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BY

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MARKET, WELFARE AND LAND-USE IMPLICATIONS OF LIGNOCELLULOSIC BIOETHANOL IN HAWAI‘I

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Abstract

This article examines land-use, market and welfare implications of lignocellulosic bioethanol production in Hawai‘i to satisfy 10% and 20% of the State's gasoline demand in line with the State's ethanol blending mandate and Alternative Fuels Standard (AFS). A static computable general equilibrium (CGE) model is used to evaluate four alternative support mechanisms for bioethanol. Namely: i) a federal blending tax credit, ii) a long-term purchase contract, iii) a state production subsidy financed by a lump-sum tax and iv) a state production subsidy financed by an ad valorem gasoline tax. We find that because Hawaii-produced bioethanol is relatively costly, all scenarios are welfare reducing for Hawaii residents: estimated between -0.14% and -0.32%. Unsurprisingly, Hawaii's economy and its residents fair best under the federal blending tax credit scenario, with a positive impact to gross state product of $49 million. Otherwise, impacts to gross state product are negative (up to -$63 million). We additionally find that Hawaii-based bioethanol is not likely to offer substantial greenhouse gas emissions savings in comparison to imported biofuel, and as such the policy cost per tonne of emissions displaced ranges between $130 to $2,100/tonne of CO2e. The policies serve to increase the value of agricultural lands, where we estimate that the value of pasture land could increase as much as 150% in the 20% AFS scenario.

Keywords: Computable General Equilibrium Modeling, Lignocellulosic Bioethanol, Land Use Impact, Welfare Impact, Greenhouse Gas Emissions

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1. Introduction

Government interventions in the form of mandates, subsidies and tariffs have served as major drivers behind the rapid growth in the global biofuels industry. The U.S. is the largest producer of ethanol in the world and has grown from producing 1.02 billion liters in 1980 to nearly 49 billion liters in 2010 (Cardno Entrix, 2010). Rigorous research and development efforts are now being made to develop next-generation biofuels that do not compete directly with food production. Lignocellulose bioethanol is derived from a range of plant materials is one such alternative nearing commercialization. Depending on the feedstocks and conversion technologies chosen, second-generation bioethanol could offer a myriad of benefits such as reduced greenhouse gas emissions, reduced competition with food production, soil conservation, carbon sequestration, water quality improvement and habitat improvement (Tilman et al., 2009). The US Renewable Fuels Standard (RFS) now foresees that the use of biofuels could reach 136 billion liters by 2022 with cellulosic biofuels expected to supply 60 billion liters (National Research Council, 2011).

Hawai‘i is the most fossil fuel-dependent state within the US (Hawaii Clean Energy Initiative 2010). The state has a wide array of incentives to support bioethanol, including a tax credit for producers, and state and county government procurement preference (United States Department of Energy, 2013). In 1994, the state adopted an ethanol blending mandate requiring the use of 10% ethanol in 85% of gasoline consumed. The state additionally has an AFS[1] goal to encourage bioethanol production (State of Hawai‘i, 2010). Even with these aggressive policies, there is no active local production of bioethanol. A number of potential feedstock options – including sugarcane, banagrass, eucalyptus, and leucaena – have been evaluated for their technical and economic feasibility (DBEDT, 2009). Among these options, biochemical conversion of banagrass (*Pennisetum purpureum*), one of the highest yielding grass species, has also been identified in Hawai‘i as a potentially promising bioethanol option due to its high yield and agroclimatic advantages (Black and Veatch, 2010; Tran et al., 2011). The use of banagrass as sources of biofuel and bioenergy has been widely evaluated in a number of countries, including Australia, China, Philippines, Thailand and the US (Holm 2010; Manila Times 2011,Changsorn 2012, Jessen 2012); however, no studies have been conducted to evaluate macroeconomic impacts of this feedstock option as an alternative source of fuel The present study therefore examines and quantifies the economy-wide impacts of this technology using Hawai‘i as a case study.

In particular, this study examines land-use, market and welfare implications of lignocellulosic bioethanol production in Hawai‘i to satisfy 10% and 20% of the State’s gasoline demand. Four alternative support mechanisms are examined, namely: i) a federal blending tax credit, ii) a long-term purchase contract, iii) a state production subsidy financed by a lump-sum tax and iv) a state production subsidy financed by an ad valorem gasoline tax. The study finds that Hawaii-produced bioethanol is relatively costly, hence welfare reducing. The local residents fair best under the federal blending tax credit scenario, but impacts to gross state product are negative in the remaining cases. Hawaii-based bioethanol is unlikely to offer substantial greenhouse gas emissions savings in comparison to imported biofuel, and the policies serve to increase the value of agricultural lands.

