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Biofuels in India: Trading off Climate Mitigation with Water Security Goals

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Introduction

Biofuels are recognized as a renewable alternative to fossil sources of energy like petroleum or gas. Liquid biofuels, such as bioethanol and biodiesel are blended with petrol or diesel and used for road, aviation and marine transport; they are expected to account for 6% of total renewable transportation fuel use by 2030. Biofuels can not only support a country's mitigation goals; but also reduce the need for foreign exchange and support agricultural growth.

In India, 22% of total energy supply is provided by renewables, most of it from biomass for heating; while biofuels account for less than 1% of transportation energy. Over 90% of bioethanol and biodiesel are produced from food crops such as maize, sugarcane, soybeans, and vegetable oils, with sugarcane serving as the primary feedstock. As a signatory to the Paris Agreement on Climate Change and the United Nations Framework Convention on Climate Change (UNFCCC), India submitted its Long-Term Low Emission Development Strategy (LT-LEDS) to the UNFCCC in 2022, emphasizing the reduction of greenhouse gas (GHG) emissions from the transport sector. Achieving this goal is supported, among others, by India's biofuel policy of 2018 (modified from the original policy of 2009), which aims to achieve blending targets of 20% for ethanol and 5% for biodiesel by 2025.

Similar to the US Energy Independence and Security Act of 2007, India's biofuel strategy pursues multiple goals beyond climate mitigation; it also aims to reduce the crude oil import bill, enhance national energy security amidst global conflicts, and create co-benefits for rural economic development by establishing new markets for agricultural products, increasing farmers' incomes, and promoting sustainable agricultural practices. This vision was further cemented in the 2023 G20 meeting, which established the Global Biofuels Alliance aimed at facilitating cooperation and enhancing the use of sustainable biofuels.

Considering indirect land use changes as well as lifecycle analysis, GHG emission reductions from biofuels are often lower than originally thought but generally positive for first-generation (1G) feedstock sources, such as maize, sugarcane and soybeans, when compared to fossil fuels. However, concerns have been raised regarding their impact on food prices and water security. A systematic review highlighted uncertainty about commodity price impacts from 1G biofuel development. For instance, the surge in demand for ethanol from maize in the United States is estimated to have contributed to a significant increase in grain prices between 2000 and 2007. Moreover, a global modelling analysis suggests that large-scale bioenergy production is bound to have trade-offs unless substantial complementary policy measures focussed on efficient land and water resource use are implemented. However, much less is known about impacts from biofuel expansion on water and food security in India. Impacts on water security might be particularly severe given the already challenging water situation in much of the country.

Originally prioritizing second-generation (2G) technology that leverages waste biomass for ethanol production, India's 2018 Biofuel Policy underwent a pivotal shift in 2022. An amendment to the 2018 policy, along with recommendations from an expert committee at the National Institution for Transforming India (NITI Aayog), intensified the focus on 1G sources and advanced blending targets of 20% for ethanol by 2025 and of 5% for biodiesel by 2030. This policy change, facilitated by financial incentives, led to accelerated ethanol production from sugarcane-based raw materials, including heavy molasses, as well as from damaged grains. As a result of this policy shift, India's ethanol blending reached almost 20% in 2025, up from just 1.5% in 2013, with almost 75% coming from sugarcane and maize. The NITI Aayog's roadmap outlines plans to augment ethanol production by an additional 13.5 billion litres—with roughly half contributed from sugarcane and half from food grains—to meet these targets. This envisioned increase relies on diverting surplus edible crops and potentially channelling more production towards ethanol generation. Some preliminary statistics suggest that grain-based ethanol production capacity has increased to approximately 40% of total ethanol production. Based on biofuel yields of 70, 350, and 400 litres per ton from sugarcane, rice, and maize, respectively, the roadmap envisages converting 6 million metric tonnes (MMT) of sugar surplus, and 16.5 MMT of grain surplus to meet blending targets.

