Economic Evaluation of Achieving Biofuel Mandate through Advanced Biofuels in Developing Country: Case of India

by

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Abstract

India's biofuel blending has fallen short of goals since its implementation in 2003. Policy regulation for using only non-food and non-arable land for feedstock production have caused inadequacy in feedstock availability raising mandate compliance challenges. India's New Biofuel Policy, 2018 allowed expansion of feedstocks to include agricultural residues for biofuel production. As a first attempt, this study aims to assess biofuel impact with cellulosic biomass in a unified framework of food and fuel for India. The study intends to identify the optimal feedstock mix and assess the potential of cellulosic biofuels in achieving 20% blending mandate by 2030. We use price endogenous mathematical programming model to analyse impacts of alternate feedstock combinations on food, land use and economic surpluses of food and fuel consumers and producers. The study undertakes analysis of three policy scenarios that allows alterations induced by different feedstock combinations. The findings of our study suggest that with limited scope for area expansion, cellulosic ethanol can potentially help dampen the pressure of land expansion for sugarcane crop as compared to situations where the mandate is met with only sugarcane-based feedstocks. Our results indicate that cellulosic biomass producers can enjoy significant economic benefits from sale of agriculture residues.

Key words: Biofuel policy, biomass, Partial Equilibrium Model

JEL Codes: Q160, Q180, C610

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1. Introduction

India's endeavour towards biofuel is guided by multiple policy goals. With a relatively high crude oil import dependency of about 84% in 2018-19 (PPAC, 2019), India aims to achieve energy security by reducing import dependencies by 10% by 2022 through biofuels as one of the identified approaches (MoPNG, 2018). In addition to achieving energy security through fossil fuel replacement, biofuels are also of strategic importance in India's endeavour to double farmers' income, employment generation and GHG reduction targets. India has been aggressively promoting biofuels with the implementation of National Policy on Biofuels, 2009 through an indicative blending mandate of 20% for both ethanol and biodiesel targeted to be achieved by 2017. Nevertheless, India's biofuel blending obligations has always fallen short of goals since its implementation.

Risks of biofuel induced food insecurity and land use change have seriously hindered growth of biofuels in developing countries (Msangi and Evans, 2013). However, Indian policy makers have pursued biofuels with caution (Findalter and Kandilkar, 2011; Ray et al., 2012). To avoid any negative market mediated impacts, India's biofuel policy relied only on use of non-edible feedstocks and non-arable land for feedstock cultivation i.e., molasses ethanol (a by-product of sugarcane processing) and Jatropha cultivated on marginal lands (MoPNG, 2009). Despite of such unique approach in biofuel promotion, multiple factors like feedstock supply shortage, competing demand for ethanol for other industrial uses, inefficient pricing mechanism of ethanol, restricted feedstock options, regional administrative challenges in implementing the mandate and mismatch between market conditions for ethanol, sugar, and petrol lead to the failure of Ethanol Blending Programme (EBP) (Saravanan et al., 2018; Ray et al., 2011). Even biodiesel production from Jatropha never really took off commercially due to inefficient supply-chain, lower Jatropha yields, and miscalculation of potential availability of wasteland (Kumar et al., 2012; Axelsson et al., 2012; Montobbio and Lele, 2010), overtly leading to the failure of National Biodiesel Mission (NBM). Biofuels market penetration rate in 2019 was only about 5.8% for ethanol with consumption of about 2400 million litres and 0.14% for biodiesel with a consumption of about 85 million litres (GAIN, 2019).

India allowed expansion of feedstock options to include cellulosic feedstocks from agricultural residues for ethanol production with the formulation of the New Biofuel Policy, 2018. The new policy promotes advanced biofuels from agricultural biomass, direct sugarcane juice from excess sugarcane produces and other feedstocks which are in surplus availability. Ethanol from agricultural residues can prove to be a solution to India's longstanding residue burning problem. In addition, ethanol from sugarcane and bagasse can potentially help in revenue diversification for its financially strained sugar industry (Ray et al., 2012; Lavanya and Manjunatha, 2018). With around 611 MT to 686 MT of annual gross residue production of which nearly 25%-34% is available as surplus for bioenergy purposes (Hiloidhari et al., 2014;

Cardoen et al., 2015), if implemented sustainably and efficiently, biofuels from agricultural residues can prove to be a win-win condition for both farmers and biofuel producers of India.

There is a growing body of literature on biofuel impact assessment on food prices, land use change and GHG emissions. However, most of the studies have visibly remained biased towards developed country, with an emphasis on U.S., EU biofuel policies. Literature review indicates a dearth of impact assessment studies for India. Existing studies are limited to first generation feedstocks for ethanol and non-edible oilseeds for biodiesel (Khanna et al., 2013; Gunatilake et al., 2014; Woltjer and Smeets, 2016). These studies indicate inefficacy of molasses feedstock and strong ability of Jatropha on marginal lands in meeting the national blending targets. However, to the best of our knowledge, none of the study has attempted to evaluate the differential impact of ethanol from cellulosic biomass on food and land use for India. The primary objective of the study is to identify the optimal feedstock mix in achieving 20% ethanol blending mandate by 2030 and analyse its impact on food and land use, prices, and the welfare impacts on food and fuel consumers and producers. The study also aims to assess the potential of cellulosic biofuels in achieving India’s biofuel obligation. Biofuel policy scenarios in the study helps assess alterations induced by changes in feedstock mix to attain the 20% blend requirement by 2030. The focus here is on evaluating the feasibility of achieving the biofuel mandate with alternate mix of first and second-generation feedstocks.

