Multicriteria comparison of fuel policies: Renewable-fuel mandate, emission standard, and carbon tax

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Abstract

We develop a two-region partial equilibrium model of the global market for liquid fuel and analyze different policies, such as biofuel mandate, emission standard, and fuel carbon tax. We rank these policies under different criteria, such as greenhouse-gas (GHG) emissions, expenditure on fuel imports, the impact on fuel consumers and producers, the quantity of biofuel, etc. Our analysis suggests that supporting the domestic biofuel industry and reducing energy imports appear to be the main goals for policy makers in adopting the U.S. Renewable Fuel Standard while GHG emission reduction appears to be the main criterion in adopting the Low Carbon Fuel Standard (LCFS) in California. The non-adoption of GHG tax suggests that supporting the domestic renewable fuel industry and limiting the impact on fuel consumers are also important criteria for policy makers.

Keywords: climate change, transportation, energy security, renewable energy, biofuel, GHG tax, mandate, GHG standard

1 Introduction

Governments have enacted policies in support of alternatives to crude oil. These policies aim to achieve multiple objectives, such as greater energy security, reduction in greenhouse-gas (GHG) emissions, lower energy prices, support for infant domestic industries, employment generation, etc. (CBO, 2007; Sobrino and Monroy, 2009; CARB, 2009). Biofuel regulations comprise a predominant share of these policies and can be divided into two categories. One category is biofuel mandate, which may specify either a target quantity of biofuel (as in the United States with the Renewable Fuel Standard (RFS)) or a target market share for biofuel (as in several countries in Europe, and which is not biofuel-specific) in domestic fuel consumption (Martinot and Sawin, 2009). Another category of regulation, which is being implemented in California is called the Low Carbon Fuel Standard (LCFS). This type of regulation is under consideration also in the European Union (EU) and China. Whereas a biofuel mandate may explicitly or implicitly specify the type and quantity of biofuel to be consumed, the LCFS specifies an

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upperbound on the average GHG intensity of transportation fuel consumed within a region. The RFS and LCFS are equivalent when there is only one type of fossil fuel with a fixed GHG intensity and one type of renewable fuel with a fixed GHG intensity. However, when there is variation in the GHG intensity of fossil or renewable fuels and when regulations are partial (i.e., not global in scope), the two regulations may lead to different outcomes. Since both the RFS and LCFS are applied partially, which may lead to leakage of emissions (Bushnell et al., 2008). Pollution leakage may manifest in two ways: (i) pollution shuffling, which refers to reallocation of the different fuel types so that the more polluting fuels are consumed in unregulated markets and regions and (ii) a rebound effect, which refers to an increase in fossil fuel consumption due a reduction in the world price of fossil fuel as a result of policies in one part of the world. Depending on the cost and GHG intensity of the different fossil fuels and biofuels, and their origin, the two regulations may lead to different trade-off between the multiple policy objectives. The political economic literature suggests that policies are selected based on multiple performance measures (see Rausser et al. (2011)). Our goal is to compare different policies based on multiple criteria. Our challenge is to develop an analytical framework with the least amount of complexity that can capture the major considerations. For instance, the fuel market is global but policies are sub-global, variation in GHG intensity of fossil fuels and renewable fuels, the lifecycle GHG emission intensity of biofuels is more uncertain than that of fossil fuels (for reasons described later) etc.

We analyze five different policy instruments that are either being used or have been suggested: (1) market-share mandate (SM) for biofuel; (2) market-share mandate for a given biofuel, specifically, corn ethanol (SMC) - a policy with features akin to the US RFS; (3) fuel emission-intensity standard (ES) - a policy with features akin to the LCFS; (4) fuel GHG tax (CT) - a policy favored by economists; and (5) a combination of SM and CT - a policy that is considered to be superior to a pure mandate from a social welfare perspective. We develop a two-region partial equilibrium model of the global market for liquid fuel and simulate these policies under different assumptions about price elasticities, fuel emission intensities, and other model parameters. We rank these policies based on multiple criteria such as greenhouse gas (GHG) emissions, outlay on fuel imports, the impact on fuel consumers and producers, the quantity of biofuel consumed globally, etc. Since we do not model the impact on the food sector, and since biofuels have been shown to increase food prices and result in net surplus losses in food markets (Rajagopal et al., 2007; de Gorter and Just, 2009), the quantity of biofuel as a criterion. Thus, if policy A achieves better performance with respect to criterion X relative to policy B while resulting in an equal or lower consumption of biofuel, then policy A can be considered as superior to policy B with respect to criterion X. We also then identify the criteria that explain the selection of policies such as the RFS and LCFS and discuss how partial policies may be chosen to improve cost effectiveness with respect to GHG emission reduction or reduce expenditure on energy imports while satisfying distributional objectives.

This paper contributes to a growing literature that evaluates biofuel policies based on different criteria.

\(^1\)We prefer to use the terms SM and ES etc. instead of the actual policies such as RFS and LCFS respectively for the reason that the our modeling of these policies and the markets is simple relative to the real world and also since our conclusions are not intended to be interpreted as the actual performance of the real policies.
Using an open-economy general-equilibrium model to compare various policies, Lapan and Moschini (2009) show that a combination of biofuel mandates and fuel GHG taxes would result in a higher fuel-market surplus than mandates along with subsidies. Applying the same framework, Cui et al. (2010) suggest that US mandates and subsidies do not contribute to GHG reduction but do contribute to fuel security and improve farmers’ welfare. de Gorter and Just (2009) argue that the welfare loss, taking into account the corn market surplus and tax payer cost of biofuel excise tax credits, dwarfs the welfare gains from reduction in farm subsidies. Khanna et al. (2008) focused on GHG emissions and congestion from driving and argue that biofuel subsidies lead to a marginal reduction in GHG emissions, an increase in vehicle miles driven, and a net loss in social welfare. Other studies employing the cost-effectiveness criterion to evaluate current biofuel policies conclude that biofuels are not as cost-effective as a GHG mitigation strategy relative to a carbon tax (Creys, 2007; Holland et al., 2009). Jaeger and Egelkraut (2011) evaluate different policy interventions in terms of their cost-effectiveness for achieving two objectives, namely, reducing GHG emissions and reducing fossil-fuel use and find biofuel policies costly. Focusing on the energy security related impact of biofuels, Leiby (2008) estimates that the RFS2 regulations confer a monopsony benefit of $7.86 per barrel of renewable fuel, and a benefit of $6.56 per barrel due to reduced macroeconomic risk from oil price shocks. Rajagopal et al. (2007) show that U.S. biofuel policies not only raise food prices but, by lowering the world price of oil, lead to leakage of GHG emissions through greater oil consumption abroad. Interestingly, Holland (2009) finds that an ES-like policy may yield higher social welfare than an emission tax when GHG regulation is incomplete or when there is market power. The rich literature on biofuel policies recognized and demonstrated the multidimensionality of the policy objectives and policy tools, but individual papers usually consider one or two criteria and ignore important dimensions of the fuel market. There have been only a few comparisons of RFS and LCFS, and most studies do not distinguish between global and regional policies. The contribution of this paper is in comparing different commonly used or suggested policy instruments with respect to multiple criteria taking into account important aspects of fuels and markets.