The remainder of the study is organized as follows: Section 2 provides a brief literature background regarding the macroeconomic assessment of biofuel policy. This is followed by

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[1] AFS calls for 10%, 20% and 30% of highway fuels to be supplied by alternative fuels in 2010, 2020 and 2030 respectively.

section 3 on the model structure and data sources, Section 4 on the results regarding market, welfare, land price and GHG emissions impacts of alternative support policies. Section 5 conducts sensitivity analyses with regards to key elasticity parameters. Section 6 provides discussions, and Section 7 provides the conclusion of this study.

2. Literature background

The existing literature indicates that the effects of biofuels policy are felt widely across a range of economic sectors including energy and agricultural markets, making the general equilibrium (GE) framework a preferred policy analysis tool. In particular, computable general equilibrium (CGE) models are widely used in assessing biofuels policy impacts,[2] with market, welfare and land-use implications being some of the more frequently examined aspects. In a pioneering work examining biofuels policy impact on global land-use changes, Hertel et al. (2008a) evaluated the combined effects of US and European mid-term biofuels mandates up to 2015 on global agricultural commodity output, land-cover, and welfare changes. They conclude that crop cover will rise substantially in Latin America, Oceania and Africa and replace pastureland and commercial forestland. Evaluating a longer term trend, up to the year 2100, Gurgel et al. (2008) estimate global land-use impacts of lignocelluloisc biofuels and conclude that when unrestricted land conversion is allowed (taking into account the conversion costs), an expansion of biofuels production leads to a substantial conversion of natural forests. When land cover conversion is modeled to follow observed land supply response, however, biofuels expansion leads to a sizable decline in pasture land. In both cases, the majority of biomass production takes place in the regions of Latin America and Africa. Other studies such as Timilsina et al. (2010), Beckman et al. (2011), and Timilsina and Mevel (2011) also conclude that notable land cover conversion is likely, particularly under aggressive promotion of biofuels consumption.

Welfare implications of biofuels policy also differ considerably across cases, due to underlying assumptions regarding existing market distortions (Gitiaux et al., 2009), policy interactions (Kretschmer et al., 2009; Taheripour and Tyner, 2012), and the presence of tariff barriers (Gitiaux et al., 2009). A policy to promote locally-sourced biofuels is generally found to reduce welfare, because it is often a costlier alternative than fossil fuels (Kretschmer et al., 2009; McCullough et al., 2011; Satyakti et al., 2012; Taheripoyr and Tyner, 2012); though other studies suggest that alternative policy and fuel price assumptions could lead to overall welfare gains due to biofuel promotion (Painter et al., 2009; Gunatilake et al., 2011; McCullough et al., 2011; Huang et al., 2012). For example, evaluating the alternative policy scenarios to promote bioethanol and biodiesel production in Washington State, Painter et al. (2009) conclude that consumer welfare, as measured by the average value of equivalent variation across all income categories, generally increased under the feedstock subsidies and volumetric and carbon-based renewable fuel subsidies, and decreased under the mandate-only, volumetric fossil fuel tax and carbon tax scenarios. This is plausibly because subsidies tend to lower price levels while taxes

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[2] There are number of reasons why CGE has become dominant in the field of biofuels policy analysis: i) the biofuels industry will likely have economy-wide impacts through its forward and backward linkages; ii) the rise in biofuels production affects a number of key variables including direct and indirect land-uses and energy market compositions; and iii) the lack of time series data on biofuels production makes an alternative of econometric analysis difficult.

lead to higher prices, but exact price impacts of alternative policy options are unreported in their study.

The existing studies using CGE suggest that fuel mandates result in upward pressure on market prices of agricultural goods due to biofuel and other agricultural production competing for similar factor inputs (Gurgel et al., 2008; Kretschmer et al., 2009; Arndt et al., 2012). Biofuel policy has also been found to have a mixed impact on fuel prices, as Taheripor and Tyner (2012) report that the US 2015 mandate of 15 billion gallons of ethanol, depending on policy assumptions, would either dampen the gasoline price by 1.6% or raise it by 4.3%. The market impacts of biofuels has been intensely debated with mixed findings, largely driven by regional differences and modeling assumptions.