2. Overview of biofuel policy in India

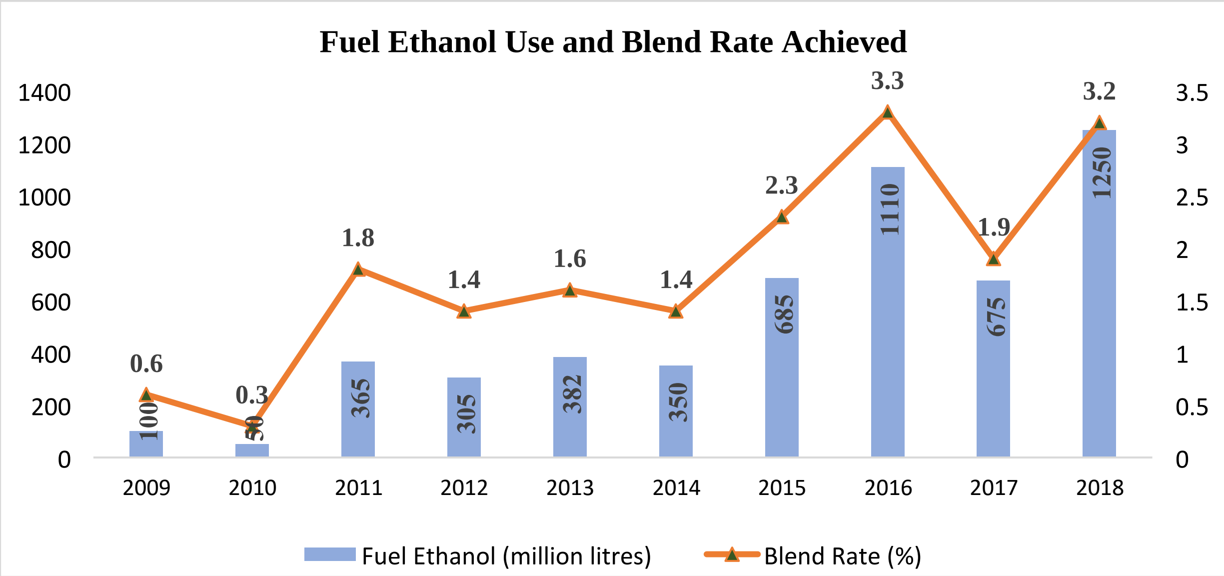
India initiated its effort to develop a sustainable biofuel industry since the early 2000s. The country introduced a 5% ethanol blending pilot program in 2001 which was later transformed into 5% blending mandate applicable to nine states and four Union Territories (UTs) in 2003, which was then expanded to the whole country except for few north-eastern states in 2006. This was accompanied by National biodiesel Mission (NBM) in 2003 with a 20% biodiesel blending target, set to be achieved in a phased manner by 2011-12. However, faced with serious supply shortages of feedstocks for both ethanol and biodiesel, India’s biofuel policy never really took off the planned way. Finally, the National Policy on Biofuels (NPB) was implemented in 2009 (hereafter referred as NPB, 2009) with a proposal of achieving 20% blending mandate for both ethanol and biodiesel by 2017 (MNRE, 2009). The NPB, 2009 was implemented with a unique concept of biofuel promotion with indigenous non-food feedstocks grown on non-arable land with two integral components of the policy i.e., Ethanol Blending Program (EBP) and the National Biodiesel Mission (NBM). Intending to avoid any food-security concerns and to fully utilize the already established ethanol production capacity by distillers for potable liquor and industrial use, the EBP was initiated with molasses feedstock which is a by-product of sugar processing. The NBM pursues biodiesel[3] processing from Jatropha oilseeds, supposed to be grown on non-arable land or wasteland.

With continuous government interventions, ethanol blending in India caught some pace since 2014. Due to favourable pricing conditions, the all-India ethanol blending rate increased from

[3] Since in this paper we have only included ethanol, policy overview for biodiesel is not discussed in detail here.

1.8% in 2011 to 3.2% in 2014-15. Figure 1 presents the fuel ethanol use and blend rate achieved over the years.

Figure 1: Fuel Ethanol Use and Blending Rate India, 2009-2018



Source: Biofuels Annual, 2018, GAIN

The two major policy issues in India's biofuel sector are availability of alternate feedstock options, and pricing mechanism of biofuels. Therefore, amending the previous policy, the renewed National Policy on Biofuels was initiated in May, 2018 (hereafter referred as NPB, 2018) aiming to achieve an indicative blending target of 20% ethanol and 5% for biodiesel by 2030. Effective realization of the policy is based on five identified approaches i.e., enhancing domestic supplies, setting up 2G biorefineries, new feedstock development, developing new technology for biofuel conversions, and creating enabling environment for its integration with conventional fuel. Efforts to exploit all possible first-generation feedstock option that including B-heavy molasses, direct sugarcane juice, and damaged food grains like wheat, broken rice etc. which are unfit for human consumption and surplus food grains in years of excess production will also be made through the new policy,

3. Objective of the study

The primary objective of the study is to assess policy scenarios in coherence with the National Policy on Biofuels 2018 focussing only on ethanol. Few critical policy questions that arise related to India's ethanol blend mandate are- 1) Is it feasible to meet 20% ethanol blending mandate by 2030? In accordance, what are the optimal feedstock mix required to meet the blending mandate for 2030 and what will be the effect of different feedstock mix on food and land use? 2) How can cellulosic ethanol potentially contribute towards achieving the blending mandate by 2030? 3) What are the distributional impacts of alternate feedstock mix on different stakeholders i.e., producers and consumers of food and fuel, and the government.

This study aims to answer these critical policy questions using a price endogenous mathematical programming model.

4. Methodology

The method used for evaluation is theoretically analogous to several studies undertaken for agricultural policy analysis under market equilibrium condition. Specifically, the study uses price endogenous mathematical model as an analytical tool to evaluate the above research questions. The conceptual underpinning of the model is based on the seminal work of Samuelson (1952) which was later enhanced and reformulated by Takayama and Judge (1971, 1964 a, c) into a quadratic programming formulation. McCarl and Spreen (1980) extensively discusses the microeconomic foundations and underlying premises of quadratic programming models wherein each producing unit individually behave as small competitive units, but collectively, prices and quantities are endogenous to the model. The modelling approach has been widely applied for environmental and agricultural policy analysis and bioenergy impact assessment. Specific to India, Khanna et al., (2013) used price endogenous partial equilibrium model for assessing impact of meeting ethanol mandates with first generation feedstocks.