2 Model

Fischer (2010) provided a partial equilibrium framework to analyze the impact of renewable portfolio standards in the electricity sector and in a single-region context. We introduce a microeconomic framework that builds on it and is capable of analyzing different types of fuel policies in a multi-region partial context. Our model has two regions - home and rest of the world (ROW). We assume open economies and competitive markets. We consider two categories of liquid fuels: crude oil and renewable fuel, more specifically, biofuel. Crude oil refining yields multiple types of fuel and petrochemical products. However, rather than modeling the complete petroleum products sector, we make a simplifying assumption that reducing gasoline demand by 1 megajoule (MJ) reduces petroleum demand by 1 MJ. It also implies that, in response to reduced gasoline demand, less oil will be demanded. Thus, we effectively model biofuel as
a substitute for oil after adjusting for energy equivalence. Gasoline is approximately only 50% to 60% by volume of all oil products in the United States while diesel tends to the single largest refined fraction in several other markets. Our assumption is extreme, and so leads to an extreme prediction of oil use reduction and emissions. While more precise assumptions may affect the absolute value of our predictions, they are unlikely to affect the relative performance of the different policies, which is the focus of this paper. We further classify fossil fuels into conventional crude oil (CC), and synthetic crude (SC), which are considered as perfect substitute. In this paper, SC refers mainly to oil from oilsand in Canada.\(^2\) We model one type of renewable fuel, namely, biofuel and for simplicity, consider only two types of biofuel, namely corn ethanol and sugarcane ethanol.

The GHG intensity differs across the different fuels considered, but is fixed for each type of fuel. On account of the greater energy for processing the primary feedstock, oilsands, the lifecycle GHG intensity of SC is reported to be as much as 20% or more larger compared to CC. The lifecycle GHG intensity of biofuels is assumed to be the sum of two components. The first is the GHG emission intensity calculated based on emissions traceable to the processes involved in the production and use of biofuel, and which is generally considered to be lower for biofuels than petroleum-based liquid fuels (de Carvalho, 1998; Farrell et al., 2006; Liska et al., 2008). The second is the emission intensity associated with what is referred to as the indirect land use change (ILUC) effect, which arises as a consequence of biofuel policies and is shown to reduce the GHG benefits of biofuel (Searchinger et al., 2008; Hertel et al., 2010; Tyner et al., 2010; Plevin et al., 2010). The magnitude of ILUC emissions and the policy response to ILUC are a matter of much controversy. We, therefore, adopt an intermediate strategy. We assume that from a regulatory perspective ILUC emissions are not included in determination of compliance with a chosen standard whether it is an upper-bound on the GHG intensity of biofuel as in the case of RFS or the average GHG intensity of transportation fuel as in the case of the California LCFS. However, we calculate total emissions under each policy taking into account ILUC emissions.

We use the following mathematical notation. Superscripts \(h\), \(a\), and \(w\) denote the home, ROW, and the world, respectively. Subscripts \(cc\), \(sc\), \(cb\), and \(sb\) refer to conventional crude oil, synthetic crude oil, corn ethanol, and sugarcane ethanol respectively. Let \(R = \{h, a\}\) denote the set of two regions, \(L = \{cc, sc, cb, sb\}\) denote the set of all fuels, \(F = \{cc, sc\}\) denote the set of fossil fuels, \(B = \{cb, sb\}\) denote the set of biofuels, \(D = \{cc, cb\}\) denote the set of fuels produced domestically, and \(I = \{sb\}\) denote the set of fuels that face an import tariff. Let \(p\) denote the fuel price, \(q\) denote the quantity of fuel, \(z\) denote the lifecycle GHG intensity of fuel (with \(z_b < z_{cc} < z_{sc}\)), and \(Z\) denote GHG emissions.

Let \(D\) and \(D^{-1}\) denote the demand and inverse demand functions respectively. Let \(S\) and \(S^{-1}\) denote fuel supply function and the inverse supply function, respectively. We assume that the functions are well-behaved and that the inverse function exists. Transportation costs are assumed to be a negligibly small component of the price of fuel, and hence, set to zero. We assume that the blending of fossil fuel

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\(^2\)According to the International Energy Agency’s World Energy Outlook 2008, SC is expected to comprise about 75% of the incremental supply between 2006 and 2030.
and renewable fuel is perfectly competitive. Next we describe the equilibrium conditions under different policies. We begin by describing a future business-as-usual baseline scenario, which is assumed to involve no government intervention in the fuel market in either region.

Baseline: In the baseline, the world fuel price is determined by the equilibration of global supply and global demand for fuel. The market-clearing condition is

\[
\sum_{k \in L} S_k(p^w) = \sum_{r \in R} D^r(p^w) \tag{1}
\]

This can be rewritten as the system of equations (2).

\[
\begin{align*}
    p^w &= D^{h^{-1}}(q^h) \tag{2a} \\
    p^w &= D^{a^{-1}}(q^a) \tag{2b} \\
    \sum_{k \in L} q_k &= q^h + q^a \tag{2c} \\
    p^w &\leq S_k^{-1}(q_k), \forall k \in L \tag{2d}
\end{align*}
\]

