporters by volume globally, and its cultivation efficiency is on par with that of Brazil. Five sugar mills with ethanol refining capabilities process 25 MMT of sugarcane and produce 3 million liters of ethanol annually. As seen in Figure 9, sugarcane covers just over 10% of cultivated land in Guatemala.

Palm oil, for biodiesel and other uses, is beginning to gain ground in Guatemala, which is now Central America's second largest producer. The impact that palm oil can have on water recently gained national and international attention, when a palm oil processing plant leaked a pesticide into La Pasión River. More than sixty miles of river were contaminated, adversely affecting hundreds of fisherman whose livelihoods were dependent on the river's health. While this report is focused on feedstock production rather than processing, this case demonstrates how crucial water is for local communities and how devastating the effective loss of even relatively small amounts of water can be.

Indonesia

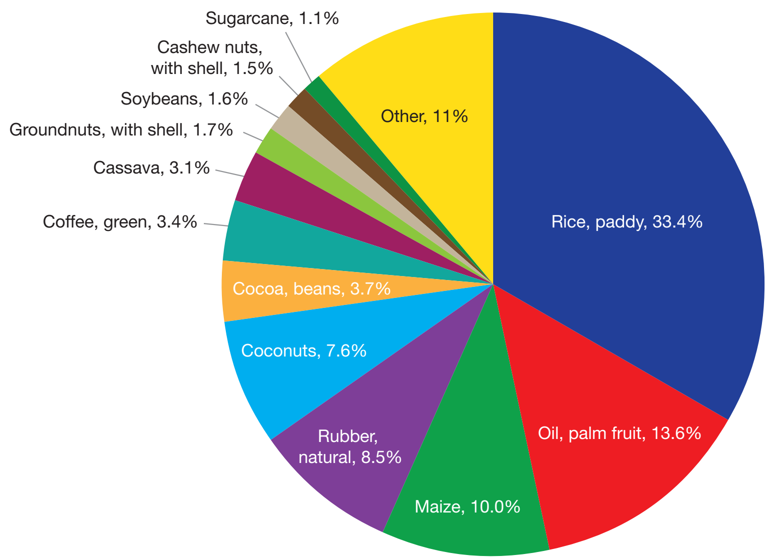


FIGURE 10: INDONESIAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (DATA: FAOSTAT, 2015).

There are 19.4 million chronically hungry people in Indonesia. However, mandatory liquid fuel blend targets in Indonesia are currently 5-10% for both biodiesel and ethanol, depending on the industry sector. At present, palm oil is the only major domestic feedstock, though several other oil crops are being considered and could become viable, including coconut oil. In 2014, about 70% of production was consumed domestically, with the rest exported mainly to the European market. Indonesia's government has also repeatedly sought ways to increase production and consumption of biofuels.

Indonesia's BAU cultivation, as seen in figure 10, contains a variety of food crops, of which rice is the largest. Displacing the BAU cultivation would mean displacing a notable amount of rice, which could actually lower the net water footprint because rice is highly water intensive. However, this would also mean displacing needed food. Rubber is the low dollar cultivation crop that would be displaced in scenario three.

Malaysia

As of November 2014, Malaysia has a blend mandate of 7% biodiesel, but the program has experienced delays and has yet to be implemented nationwide (Graphene, 2014). As in the case of Indonesia, most of Malaysia's palm biodiesel is consumed domestically and Europe is the major importer. Increasingly, the reliance on palm oil and its detrimental environmental impacts have been a concern for some importers. As seen in Figure 11, oil palm covers over 60% of cultivated Malaysian land. In a low dollar cultivation scenario, rubber would be displaced for biofuels production.

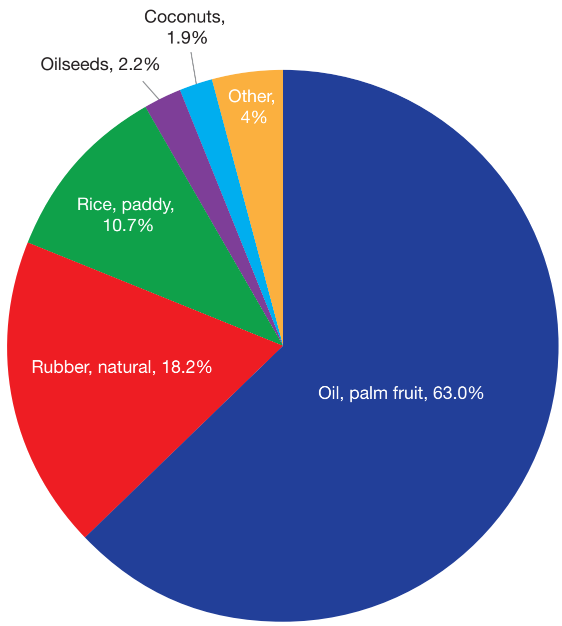


FIGURE 11: MALAYSIAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (FAOSTAT, 2015).

Malaysia has also struggled with drought in recent years, which has led to water shut offs in its capital city as reservoirs went dry.

Paraguay

Paraguay suffered a major drought in 2013 that left many communities without access to sufficient water. Paraguay has a domestic biofuels mandate as well as exporting biodiesel feedstock. A Paraguayan law was passed this July requiring an ethanol blend mandate that will be set according to domestic supply. Currently, around 25% of Paraguay's transportation fuel is biofuels.

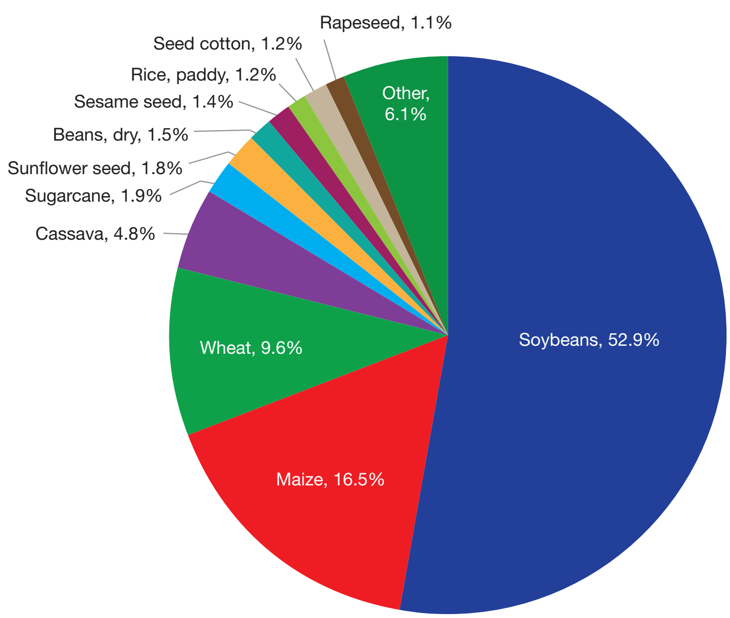


FIGURE 12: PARAGUAYAN CULTIVATION PERCENTAGES BY AREA OF CROP HARVESTED (FAOSTAT, 2015).

The ethanol and biodiesel processed in Paraguay is consumed domestically, but it exports biodiesel feedstocks to be refined into biodiesel elsewhere.

Most of this fuel is soybean-based, but canola and sunflower oils are occasionally used as feedstocks as well. Paraguay produces 8-9 million MT of soy annually, making it the sixth largest soybean producer in the world. The other major cultivars can be seen in Figure 12.

5. Results

The results of this study, in all three scenarios, show that biofuels feedstock production has a significant impact on water. The results from the first scenario, where biofuels feedstock production occurs on previously uncultivated land, are found in Table 2 and Figure 13. Table 2 lays out the gross water footprints of each study case as well as the total annual virtual water flow driven by U.S. biofuels demand. Since the biofuels production in this scenario is not replacing cultivation, the entire WF is attributable to biofuels[11]. This water could have been devoted to other uses if not used to cultivate biofuels feedstock, and therefore represents a cost of the biofuels production. Water plays a key role in ecosystem maintenance, so while the land may have been previously uncultivated, the water may have been serving an important environmental purpose.

TABLE 2: TOTAL GROSS WF VALUES FOR SELECTED FEEDSTOCKS, AND "VIRTUAL WATER" EMBEDDED INTO U.S. BIOFUELS IMPORT VOLUMES FROM EACH COUNTRY.

Feedstock	Gross WF (gal water/gal fuel)	Virtual Water (billion gal/yr)
Argentinean soybean	4,620	170
Brazilian soybean	4,811	13
Brazilian sugarcane	1,320	484
Guatemalan sugarcane	1,637	3
Indonesian palm	1,383	7
Malaysian palm	4,224	97
Paraguayan soybean	5,495	5
Salvadoran sugarcane	3,744	13

Many of the biofuels imported to the U.S. are very water intensive, and represent a significant flow of "virtual water" from their countries of origin to the United States. The virtual water trade is an important consideration for biofuels, especially if they are exported from poor countries and imported by developed countries. Virtual water is the water consumed in the production of the biofuels feedstock. If that resulting fuel (or feedstock) is then exported, the water that was consumed is essentially exported as well. As Table 2 demonstrates, the biofuels imported to the U.S. are very water intensive and represent a significant flow of water. The total amount of virtual water being exported may not fully illustrated the costs to the country; for example, the virtual water flowing from Guatemala to the United States as part of their biofuels exports is the least of any other country considered in this report. However, due to water stress and water quality issues, exporting that much virtual water may be a greater burden to Guatemala than other countries' with higher virtual water flows.

The WF in this scenario are broken out into blue, green, and grey fractions in Figure 13 and displayed on a per acre basis, indicating the total amount of each type of water consumption that is required for cultivation of each feedstock in the study countries.