This study builds on the modelling framework of Khanna et al., (2013) and uses Chen et al., (2014) and Nunez et al., (2013) frameworks to allow for inclusion of cellulosic ethanol and ethanol from other first-generation feedstocks. For this purpose, we develop a multicommodity, price endogenous, partial equilibrium model with an objective function maximizing society's welfare. The quasi-welfare function is represented by the sum of consumers' and producers' surplus derived from production and consumption of several agricultural commodities, fuel, and biofuels. The model includes spatially explicit agricultural supply functions and defines commodity demand at all India level. The model distinguishes between biofuel types produced from three different feedstocks i.e., molasses, sugarcane juice and cellulosic biomass. Specifically, the study includes three different sources of biomass i.e., rice straw, wheat straw and bagasse.

The supply response of agricultural sector is represented by a Leontief production function in which land as the only primary input, while availability of all other inputs (e.g., fertilizers, pesticides, irrigation, labour etc.) is assumed to be unlimited at constant prices observed in the base year. Land use in each region is restricted to the total cropland available in the base year. Historically observed allocation of land in each region among the crops are used to constrain land use decisions to avoid abrupt and unrealistic changes in land allocation (McCarl, 1982; Onal and McCarl, 1989). The model operates under perfectly competitive market, in which each individual producer are price takers. The consumer demand functions for agricultural commodities are explicitly defined by price-quantity relationship using the base year price and quantity level and elasticity of demand which is assumed to remain constant for future period. The domestic and export demand function for commodities and export supply functions are assumed to be linear and separable. Demand for ethanol is expected to shift the demand curve for sugarcane and other biofuel feedstock crops (rice and wheat for straw) to the right.

4.1. Data description and assumptions

The data for the model comes from 16 major agricultural supply regions, together representing nearly 96% of India's gross cropped area and nine different crops. The selected nine crops include rice, wheat, sorghum, maize, groundnut, rapeseed, soybean, and cotton. The model currently considers only sugar[4] as the processed commodity. Regional heterogeneity in the model is explained by state specific data on available land resources, crop productivity, costs of crop production and biomass yield. Data inputs for model simulation includes base year data for domestic demand and export-import quantity and prices of modelled commodities, historical crop production possibilities of selected crops, crop yields, crop production costs, technological costs for crop processing and biofuels processing, biomass yields, residue-to-crop (RCR) ratios, and processing factors of different processed commodities including biofuels.

Costs of production of row crops include operational costs and fixed costs. Operating costs are yield dependent and include costs of labour (human labour, animal labour and machinery costs), seeds, fertilizer and manure costs, irrigation charges, insecticides, interest on working capital and other miscellaneous costs. The study uses three-year average (2009-2011 adjusted to 2011 prices) costs for each cost component to represent crop production costs at the base year. Data for crop production costs is obtained from crop production budgets compiled for each state through the Cost of Cultivation Surveys published by Directorate of Economics and Statistics (DES), Ministry of Agriculture (MoA). In the model, land allocation decisions are endogenous and changes in cropland allocation is determined by relative prices of the crops. Cropland availability limits the total regional cropland usage to the available hectares of land in that region i.e., limited to the initial (base year) agricultural endowment of cropland. State specific planted areas for the nine selected crops for period 2000 to 2011 was obtained from DES. The data obtained was used to construct the cropland available in 2011.

We use Khanna et al., (2013) crop calendar approach to specify cropping activity pattern for different regions and crops. Crop calendar information for each state and crop was obtained from the Indian Council of Agricultural Research (ICAR) and MoA. Crop-mixes have been restricted to 2001-2011 period. The model includes crop-mix restrictions on a state basis covering all the major crops in the model. Historical data for crop yield is obtained from DES. The model uses state-wise historical three-year average (2009-2011) yield per hectare for crops by agricultural seasons as the representative yield for that state for specific cropping seasons. Domestic demand quantity, prices and elasticity parameters are the key inputs calibrating the demand curves for commodities in base-year. The base year demand quantities were obtained from USDA and CACP and represent an average of 2009-2011 quantities. Domestic demand quantities represent total demand and includes food and feed

[4] In India, though sugarcane is primarily used for sugar production, there are also alternate uses like manufacturing of Gur, Khandsari, seed and others. The model does not capture the market of Gur and Khandsari.

demand. Domestic prices for agricultural commodities are represented by farm harvest prices. The model uses average of 2009-11 farm harvest prices (adjusted to a constant 2011 prices). Price elasticities of commodities were obtained from different sources.

The model includes two major ethanol types i.e., ethanol made from sugar-based feedstocks and cellulosic ethanol. The model allows hydrous ethanol production only from molasses while anhydrous ethanol can be produced from all feedstocks included in the model. The model considers regional heterogeneity in technical parameters like sugarcane processing[5], molasses recovery rates and sugar recovery rates. Cellulosic feedstock includes rice and wheat straw and sugarcane bagasse. Yields and costs of production of crop residues are region specific and which were computed based on the RCR ratios, moisture content and residue collection rates which are dependent on alternate residue uses. In India, conservation agriculture (CA) adoption is still in the initial phases (Bhan and Behra, 2014) and rice-wheat cropping system in India involves intensive tillage along with complete removal of crop residues. Therefore, the model assumes that entire land under respective feedstock crop is available for residue collection and accordingly no residue is used for in-situ uses. However, the model accounts for competing exsitu uses of residues and uses residue utilization rates reported in Cardoen et al. (2015b). Cost of agriculture residues in the model includes costs of residue production, harvesting, collection, transportation and storage of agricultural residues, all evaluated using Tripathi et al. (1998) approach. We assume manual collection of residues.

In the fuel module, we assume a linear and downward sloping inverse demand function for fuel (blended gasoline and ethanol). The aggregate demand for fuel is defined to include both anhydrous ethanol and gasoline (petrol) which was around 21519 million litres in 2011 of which only 365 million litres were ethanol. Retail prices for gasoline was obtained from Indian PNG Statistics (2011). For calibrating the demand curve of blended fuel, the study uses Gorter et al., (2015) and Khanna et al., (2016) approach. Ideally, the consumer price of blended fuel is the weighted average of anhydrous ethanol and gasoline prices (inclusive of taxes), where the weights are the shares of ethanol and gasoline in the final fuel blend. We use the central and state tax information on gasoline and ethanol along with marketing margins and other taxes to get the retail prices of blended fuel. The tax rates assumed here are based on rates levied in the state of Delhi in 2011. Finally, the demand curve for blended fuel is defined by using the weighted average of gasoline and ethanol prices and quantity and a fuel demand elasticity. Since, blended fuel is not segregated with non-blended fuel at pump, we assume elasticity of gasoline to be same as elasticity of blended fuel. Specifically, the study uses gasoline price elasticity of -0.36 as reported in Dahl, (2012). Since, India's vehicle fleet structure is constrained from operating on high ethanol blends, we assume that gasoline and biofuels are imperfect substitutes in producing the blended fuel. Since trading of ethanol for