Equations (2a) and (2b) relate demand in each region to the world fuel price. Equation (2c) implies that the total quantity produced of all fuels is equal to total consumption. Since, the marginal cost of a fuel may exceed (in which case it will not be supplied) or equal the market price (for it is below the below market price there will be positive profits and so not an equilibrium), equation(2d) is expressed as an inequality. For computational purposes, such inequalities are expressed in the form of a complimentary slackness condition as \( q_k(p^w - S_k^{-1}(q_k)) = 0, \forall k \in L \) This condition ensures that either \( q_k = 0 \), in which case (2d) no longer applies or \( q_k > 0 \) so that \( p^w = S_k^{-1}(q_k) \). Henceforth, when describing the system of equations for the various policies, we will only depict the complimentary slackness condition. We have seven unknowns, \( p^w, q^h, q^a, q_{cc}, q_{sc}, q_{cb}, \) and \( q_{sb} \) and seven equations namely, (2a), (2b), (2c), and the four complementary slackness conditions (one for each of the four fuels that we consider). After solving for \( p^w \), if we know the supply function for each type of fuel in each region, \( S_k^r(\cdot) \), we can determine the quantity produced of each type of fuel from each region as \( S_k^{-1}(p^w) \). However, the quantity consumed of each type of fuel in each region is indeterminate.
Fuel GHG tax:

\[
p^h = D^h \left( \sum_{k \in L} q^h_k \right) \tag{3a}
\]

\[
p^w = D^w \left( \sum_{k \in L} q^w_k \right) \tag{3b}
\]

\[
\left( \sum_{r \in R} q^r_k (p_k - S_k^{-1} (\sum_{r \in R} q^r_k)) \right) = 0, \forall k \in L \tag{3c}
\]

\[
q^h_k (p_k - p^w) = 0, \forall k \in L \tag{3d}
\]

\[
q^h_k (p_k + tz_k - s_k + \tau_k - p^h) = 0, \forall k \in L \tag{3e}
\]

The fuel GHG tax can either be interpreted as the marginal social cost of emissions or as the shadow price of an exogenous emission target. Equations (3a) through (3e) describe the equilibrium under a GHG tax. Equation (3a) relates domestic fuel price to domestic total fuel consumption through the demand function while equation (3b) represents the same for ROW. Equation (3c) determines the world price of a given fuel when a positive quantity of the fuel is consumed. Equation (3e) relates the world price of a given fuel to the home fuel price when a positive quantity of the fossil fuel is consumed at home taking into account taxes, subsidy and tariff on the given fuel. Say that \(q^h_k > 0\), and \(p_k + tz_k - s_k + \tau_k - p^h < 0\). Then since \(p_k + tz_k - s_k + \tau_k < p^h\), then the market price in the home region exceeds the marginal cost of fuel \(k\), which cannot be an equilibrium. Alternatively, say that \(q^h_k > 0\), and \(p_k + tz_k - s_k + \tau_k - p^h > 0\). Then since \(p_k + tz_k - s_k + \tau_k > p^h\), then one is incurring a loss by selling fuel \(k\), which cannot result in an equilibrium. Therefore, if \(q^h_k > 0\), then \(p_k + tz_k - s_k + \tau_k - p^h = 0\). Similarly, equation (3d) says that the price of a given fuel equals the world fuel price when a positive quantity of the fuel is consumed abroad. We have 14 unknowns, \(p^w, p^h, p_{cc}, p_{sc}, p_{cb}, p_{sb}, q^h_{cc}, q^h_{sc}, q^h_{cb}, q^h_{sb}, q^a_{cc}, q^a_{sc}, q^a_{cb}, q^a_{sb}\) and \(q^h_{sb}\) and 14 equations namely, (3a), (3b) and the 12 complementary slackness conditions represented by equations (3c), (3e) and (3d) (three for each of the four fuels that we consider).

Renewable fuel market-share mandate (\(\bar{\alpha}\)):

\[
p^h = D^h \left( \sum_{k \in L} q^h_k \right) \tag{4a}
\]

\[
p^w = D^w \left( \sum_{k \in L} q^w_k \right) \tag{4b}
\]

\[
\left( \sum_{r \in R} q^r_k (p_k - S_k^{-1} (\sum_{r \in R} q^r_k)) \right) = 0, \forall k \in L \tag{4c}
\]

\[
q^h_k (p_k - p^w) = 0, \forall k \in L \tag{4d}
\]

\[
q^h_k (p^h - (1 - \bar{\alpha})p_f + \bar{\alpha}(p_b - s_b + \tau_b)) = 0, \forall b \in B, \forall f \in F \tag{4e}
\]

\[
\frac{\sum_{b \in B} q^h_b}{\sum_{k \in L} q^h_k} = \bar{\alpha} \tag{4f}
\]
Under this policy, the total quantity of renewable fuel consumed within the home region is such that its share in total fuel consumption is not less than $\bar{\alpha}$. Equations (4a) through (2) describe the equilibrium under an SM. Equations (4a) through (4d) are same as that under the fuel GHG tax. Equation (4e) represents the competitive-blending condition under the SM for each renewable fuel and fossil fuel pair. Say that $q_{hb}^h > 0, b \in B$ and $p^h > ((1 - \bar{\alpha})p_f + \bar{\alpha}(p_b - s_b + \tau_b))$. Then, the marginal cost of the blend $\{(1 - \bar{\alpha})f, \bar{\alpha}b\}$ is lower than the home fuel price, which cannot be an equilibrium. Say that $q_{hb}^h > 0, b \in B$ and $p^h < ((1 - \bar{\alpha})p_f + \bar{\alpha}(p_b - s_b + \tau_b))$. Then the marginal cost of the blend is below the market price, which again cannot result in an equilibrium. Therefore, if $q_{hb}^h > 0$, then $p^h = ((1 - \bar{\alpha})p_f + \bar{\alpha}(p_b - s_b + \tau_b))$. If $q_{hb}^h = 0$, then the equation (4e) does not apply. Equation (2) represents the constraint on the market-share of renewable fuels in domestic fuel consumption imposed by the SM.

**Corn biofuel market-share mandate ($\bar{\alpha}_c$):** Under this policy, the total quantity of corn biofuel consumed within the home region is such that its share in total fuel consumption is not less than $\bar{\alpha}_c$. Equations (4a) through (4e) are identical under both SM and SMC with the only change being in equation (5), which is rewritten as,

$$\frac{\sum_{k \in B} q_{hk}^h}{\sum_{k \in L} q_{hk}^h} = \bar{\alpha}_c$$

**Emission intensity standard ($\bar{\varepsilon}$):**

$$p^h = D_h^{-1}(\sum_{k \in L} q_{hk}^h)$$

$$p^w = D_a^{-1}(\sum_{k \in L} q_{hk}^w)$$

$$\sum_{r \in R}(q_{rk}^h)(p_r - S_{rk}^{-1}(\sum_{r \in R} q_{rk}^h)) = 0, \forall k \in L$$

$$q_{rk}^h(p_r - p^w) = 0, \forall k \in L$$

$$q_{bh}^h(p^h - ((1 - \alpha_fb)p_f + \alpha_fb(p_b - s_b + \tau_b))) = 0, \forall b \in B, \forall f \in F$$