Potential Food and Water Security Trade-offs of Biofuel Development

The emphasis on using sugarcane, maize and rice for ethanol production raises important water and food security concerns. First there is potential competition with procurement by the Food Corporation of India (FCI), coupled with strains on the Public Distribution System (PDS). Specifically for rice, the estimated demand of 20 MMT places considerable pressure on surplus rice for conversion into transportation fuel. The result is potential upward pressure on rice prices, coupled with accelerated downward pressures on groundwater tables in the states of Haryana and Punjab.

Although increased conversion of maize could eventually ease the strain on rice supplies, current yields and production remain inadequate to fulfil this role. Second, both sugarcane and rice are highly water-intensive crops that already place significant pressures on India's water resources. These two crops jointly utilize approximately 70% of the country's irrigation water. While sugarcane is preferred due to its lower water use per litre of ethanol produced, expanding its cultivation to meet rising ethanol demands may further exacerbate existing water stress levels and counteract measures put in place to address worsening water scarcity and groundwater depletion, such as the financial supported provided by Atal Bhujal Yojana to states and communities that reduce groundwater depletion. Of note, the needed production increase is expected to primarily occur in districts that already contribute significantly to sugarcane production due to established processing infrastructure; in particular, 37 districts in Uttar Pradesh, Maharashtra and Karnataka that collectively account for 75% of the country's sugarcane production.

Ethanol can be produced either as a by-product of sugar production, such as molasses, or directly from sugarcane juice. Currently, 80% of India's ethanol is derived from C-molasses, 19% from B-molasses, and only 1% from the first press of raw sugar, which yields most ethanol and thus exacts less of a toll on land and water resources, but may affect domestic sugar supplies. Given these challenges, the Indian government has at times shifted stances between favouring ethanol production from sugarcane juice and B-molasses and the use of C-molasses with lower sugar content to safeguard sugar supply while meeting blending targets. These issues highlight the urgent need for a comprehensive assessment of India's biofuel policy to ensure sustainability and economic viability while addressing food and water security concerns.

The Consequences of Alternative Biofuel Development Strategies

We used an exploratory modelling approach to assess the impacts of India's updated 2018 Biofuel Policy drawing on the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). IMPACT integrates climate, water, agricultural production and trade modelling to support the analysis of alternative policy and investment scenarios under changing climate and socioeconomic conditions. The IMPACT modelling framework integrates a global partial equilibrium agricultural sector model with crop simulation models as well as water simulation models that allocate water to different productive and environmental uses, including irrigated agriculture. Using a global model is particularly important in this context because India's biofuel policy does not operate in isolation. Changes in sugarcane demand, ethanol blending, or water use can have cascading effects on trade flows, global agricultural commodity prices, and resource allocation beyond national boundaries. Given India's growing role in global commodity markets, using a global model allows us, moreover, to account for cross-border price and trade effects.