[5] In India, sugarcane harvested is not equal to sugarcane crushed for sugar purpose. Since, the study does not include gur and Khandsari in the processed commodity list, sugarcane use for processing has also been adjusted accordingly (sugarcane use for gur and khandsari excluded). The proportion of sugarcane crushed for sugar varies by region depending upon the importance of sugar-based products (sugar, gur, khandsari, seeds etc.) in specific region.

fuel blending is prohibited by policy in India, the model does not allow trading of ethanol for fuel blending, however ethanol trading for industrial uses is allowed in the model.

The model is calibrated using 2011 as the base year. For simulating the 2030 case, we use exogenous shocks to update the model. The model projected forward to 2030 i.e. the year by which NPB, 2018 policy target is expected to be achieved. The crop yields are assumed to increase over time at an exogenously specified rate estimated using historical data for the period 1980-2014. A critical assumption made over here is that although each region (states) may have different yield in the base year, they are all expected to grow at the same annual growth rate. In the fuel sector, we assume that the historical trend of petrol demand i.e., average annual growth rate of 8.5% between 2001-2018 (PPAC) to continue between 2011-2030. Domestic demand for commodities is assumed to change over time based on historical growth trend and future requirements. To simulate for 2030, domestic demand curves are shifted upward over time at exogenously specified rates. The shift parameters or the annual growth rates were estimated based on OECD-FAO Agricultural Outlook projections from 2014-2023 which provides country wise growth projections in agricultural exports, imports, production and consumption. For alcohol, due to unavailability of any recent data on future demand for industrial ethanol (alcohol) we use the alcohol demand growth rate estimates of other studies. According to Shinoj et al., (2011) and Purohit and Fischer (2014) the industrial ethanol demand growth rate increased by 3% and potable ethanol by 3.3%, and the trend is likely to remain same in the future. Since, the model considers combined demand for alcohol (industrial ethanol and potable ethanol), the projected demand is expected to grow at an annual rate of 6.3%. For the 2030 case, expansion of agriculture production is modelled as a product of yield improvements on the agricultural land currently in use. The equilibrium price of ethanol in the national market, the amount of land cultivated and the prices and quantities of sugar, alcohol, and all primary agricultural commodities are determined endogenously by the model.

The mathematical representation of the model can be found in the Appendix. The model is coded using the Generalized Algebraic Modeling System (GAMS) language.

5. Results

5.1. Description of biofuel scenarios

Policy scenarios for assessment have been designed in coherence with the National Policy on Biofuels 2018, which allows alterations induced by changes in feedstock mix to attain the 20% ethanol blending requirement by 2030. Specifically, we assess three policy scenarios engaging alternate feedstock mix. The first scenario considers 20% ethanol blending mandate by 2030 to be achieved through only molasses feedstock. With insufficient advancement in availability of alternate feedstocks, it is expected that ethanol would continue to be produced primarily from molasses. This scenario is referred as the ‘*Baseline Scenario’* from here on. We compare this 2030 baseline with two alternative policy scenarios. The new biofuel policy allows use of surplus food grains for production of ethanol including sugarcane. With this policy sanction, despite of the fact that producing ethanol from sugarcane will require major capacity expansion it is quite evident that in the surplus production years sugar mills will divert sugarcane towards ethanol production. While ethanol supply from molasses is likely to continue, this scenario referred as "*Combined Molasses & Sugarcane*" scenario considers the case in which the 20% blending requirement is to be met through a mix of molasses and sugarcane feedstock. To avoid unrestricted diversion of sugarcane for ethanol production, this scenario considers the case in which by assumption only the leading sugarcane producing states (i.e., U.P., Maharashtra, Karnataka, and Tamil Nadu) can divert 10% of the sugarcane for ethanol production. An additional scenario for unrestricted sugarcane uses for ethanol has also been tested. The second alternative scenario referred as "*All-feedstock*" scenario considers the case in which the 20% ethanol blend mandate is supposed to be met with cellulosic feedstocks in combination with molasses and sugarcane juice. The scenario particularly considers ethanol production from bagasse, rice straw and wheat straw. mandate with

5.2. Model validation

As a first step in testing for model performance, the model is first validated for year 2011 and a comparison is drawn for the simulated model on land allocation, crop production, fuel use and commodity prices with the corresponding observed values in the base year i.e., 2011. Domestic transportation of crops to consumers is not considered for model simulation and therefore, the crop prices solved by the model represent producer prices at the farm-gate. Further, international transportation costs are also not considered in case of exports and imports and therefore, it is quite likely that the model is mis specified. To overcome misspecification error, we follow Fajardo et al., (1981) approach, in which difference between domestic and foreign prices of commodities are considered as marketing margins which is then adjusted in the objective function.

Table 1 summarizes the validation results for land use and fuel sector. The land use of agricultural crops is within acceptable margin of errors. The fuel consumption values are also within a small deviation range around the observed values. This indicates good simulation performance of the model. These small deviations notwithstanding, the model appears to reasonably replicate the base year market equilibrium conditions in the food and fuel sectors.