$$\alpha_{fb} = \frac{z_f - \bar{z}}{z_f - z_b}, \forall b \in B, \forall f \in F$$

$$\sum_{k \in L} z_k q_{hk}^h = \bar{z}$$

Under this regulation, a fuel supplier is required to sell a quantity (or possess credits) of clean-fuel (in this case biofuel) such that the average GHG intensity of all fuels sold is not below $\bar{\varepsilon}$. Equations (6a) through (6g) describe the equilibrium under an emission standard. Equations (6a) through (6d) are same as that under the fuel GHG tax and SM. Similar to the SM, equation (6e) represents the competitive-blending condition under the ES for each renewable fuel and fossil fuel pair. The difference is that the proportion in which the two fuels are blended is specific to each clean fuel and fossil fuel pair, i.e., $\alpha_{fb}$ and given by equation (6f). Equation (6g) represents the overall constraint on the emission intensity imposed by the ES for the home region.
For the sake of brevity, we do not show the equations for the combination of tax and mandate (CT+SM).

3 Numerical exercise

To illustrate the nature and order of magnitude of the various types of impacts under the different policies we perform simulations. Since the model parameters, such as the price elasticities of fuel supply and demand, emission parameters, etc., are uncertain, we simulate each policy 5,000 times, each time using a different and randomly chosen combination of such inputs. We assume that each input parameter is distributed uniformly within the range of values shown in 1. The high and low values for each parameter is based on estimates found in the literature. We simulate each type of policy for two different levels of stringency as shown in table 2.

Insert Table 1 here.

Insert Table 2 here.

For the simulation, we assume that CC is produced in both the home and ROW regions, SC from oilsands is produced only in the ROW region, corn biofuel is produced only in the home region, and cane biofuel is produced only in the ROW region. We assume the following functional forms. For supply of CC and biofuels, we assume a linear function of the form $q = a + bp$, which is calibrated as follows. Based on estimates in the literature, we first choose an elasticity of supply for each type of fuel, $\epsilon^s$, and using the world oil price and quantity produced of that fuel in the year 2007 in each region, we determine the constant, $a$, and the slope coefficient, $b$, of the linear function as

$$b^f_r = \epsilon^{s,r} \frac{q^{s,r,2007}_f}{p_{2007}} , \forall k \in \{cc, cb, sb\} , \forall r \in R \quad (7)$$

$$a^f_r = q^{s,r,2007}_f - b^f_r p_{2007} , \forall k \in \{cc, cb, sb\} , \forall r \in R \quad (8)$$

The superscript, $s$, is used to indicate that $q$ refers to the quantity supplied. For SC, we employ a supply function that is characterized by an almost constant marginal cost, and which increases steeply as supply approaches a capacity constraint (i.e., one that is shaped like a hockey-stick). Mathematically this is represented as, $p = \beta(\bar{Q} - q)^\alpha + \gamma$, where, $\bar{Q}$ is the capacity at any given time. Given the maximum capacity for synthetic crude production from oilsands in 2007, $\bar{Q}_{sc,2007}$, the minimum price of oil above which oilsands are produced, $p_{sc}$, and the elasticity of supply of oilsands in 2007, $\epsilon^{2007}_{sc}$, (since oilsand production was close to capacity and the price of oil exceeded the minimum price, this is assumed to be
a small number) we calibrate, $\alpha, \beta$ and $\gamma$ as follows

$$\alpha_{sc} = -\frac{Q_{sc,2007} / q_{sc,2007}^{2007} - 1}{\bar{Q}_{sc,2007}}$$

(9)

$$\beta_{sc} = \frac{(p - p_{sc})}{(Q_{sc,2007} - q_{sc,2007}^{2007})^{\alpha_{sc} - Q_{sc,2007}^{2007}}}$$

(10)

$$\gamma_{sc} = p_{sc} - \beta_{sc} \bar{Q}_{sc,t}^{2007}$$

(11)

We model the shifting of the supply function in response to capacity addition by re-computing the parameter $\gamma_{sc}$. Therefore, we recalculate $\gamma_{sc} = p_{sc} - \beta_{sc} \bar{Q}_{sc,t}^{2007}$, where $\bar{Q}_{sc,t}^{2007} = \bar{Q}_{sc,2007} (1 + \delta_{sc}^{t-2007})$, with $\delta_{sc}$ being the growth rate of production capacity. We assume that the function is still characterized by the same minimum marginal cost of extraction, $p_{sc}$. The cost and capacity constraints were chosen based on projections reported in Timilsina et al. (2005) and the assumed values are shown in Table 1.

Finally, we assume a linear function for the demand for fuel in the two regions as $q = c - dp$, which is calibrated as follows. Assuming an elasticity of demand for fuel, we compute the slope coefficient, $d$, as $d = \frac{\epsilon_{d,r} q_{d,r}^{2007}}{p_{2007}}$, $\forall r \in R$. We calibrate the constant term, $c$, in the demand function differently from the supply function. We first choose the future year for which we will compare the outcomes under the different policy regimes. We choose this as the year 2020. Using an exogenous growth in demand for fuel in each region, $\delta_{r}$, we compute the projected consumption in the future baseline year as, $q_{r,2020} = q_{r,2007} (1 + \delta_{r})^{(2020-2007)}$. Knowing the projected total fuel consumption in the two regions, and since there is an ethanol oxygenate mandate in the home region, which represents a lower bound on biofuel consumption even in the absence of any renewable fuel or clean fuel policies, we use the same system of equations as used for the SM. The unknown quantities $q_{r}^{j}$ and $q_{r}^{h}$ in the equations (4a) through (2), which are now known, are replaced with the now unknowns $c^{US}$ and $c^{ROW}$ and solved for. Table 1 describes the range of values for the various parameters of the model. Let $Z$ denote emissions, $CS$ denote the consumer surplus, $PS$ denote the producer surplus, $G$ denote the change in government revenue, and $W$ denote the fuel market surplus. Then,

$$Z^r = \sum_{k \in R} \tilde{z}_k q_k^r$$

(12)

$$CS^r = \int_0^{q_k^r} D^r q - p^r \sum_{k \in L} q_k^r , \forall r \in R$$

(13)

$$PS^r_k = p_k S_k^r (p_k) - \int_0^{S_k^r (p_k)} S_k^{r-1}(q) dq, \forall k \in L, \forall r \in R$$

(14)

$$G^h = t \sum_{k \in L} \tilde{z}_k q_k^h - \sum_{k \in B} s_k g_k^h + \sum_{i \in I} \tau_i (q_i^h - S_i^h (p_i))$$

(15)

$$W^h = CS^h + \sum_{k \in L} PS^h_k + G^h$$

(16)

where, $\tilde{z}_k$, is the actual average emission intensity of fuel of type $k$. This value is however unknown to the policy maker, who chooses a value $z_k$, and $\tilde{z}_k = z_k + \epsilon$, where $\epsilon$ is an error term with $\sim [0, \sigma^2]$. Therefore, $z_k = E[\tilde{z}_k]$. 