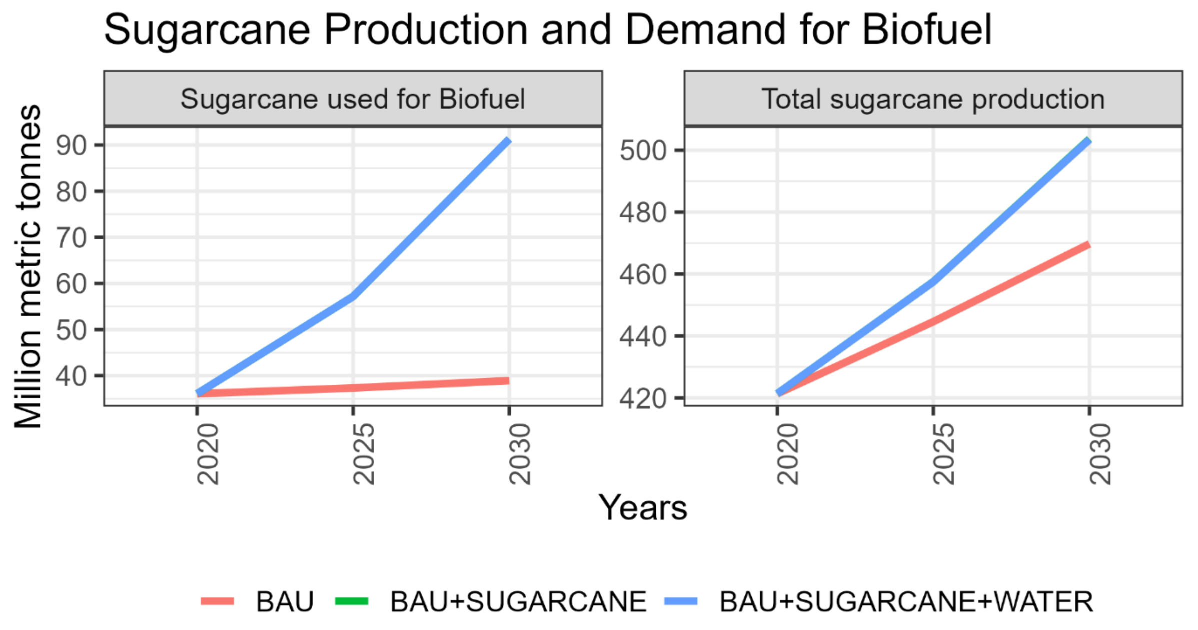
To analyze India's biofuel futures, we develop three alternative scenarios: a business-as-usual (BAU) scenario that postulates production of sugarcane and sugar based on India's 2018 Biofuel Policy, an Accelerated Biofuel Policy scenario (BAU+SUGARCANE) that uses both sugarcane and maize to meet the 20% blending target, drawing on the 2022 amendment ; and an Accelerated Biofuel Policy with Water Security scenario (BAU+SUGARCANE+WATER) that in addition to prioritizing sugarcane for meeting blending targets limits excessive groundwater withdrawals. The analysis does not include rice in blending targets as no use of surplus rice or other grains were reported in the most recent data for India. These three alternative pathways are summarized in Table 1. The two scenarios focused on sugarcane as feedstock more than double 2030 sugarcane needs over the BAU scenario.

Table 1: Alternative scenarios of India's biofuel futures

<table>
<tr><th rowspan="2">Scenario name</th><th rowspan="2">Description</th><th colspan="2">Sugarcane demand for biofuel (million metric tons)</th></tr>
<tr><th>2020</th><th>2030</th></tr>
<tr><td>Business-as-usual (BAU)</td><td>Continued production of sugar and sugarcane as per the 2018 policy</td><td rowspan="3">36.1</td><td>38.9</td></tr>
<tr><td>BAU+SUGARCANE</td><td>Increased demand for sugarcane (and maize) to meet the 2025 blending target of 20% for ethanol. No restriction on groundwater extractions.</td><td rowspan="2">91.3</td></tr>
<tr><td>BAU+SUGARCANE+WATER</td><td>Increased demand for sugarcane and maize to meet the 2025 blending target of 20% for ethanol combined with restrictions on groundwater withdrawals after 2025.</td></tr>
</table>

Compared to the BAU scenario, sugarcane production expands by 150% (to 91 MMT from 36 MMT under BAU) to meet the biofuel blending target from sugarcane (Figure 1). We find no impact on expanded sugarcane production from more restrictive groundwater extraction limits, as reduced water availability instead translates into lower production of other crops, such as wheat. Demand for maize and rice for biofuel production also increases slightly, although rice is not included as an input for biofuels. This increased demand in our model is reflective of the projections in biofuel demand described in the policy roadmap of Niti Aayog.

Figure 1: Total sugarcane production and demand for biofuel across scenarios and years until 2030



yrs	description	BAU	BAU+SUGARCANE	BAU+SUGARCANE+WATER
2020	Sugarcane used for Biofuel	36.1	36.1	36.1
2030	Sugarcane used for Biofuel	38.9	91.3	91.3
2020	Total sugarcane production	421.3	421.3	421.3
2030	Total sugarcane production	469.8	503.6	503.5

The increase in sugarcane demand for biofuel leads to increased irrigated agricultural production with variations across river basins. In the Ganges Basin, irrigation water consumption would increase from 162 billion cubic meters (BCM) in 2020 to 167 BCM in 2030 under the BAU+SUGARCANE scenario. With restrictions on groundwater extraction, the increase by 2030 would be lower, at 164 BCM (Figure 2). Similar trends are observed for the other basins as well. Increases in water consumptive use would be largest in the Indus, Mahi-Tapti, Eastern Ghats, and Chota Nagpur basins, each exceeding 15% and reaching up to 25%; while increases are more moderate in most other basins, including the Ganges, Mahanadi, Brahmaputra, Godavari, and Sahyadri basins.