11 This is unambiguously true for blue and grey water, but is complicated in the case of green water, since existing vegetation on the natural or abandoned agricultural landscape being converted would have consumed some green water. Since this water is providing environmental services, and is not a water diversion for human use, we do not consider it a water footprint.

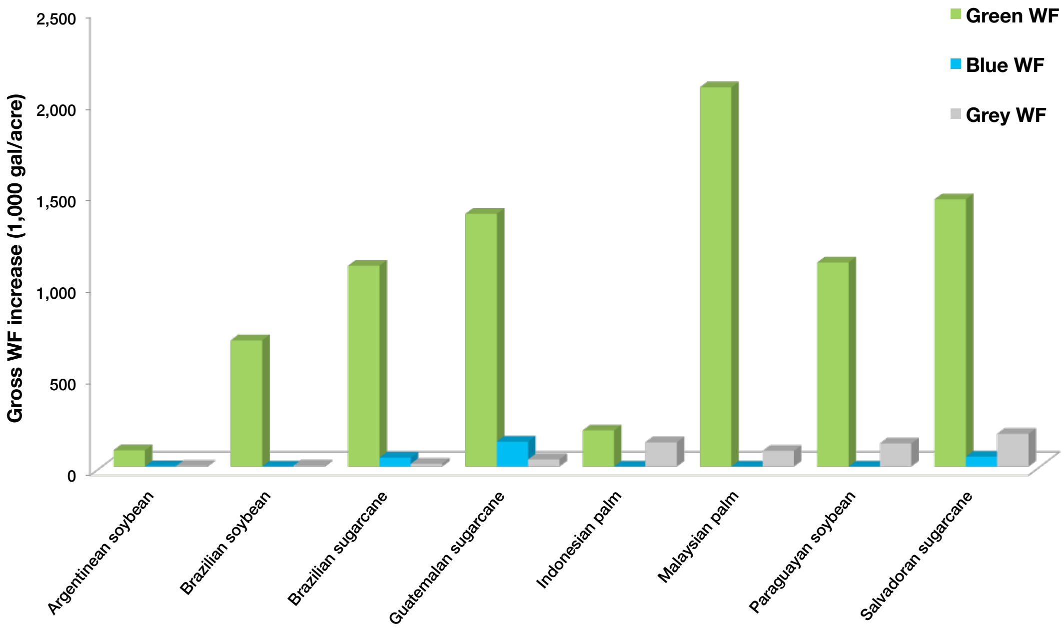


FIGURE 13: GROSS WATER FOOTPRINT OF BIOFUELS FEEDSTOCK CULTIVATION IN COUNTRIES OF INTEREST.

Gross water footprint values such as those presented in Table 2 and Figure 13 can be useful in understanding the differences between types of biofuels and capturing the cost of biofuels consumption. Some biofuels are more water intensive and costly than others, and can also create different types of trade-offs. For example, Guatemalan sugarcane has a much higher blue and green footprint than Indonesian palm oil biodiesel. However, the greywater footprint for palm oil is much higher.

Of course, if the biofuels feedstock is displacing other cultivation, the gross footprint does not account for the water consumption that would have occurred in its absence. If other agricultural production is being displaced by feedstock cultivation, the water footprint of this alternate cropping system must be considered if we are to characterize the net effect of biofuels feedstock cultivation. As described in section 3.4, we use an area-weighted average of all crops representing more than 1% of cultivated acreage in each country as a proxy for BAU cultivation. Table 3 and Figure 14 present the results for the net effect of displacing BAU cultivation with biofuels feedstock.

TABLE 3: PERCENT CHANGE IN GREEN, BLUE, AND GREY WF OF REPLACING BAU AVERAGE CULTIVATION WITH BIOFUELS FEEDSTOCK.

Feedstock	Green WF	Blue WF	Grey WF
Argentinean soybean	-36%	-71%	-70%
Brazilian soybean	33%	-98%	-78%
Brazilian sugarcane	111%	186%	-32%
Guatemalan sugarcane	154%	626%	-25%
Indonesian palm	-72%	-100%	173%
Malaysian palm	39%	-100%	35%
Paraguayan soybean	-11%	-100%	47%
Salvadoran sugarcane	196%	877%	167%

As demonstrated in Table 3 and Figure 14, results indicate that the net effect of shifting cultivation away from existing cropping patterns to biofuels feedstock production involves tradeoffs among these different water types. In some cases, such as Indonesian palm and Paraguayan soy, the biofuels crop demands less rain and applied water than the mix of BAU crops, but at the expense of increased pollution. For cultivation of Brazilian and Guatemalan sugarcane, the situation is the opposite. Argentinean soy cultivation causes all three WF types to decrease, while Salvadoran cane causes all to increase. Overall, there is a net increase in water footprint for five out of the eight study cases with the switch from average cultivation to fuel crop cultivation. Two of the three that do not experience a net increase see significant increases in their grey water footprint (Indonesia and Malaysia). Argentinean soybean production sees a decrease in the net WF, possibly because Argentina's BAU cultivation is already water intensive, so displacing BAU cultivation for soy means a relatively lower WF.

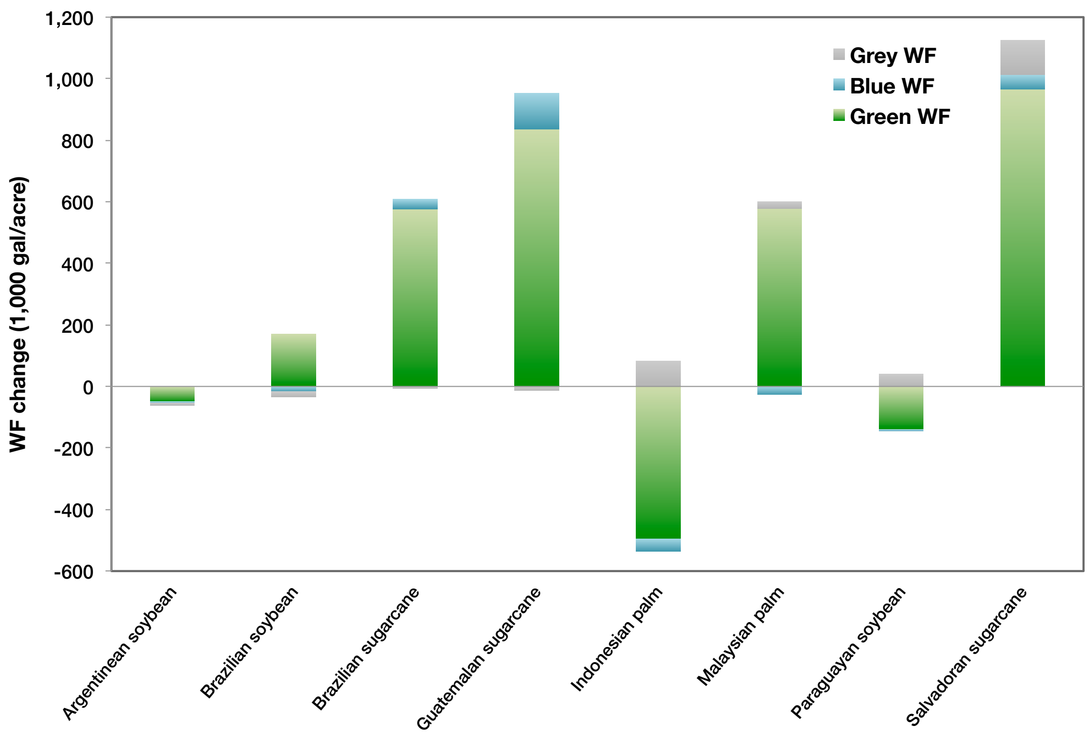


FIGURE 14: NET CHANGE IN BLUE, GREEN, AND GREY WATER CONSUMPTION PER ACRE ASSOCIATED WITH THE SHIFT FROM BAU CULTIVATION TO BIOFUELS FEEDSTOCK IN THE STUDY COUNTRIES.

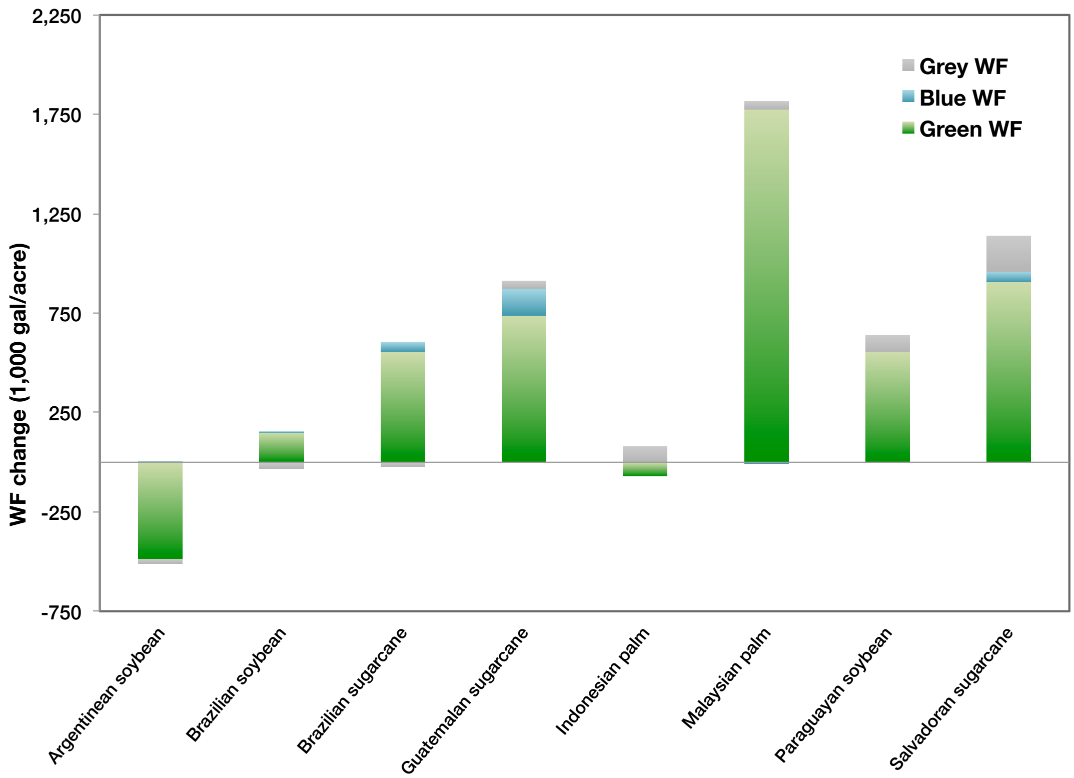


FIGURE 15: NET CHANGE IN BLUE, GREEN, AND GREY WATER CONSUMPTION PER ACRE ASSOCIATED WITH CONVERSION OF LOW-VALUE CROPS TO BIOFUELS CROPS IN THE STUDY COUNTRIES.