4 Simulation results

We describe first the trade-off between different pairs of criteria under the different policies. This is shown graphically in Figure 1. The x-axis in each subfigure is the reduction in annual global GHG emissions in million tonnes of $CO_2$ per year (mt$CO_2$/yr) from the year 2020 onwards. Henceforth, SM20 refers to the biofuel share mandate (SM) at the stringency level of 20% (see table 2). Similar interpretation applies to the notation for the other policies. Figure 1(a) shows the relationship between expected (i.e., mean) change in fuel price in the home region and global emissions. The CT5 and CT10 both result in both greater emission reduction and higher fuel price in the home region compared to the other two regulations. It should be pointed out that whereas a GHG tax always increases the fuel price in the home region, a renewable fuel policy such as SM or ES, may either raise or lower fuel price in the home region. (The mathematical proof is available upon request)The home fuel price increases as policies becomes more stringent. Figure 1(b) shows the relationship between change in global fuel consumption and global emissions. Whereas biofuel regulations raise global biofuel consumption, a GHG tax lowers the same and yet achieves greater reduction in global emissions. Comparing SM and ES, we see that for a similar change in biofuel consumption, ES leads to greater emission reduction than SM. Alternatively, a given emission reduction can be achieved with less biofuel using ES rather than SM. This is intuitive when one considers the fact that since sugarcane ethanol is more cost-effective than corn ethanol in reducing GHG emissions, for any given increase in biofuel consumption, ES leads to greater share for sugarcane ethanol relative to corn ethanol, and therefore less emissions. Therefore, emission standards are more cost-effective compared to biofuel mandates from a GHG perspective. Since we do not model the food market, we purposely chose, through a trial and error approach, the levels of stringency for the SM and ES such that they might be compared more easily.

Figure 1(c) shows the trade-off between change in fuel market surplus -calculated using equation (16), in the home region and global emissions. Fuel market surplus decreases under all policies. However, whereas for SM and ES, the decline in surplus becomes larger as each of these regulations become more stringent, the GHG tax exhibits an opposite trend. This occurs in our model because as the GHG tax becomes more stringent, tax revenues increase at a faster rate relative to the decline in fuel consumer and oil producer surplus. However, this trend is likely to sustain only up to a certain level of GHG tax, beyond which further increase in GHG tax may lead to a reduction in tax collection, an effect similar to one that is used to explain the Laffer curve. Figure 1(d) shows the trade-off between the home region’s outlay on fuel imports and global emissions. Whereas a GHG tax lowers import expenditure, renewable fuel regulations may increase the same because of an increase in consumption of imported biofuel. The increase in import expenditure is larger under ES than SM and moreover, the rate of increase in import expenditure with respect to emissions is also larger for ES. This is again because imported sugarcane ethanol is more cost-effective relative to domestic corn ethanol under ES.
Figure 1(e) shows the trade-off between home emissions and global emissions. It shows that under any domestic policy, the reduction in domestic emissions is much larger compared to the change in global emissions. The principal reason for this is that, the reduction in the world price of oil causes an unintended increase in oil consumption in the ROW. There is also a small but positive rebound in domestic oil consumption due to the decline in world oil price. Another reason is that domestic policies also increase the consumption of renewable fuel in the home region partially by reducing the consumption of renewable fuel in the ROW, which is an example of pollution shuffling. Furthermore, policies such as CT and ES reduce the consumption of SC, the more GHG intensive fossil fuel, and increase the consumption of CC, the less GHG intensive fossil fuel, at home while having the opposite effect on the ROW. This effect does not occur under a biofuel mandate since this policy does not distinguish fossil fuels based on the GHG intensity and only simply mandates the consumption of biofuel. For this reason, CT and ES policies achieve a greater reduction in domestic emissions relative to a biofuel mandate. Both, the absolute increase in oil consumption abroad and the shuffling of the types of fuels between the home and the ROW, contribute to pollution leakage from ROW.

Figures 1(f), 1(g), and 1(h) show the relationship between the change in surplus of fuel consumers, oil producers, and ethanol producers in the home region, each with respect to global emissions. Since fuel price increases in the home region, fuel consumption and fuel consumer surplus both decline. The greater the increase in fuel price, the larger the reduction in fuel consumer surplus. Thus both CT5 and CT10 lead to greater reductions in fuel consumer surplus relative to SM and ES. Interestingly, however, CT leads to a smaller reduction in domestic oil producer surplus relative to the two levels of SM and ES. Renewable fuel policies represent an implicit tax on oil producers and our calculations suggest that the implicit tax of a 20% ethanol share mandate is greater than $10 per t\text{CO}_2 GHG tax. Domestic biofuel producer surplus decreases under a GHG tax but may increase or decrease depending on the stringency of the biofuel regulation or emission standard. Furthermore, since, for the home region, the share of domestic corn ethanol relative to imported sugarcane ethanol is higher under SM compared to the same under ES, (see discussion of figure 1(e) above) corn ethanol producer surplus is higher under SM.

To summarize, the fuel-market surplus, the reduction in outlay on fuel imports, and the reduction in global GHG emissions are all higher while the increase in global biofuel consumption is smaller under a GHG tax when compared to the expected outcomes under a renewable fuel mandate (i.e., SM), or a GHG fuel standard (i.e., ES). Unlike SM or ES, a GHG tax can achieve these outcomes while lowering global biofuel consumption. When comparing SM and ES for any given level of global biofuel consumption, the latter leads to lower global and domestic emissions, lower domestic fuel market surplus, higher outlay on fuel imports, similar or lower fuel consumer surplus, similar or lower domestic oil producer surplus and lower domestic biofuel producer surplus. Therefore, if one assumes that the impact of biofuels on the net food market surplus is negative (see de Gorter and Just (2009)), then from a global perspective an emission intensity standard is superior to a biofuel share mandate. However, from a domestic perspective, on account of the smaller decline in fuel consumer surplus, larger increase in domestic biofuel producer
surplus, and the smaller increase in fuel market outlay, SM may be preferred over ES. This is one possible explanation for the greater popularity of biofuel mandates compared to emission intensity standards worldwide.