Table 1: Model Validation results for land use and fuel sector

	Observed Base Year	Model Base Year	Deviation (%)
	Land Use (in million Ha)		
Rice	40.9	43.0	5
Sorghum	6.2	6.4	2
Maize	7.8	7.6	-1
Groundnut	5.2	5.5	5
Wheat	29.0	28.7	-1
Soybean	10.1	9.9	-1
Rapeseed	5.5	6.7	22
Cotton	12.1	12.0	-1
Sugarcane	5.0	4.9	-2
	Fuel Sector		
Gasoline Prices (Rs./litre)	65	64	-1.2
Gasohol Prices (Rs./litre)	65	64	-1.7
Alcohol Prices (Rs./litre)	43	43	0.0
Gasoline Consumption (million litres)	21154	21298	0.7
Ethanol Use (million litres)	365	372.7	2.1

5.3. Feasibility of achieving 20% blend mandate by 2030- identifying the optimal feedstock mix

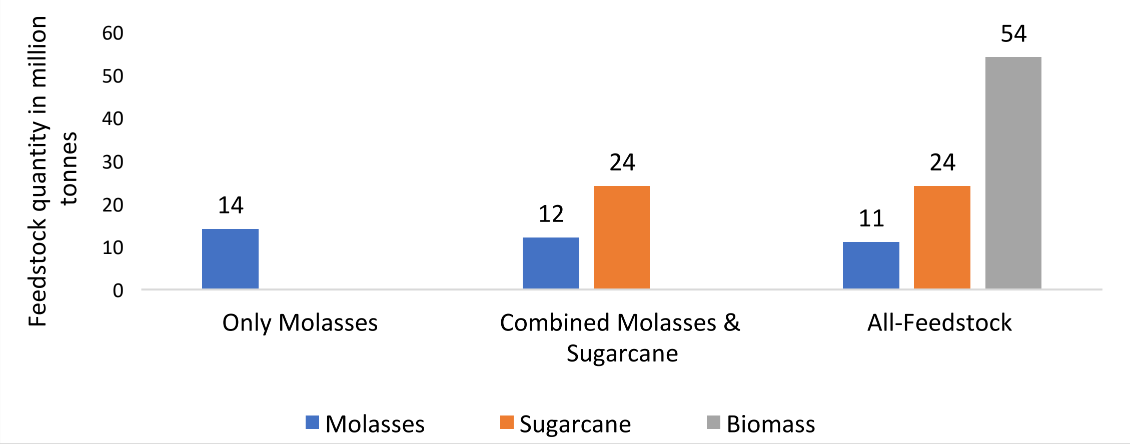
5.3.1 *Only molasses ethanol 2030*: In this scenario, the results suggest that only 2810 million litres of ethanol can be produced from molasses in 2030. The maximum achievable blending rate with only molasses feedstock is only 2.92%. Molasses production of about 12.8 million tonnes is likely to be insufficient to meet the increasing demand for both fuel blending and industrial alcohol production. Due to increased demand of molasses for fuel purpose all molasses produced is diverted to fuel ethanol production as a result of which domestic supply of alcohol falls to almost zero and therefore entire domestic requirement of alcohol is met through imports (5475.152 million litres). No significant increase in area under sugarcane is observed as scope of area expansion under sugarcane is limited due to increase pressure on land use for supply of other crops. This implies that sugarcane supply increase is majorly due to increased sugarcane yields. Sugarcane yields increase by 11.06% between 2011 and 2030. Without any major expansion in area under sugarcane, only 28.4 MT of sugar is produced which is incapable of meeting the projected sugar demand of about 33 MT in 2030 leading to price increase of sugar. Price of molasses is expected to increase by almost 54% to Rs. 9608 per tonne in comparison to 2011 levels and sugarcane price is around Rs. 2847 per tonne. A rise in molasses prices raises the molasses ethanol prices (at refinery gate) to Rs. 51.62 per litre.

5.3.2 *Molasses and sugarcane scenario:* Under the combined molasses and sugarcane ethanol case, no significant increase in area under sugarcane is observed in comparison to baseline scenario. In absence of any significant expansion of area under sugarcane, diverting only 10% of sugarcane by the major sugarcane producing states leaves only to 255.3 MT of sugarcane for sugar production (which is almost 63% of total sugarcane produced), a fall of 8.3% in comparison to the baseline. As a consequence of reduced sugarcane supply for sugar domestic sugar production falls by 9% leading to increase in prices of sugar by about 16.6% in comparison to the baseline case. Accordingly, molasses production also decreases by about 33.7% to 8.5 MT which equally impacts molasses ethanol supply in comparison to the baseline scenario. However, total ethanol supply in this scenario increases by about 28% to 3596.6 million litres in comparison to the baseline case. The ethanol mix is 1861.7 million litres of molasses ethanol and 1734.9 million litres is sugarcane ethanol. The maximum achievable blending rate through mix of molasses and sugarcane feedstock is 3.7% which is comparatively higher than the baseline case. Increased blending rate however comes at the cost of loss in domestic sugar supply and higher prices of sugar, which may raise food security concerns. The optimal feedstock mix comprises of 23 million tonnes of sugarcane (about 6% of total sugarcane produced) and about 8.5 million tonnes of molasses. Even with a combination of molasses and sugarcane ethanol meeting 20% blending mandate by 2030 is challenging unless there is large area expansion under sugarcane. Feedstock prices i.e., molasses and sugarcane prices under this scenario are Rs. 9609 per tonne and Rs. 3133 per tonne respectively. Increase in sugarcane requirement for both ethanol and sugar has positive impact on prices since sugarcane price is almost 10% higher than the baseline scenario. The refinery gate price of sugarcane ethanol is Rs. 48.3 per litre and molasses ethanol is Rs. 51.6 per litre.

Analysis of both the scenarios with first generation feedstock suggest that it is impossible to meet increasing biofuels demand from only molasses feedstock and even with a mix of sugarcane and molasses feedstock in 2030, without any significant expansion in sugarcane acreage. In a previous study, Khanna et al., (2013) found that achieving 20% blending mandate by 2017 with a mix of molasses and sugarcane feedstock is possible without any significant food and land use impacts. However, our study results indicate that gasoline consumption growth rate is expected to surpass ethanol consumption growth rate as a result of which despite of increasing ethanol consumption in comparison to 2011 level, the ethanol blending rate will be decreasing by 2030. It will be difficult to sustain 20% blend rate or even 10% blend rate without any diversification of feedstock sources. Therefore, for India to achieve the mandate by 2030 it is necessary to complement the existing ethanol feedstock basket with second generation feedstocks.