3. Material and Methods

3.1. Modeling Structure

The modeling structure and parameters are based primarily on the Hawaiʻi General Equilibrium Model (H-GEM) (Coffman, 2010), updated with the most recent IO table and the Applied Dynamic Analysis of the Global Economy (ADAGE) Model (Ross, 2008). The model consists of 25 production sectors, a representative resident and visitor consumption sector, and a federal and state government sector. It includes labor, capital, and energy as sectorally mobile factors of production, while agricultural land is explicitly modeled as a sector-specific factor with a fixed level of initial endowment.

3.1.1. Production Block

In the base model, the production sector is divided into i) Non-Energy (i.e., agriculture, industrial, and commercial), ii) Petroleum (i.e., gasoline and non-gasoline), and iii) Electricity. In the benchmark year, the State of Hawaiʻi mandates 10% of ethanol for use in at least 85% of gasoline consumption, but this ethanol is imported from outside of the state. In the counter-factual scenario of a 10% bioethanol mandate, local production of lignocellulosic ethanol will replace this import. In the case of a 20% mandate, local ethanol will further replace a portion of gasoline demand to achieve 20% of alternative fuel use.[3]

Following standard CGE assumptions, the production sector includes a representative producer who maximizes profit subject to a given technological constraint that has constant returns to scale. The production function takes the form of a nested Constant Elasticity of Substitution (CES) function, in which domestically produced intermediate inputs, factors of production, and imports enter as production inputs. Domestically produced goods are then allocated for domestic and export consumption through a constant elasticity of transformation (CET) function.

Insert Figure 1.

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[3] What constitutes a ‘baseline’ scenario in the 20% mandate for Hawai’i is open to interpretation. For example, it is possible to assume that Hawai’i may import 20% of its bioethanol in the baseline year and locally produced bioethanol will replace these imports in the counterfactual scenario. While this interpretation is possible, this study assumes an alternative baseline, which corresponds to the existing 10% mandate being met through bioethanol imports, corresponding to the actual consumption and importation data in the base-year dataset.

Fig. 1 above shows the nested production structure of the agricultural commodity. The production functions make a distinction between land, material and energy inputs on the one hand, and capital and labor inputs on the other. Given the lack of data on detailed agricultural land-use, this study uses individual agricultural sector payments to the real estate sector in the input-output table as a proxy for land inputs in the benchmark year.[4] This distinction allows the producer to increase agricultural output either by expanding land areas (expansive production), adding materials and energy such as fertilizer and fuel, and/or by adding labor and capital (intensive production). Existing studies such as Bouet et al. (2010) assume the substitutability of land and fertilizer inputs to be as low as 0.05 in the case of developing countries; however, it is assumed that banagrass growth under Hawaiʻi's soil condition is more favorable as past and current field trials have demonstrated that banagrass yields respond favorably to irrigation and fertilizer application (Wilsie and Takahashi, 1934; Ogoshi, 2013). Land and other material (e.g. fertilizer) and energy are thus assumed to be substitutable based on an elasticity parameter of 0.6. This land, material and energy composite may also be substituted with value-added based on an elasticity parameter of 0.6 (Ross, 2008). Substitutability of these inputs depends on many factors including agro-climatic conditions, and will likely affect the magnitude of policy impacts; therefore, sensitivity analyses will be conducted regarding these parameters. The production structure of other non-energy commodities is shown in Appendix A.

The gasoline sector has a relatively rigid production technology in which material and energy must be used in fixed proportion while substitution of capital and labor is allowed. In the base-case scenario, imported ethanol enters as an intermediate input as shown in Fig. 2.

Insert Figure 2.

In the 10% mandate scenario, the gasoline industry will buy locally produced bioethanol instead of imported bioethanol, while in the 20% scenario, the industry will further replace a portion of its gasoline consumption. Because local bioethanol is entered as an input into gasoline production, bioethanol is treated as a complementary good of gasoline. Non-gasoline petroleum commodity production takes an identical production structure without intermediate consumption of bioethanol. The electricity sector production function is described in Appendix A.