Insert Figure 2 here.

To illustrate the different implications of the policies, we compare outcomes for one level of stringency for each policy. We chose the level of SM and ES that leads to approximately the same expected increase in global biofuel consumption. In particular, we chose SM20 (the 20% share mandate) and ES7.5 (the 7.5% emission intensity reduction standard). For the GHG tax, we simply choose the $10 per tCO₂. To illustrate the difference between the generic share mandate and a biofuel-specific share mandate, i.e., corn ethanol mandate (SMC), we chose the latter at the same stringency level as the former, i.e., SMC20. Finally, we chose a combination of a combination of biofuel share mandate and GHG tax, denoted as CT5+SM20. For this combination policy, we chose a $5 per tCO₂ tax to illustrate the effect of an even smaller tax relative to CT10 when employed in combination with a biofuel mandate. Figure 2 shows both the mean and the variability in outcome, depicted through the error bars, which encompass the 95% confidence interval. Table 3 shows the mean value and the ranking (shown within parentheses) of each policy (rows) under each criterion (columns).

Insert Table 3 here.

We compare the performance of these five specific policies with respect to each criterion.

i) Global biofuel consumption: The corn ethanol mandate, SMC20, leads to the largest increase in biofuel consumption and an almost three fold larger increase relative to the ES7.5. The GHG tax, CT10, reduces biofuel consumption compared to the baseline. Under the assumption that increasing biofuel consumption has an overall negative impact on food market surplus, the CT10 is the highest ranked policy while SMC20 is the least preferred policy. The expected increase in biofuel consumption is similar under the other three policies.

ii) Global GHG emissions: The GHG tax CT10 leads to the largest decline in global GHG emissions while the SMC20 is the only policy expected to accelerate GHG emissions. The latter does lower emissions under certain conditions. The other policies all lead to an intermediate level of emissions and are likely to reduce global GHG emissions although the combination of biofuel mandate and a small tax (CT5+SM20) performs much better relative to the remaining two.

iii) Domestic import outlay: The corn ethanol mandate, SMC20, is the highest ranked policy with respect to this criterion (since in our simulations corn ethanol is the only biofuel produced in the home region) followed by the carbon tax. Interestingly however, both the generic biofuel mandate, SM20, and emission standard, ES7.5, increase import outlay because they increase consumption of imported sugarcane ethanol.
iv) Home fuel consumer surplus: Fuel consumers in the policy region are expected to lose under all policies. However, the two policies involving a tax and the corn ethanol mandate, SMC20, entail a larger negative impact on fuel consumers relative to a biofuel mandate and emission standard. This is due to the higher consumption of cheaper imported sugarcane ethanol under the latter two policies.

v) Home oil producer surplus: Oil suppliers, not only in the home region, are expected to be negatively impacted under all policies. The corn ethanol mandate, SMC20, leads to the largest negative impact because it entails the largest increase in biofuel consumption and a correspondingly largest decrease in world oil price and oil consumption. The emission standard, ES7.5, leads to a smaller negative impact on this group relative to both SM20 and SMC20 while achieving greater emission reduction.

vi) Home biofuel producer surplus: The corn ethanol mandate, SMC20, is the only policy that is expected to benefit home biofuel producers (again due to the fact that the home region produces corn ethanol only) while the GHG tax, CT10, has the largest negative impact on this group. The other three policies increase consumption of imported sugarcane ethanol and reduce consumption of corn ethanol.

vii) Home government revenue: All policies that we consider lead to an increase in government revenue relative to baseline. For the nontax-based policies the increase in revenue is due to the elimination of biofuel blending subsidy.

As a sensitivity test, we repeated the simulations in the presence of a subsidy of $0.45 per gallon of ethanol, which was the level of the volumetric ethanol excise tax credit and a $0.5 per gallon tariff on ethanol imports in the home region. The results are shown in table 4. Comparing Table 4 to Table 3, we find that global fuel consumption, global emissions, and the home region’s fuel consumer surplus, oil producer surplus, and ethanol producer surplus are all higher in the presence of a subsidy and tariff. Net government revenue is lower due to the burden of the subsidy, which exceeds the revenue from import tariffs since the share of domestic biofuels in the home region is now larger relative to the scenario with subsidy and tariff.

As discussed earlier, an important aspect of biofuel policies is the notion of ILUC. For reasons mentioned earlier (see Section 2) our approach was to assume that policies ignore ILUC but to compute global emissions taking into account an estimate of ILUC effect. One approach to ILUC that is being debated under the California LCFS is to include an estimate of ILUC as part of the lifecycle GHG intensity of biofuel used for calculating compliance. One can hypothesize that as the emission intensity of biofuels increase, more biofuel will be required to attain a given emission standard. The effect of greater biofuel consumption on total emissions is however ambiguous. Using an estimate of 30 gCO₂/MJ and 20 gCO₂/MJ for the ILUC GHG intensity of corn and sugarcane ethanol respectively, we found that
mean (of the 5000 simulations) global total biofuel consumption increases by 22.3% under ES7.5 and by 39.8% under ES10, due to the inclusion of ILUC. The mean estimate of global emissions is however only 0.03% lower under ES7.5 and 0.18% lower under ES10 relative to the respective outcomes under these two policies when ILUC is ignored by policy makers. This suggests that alternative strategies need to be considered for mitigation of risks due to ILUC. A more detailed discussion of this topic is beyond the scope of this paper.

5 Policy discussion

Economists have known for a long time that every independent policy objective requires an independent policy instrument (Tinbergen, 1952). Therefore a single instrument such as a GHG tax, emission intensity standard or renewable energy mandate cannot serve multiple independent goals such as addressing externalities related to environment, concerns related to excess reliance on imports, distributional objectives, etc. One can immediately conclude that employing a single instrument will be ineffective and may even be counter-productive to some goals. Real world policies are the outcome of a political process that reflects the power and influence of different interest groups rather than welfare maximization or cost minimization. Therefore, the role of an economist is often then restricted to identifying ways of improving the overall outcome, assuming the power of various interest groups as given. Energy policies need to be designed recognizing that oil is a global commodity and that this implies potential for fuel shuffling, rebound effects and pollution leakage. Furthermore, biofuels have been associated with food-price inflation and expansion of agricultural land use. This paper presents a framework to analyze different policies taking these aspects into consideration and to compare them based on multiple attributes, such as emissions, outlay on imports, quantity of renewable fuel, and several variables related to distributional impacts.