Across all the basins, the BAU+SUGARCANE+WATER limits increases in consumptive water use, suggesting that complementary policies that implement restrictions on water withdrawals may be helpful in reducing overextraction of water under more aggressive biofuel policies. However, as shown in Figure 2, groundwater restrictions lead to large reductions in the production of wheat (Ganges, Luni and Mahi Tapti basins), rice (Cauvery basin), and sugarcane (Krishna basin). We acknowledge that aggregating results at the basin level does not capture intra-basin variation in groundwater levels, which would need to be explored in further detail.

Figure 2: Irrigation consumptive use across scenarios, crops and river basins in 2030, compared to 2020

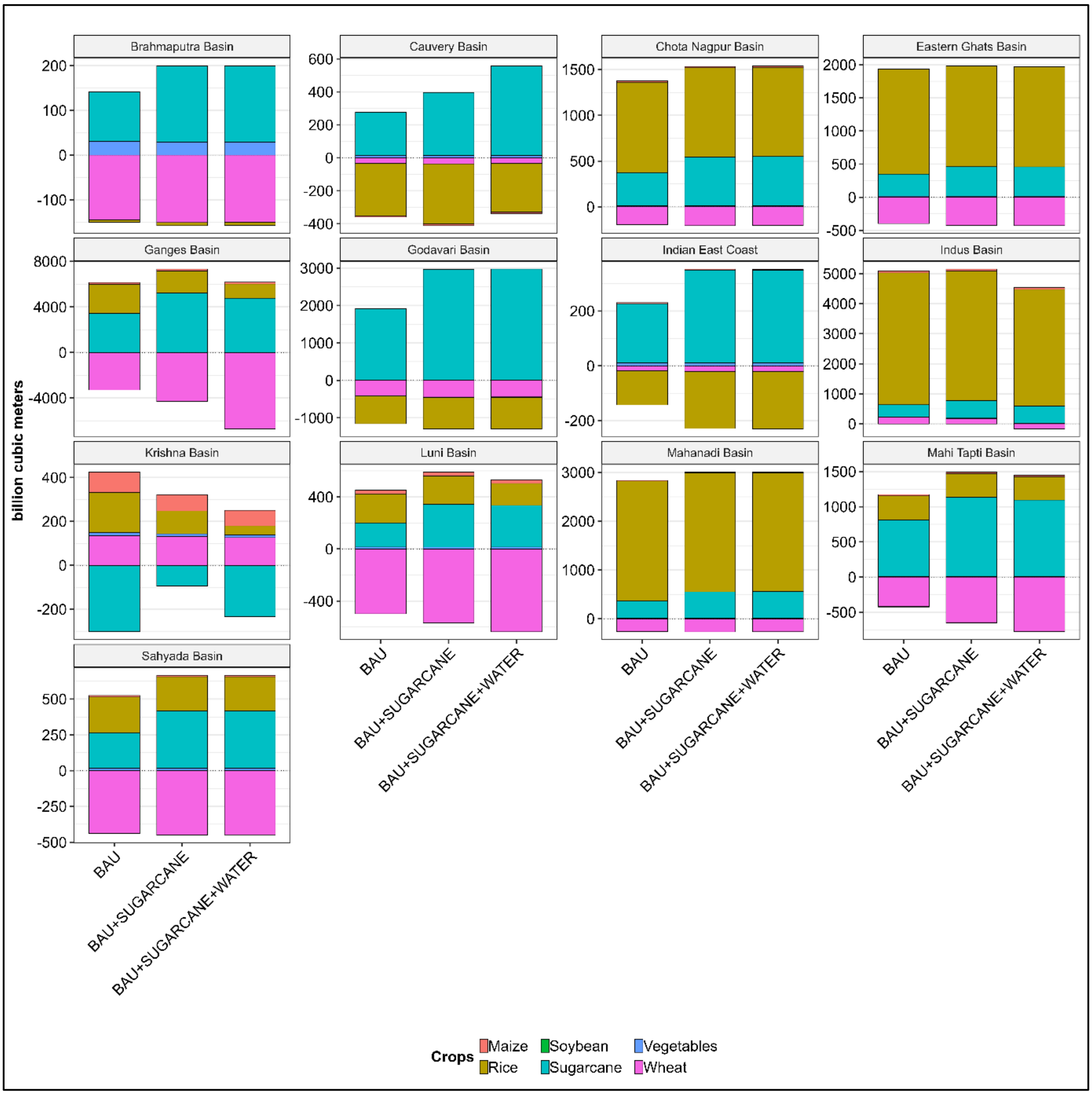
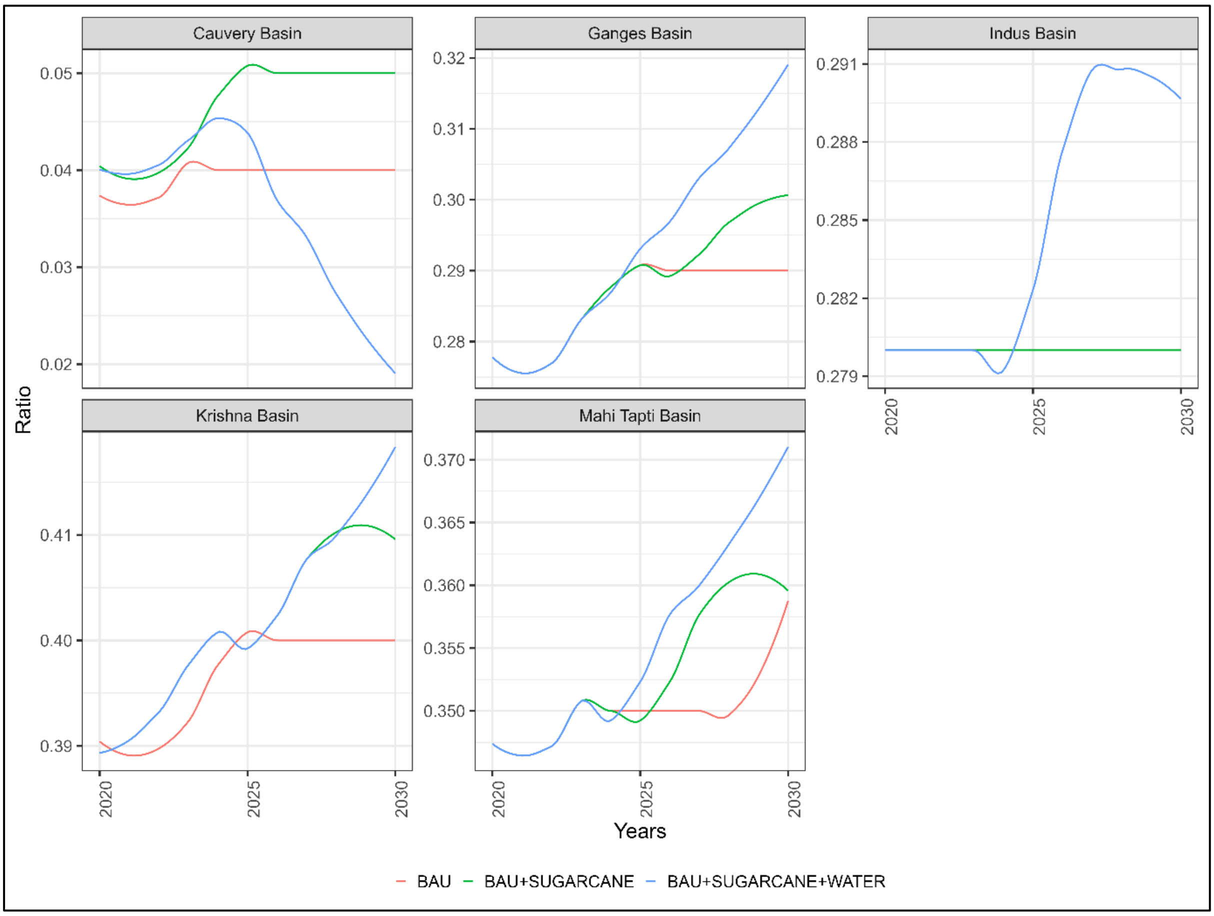