3.1.2. Land-Use

Agricultural and forest lands are explicitly modeled as factors of production with a fixed level of initial endowment. Referring to Hertel et al. (2008b), land is allocated to each sector based on a CET function (Fig. 3). Land uses adopted for this study include crop land, pasture land, forestland and other uses (e.g., agricultural services and aquaculture). Banagrass production is assumed to occur in non-prime, non-unique land, based on the Agricultural Land of Importance to the State of Hawaiʻi (ALISH) categorization as prime and unique land is too costly for biofuels production and will compete with local food production (Black and Veach, 2010). Prime agricultural land is considered to be most suited for high value crops, including irrigated sugarcane, pineapple, and other orchards (e.g., macadamia and papaya), while the unique

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[4] Since this study treats agricultural land as an endowment, other capital payments into the real estate sector are reduced by the equivalent value of this newly created land endowment to balance the IO table. This is of course a crude assumption and detailed estimation of agricultural rent based on unit rent values and existing acreage of crop production within the state will allow for a more accurate modeling of land-use impacts.

agricultural lands are areas that are primarily suited to other crops including coffee, taro, and non-irrigated pineapple (State of Hawaiʻi, 1977). While the non-prime, non-unique category of land is currently dominated by pasture-use (Melrose and Delparte, 2012), this study assumes that banagrass production requires an input of pasture land in the base-case.

Insert Figure 3.

The remaining agricultural sectors use non-pasture land for production. Crop land is used by the sugarcane, pineapple, orchard, and flower sectors. Forestland is used by the forestry sector, while other land is used by the agricultural services and aquaculture sectors respectively. A limitation of the CET approach to modeling land-use is that the model only constrains the rent-weighted sum of land areas as an endowment instead of actual land areas in production (Hertel et al., 2008c), while important attributes of land which determine yield, such as soil characteristics and water availability, are not taken into account. The cross-island mobility of land is unconstrained.[5]

3.1.3. Consumption Block

The consumption block includes five agents consisting of a resident consumer, a visitor consumer, the state government, the federal government and an investment agent. A resident consumer is assumed to maximize his/her utility based on a nested utility function consisting of transport and non-transport goods that are subject to a budget constraint (Fig. 4).

Insert Figure 4.

The transport goods are further divided into purchased transport (i.e., water, air and ground transportation commodities) and private transport demand, a demand consisting primarily of gasoline and ethanol consumption. A representative agent has a budget constraint equal to his/her income based on labor, capital and land endowment as well as foreign exchange earnings from the balance of payment and lump-sum tax or transfer. The visitor consumer and federal government demands are treated as exogenous while the state government maintains a minimal provision of public goods and services based on a Leontief utility function. The state government's budget constraint equals its general exercise tax revenue plus lump-sum tax/transfer and fuel tax in applicable scenarios.

3.1.4. Market Clearing Conditions and Closure

Under perfect competition with constant returns to scale, equilibrium is achieved when marginal cost of production equals its producer price. Market clearing conditions ensures that all goods produced in a market are consumed. Therefore, the sum of intermediate demand and final demand – by resident, visitor, state, federal, investment, and export – equals the sum of domestic supply and import of goods in each sector. All factor markets also clear so that the sum of labor, capital and land employed equals its respective initial endowment. The model also assumes that Hawaiʻi is a small economy and does not affect world commodity prices. The level of state

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[5] In the context of Hawai'i, where the diverse set of soils (190 soil series in 10 out of 12 soil orders in the world are found locally) offers a wide range of properties and behaviors (Hue et al. 2007), and rainfall variability ranges widely within islands, the aggregated treatment of land adopted in this study should be treated with caution.

government goods and services provision is assumed fixed, and the model must adjust its revenue through the use of endogenous taxation.

3.2. Data

We calibrate the model to the most recent, 2007, Hawai‘i State Input Output Table (DBEDT, 2011b). All price information has been converted into 2007 prices using the US Bureau of Labor Statistics’ consumer price index of Hawai‘i (US Bureau of Labor Statistics, 2013). For data on fuel and ethanol use and production, a detailed breakdown of fuel demand is first estimated based on a number of sources including the State Energy Data System (EIA, 2012), agricultural fuel use (Schnepf, 2004), and military fuel use (Defense Logistics Agency, 2010). Bioethanol imports in the base-year is estimated using the State of Hawai‘i Databook (DBEDT, 2007) and an average rack price of US ethanol in 2007 ($0.56/liter) is taken from Bloomberg Finance L.P. (2013). The base year gasoline price of $0.71/liter is taken from (EIA, 2012). Production costs of banagrass are estimated using sugarcane industry data available from an input-output table based on the following: an earlier year (Sharma et al., 1997); acreage in production available from (USDA, 2013); and the average difference between per acre sugarcane and banagrass production cost as estimated by Kinoshita et al. (1995) (see Appendix B).[6] The value of each input used in sugarcane production is first divided by the acreage in production to yield per acre input requirements. These are then multiplied by a factor of 0.51 (the estimated average costs of labor, material and services used in banagrass production relative to sugarcane production). This study assumes that banagrass yields 1 plant crop followed by 5 ratoon crops which are harvested every 8 months (Kinoshita et al., 1995), while that of sugarcane yields 1 ratoon crop. Banagrass yield was assumed to be 48.1 tonnes/ha/year (Tran et al., 2011).