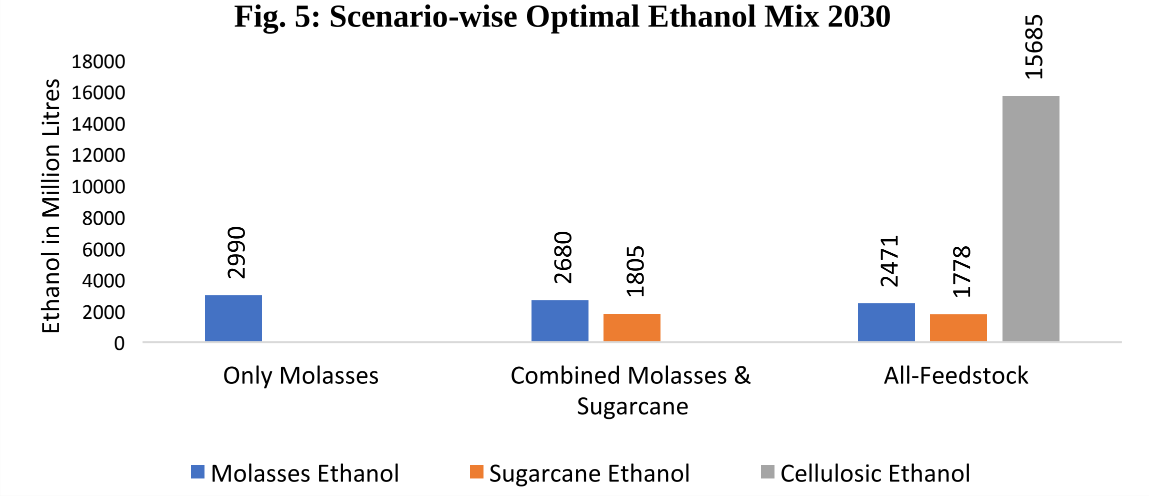
5.3.4 ***All feedstocks scenario:*** Under this scenario, when all feedstocks (molasses, sugarcane juice and cellulosic biomass is considered for ethanol production, the ethanol supply increases substantially to 19301 million litres which helps achieve 20% blending mandate by 2030. The biofuel mix under this case comprises of 2580 million litres of molasses ethanol, 1735 million litres of sugarcane ethanol, and 14985 million litres of cellulosic ethanol. In total cellulosic ethanol, bagasse and wheat straw ethanol are the major contributors 13442 million litres and 1532 million litres respectively and almost nil ethanol from rice straw. This is most likely due to relatively lower ethanol recovery rate (by assumption ethanol recovery rate from rice straw is almost 15% lower than bagasse and 4% lower than wheat straw) and higher processing cost of ethanol from rice straw in comparison to other cellulosic feedstocks (by assumption ethanol processing cost from rice straw is almost 9.2% higher than bagasse ethanol and about 6% higher than processing cost of wheat straw ethanol). Producing 14974 million litres of cellulosic ethanol, approximately requires 51.3 MT of biomass. Optimal feedstock mix under this scenario is 45.6 million tonnes bagasse, 5.7 million tonnes of wheat straw, 11.7 million tonnes of molasses and about 23 million tonnes of sugarcane. Wheat straw harvested area is about 23% of wheat acres while bagasse requirement is met from total area under sugarcane. Biomass price under this scenario turns out to be Rs. 2,548 per tonne. Comparing with the baseline case, the results suggest that sugarcane area expansion falls by 0.3% to 5.12 Mha. In fact, area expansion under sugarcane is negligible. However, due to low flexibility in cropland expansion the domestic sugar supply is insufficient to meet the domestic sugar requirement as a result of which sugar prices are 14% higher in comparison to the baseline case. Additional ethanol supply from cellulosic feedstocks in 2030 eases demand pressure on molasses for biofuel and industrial use purposes leading to fall in molasses prices (4%) in comparison to baseline. Lower molasses prices reduce the refinery gate price of molasses ethanol by about 3.4% to Rs. 49.4 per litre. In similar condition, refinery gate price of sugarcane ethanol is Rs. 49 per litre and cellulosic ethanol is Rs. 48.3. Further, in the case of ‘All feedstock’ since ethanol displaces considerable amount of petrol, the price of petrol marginally falls by 0.7% due to reduced demand for petrol.

Fig. 4: Scenario-wise Optimal Feedstock Mix 2030



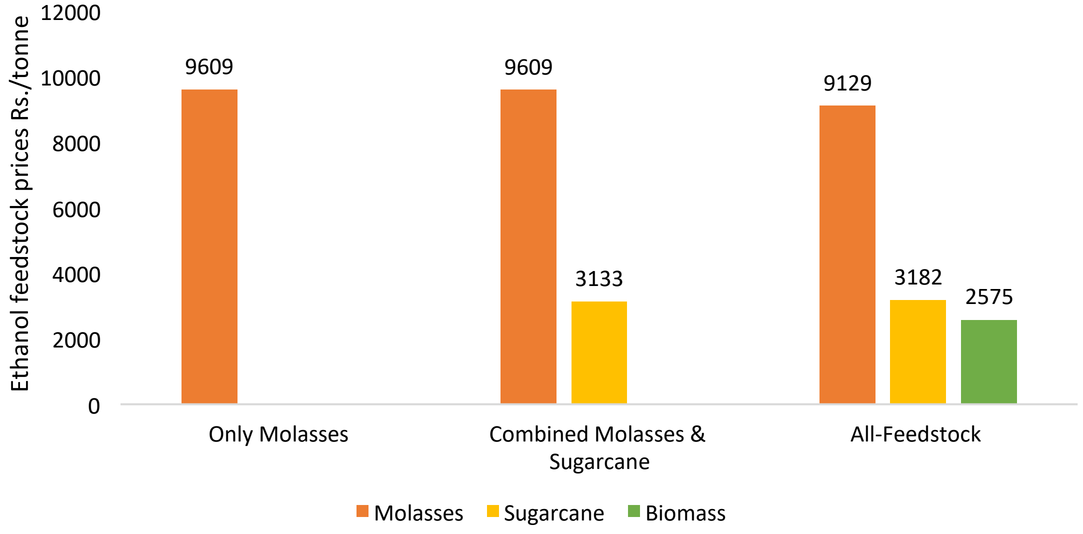
Source: Author’s Estimates

Fig. 5: Scenario-wise Optimal Ethanol Mix 2030



Source: Author’s estimates

Figure 6: Scenario-wise feedstock prices 2030



Source: Author's estimates

5.4. Welfare impacts of alternate feedstock mix

As compared to the baseline case, the 'Combined Molasses and Sugarcane Ethanol' leads to marginal increase in income gain (0.02%) for fuel producers and no change in income for fuel consumers. Under the 'All-feedstock' scenario income gains for fuel producers marginally increases (0.1%). As far as fuel consumers are concerned, fuel consumers is expected experience economic gains (0.5%) mainly due to comparatively lower blended fuel prices.