Figure 3 presents results for water scarcity, calculated as the ratio of groundwater demand over accessible groundwater supply for five key river basins. Values range from 0 to 1 and a higher value suggests more severe scarcity. In 2020, the Krishna basin experienced the highest level of groundwater scarcity, driving declines in sugarcane production, followed by the Mahi Tapti basin, driving declines in wheat production, while pressure on groundwater levels was lowest in the Cauvery basin.

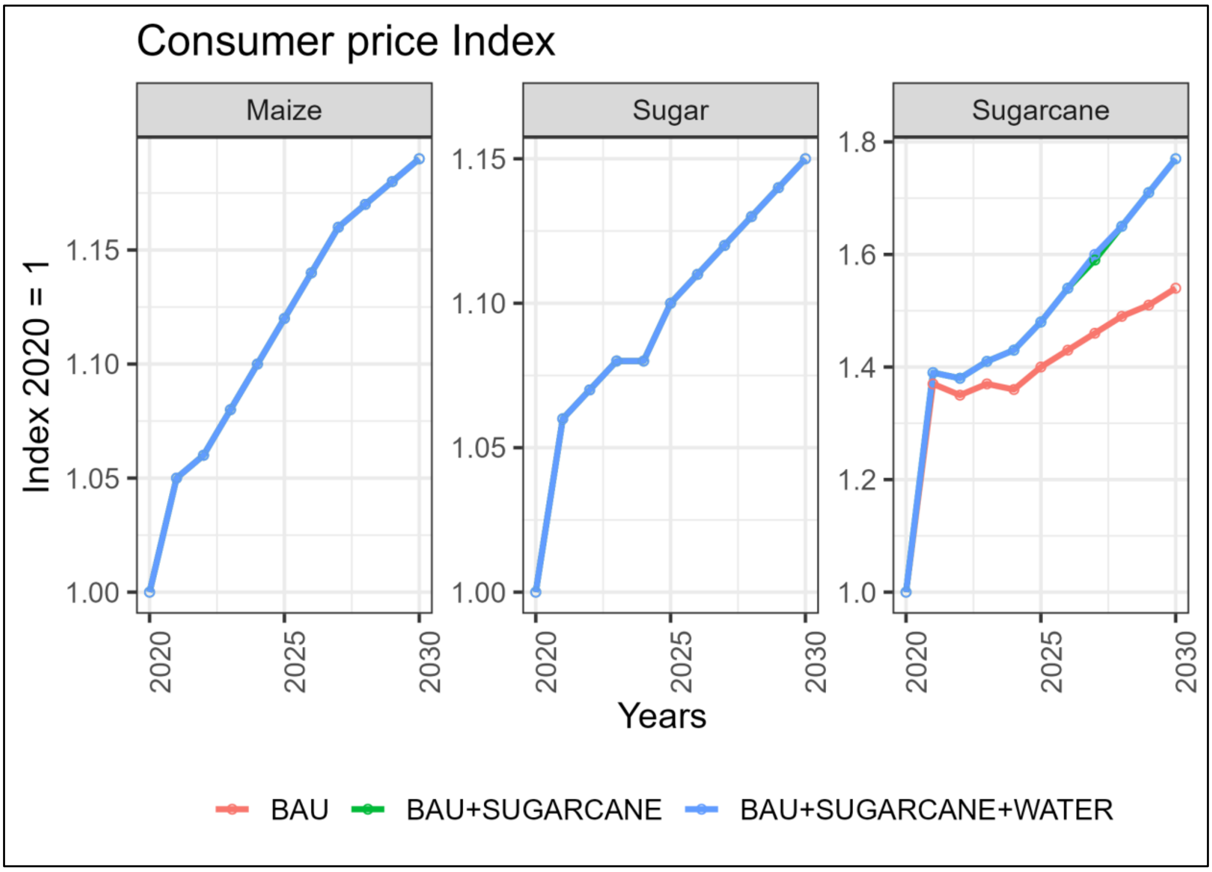
Across years and scenarios, water scarcity increases in all basins, with increases generally largest for the increased sugarcane blending scenario with and without restrictions on groundwater use. Under the BAU+SUGARCANE scenario, groundwater scarcity levels are largest in the Krishna, Mahi Tapti and Ganges basins by 2030. Only the Cauvery basin that like the Indian coast basin replaces rice production with sugarcane production under this scenario sees a decline in groundwater scarcity, presumably as groundwater is freed up from the shift from rice to sugarcane production. The Indus basin is a further anomaly in that there is little sugarcane production historically and thus also limited expansion in the two accelerated sugarcane blending scenarios. Instead, the introduction of restrictions on groundwater extraction affects groundwater scarcity directly, leading to a reduction in rice and wheat production.