The production cost of lignocellulosic bioethanol is estimated using the bottom-up techno-economic model of Kumar and Murthy (2011) using SuperPro Designer (Intelligen, Inc., Scotch Plains, NJ).[7] This model adopts a biochemical conversion of lignocellulosic materials using dilute acid pretreatment and simultaneous scarification and co-fermentation (SSCoF). The Kumar and Murthy (2011) model was modified to reflect local costs and feedstock choice in Hawai‘i including electricity cost at $0.29/kWh (HECO, 2012), water cost at $1.60/tonne (Hawai‘i Department of Water Supply, 2012), waste-water treatment cost at $5.8/1,000 liters (Hawai‘i County, 2012), and operator wage at $19/hr (US Bureau of Labor Statistics, 2011). The composition of banagrass was taken from Takara (2012), with the carbohydrate content consisting of approximately 37% of cellulose and 22% hemicellulose.[8] In addition, the further cost of running the industry (rent, insurance and other administrative costs) was estimated using “other manufacturing” production sectors present in the 2007 IO table.

Finally, life-cycle emission factors for individual fuel types are taken from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model 1 2012 version (Argonne National Laboratory, 2012). It is assumed that the fuel mixes within

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[6] At present, sugarcane production takes place on a limited scale at two firms in Hawai‘i as of 2007. The existing economic feasibility studies of banagrass production are based on commercial and experimental scale operations which took place in the early to mid-1990s when the local sugarcane industry had a sizable production capacity. Given the paucity of detailed bottom-up cost estimates conducted in recent years, it was deemed appropriate to use an earlier IO table reported in the early to mid-1990s, which corresponds to the years in which these economic studies were conducted, taking into account factors such as inflation rates and changes in real prices of crude oil and electricity (DBEDT, 2011a).

[7] For more information on SuperPro Designer see:http://www.intelligen.com/superpro_overview.html.

[8] Regarding the detailed cost estimation methodology used in SuperPro Designer, see for example Petrides (2012).

sectoral energy demand (i.e., power generation fuel mix and non-gasoline fuel demand breakdown) remain unchanged and a blend of 26% US corn-derived ethanol and 74% Brazilian sugarcane-derived ethanol are used as a proxy for imported biofuel emissions intensity corresponding to the proportion of US and Caribbean ethanol shipped to Hawaii in 2007 (EIA 2007). For the life-cycle GHG emissions intensity of banagrass-derived ethanol, it was assumed to be equivalent to that of switchgrass-derived ethanol (Argonne National Laboratory, 2012).

3.3. Policy Scenarios

As a remote chain of islands with limited indigenous sources of conventional energy, the State of Hawaiʻi is the most oil-dependent state within the United States. Imported fossil fuels (predominantly petroleum products) supply over 85% of the state's primary energy (DBEDT, 2011a). In 2007, the State of Hawaiʻi spent $4.67 billion on petroleum products, of which gasoline consumption accounted for some $1.37 billion.[9] Regarding bioethanol, Hawaiʻi's 10% ethanol blending mandate and ethanol facility tax credit provide direct impetus for bioethanol development in Hawaiʻi (DBEDT, 2012).

The simulation estimates the land-use, market and welfare implications of banagrass-based bioethanol under eight scenarios reflecting the current and potential policy environment in Hawaiʻi and the U.S. in regards to bioethanol development (Table 1). There are two primary scenarios. The first is that Hawaii meets 10%.... In this scenario, Hawaii-grown bioethanol serves to substitute existing imported ethanol. The second is that Hawaii meets 20%... In this scenario, Hawaii-grown bioethanol additionally substitutes wtih motor gasoline. These are deemed "A" and B," respectively. Scenarios 1A and 1B are termed "federal credit-10%" and "federal credit-20%" cases and assume that a federal government tax credit of $0.27/liter is extended to blenders, which echoes the existing cellulosic bioethanol tax credit effective until December 31, 2013 (Renewable Fuels Association, 2012). Scenarios 2A and 2B, termed "mandate only-10%" and "mandate only-20%" cases, assume that there is neither a federal mandate nor state-level subsidies for bioethanol production, and that local bioethanol must be bought based on long-term contracts between ethanol producers and blenders. Scenarios 3A and 3B, termed "lump-sum-10%" and "lump-sum-20%" cases, assume that the state government extends a production subsidy to cover 30% of ethanol production costs, and that this subsidy is financed through a lump-sum tax on consumers. Scenarios 4A and 4B, termed "fuel tax-10%" and "fuel tax-20%" cases, assume that the state government extends production subsidies of 30%, financed through an ad valorem tax on gasoline consumption.