We find that a fuel GHG tax achieves a higher ranking under more criteria compared to any other policy. Specifically, it ranks the highest with respect to three criteria: minimizing GHG emissions, minimizing the quantity of biofuel and maximizing government revenue, while also ranking second with respect to reducing the outlay on fuel imports. On the other hand, a corn ethanol mandate (a policy akin to the US Renewable Fuel Standard) ranks the lowest with respect more criteria compared to any other policy. Specifically, it ranks the lowest with respect to reducing (and even expected to accelerate) GHG emissions and minimizing the requirement of biofuels from food grains. An emission intensity standard and biofuel mandate each rank higher on an equal number of criteria relative to the other. Both emission intensity standard and biofuel mandate rank higher under more number of criteria than corn ethanol biofuel mandate. From a GHG perspective, a corn ethanol mandate ranks the lowest and is the only policy that is expected to accelerate GHG emissions with respect to the counterfactual baseline while other policies reduces emissions and entail much less biofuel consumption. However, corn ethanol mandate ranks highest with respect to domestic fuel import outlay. Furthermore, whereas domestic fuel import
outlay declines under a corn ethanol mandate it increases under both biofuel mandate and emission intensity standard. A combination of a tax and biofuel mandate ranks higher under more number of criteria than a biofuel mandate, a corn ethanol mandate, and an emission intensity standard. Unlike the other four policies, the combination policy ranks neither highest nor lowest with respect to any single criterion.

Our analysis suggests that fostering the domestic renewable fuel industry and reducing the outlay on energy imports are the main goals for policy makers in adopting the US RFS. The impact on domestic fuel consumers seems to be a less important criterion since the corn ethanol mandate has a negative impact that is second only to a GHG tax. A policy that does not discriminate biofuels simply based on their type or region of origin is better for GHG emission reduction, fuel consumers, fossil fuel producers and the food consumers as well. However, GHG emission reduction appears to be the main criterion in adopting the Low Carbon Fuel Standard (LCFS) in California. This policy also has a smaller negative impact on the domestic oil industry relative to both biofuel mandate and corn ethanol mandate, while achieving greater emission reduction. However, a national LCFS may not contribute to the goal of reducing outlay on energy imports when imported biofuel is both a cheaper and cleaner relative to domestic biofuel. The non-adoption of a GHG tax, which ranks highest with respect to GHG emission reduction and second highest with regard to reducing energy imports, suggests that supporting the domestic renewable fuel industry and mitigating the loss to domestic fuel consumers are also important criteria for policy makers. As intuition would suggest a combination of these policies has the potential to achieve an outcome that may not be the best nor worst with respect to any single criterion but may be satisfactory with respect to either all or the largest number criteria. Fuel subsidies lead to both higher biofuel consumption and higher emissions under any regulation or tax. The recent decision by the US federal government to allow the legislations supporting the ethanol subsidy and ethanol import tariff to expire is therefore beneficial to the environment, to food consumers and the government’s fiscal balance.

Finally, renewable fuel regulations represent an implicit tax on domestic fuel consumers and producers of fossil fuel, and an implicit subsidy to producers of renewable fuels. These regulations represent a subsidy to fuel consumers abroad who benefit from lower oil price, which has the unintended consequence of increasing fuel consumption and emissions. While the latter is true also for a carbon tax, the economists’ prescription and for energy efficiency regulations, the risk of counter-productive outcomes appears to be higher under certain renewable fuel policies relative to other policies.

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**Tables and Figures**
Table 1: Range of values for input parameters used for simulation. All parameters are assumed to be uniformly distributed within the specified range. “Home” refers the region implementing the fuel policy; ROW = rest of world. We use data for the US for “home” region parameters.

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity of demand for fuel, home</td>
<td>(-0.39, -0.11)</td>
</tr>
<tr>
<td>Elasticity of supply of crude oil, home</td>
<td>(0.2, 0.47)</td>
</tr>
<tr>
<td>Elasticity of demand for fuel, ROW</td>
<td>(-0.15, -0.05)</td>
</tr>
<tr>
<td>Elasticity of supply of crude oil, ROW</td>
<td>(0.07, 0.1)</td>
</tr>
<tr>
<td>Elasticity of supply of corn biofuel, home</td>
<td>(1, 2)</td>
</tr>
<tr>
<td>Elasticity of supply of cane ethanol, ROW</td>
<td>(1, 2)</td>
</tr>
<tr>
<td>Direct GHG intensity Corn ethanol (g CO$_2$e MJ$^{-1}$)</td>
<td>(55, 70)</td>
</tr>
<tr>
<td>Direct GHG intensity Cane ethanol (g CO$_2$e MJ$^{-1}$)</td>
<td>(20, 30)</td>
</tr>
<tr>
<td>ILUC GHG intensity Corn ethanol (g CO$_2$e MJ$^{-1}$)</td>
<td>(10, 100)</td>
</tr>
<tr>
<td>ILUC GHG intensity Cane ethanol (g CO$_2$e MJ$^{-1}$)</td>
<td>(5, 50)</td>
</tr>
<tr>
<td>GHG intensity of Crude oil (g CO$_2$e MJ$^{-1}$)</td>
<td>(80, 90)</td>
</tr>
<tr>
<td>GHG intensity of Oilsand (g CO$_2$e MJ$^{-1}$)</td>
<td>(110, 120)</td>
</tr>
<tr>
<td>Annual growth rate in global Oilsand capacity</td>
<td>4%, 9.2%</td>
</tr>
<tr>
<td>Minimum price for oilsand supply ($/bbl$)</td>
<td>(25, 40)</td>
</tr>
<tr>
<td>Annual growth rate of fuel demand, home</td>
<td>0.3%, 0.7%</td>
</tr>
<tr>
<td>Annual growth rate of fuel demand, ROW</td>
<td>0.7%, 1%</td>
</tr>
</tbody>
</table>

a Greene (2010) estimates the short-run US oil demand elasticity ranges from -0.058 to -0.017 and the short-run elasticity of US oil supply varies between 0.03 and 0.07 and suggests that based on an adjustment rate of 0.15 is assumed, long–run elasticities will be 6.7 times the short-run elasticities.

b Knowing the elasticity for US and elasticity of the world and the share of fuels supplied or consumed in US and ROW, we impute the elasticity of ROW. The elasticity of world oil supply and oil demand was obtained from Krichene (2002).

c Econometric estimates of elasticity for biofuel supply are scarce. Following previous research by Holland et al. (2009), we use a range of 1–2.

d Plevin (2010)

e Searchinger et al. (2008) first predicted a value close to 107 gCO2/MJ. Hertel et al. (2010) predict a value of 30 gCO2/MJ and Tyner et al. (2010) predict it to lie between 13.9 and 22.9 gCO2/MJ. We simply chose a range from 10 to 100 gCO2/MJ for corn ethanol ILUC and simply assumed cane ethanol’s ILUC to be half of corn ethanol because of its significantly higher yield of ethanol per hectare of land.