In the third scenario, where the lowest value crop is displaced by biofuels feedstock cultivation, the displaced crops are barley in Argentina and Paraguay, sorghum in El Salvador and Guatemala, rubber in Indonesia and Malaysia, and wheat in Brazil. In this scenario, we see a net increase in WF values in six out of the eight study cases (Figure 15). As with the previous scenario, there are tradeoffs between WF types, such as the increase of polluted water with the savings of rain and applied water for the switch to palm in Indonesia. In general, it appears that displacing just the low-value crops produces WF changes in the same direction, but to a greater extent, than displacing BAU cultivation.

While the above results shed light on the macro-scale global impacts of shifts to biofuels cultivation, these values can best be understood in light of existing water scarcity or pollution conditions. This study also seeks to identify trends at a smaller scale, and to show where the potential impacts to water sources in the previous scenarios overlap with existing water scarcity. To this end, we combined spatial data on pollution levels and water scarcity, with blue and grey water footprint figures to identify potential localized hot spots for increased impact on already strained resources. Figure 15 shows the global spread of these hot spots.

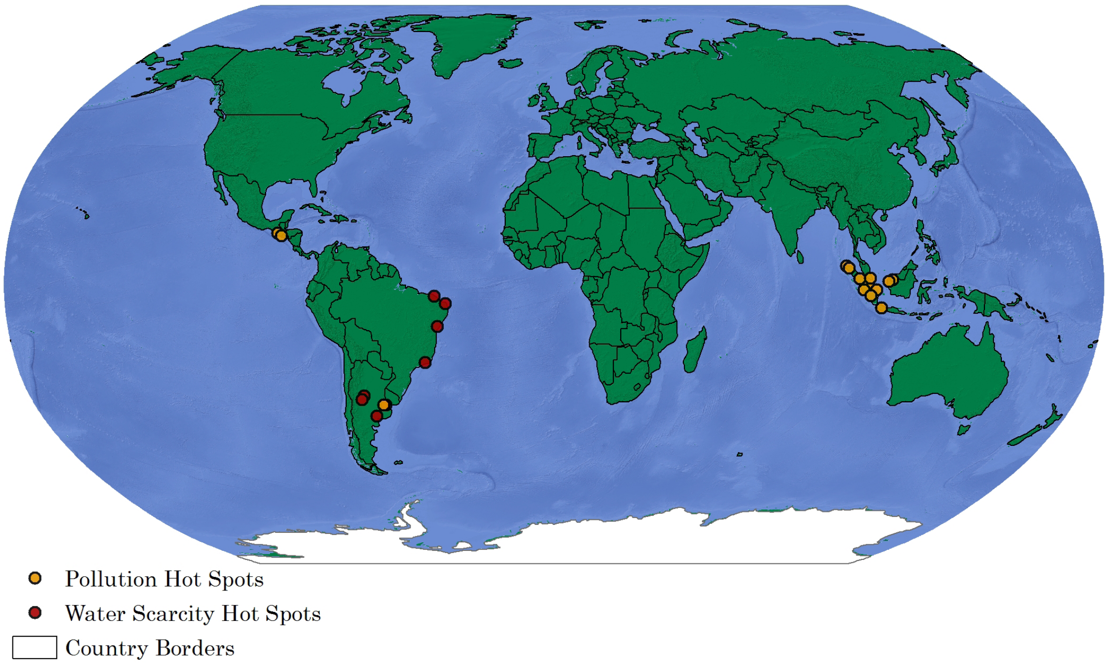


FIGURE 16: GLOBAL MAP OF HOT SPOTS WHERE BIOFUELS CROP WATER FOOTPRINTS INTERSECT WITH EXISTING WATER SCARCITY (RED) AND WATER POLLUTION (YELLOW) IN THE STUDY COUNTRIES (DATA: WFN, IWMI).

The above figure provides a global perspective of what regions stand at risk of exacerbated water scarcity or water pollution due to biofuels feedstock cultivation. The water scarcity hot spots are places where the irrigated water used on the biofuels crop occurs in areas that have significant water scarcity index values. Some of these areas correlate with higher population areas, where the demand for water for non-agriculture human needs, would be higher. The water pollution hot spots are places where the resulting runoff impacts of the biofuels crops occur in areas that have significant nitrogen pollution levels.

The countries with identified areas of water quantity concern are Argentina, for soybeans, and Brazil, for sugarcane. In Argentina, the “hot spot” regions are located in the provinces of Ciudad de Buenos Aires and San Luis, with a small section in Córdoba. The hot spots in Brazil are located along the coast in the states of Ceará, Rio Grande do Norte, Bahia, and Rio de Janeiro. In Brazil, these regions have several large and medium sized cities, as well as being semi-arid where they experience dry seasons. Biofuels expansion in Brazil recently has been more in the middle of the country, which is also associated with challenges. The state of São Paulo for example is a major sugarcane and ethanol producer, but the state is also urbanized and facing issues of water scarcity. Higher resolution maps of the water quantity hot spots in individual countries can be found in Appendix 1.

The countries we find to possess areas of water quality concern are Argentina, El Salvador, Guatemala, Indonesia, and Malaysia. These can be seen in greater detail in Appendix 2. In Argentina, the single nitrogen pollution hot spot is located in the province of Ciudad de Buenos Aires. The hot spot in El Salvador is located in the western part of the country in the department of Ahuachapán. In Guatemala, the regions of nitrogen pollution concern are in the southern part of the country, mainly in the departments of San Marcos, Quezaltenango, Sololá, Chimaltenango, and Sacatepéquez. Smaller regions are also identified in the Guatemalan departments of Retalhuleu, Escuintla, Guatemal a, Suchitepéquez, Totonicapán, Santa Rosa, Jutiapa, and Quiché. Indonesian nitrogen hot spots are mostly located in the western part of the country in the provinces of Aceh, Sumatera Utara, Riau, Sumatera Selatan, Jawa Barat, and Kalimantan Barat. Smaller regions are also identified in the provinces of Bengkulu, Banten, Jakarta Raya, Lampung, and Jambi. In Malaysia, the pollution hot spot regions are in the southern portions of the country in the provinces of Johor and Sarawak.

6. Discussion

Water's critical role in human rights and poverty has already been discussed, but it is important to consider water security in the context of increased demand from biofuels markets. Water devoted to biofuels production is not available for other human or ecosystem uses – a dynamic that is problematic in locations where the water resource base for consumption, sanitation, or food cultivation is degraded. In addition to current impacts, the future risks to the water system should also be considered. Population growth and changing diets will increase demands on water resources, which are expected to become scarcer in some key regions due to climate change. Where import pressures from the developed countries are driving local resource scarcity, especially where those pressures are the result of policy frameworks, these impacts must be re-evaluated.

As these results make clear, biofuels feedstock production has an impact on water that is far too significant to be ignored. The gross water footprint for biofuels, which is the full cost when biofuels production is expanding into previously uncultivated areas, is considerable. In some areas, this new demand for water to produce fuel could strain existing water systems.

These results indicate that the shift towards biofuels crop cultivation (either in the BAU or low-dollar cultivation scenario), while mixed, is largely detrimental to the water resource bases of producer nations. It is also notable that biofuels imports represent a significant transfer of "virtual water" from producer nations to the U.S., most notably 497 billion gallons per year from Brazil and 170 billion from Argentina.

The most WF changes from the various cultivation scenarios are in the form of green water, but the significance of the irrigation and pollution changes (blue and grey WF) should not be underestimated. In particular, with the displacement of average cultivation, the blue WF increases in all sugarcane countries, but decreases in both oil palm countries. The former is due to the heavy water demand for sugarcane as a crop overall, while the latter is due to the fact that the growth of oil palm in Indonesia and Malaysia – by far the largest producers in the world – is almost entirely rain-fed. However, it is important to remember blue water is not the whole story and palm oil cultivation was found to increase the grey WF in both countries.

Of the cases investigated, Brazilian sugarcane and Argentinean soy were found to create potential hot spots for risk of exacerbating water scarcity (see Appendix 1). Hot spots were particularly prevalent in peri-urban regions of coastal Brazil. This may be due to the fact that larger populations in these regions draw more heavily on the available resource base. This scarcity would be exacerbated by a shift to sugarcane, which we found to consume 186% more water than the average BAU cultivated acre it could stand to replace. As with the BAU-displacement scenario, displacement of low-value crops would lead to an increase in irrigation demand per acre in all of the sugarcane cases. It is important to remember that these hotspots do not capture all areas of concern in each country. Biofuels are currently expanding in the middle of Brazil rather than the coastal areas, and this is impacting water in those regions such as São Paulo. Additionally, the net blue WF of Argentinean soybeans changes from negative to positive when low-value crops are displaced rather than BAU cultivation.