Insert Table 1.

4. Results

4.1. Market Impacts

To replace bioethanol imports of 154 million liters (10%) and further gasoline inputs of 363 million liters (20%) respectively in the benchmark year, it is estimated that around 463,000 and 1,090,000 tonnes of banagrass must be produced based on the conversion rate of 334 liters/dry-tonne of biomass (Black and Veatch, 2010). Locally sourced lignocellulosic ethanol will require

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[9] Estimated based on EIA statistics (EIA 2012) and 2007 input-output data (DBEDT 2011b). Please see appendix C for details.

a range of inputs throughout its supply chain: feedstock production requires seedling, agrochemicals, fuels, other support activities and factor inputs of land, labor, and capital (Kinoshita et al., 1995), while ethanol processing requires inputs of feedstock, enzymes, yeast, acid, lime, gasoline with electricity, land, labor, and capital (Kumar and Murthy, 2011). The lignin-rich waste product can be recycled as a source of heat and power through technologies such as anaerobic digestion for biogas generation and rankine cycle for power generation. Our techno-economic modeling results indicate that lignocellulosic ethanol production based on SSCoF technology with dilute acid pretreatment of banagrass will supply around 80% of a plant's power needs while the remaining power needs must be purchased from outside sources. Thus, the emergence of a local ethanol industry will increase demands for these commodities, and combined with other general equilibrium effects, this industry will stimulate the local economy (Table 2).

In the benchmark year, the cost of banagrass feedstock production is estimated at \$98/tonne while the cost of processing based on biochemical conversion is estimated at \$0.80/liter. Local bioethanol production will thus be worth \$124 million (10%) and \$292 million (20%). The level of economic activity will be sizable as compared to the existing in-state agricultural production. Sugarcane production in Hawaiʻi, for example, was worth \$48 million in 2007 and generated a total of 465 and 523 wage and proprietor jobs (DBEDT, 2011b).

Insert Table 2.

Through a reduction in ethanol imports and increased value-added by the local ethanol industry along with a general decline in consumption and exports, the state's economic outputs as measured in real Gross State Product (GSP) changes from -\$63 million to \$49 million depending on blending targets and the other supporting policies chosen. Commodity prices, as measured in the Consumer Price Index (CPI), increase in all cases, from 0.07 to 0.38% primarily due to a higher domestic price of ethanol as compared to imports and additional demand for ethanol inputs. The GSP impact is found to be small, confirming an observation made in the earlier study on sugarcane-derived ethanol and its impact on Hawaiʻi's economy (DBEDT, 2009), as well as those of other lignocellulosic bioethanol studies (Painter et al., 2009, McCullough et al., 2011). The local ethanol industry will demand a total of approximately 730 to 1,600 jobs with around 18% in the processing sector and 82% in the feedstock production sector, while other sectors will experience contraction in labor use.

Insert Figures 5, 6, 7, 8.

Commodity prices in all sectors are expected to increase, and impacts are particularly notable in the gasoline production (Fig.5). In this sector, costlier domestic bioethanol must be purchased as an intermediate input. The price of gasoline is expected to increase, ranging from 0.02% (federal credit-10%) to 7.1% (mandate only-20%). The extent of changes in gasoline price primarily reflects the level of subsidies available and the level of blend mandate. The value of the animal production sector is also expected to rise due mainly to an increase in pasture land prices as discussed in Section 3.3. The remaining sectors experience a small increase in prices of less than 1%; this reflects the relatively diffuse inflationary impact on the economy.

In terms of quantity, output for the agricultural services sector will rise notably in support of local banagrass production. Electricity output will also increase slightly in order to supply power for feedstock production and ethanol processing. Given the general increase in commodity and input prices, output in other agricultural sectors will decrease slightly, and the gasoline sector will contract due mainly to higher gasoline prices (in the 10% scenarios) and further bioethanol substitution (in the 20% scenarios).