Agricultural producers are expected to attain significant gains under both 'Combined Molasses and Sugarcane' scenario (28%) and 'All-Feedstock' scenario (28%) in comparison to baseline case. This is mostly due to rise in prices of crops like sugarcane, sugar and additional income from biomass sale and the spill over effects of these on other commodity prices. In the 'All feedstock scenario', cellulosic biomass producers' potential gain from sale of residues is about Rs. 24 billion[6]. This indicates that use of cellulosic biomass for ethanol can generate significant economic gains and can also help achieve the 20% blending mandate by 2030. Agricultural consumer surplus is the lowest in the 'All Feedstock scenario' due to comparatively higher prices of agricultural commodities like rice and groundnut in comparison to the baseline case.

In summary, total economic surplus would increase the maximum in the 'Combined Molasses & Sugarcane' relative to the other two scenarios. The key difference under different scenarios is the income distribution between different producer and consumer groups. The main driver

[6] Cellulosic biomass includes all three biomass sources i.e. rice straw, wheat straw and bagasse. Economic gain of cellulosic biomass producers is represented by difference between revenue earned from residues and residue costs determined at the equilibrium prices and quantities.

for changes in economic welfare is the changes in agriculture producer and consumer surplus and government revenue earnings. Under the ‘All feedstock scenario’, government revenues decline significantly (14%) due to fall in tax revenues from reduced consumption of petrol in total fuel demand (as 20% of petrol consumption is replaced with ethanol in total fuel consumption). State and central taxes on petrol together accounted for about 39% of the retail selling prices f petrol in the base year.

6. Conclusion

In this study we present an analysis of projected agriculture and fuel market conditions in India and compared a business-as-usual regime with two alternate scenarios engaging different combinations of feedstocks while maintaining the blending mandates. We use a price endogenous mathematical programming model to analyse the impacts of alternate feedstock combinations on food, land use and economic surpluses of food and fuel consumers and producers.

The main findings of our study suggest impossibility of meeting increasing biofuels demand from only molasses feedstock and even with a mix of sugarcane and molasses feedstock in 2030, without any significant expansion in sugarcane acreage. The scope of area expansion for sugarcane is highly restricted due to high demand for other crops like rice, wheat, and maize. Since gasoline consumption growth rate is expected to exceed ethanol consumption growth rate the study finds that although ethanol consumption is expected to increase in comparison to 2011 level, the ethanol blending rate will be decreasing by 2030. It will be difficult to comply 20% blend rate or even 10% blending requirement by 2030 without any significant diversification of feedstock sources.

We find that a feedstock combination of molasses, sugarcane and cellulosic biomass can help India achieve 20% mandate by 2030. With limited scope for area expansion, cellulosic ethanol can potentially help dampen the pressure of land expansion for sugarcane crop as compared to situations where the mandate is met with only sugarcane-based feedstocks. Our results indicate that cellulosic biomass producers (farmers) can enjoy significant economic benefits from sale of agricultural residues although replacing petrol with ethanol can lead to significant reduction in government revenues since, tax incidence on petrol in India is very high. Cellulosic ethanol can potentially contribute 78% of total ethanol mix with bagasse as the main residue source. Complementing the ethanol mix with cellulosic feedstock also prevents prices surge of other ethanol feedstocks i.e., molasses and sugarcane.

Biofuel impact assessment literature is well documented with biofuel induced food security and land use impacts dampening the biofuel prospects in developing countries. The results of our study have important policy implications. Our study highlights that for countries like India, where land under agriculture is nearly stagnating and forest land diversion for biofuels is regulated by law, there will possibly be only two cases i.e., missing the mandates or achieving the mandate through different feedstock combinations and ethanol conversion technologies.

Our study does not suggest unrealistic diversion of pastureland and forestland for biofuel production expansion. Therefore, this study provides useful insights in developing country context. However, an important point to note here is that the model simulation procedure is an iterative process and the findings will get finer with improved data. Therefore, the results of our study should not be interpreted as forecasts but as potential biofuel development pathways for India under the assumptions considered for respective scenarios. The model developed and used in this study can be expanded with several extensions which is of importance for further in-depth assessment of biofuel policies for India. The model used for simulation is deterministic as it fails to incorporate changes in key climate variables (i.e., temperature and rainfall) in the agricultural sector model. The model can be enhanced into a stochastic model by incorporating rainfall and temperature components to reflect the variability in crop yields. Extensions to the model can also be made by including other agriculture biomass sources like corn stover, cotton stalks etc.

Further, for cellulosic feedstocks we assumed an efficient supply chain for biomass collection, transportation, storage and use for ethanol conversions. In addition to these factors, biomass utilization for fuel in India will necessarily depend upon alternate residue uses. Currently, there are lots of uncertainty in accurate estimation of alternate biomass requirements and surplus agricultural residue availability for fuel conversions. In this direction, detailed spatial assessment of biomass supply potential can be a significant research contribution. Further, advanced biofuel conversion technologies in India are still in the nascent stage of development and far from commercial reality. Under such conditions, uncertainties in conversion costs and ethanol recovery rates is quite prominent. Although the study results indicate high potential of cellulosic biomass in augmenting India's biofuel capacity, advancement in cellulosic biofuels in India, to a large extent will depend upon the predictability of the policies. While the current policy environment for advance biofuels in India is positive, immature residue and biofuel market conditions; high ethanol production costs will be the major influencing factors in achieving the future mandates.