Figure 3: Water scarcity across key river basins in India



In response to increased use of sugarcane feedstock in biofuel production, prices for sugar rise across all scenarios from 2020 to 2030. In Figure 4, we report changes in Indian consumer prices of key crops compared to those in 2020. We find that consumer prices rise even under BAU, though at lower levels than under the BAU+SUGARCANE+WATER scenario, where groundwater restrictions and more aggressive biofuel policies exert stronger upward pressure on agricultural commodity prices, while prices for maize barely change. Projected changes in prices suggest that intensifying sugarcane cultivation while trying to address groundwater depletion could lead to considerable increases in food prices. We do not observe any significant effects on prices of other commodities, as lower production levels are compensated by increased food imports.

Figure 4: Consumer prices of products across selected crops, scenarios and years



The Way Forward

We find that the increased demand for sugarcane from 36 to 91 MMT for biofuel production following the 2022 biofuel policy shift of Niti Aayog leads to large increase in total irrigation water consumption and substantial shifts across agricultural commodities in India's river basins. The introduction of restrictions on groundwater withdrawals can reduce stress on aquifers but would lead to further changes in the agricultural commodity mix and increases in sugarcane prices.

India's Biofuel Policy 2018 and the subsequent creation of the Global Biofuels Alliance reaffirm the government's commitment to achieving energy security and reducing carbon emissions by expediting the achievement of ambitious ethanol blending goals. The policy encourages greater reliance on domestically produced feedstocks, particularly sugarcane, to meet these goals. Our analysis shows that while this pathway is effective in boosting biofuel output, with sugarcane production projected to rise by 150%, it also leads to increased water consumption and would require shifts in the production of other agricultural commodities to accommodate changes in land and water use. Heightened pressure on water resources, particularly in the Krishna, Mahi Tapti and Ganges basins, raises concerns about long-term water sustainability and tradeoffs between food security and energy self-sufficiency goals. Importantly, the policy shift increases not only national but also global prices of sugar and rice by almost 1%, with potentially large negative impacts for the food security of the poorest populations, signaling economic trade-offs that merit serious policy consideration.

As India advances its renewable energy transition, it is essential to integrate food and water security objectives into strategic planning. While the country's Biofuel Policy rightly focuses on reducing fossil fuel dependency, it must also account for regional resource constraints and potential food security impacts. To more explicitly integrate sustainability concerns into the biofuel policy, diversified feedstocks, improving water-use efficiency in agriculture, and strengthening groundwater governance should be considered, while supporting reductions in tariffs and other trade restrictions on agricultural commodities to avoid national food price spikes from accelerated blending targets. Only when water, energy, food and ecosystem health concerns are jointly assessed will India's biofuel strategy support the broader goals of climate resilience and sustainable development.

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