In response to the rising prices of domestically produced goods and a general decline in output, exports decline in most sectors (Fig 6). The extent of decline is most notable in the animal production sector, which experiences a 0.06 to 0.07% decline under the 10% mandate and a 0.16 to 0.18% decline under the 20% mandate – with remaining sectors experiencing still smaller declines, equivalent to less than 0.05% (Fig. 7). Likewise, changes in prices and output quantities affect imports in each sector. The impacts are notable in the agricultural services sector, whose imports increase by 0.81 to 0.83% under the 10% mandate and 0.17 to 0.18% under the 20% mandate to support local banagrass production. The gasoline sector imports, on the other hand, are expected decline by 0.08 to 0.10% under the 10% mandate and 0.15 to 0.20% under the 20% mandate due to sector contraction and replacement of bioethanol imports (Fig. 8).

4.2. Welfare Implications

Welfare impacts are measured in terms of the Hicksian equivalent variation. We estimate that locally produced lignocellulosic ethanol is a costlier alternative to imported bioethanol at present, and increased demand for intermediate goods created by an emerging local ethanol industry will drive up the cost of local goods and factors. As a result, the consumption of locally produced ethanol leads to a decline in the overall welfare measure. In the most relatively positive case, where the federal blender credit is extended for lignocellulosic ethanol blending, in-state resident welfare loss is estimated at -0.14% (the 10% mandate) and -0.10% (the 20% mandate). Counter-intuitively, the welfare decline in the 10% mandate is estimated to be larger. This is due to the fact that the price difference between locally produced and imported bioethanol is larger than that between the local biofuel and imported gasoline price in the benchmark year, hence the replacement of import biofuels comes at a larger cost. The use of long-term contracts and a locally financed subsidy based on fuel taxes leads to a larger decline in welfare measures, estimated at -0.23% (the 10% mandate) and -0.31% (the 20% mandate). This is mainly because the use of long-term contracts and fuel tax will increase the cost of gasoline, The magnitudes of welfare loss in both cases are found to be the same. Finally, in the case where production subsidies are financed through a lump-sum tax, the representative agent's welfare declines the most, estimated at -0.24% (the 10% mandate) and -0.32% (the 20% mandate).

4.3. Land-Use Impacts

The land requirement for banagrass is estimated to be approximately 9,600 ha (10%) and 22,600 ha (20%) respectively based on a banagrass yield of 48.1 tonnes/ha/year (Tran et al., 2011). Under the assumption that no new agricultural areas will be cultivated, additional land needed for feedstock production will increase direct competition for scarce land resources. As banagrass production is expected to occur on non-prime, non-unique agricultural land without irrigation, the price of pasture land will likely rise (Table 3). With a sluggish rate of transformation between different agricultural land uses, local banagrass production will have a sizable impact on land rental values and output levels in the agricultural sector. Price effects are estimated as: for crop land from 0.1% to 0.9%, for forestland from 0.8% to 2.4%, for pasture land from 44% to 150%, and for miscellaneous land from 1.5% to 4.4%. The quantity of land demanded remains relatively stable, with crop land-use decreasing by up to 0.01%, forestland-use decreasing by up to 0.44%, pasture-use decreasing by up to 0.01%, and miscellaneous land-use remaining virtually constant at 0.003%. Given that non-irrigated pasture rent is estimated to be $42/ha in 2010, expanded feedstock production will likely increase this rent to about $62/ha and $109/ha, which is still less expensive than irrigated land rent, estimated at $570/ha in the base-year.

Insert Table 3.

4.4. GHG Emissions Impact

Factors such as fuel prices, fossil fuel-use intensity in each sector, and a fuel's unit life-cycle GHG emissions determine the policy impact on the state's GHG emissions While a complete consequential life-cycle assessment is beyond the scope of this research, we calculate macro-level life-cycle emissions based on quantity changes and emissions intensities (see Appendix D). We estimate the changes in i) gasoline sector emissions and ii) economy-wide emissions.