Regarding changes to grey WF, it is important to note that a small sliver on the column graph translates to thousands of gallons of contaminated water per acre of cultivation. Even if the amount polluted is small compared to water resources globally or even nationally, pollution in particular areas that makes water undrinkable or damages ecosystems has a dramatic impact on local communities. The most notable trend in grey water consumption is an increase in polluted water associated with palm oil cultivation in both study cases, regardless of the scenario. Indonesia and Malaysia also contain regions of nitrogen pollution concern (see Appendix 2). This raises a significant risk of detrimental impacts on already-degraded water quality in these countries. Some regions of Malaysia, and large swaths of Indonesia, were determined to be hot spots for water quality risk from biofuels feedstock cultivation. Salvadoran cane production also returns large grey WF increases in both displacement scenarios, and was found to have a hot spot region for water quality risk.

Despite the trends that emerge from this study, the net effect of biofuels feedstock cultivation varies greatly from case to case depending on the feedstock in question, the cropping system being displaced (if any), and the existing state of the water resource base. In general, increased production of biofuels feedstock crops can lead to detrimental outcomes for the water resource base when:

1. Their cultivation or expansion leads to extensification, causing an increase in total cultivated area.
2. Biofuels feedstocks displace less water-intensive cropping systems.
3. Feedstocks are grown in locations with existing water resource scarcity.
4. Pollution from feedstock production (grey water) creates water scarcity.

Including water analysis can complicate the evaluation of the bioenergy environment. For example, the matter of indirect land use change (Searchinger et al, 2008; Hertel et al, 2010) creates interesting tradeoffs related to water. To avoid displacement of current cultivation and the attendant iLUC-derived GHG emissions, some bioenergy policies create an incentive to expand onto previously uncultivated land or to intensify production through the addition of chemical fertilizers so as to increase output. These practices, however, create a bioenergy system more likely to exacerbate water resource concerns. The poverty implications are even more complex and case-specific, since either the displacement of existing cultivation or the strain on water resources from expansion *could* exacerbate underlying poverty concerns. It bears noting that iLUC does carry an attendant indirect water use change. This is a real impact of bioenergy system expansion, but is not considered in this analysis.

While this analysis sheds light on the potential impact of bioenergy production at a national or watershed scale and identifies hot spot areas of potential concern, some of the impacts of these activities can occur at a much more localized level, and cannot be captured by this type of global-scale desk study. Some such localized effects include (adapted from Fingerman et al, 2011):

- Although the industrial processing of feedstock to biofuels represents less than 1% of the total WF for most systems (Fingerman et al, 2010), it occurs all in one location, and might have a larger impact on that location's resource base than the larger, but more spatially diffuse, feedstock cultivation.

- The nature of the local resource base being consumed or polluted can lead to larger impacts than the scale of the consumption would indicate. Water consumption or pollution in key habitats such as aquifer-recharge zones, wetlands, and floodplains can have watershed-wide effects.

- Small pollution flows, even when not sufficient to trigger "hot spot" concerns at a basin scale, can lead to localized ecological toxicity, eutrophication, or human health effects. Small pollution flows can also undermine livelihoods - such as fishing - that rely on specific local water sources and ecosystems.

- Water insecurity for local communities is not necessarily the result of absolute water scarcity. Instead, it can be driven by social dynamics such as equity of access, barriers to entry, deficient infrastructure, institutional failure, and other considerations. These considerations may be impacted by biofuels expansion, whether or not conditions of absolute scarcity exist.

- The impact of even absolute water scarcity varies with demographic and economic circumstances. Some populations are much more able than others to alter their consumption patterns, gain access to new resources such as groundwater, and import "virtual water" in the form of water-intensive consumer goods.

These local impacts should be examined in more detail through site visits to impacted areas. This study can be used to guide such efforts, identifying priority areas for further investigation and impact mitigation.

7. Policy Recommendations

As this research has illustrated, biofuels have a complicated impact on water. In aggregate, this impact is often negative and water is far too vital of a resource to leave the issue to chance. The Renewable Fuel Standard and other policies promoting biofuels must not be allowed to ignore both global and local impacts of biofuels demand on water. In addition to food security, land-use change, and greenhouse gas emissions, any comprehensive analysis of biofuels policies must include the impact on water. While a global level analysis is important, every effort should be made to include the local impacts where the feedstock will be produced. Small increases in the WF that have minimal global impact can still profoundly impact communities in vulnerable areas.

ActionAid USA also makes the following policy recommendations:

- Water usage for human needs, sanitation, ecosystem integrity, and for food security should take priority in land use planning and trade policy.
- Criteria for sustainability must include more than simply lowered emissions; impacts on water and local ecosystems must also be part of the criteria.
- Particular attention should be paid to the flow of “virtual water” from developing countries to developed ones. Water is vital to development and must not be jeopardized by governments’ trade and energy policies.

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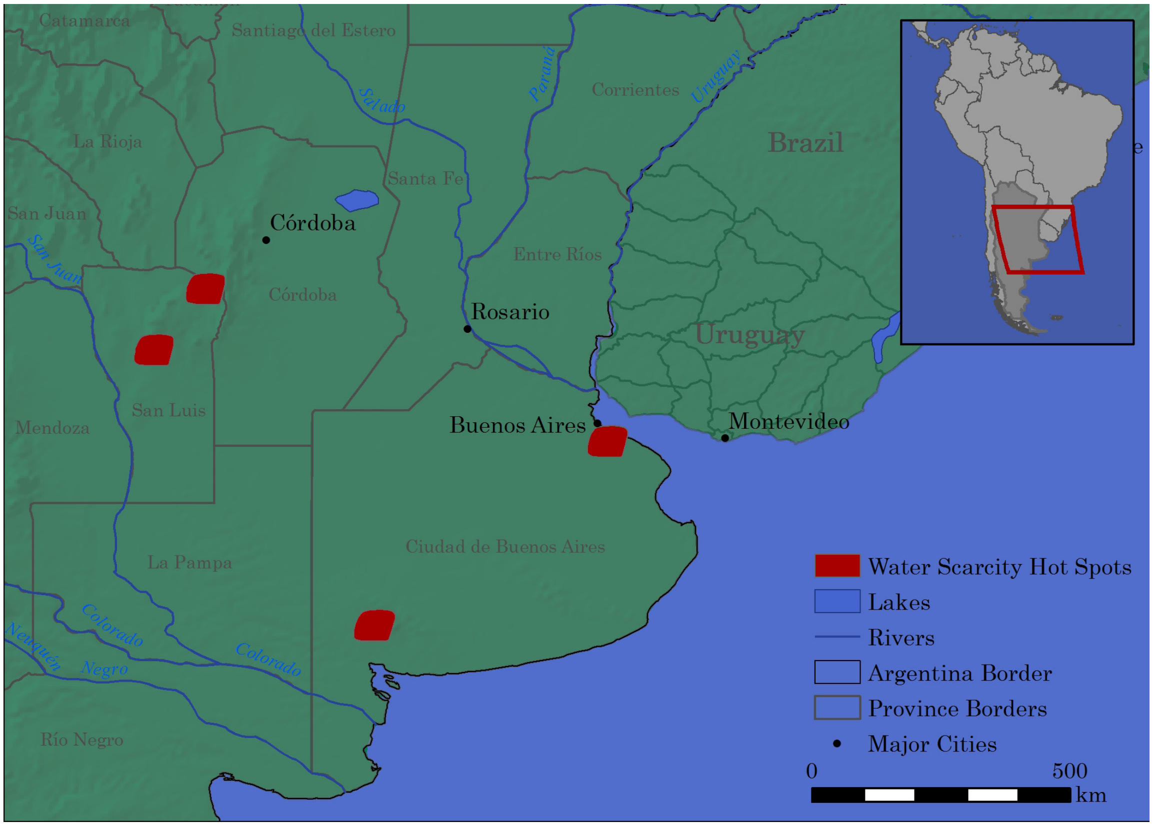
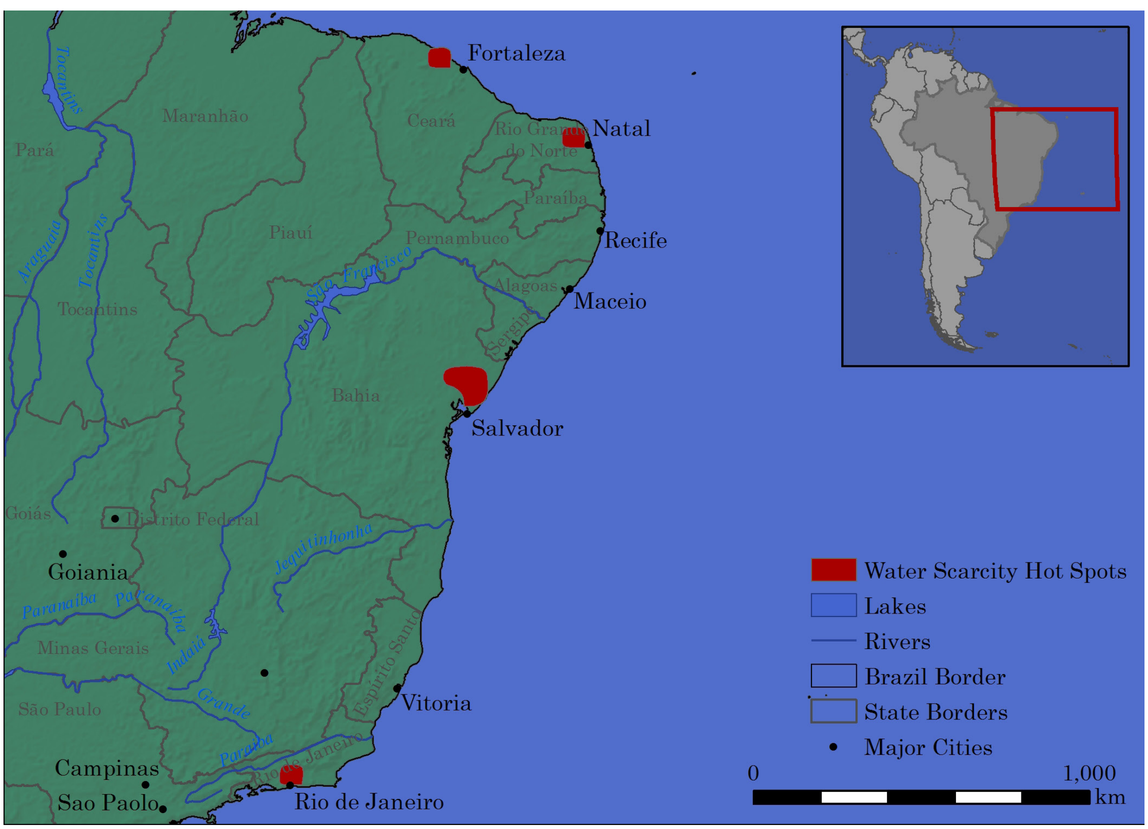
Appendix 1:

Water Scarcity Hot Spots: Argentinean soy

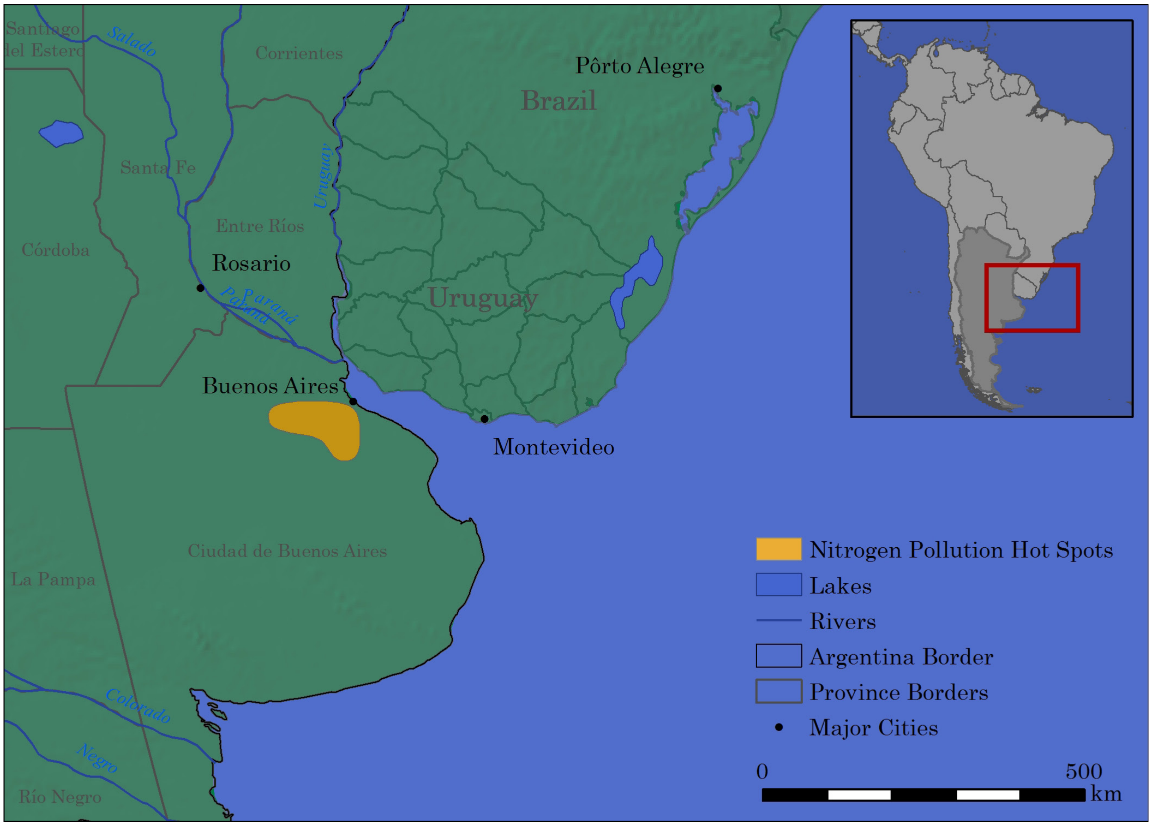


Water Scarcity Hot Spots: Brazilian sugarcane

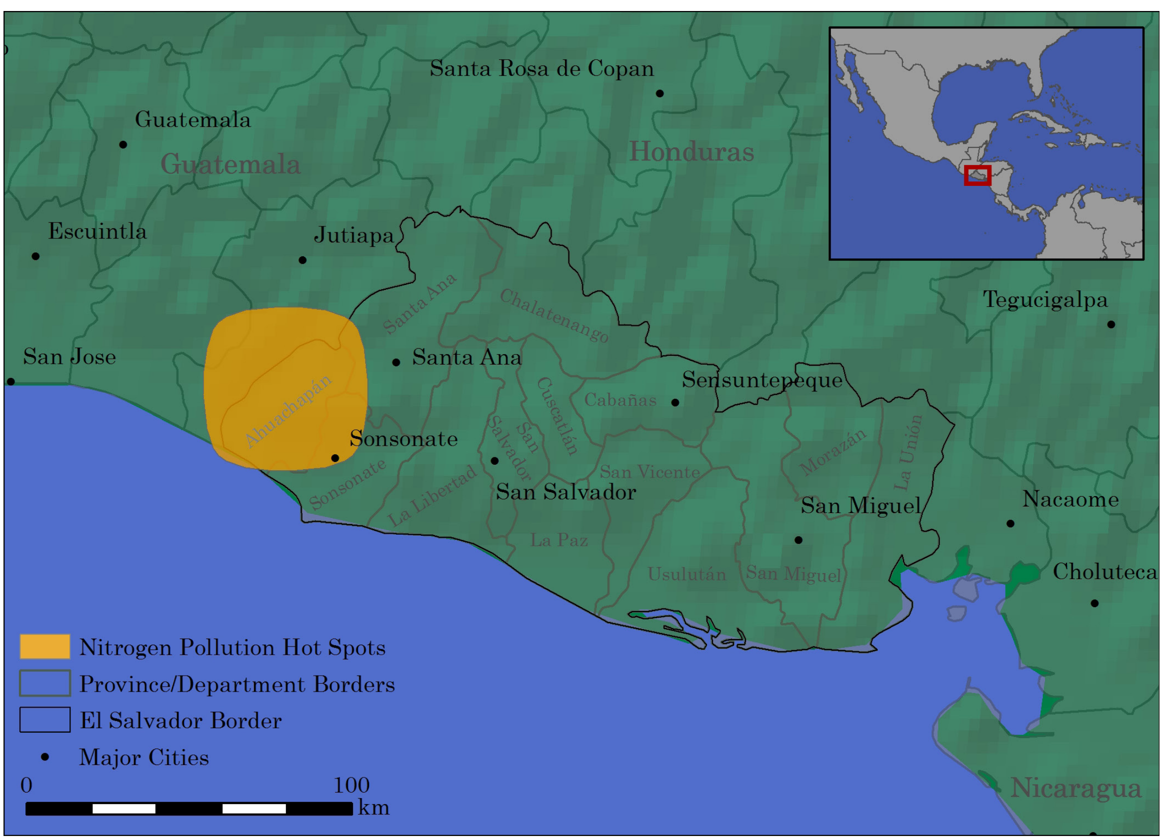


Appendix 2:

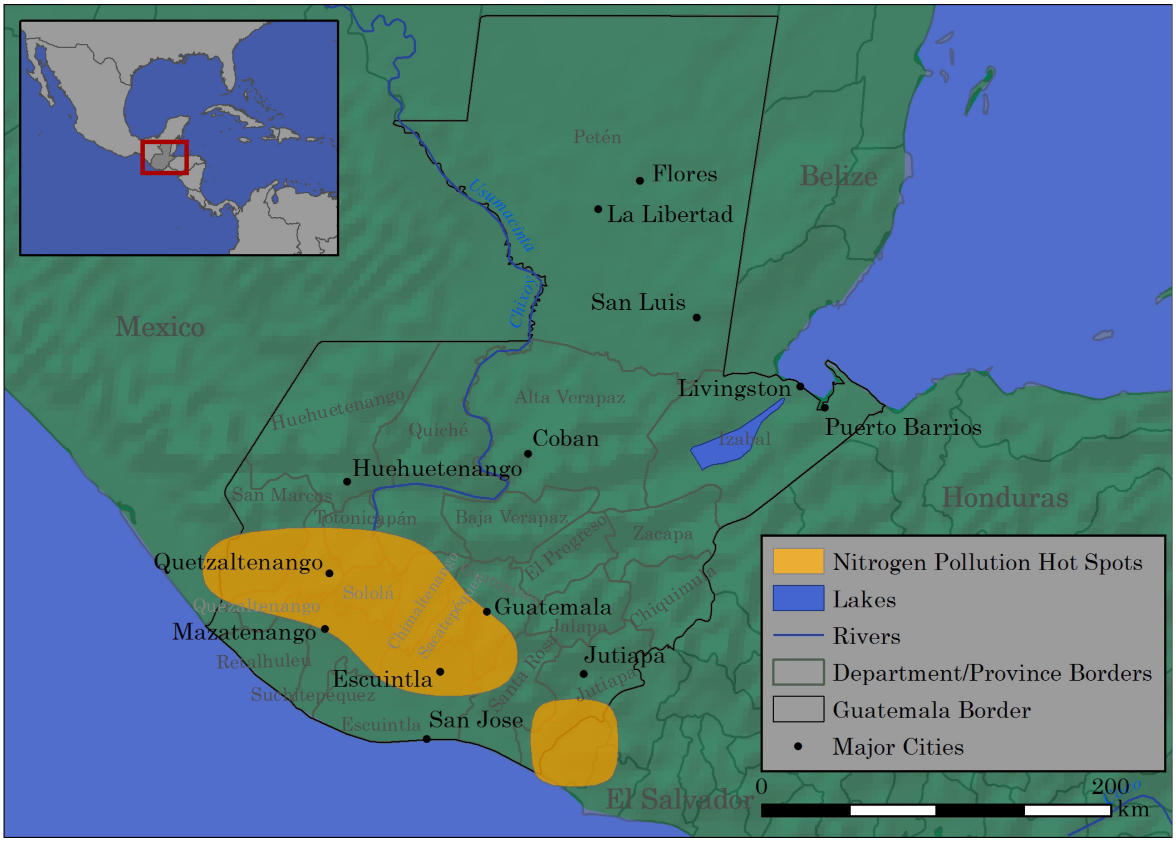
Water Quality Hot Spots: Argentinean soy



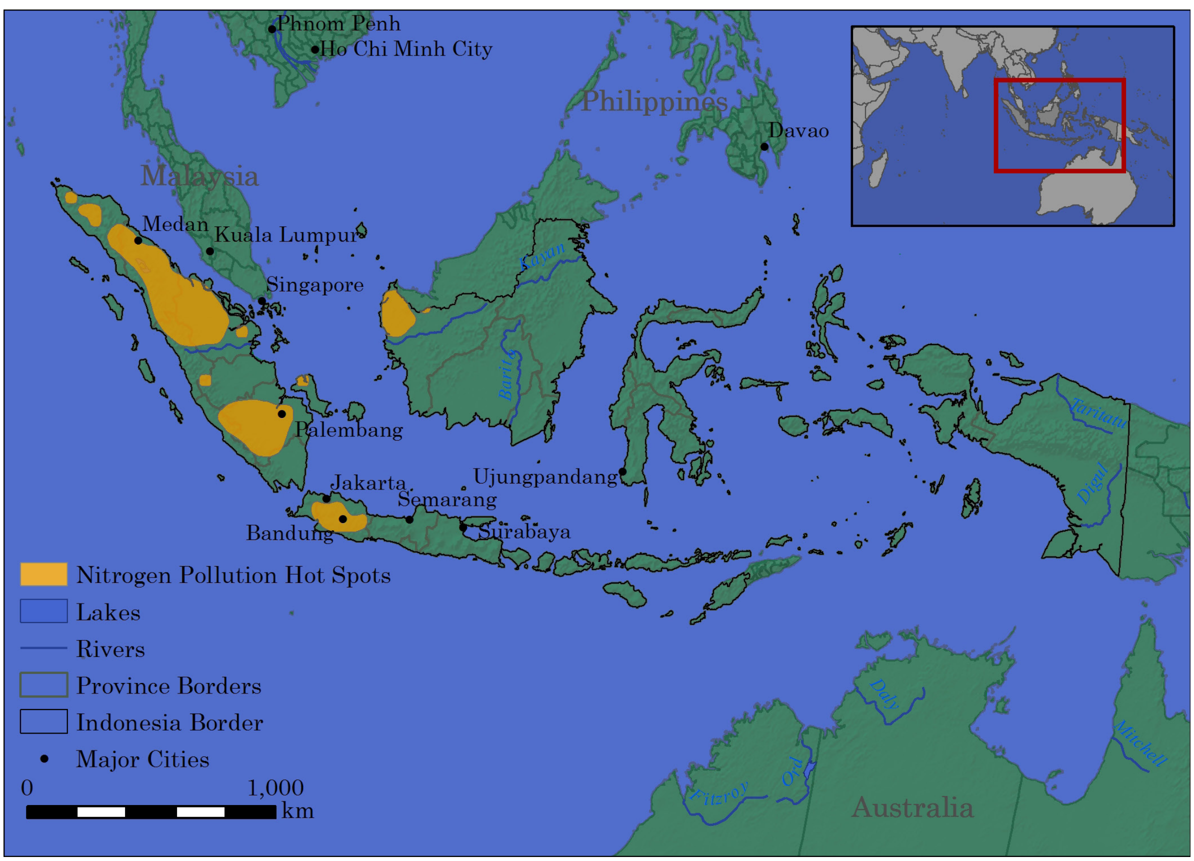
Water Quality Hot Spots: Salvadoran cane



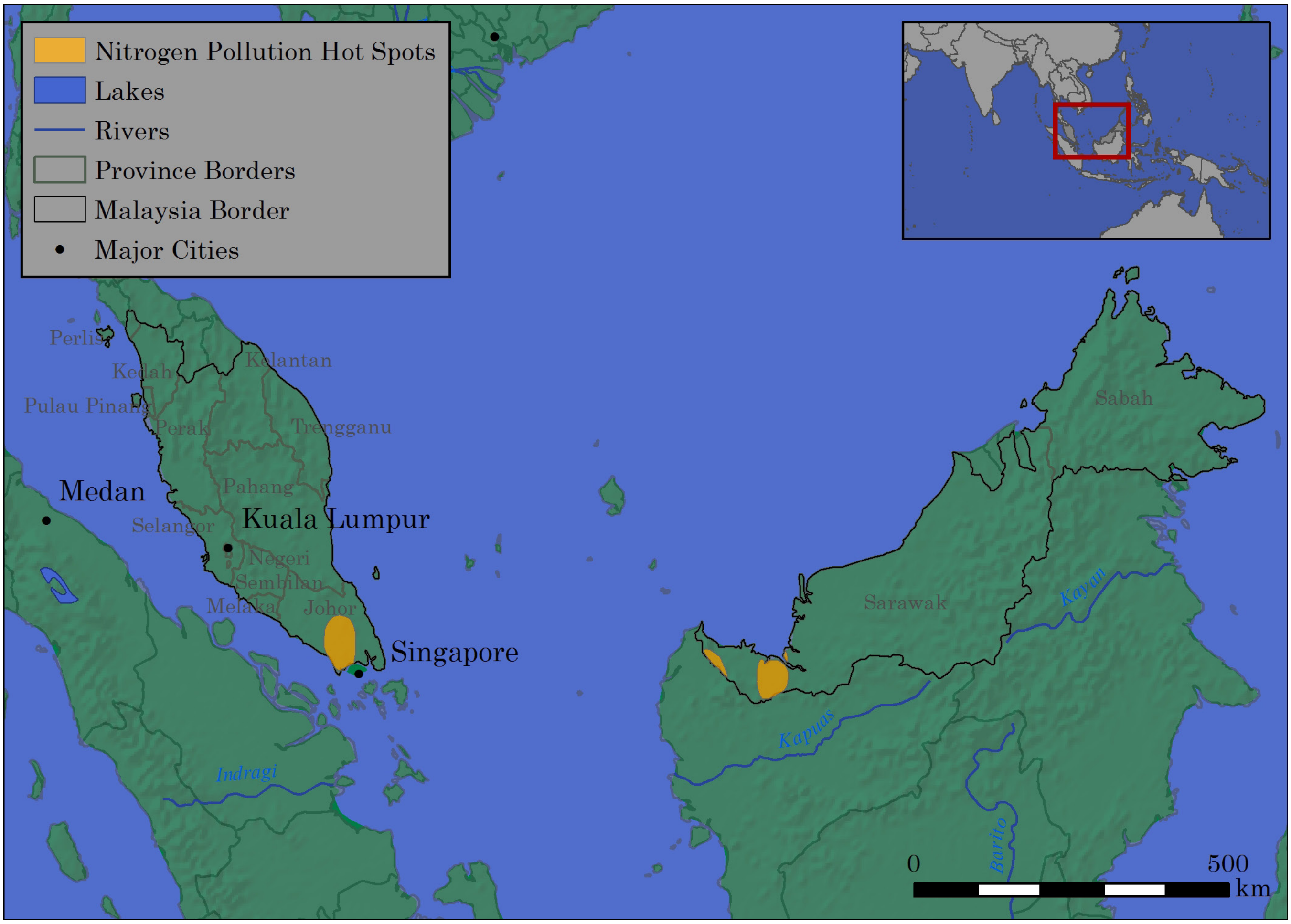
Water Quality Hot Spots: Guatemalan cane