Table 2: Simulated policy scenarios

<table>
<thead>
<tr>
<th>Policy type</th>
<th>Stringency levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuel market share mandate (SM)</td>
<td>20%, 25%</td>
</tr>
<tr>
<td>GHG emission intensity standard (ES)</td>
<td>7.5%, 10%</td>
</tr>
<tr>
<td>Carbon tax (CT) in $ per ton CO$_2$e</td>
<td>5, 10</td>
</tr>
</tbody>
</table>

* These translate into a $18 per ton of Carbon and $36 per ton of C
Table 3: Mean value for different variables under different policies. All values denote change with respect to a business-as-usual (BAU) 2020 baseline (Baseline values shown below the table)

<table>
<thead>
<tr>
<th>Outcome → Policy</th>
<th>Global biofuel(^a) (bil. gal/yr)</th>
<th>Global GHG emissions(^b) (mil. ton of CO(_2)/yr)</th>
<th>Domestic fuel import outlay (bil $/yr)</th>
<th>Domestic fuel consumer surplus (bil $/yr)</th>
<th>Domestic oil producer surplus (bil $/yr)</th>
<th>Domestic biofuel producer surplus (bil $/yr)</th>
<th>Domestic government revenue (bil $/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT10</td>
<td>-2.09 (1)</td>
<td>-44.94 (1)</td>
<td>-11.69 (2)</td>
<td>-33.12 (5)</td>
<td>-3.25 (3)</td>
<td>-10.98 (5)</td>
<td>47.08 (1)</td>
</tr>
<tr>
<td>SM20</td>
<td>2.95 (4)</td>
<td>-10.40 (4)</td>
<td>4.88 (4)</td>
<td>-5.66 (1)</td>
<td>-2.65 (2)</td>
<td>-2.32 (2)</td>
<td>4.56 (3)</td>
</tr>
<tr>
<td>ES7.5</td>
<td>2.65 (2)</td>
<td>-14.29 (3)</td>
<td>8.39 (5)</td>
<td>-5.70 (2)</td>
<td>-2.46 (1)</td>
<td>-6.13 (4)</td>
<td>4.56 (3)</td>
</tr>
<tr>
<td>CT5+SM20</td>
<td>2.74 (3)</td>
<td>-26.52 (2)</td>
<td>-3.71 (3)</td>
<td>-20.99 (3)</td>
<td>-4.63 (4)</td>
<td>-2.87 (3)</td>
<td>25.80 (2)</td>
</tr>
<tr>
<td>SMC20</td>
<td>7.40 (5)</td>
<td>11.75 (5)</td>
<td>-32.88 (1)</td>
<td>-21.51 (4)</td>
<td>-7.72 (5)</td>
<td>51.36 (1)</td>
<td>4.56 (3)</td>
</tr>
</tbody>
</table>

\(^a\) Baseline global biofuel consumption is 27.97 billion gallons per year of which the home (US) accounts for 16.72 billion billion gallons per year and ROW accounts for the remaining 11.25 billion billion gallons per year.

\(^b\) Baseline global GHG emissions is 18.18 billion tonnes of CO\(_2\)/year of which the home (US) accounts for 4.37 billion tonnes of CO\(_2\)/year and ROW accounts for the remaining 13.8 billion tonnes of CO\(_2\)/year. (Note that the table shows changes in emission in units of million tonnes of CO\(_2\)/yr)

Table 4: Mean value of different outcome variables with subsidy and import tariff. All values denote change with respect to BAU 2020 baseline (Baseline values are reported in table 3)

<table>
<thead>
<tr>
<th>Outcome → Policy</th>
<th>Global biofuel(^a) (bil. gal/yr)</th>
<th>Global GHG emissions(^b) (mil. ton of CO(_2)/yr)</th>
<th>Domestic fuel import outlay (bil $/yr)</th>
<th>Domestic fuel consumer surplus (bil $/yr)</th>
<th>Domestic oil producer surplus (bil $/yr)</th>
<th>Domestic biofuel producer surplus (bil $/yr)</th>
<th>Domestic government revenue (bil $/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT10</td>
<td>-0.28 (1)</td>
<td>-32.5 (1)</td>
<td>-17.24 (2)</td>
<td>-31.03 (5)</td>
<td>-4.12 (3)</td>
<td>-0.96 (5)</td>
<td>42.83 (1)</td>
</tr>
<tr>
<td>SM20</td>
<td>3.14 (3)</td>
<td>1.01 (4)</td>
<td>-0.96 (4)</td>
<td>-2.60 (1)</td>
<td>-2.36 (1)</td>
<td>6.14 (2)</td>
<td>-0.20 (5)</td>
</tr>
<tr>
<td>ES7.5</td>
<td>3.77 (4)</td>
<td>-1.79 (3)</td>
<td>1.92 (5)</td>
<td>-3.15 (2)</td>
<td>-2.83 (1)</td>
<td>4.04 (4)</td>
<td>0.03 (3)</td>
</tr>
<tr>
<td>CT5+SM20</td>
<td>2.94 (2)</td>
<td>-16.34 (2)</td>
<td>-9.48 (3)</td>
<td>-17.97(4)</td>
<td>-4.35 (4)</td>
<td>5.49 (3)</td>
<td>21.15 (2)</td>
</tr>
<tr>
<td>SMC20</td>
<td>7.49 (5)</td>
<td>18.59 (5)</td>
<td>-29.33 (1)</td>
<td>-15.02 (3)</td>
<td>-6.88 (5)</td>
<td>51.78 (1)</td>
<td>-4.10 (4)</td>
</tr>
</tbody>
</table>
Figure 1: Trade-off between different outcome variables at different levels of policy stringency for three different policies. All values denote change with respect to BAU 2020 baseline. The figure shows the mean or expected value for each variable for 5000 trials. (Baseline values are reported in table 3)
Figure 2: Comparison of the different outcomes under the different policies (no biofuel subsidy or biofuel import tariff in home region). All values denote change with respect to BAU 2020 baseline. (Baseline values are reported in table 3.)