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Appendix

The Mathematical Model

Maximize

$$\sum_{com}\int_0^{DEM_{com}} f(.)d(.) + \int_0^{DEM_{sug}} f(.)d(.) + \int_0^{DEM_{alc}} f(.)d(.) + \sum_{com}\int_0^{EXP_{com}} g(.)\,d(.) + \int_0^{EXP_{sug}} g(.)d(.) + \int_0^{EXP_{alc}} g(.)d(.) - \sum_{com}\int_0^{IMP_{com}} g(.)d(.) - \int_0^{IMP_{sug}} g(.)d(.) - \int_0^{IMP_{alc}} g(.)d(.) - \sum_{a,r} coc_{a,r}\, LAND_{r,a} - \sum_{r,cr} rs_{r,cr}\, LANDRES_{r,cr}$$

$$- cf_s^{sc}\theta_s^{sc} CANE_{sug} - cf_a^{mol}\theta_a^{mol} MOLASS_a - cf_e^{mol}\theta_e^{mol} MOLASS_e - cf_e^{sc}\theta_e^{sc} CANE_e - cf_e^{res}\theta_e^{res} RESIDUE_e$$

-------------------------- (1)

$$DEM_{com} + EXP_{com} \le \sum_a y_{c,a,r} LAND_{a,r} + IMP_{com}\ \forall\, c$$ ---------------- (2)

$$DEM_{sug} + EXP_{sug} \le cf_s^{sc} SCANE_s + IMP_{sug}\ for\ sug$$ ---------------------- (3)

$$SCANE_S + SCANE_E \le y_{sc,r} LAND_{sc,r}$$ -------------------------- (4)

$$DEM_{Alc} + EXP_{Alc} \le cf_a^{mol} MOLASS_{alc} + IMP_{alco}$$ (Alcohol balance) ---------------- (5)

$$MOLASS_e + MOLASS_{alc} = cf_{mol}^{sc} SCANE_S$$

------------------------(6)

$$ETHD = blend.F$$ --------------------- (7)

$$ETHD = ETH_{cane} + ETH_{molass} + ETH_{biomass}$$ -------------------------- (8)

$$ETH_{molass} \le cf_e^{mol} MOLASS_e$$ ---------------------------- (9)

$$ETH_{cane} \le cf_e^{cane} SCANE_e$$ -------------------------------- (10)

$$ETH_{biomass} \le cf_e^{biomass} RESIDUE_e$$ ------------------------- (11)

$$\sum_a \delta_{a,t,r} LAND_{a,r} \le l_r \quad \forall\, r, t$$ -------------------------------------- (12)

$$RESIDUE_e \le \sum_{r,cr} yr_{r,cr}\, LANDRES_{r,cr}$$ -------------- (13)

$$LANDRES_{r,cr} \le LAND_{a,r}$$ ----------------------- (14)

$$\sum_a LAND_{a,r} = \sum_y \lambda_{y,r} HistArea_{y,r,a} \quad \forall\ r, c$$ ---------------------- (15)

$$\sum_y \lambda_{y,r} \le 1 \quad \forall\ r$$ ------------------------------ (16)

$LAND_{a,r}$, $LANDRES_{r,cr}$, DEM_{com}, EXP_{com} ,IMP_{com} , DEM_{sug}, EXP_{sug} ,IMP_{sug} , $RESIDUE_e$, $SCANE_S$, $SCANE_E$, DEM_{Alco},IMP_{alco}, $MOLASS_{alco}$, $MOLASS_e$, ED, ET_{cane},ET_{molass}, $ET_{biomass}$, $MOLASS_e \geq 0$ --------------------- (17)

where, $f(.)$ represents the inverse demand function, $d(.)$ denotes the integration operator and $g(.)$ is represents the export-import functions for the traded goods. The objective function (1) represents the area under the demand functions and area under the gasoline supply function up to the quantities in the optimum solution minus the cost production of crops, and the processing cost of sugar and ethanol. Equation (2) is the material balance constraint for crop commodity stating that total demand for crop commodities including exports to the rest of the world (ROW) should be less than or equal to total domestic supply and imports from the ROW. Similarly, Equation (3) specifies the material balance constraint for sugar. Equation (4) is the material balance constraint for sugarcane, indicating that the sum of sugarcane used for sugar production and ethanol production should be less than total supply of sugarcane. Equation (5) is the material balance constraint for processed commodity i.e., alcohol indicating that the demand for alcohol is restricted to the supply of alcohol from molasses, which is the sum of domestic alcohol production and imported alcohol from ROW. Equation (6) states that the total molasses allocated to ethanol and alcohol production should be equal to the domestic supply of molasses generated from cane processing for sugar. Equation (7) states the policy constraint for ethanol blending. Equation (8) represents the ethanol demand-supply balance which states that the total ethanol demand cannot exceed the total ethanol supply which is composed of three ethanol types i.e., ethanol from sugarcane, ethanol from molasses and ethanol from biomass. Equation (9) provides the molasses ethanol supply balance which states that the total quantity of molasses-based ethanol produced should be restricted by total domestic molasses ethanol supplied from total molasses used for ethanol production proportional to the conversion factor of molasses to ethanol.

Similarly, equation 10 specifies the sugarcane ethanol supply balance which states that the total domestic supply of sugarcane-based ethanol should be restricted to total domestic supply of sugarcane ethanol produced from sugarcane diverted to ethanol production proportional to the conversion factor of sugarcane to ethanol. Equation 11 states that the total cellulosic ethanol produced must be produced from total quantity of biomass available for ethanol production proportional to the conversion factor of biomass to ethanol. Equation (12) is the land availability constraint which specifies that the total land allocated to different crops in a region is limited by the total available land in that region. Equation 13, states that the total supply of crop residues used for cellulosic ethanol production must match the sum of regional supply of crop residues which is a function of crop residue yield specific to crop in region and land available for residue collection in regions specific to crop for residue. Equation 14 requires that the land from which crop residues are collected cannot exceed the land allocated to crops specifically producing residues. Equation (15) and (16) provides the production possibility frontiers for farmers' acreage allocation decisions. Both the constraints determine the planting flexibility constraint which is specified by historical mix constraint. The R.H.S of the equation is the sum of historical acreages where is the weight variable for historical crop-mix. The weight variables are region specific and are endogenously determined by the model. The equation states that in each region the land allocated to all crop producing activities must be a weighted average of the historically observed acreages of that crop. In equation (15), represents the cropping possibilities for crop in region. This allows the acreage of the historical mixes to float up and down but requires that crops fall in a combination of historic and hypothetic proportions. Equation (16) states that sum of the weights should be less than equal to 1 (convexity constraint). Equation (17) is the non-negativity constraint for the decision variables of the model.