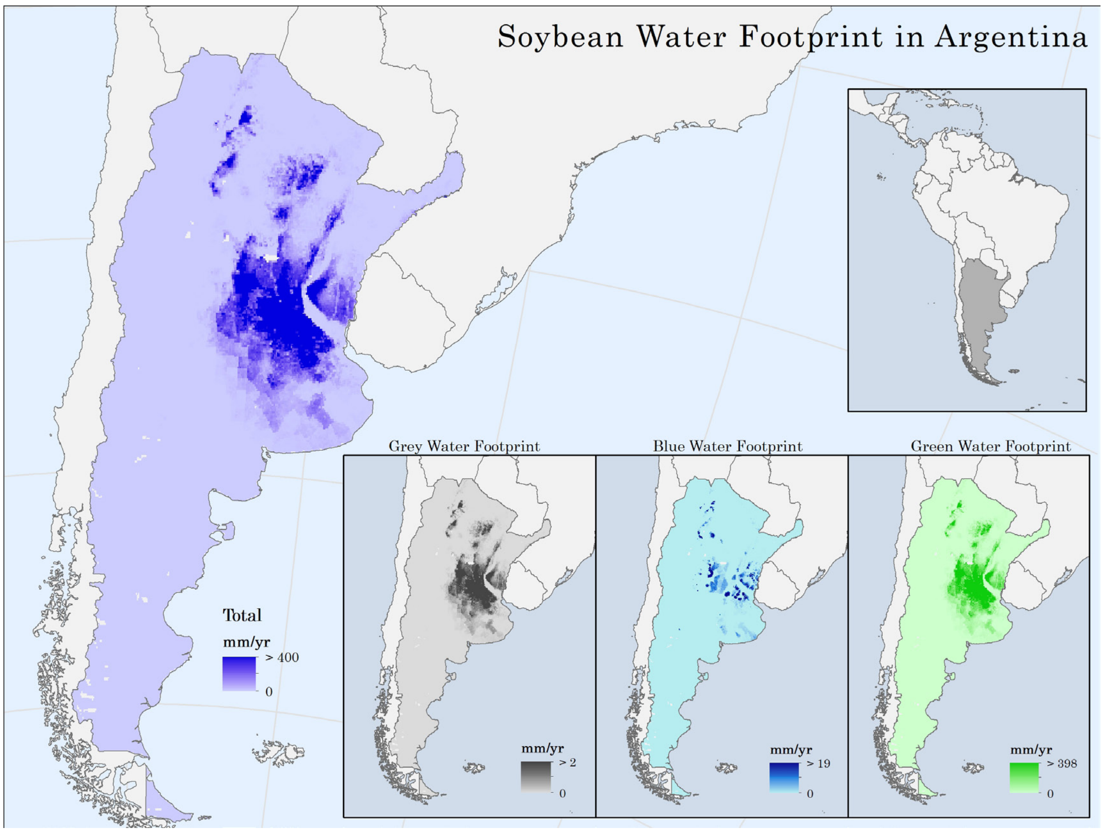
Water Quality Hot Spots: Indonesian palm

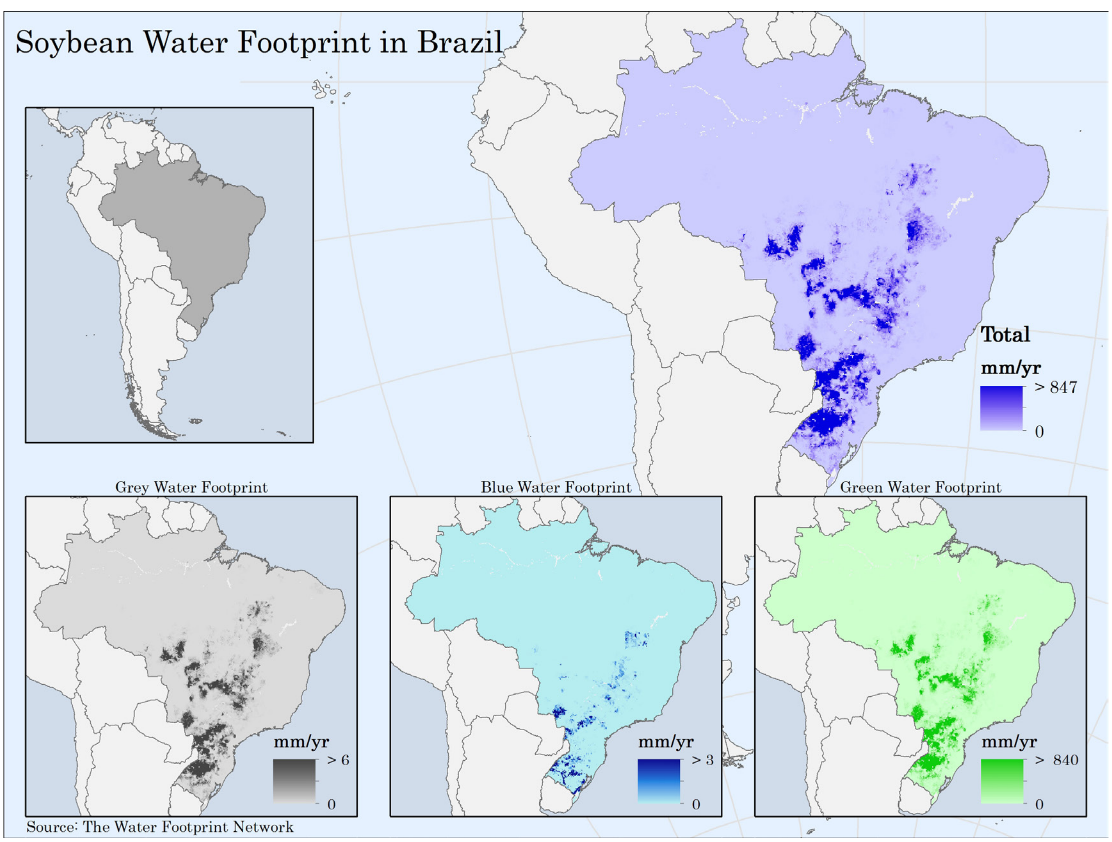


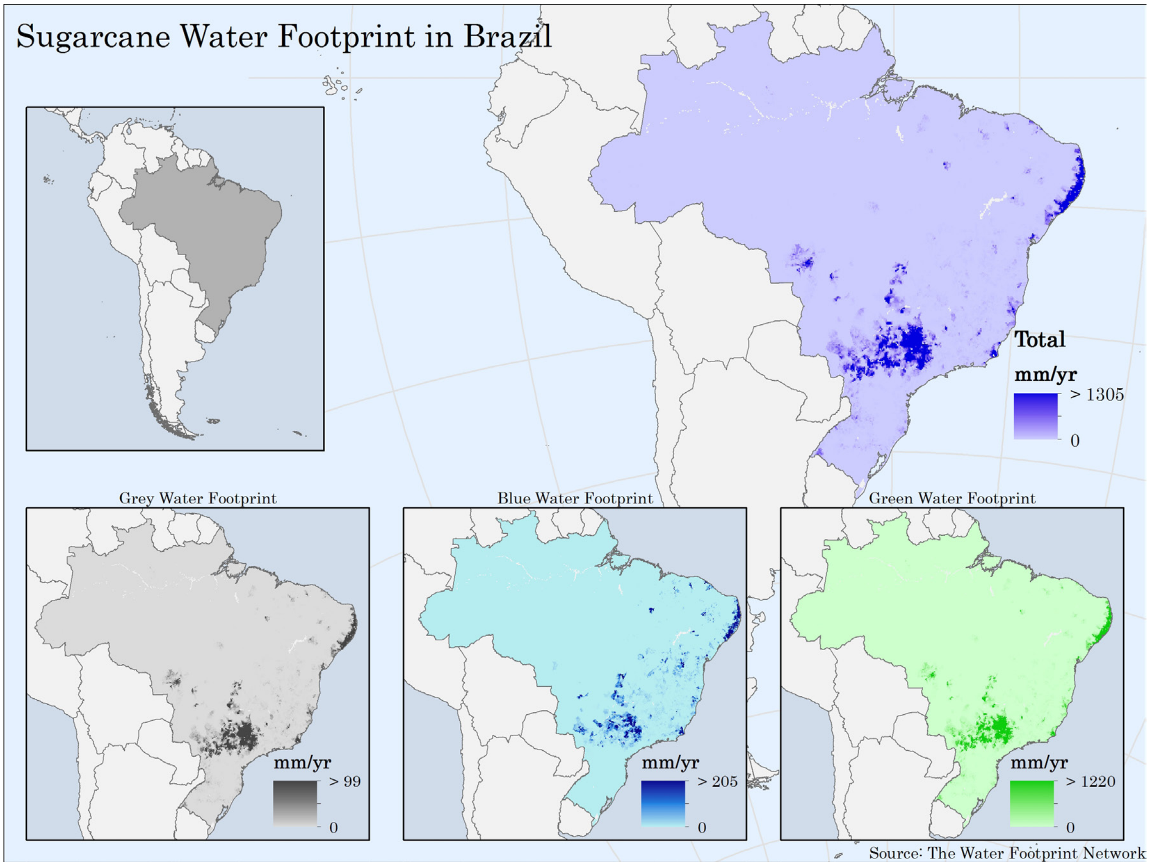
Water Quality Hot Spots: Malaysian palm

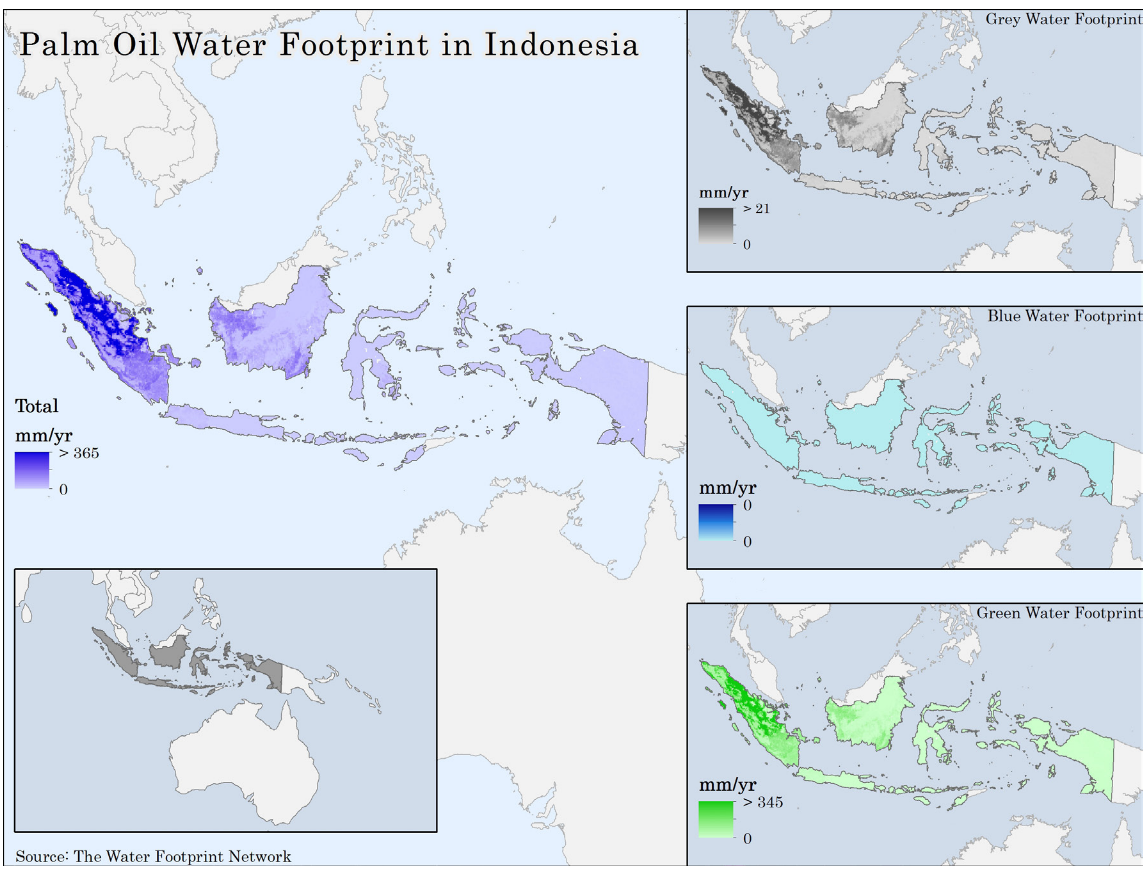


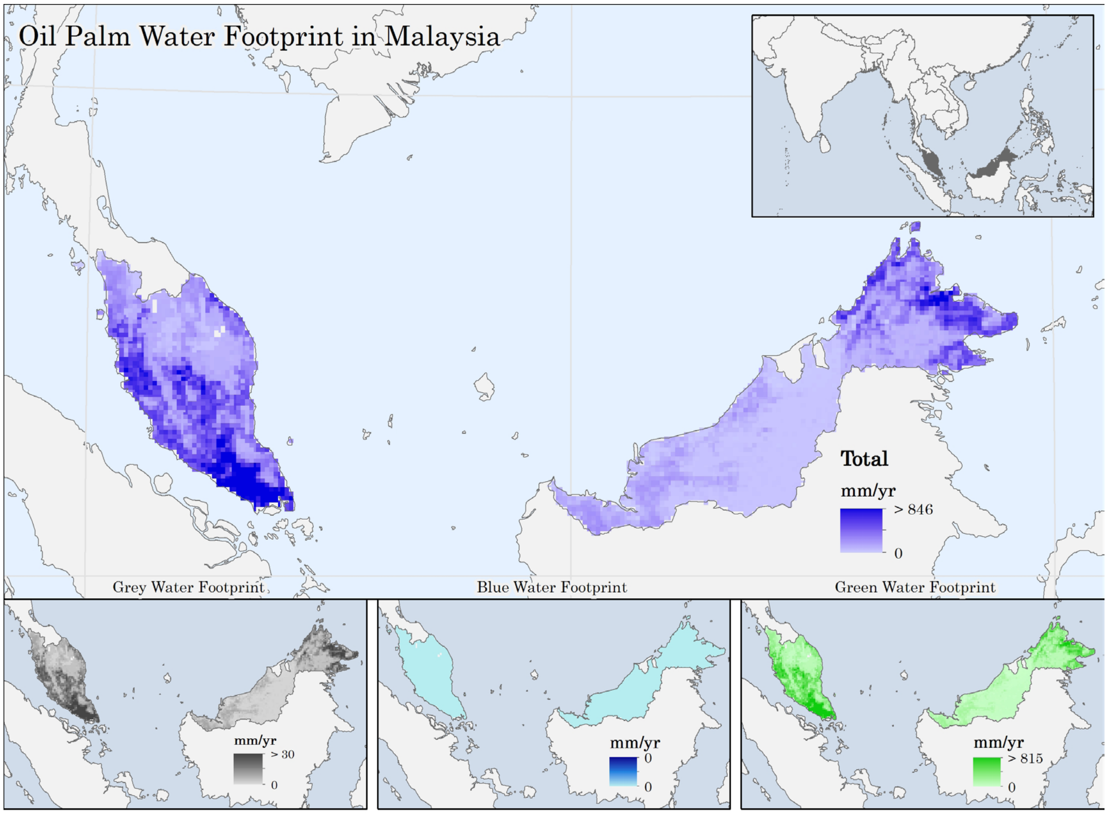
Appendix 3:


Soybean Water Footprint in Argentina
Grey Water Footprint
Blue Water Footprint
Green Water Footprint
Total
mm/yr
> 400
0
mm/yr
> 2
0
mm/yr
> 19
0
mm/yr
> 398
0

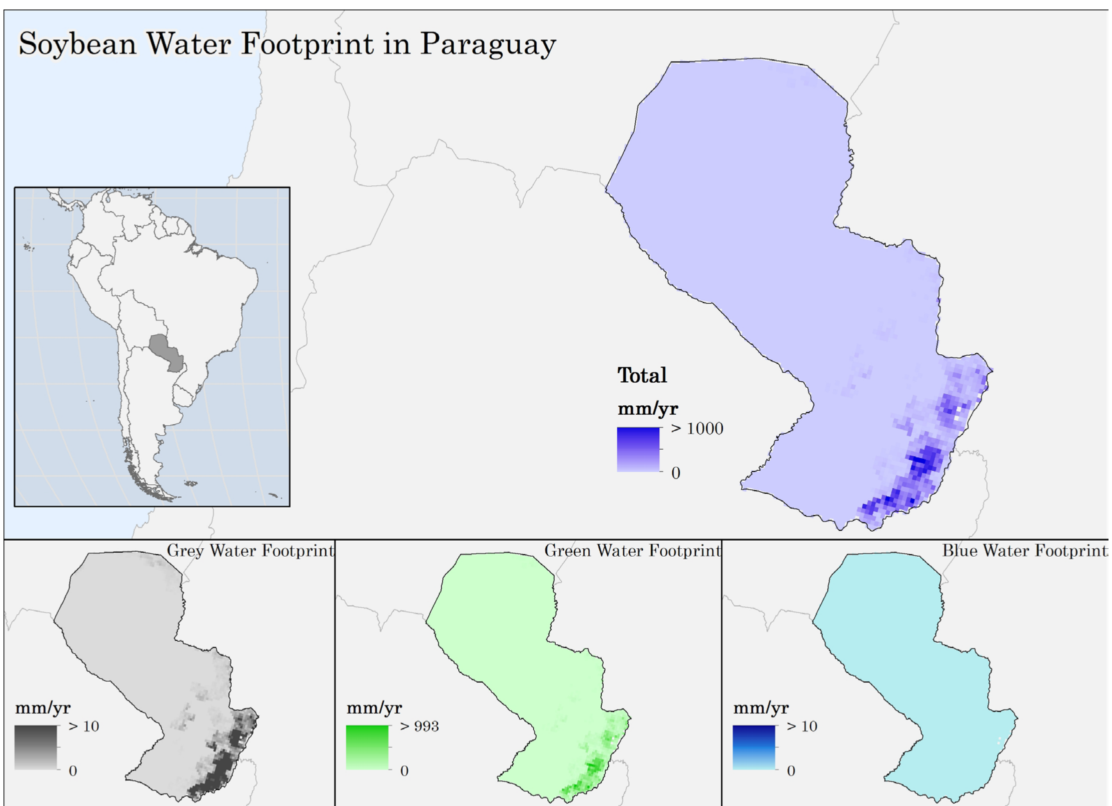

Soybean Water Footprint in Brazil
Total
mm/yr
> 847
0
Grey Water Footprint
Blue Water Footprint
Green Water Footprint
mm/yr
> 6
0
mm/yr
> 3
0
mm/yr
> 840
0
Source: The Water Footprint Network


Sugarcane Water Footprint in Brazil
Total
mm/yr
> 1305
0
Grey Water Footprint
mm/yr
> 99
0
Blue Water Footprint
mm/yr
> 205
0
Green Water Footprint
mm/yr
> 1220
0
Source: The Water Footprint Network


Palm Oil Water Footprint in Indonesia
Total
mm/yr
> 365
0
Grey Water Footprint
mm/yr
> 21
0
Blue Water Footprint
mm/yr
0
0
Green Water Footprint
mm/yr
> 345
0
Source: The Water Footprint Network



Source: The Water Footprint Network



Source: The Water Footprint Network

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FRONT COVER THE DROUGHT-HIT AREA OF MYAING IN MYANMAR
CREDIT: GREG FUNNELL/ACTIONAID

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ActionAid USA
1420 K Street NW, Suite 900
Washington, DC 20005

Telephone: **+1 202 835 1240**
www.actionaidusa.org

BACK COVER:
ILLUSTRATION:
HARRY MALT