In the gasoline sector, the 10% and 20% mandates are estimated to reduce GHG, in line with the expected changes in gasoline prices (Fig. 9). Under the 10% mandate, the fuel tax yields the largest reduction, estimated at 209,000 tonnes/yr (-3.7%), in which 66% is attributed to the gasoline sector contraction and 34% to the difference in bioethanol emissions intensity. The former contributes more since the additional tax depresses the demand in this sector. The mandate-only scenario offers the second largest reduction, estimated at 190,000 tonnes/yr (-3.3%), in which 63% is attributed to the sector decline and 37% to bioethanol replacement since a higher price of gasoline depresses the demand.

The remaining scenarios lead to smaller reduction, as the expected impacts on gasoline price and output are limited. In the case of a lump-sum tax, emissions decline by 120,000 tonnes/yr (-1.9%), with 34% due to the sector decline and 66% due to bioethanol replacement. Under the federal tax credit, a reduction of 70,000 tonnes/yr (-1.2%) is estimated, with a decline of 73,000 tonnes/yr due to bioethanol replacement, and an increase of 3,600 tonnes/yr due to gasoline sector growth. Under the 20% mandate, the fuel tax yields the largest reduction, estimated at 800,000 tonnes/yr (-14%) with 81% due to the sector contraction and 19% to bioethanol replacement.

Insert Figures 9 and 10.

Insert Tables 4 and 5.

The economy-wide emissions reduction is smaller than that of the gasoline sector, since an increase in motor fuel prices encourages the use of non-gasoline fuel options (Fig. 10). Under the 10% mandate, the fuel tax achieves the largest reduction, estimated at 160,000 tonnes of CO2e/yr (-0.5% of total GHG emissions). Emissions due to gasoline and aviation fuel-use is expected to decline (by 140,000 tonnes of CO2e/yr and 23,000 tonnes of CO2e/yr respectively), while those related to electricity, non-gasoline petroleum products, coal and gas increase (by 45,000 tonnes of CO2e/yr, 30, 000 tonnes of CO2e/yr, 500 tonnes of CO2e/yr, and 44 tonnes of CO2e/yr respectively). The federal tax credit, on the other hand, achieves the smallest reduction, estimated at 20,000 tonnes of CO2e/yr (-0.06%). Under the 20% mandate, the fuel tax achieves the largest reduction estimated at 680,000 tonnes of CO2e/yr (-2.3%), followed by the mandate-only scenario estimated at 650,000 tonnes of CO2e/yr (-2.2%), the lump-sum scenario estimated at 508,000 tonnes of CO2/yr (-1.7%), and the federal tax credit scenario estimated at 420,000 tonnes of CO2e/yr (-1.4%).

Table 4 provides the unit costs of GHG emissions as measured in subsidy expenditure and the decline in consumer spending. In general, the economy-wide unit abatement costs are found to be higher than in the gasoline sector, suggesting that exclusion of general equilibrium effects will likely underestimate the GHG abatement cost of biofuels policy. In terms of economy-wide emissions, it will cost \$270 to \$2,100/tonne of subsidies under the 10% mandate and \$130 to \$220/tonnes under the 20% mandate. The use of locally sourced ethanol will cost \$710 to \$3020/tonnes in terms of consumer expenditure decline under the 10% mandate, and \$104 to \$270/tonnes under the 20% mandate. The unit subsidy costs estimated for this study appear to fall within the range of those estimated in recent literature (see Table 5), confirming that the costs of GHG reduction using lignocellulosic ethanol are more than an order of magnitude higher than the price of carbon traded in existing carbon markets.

5. Sensitivity Analysis

To examine the robustness of modeling results three sensitivity analyses were performed to see how particular assumptions on substitutability between i) land and material and energy inputs, ii) energy and other value-added inputs, and iii) labor and capital inputs affect simulation outputs. First, the substitution parameter between the land-material-energy composite and the value-added composite (originally set as 0.6) and that between the land and material-energy composite (originally set as 0.6) are gradually decreased to zero, and the following two cases were evaluated: i) land endowment is fixed; and ii) 50% of land needed for banagrass production comes from new cultivation of fallow land.

Insert Figures 11 and 12.

As Fig. 11 and 12 show, both elasticity parameters and land endowment assumptions have a large impact on land prices, especially for pasture land. Taking the federal credit scenario as an example, under the original assumption that land may be partially substituted by other material and energy inputs with substitution elasticity of 0.6, the price of pasture land increases by 46% (land is fixed) and 20% (50% of new land becomes available) based on the 10% mandate, and by 150% (land is fixed) and 51% (50% of new land) based on the 20% mandate. When this model assumes more rigid production technologies, however, land price increases sharply: 270% (land is fixed) and 97% (50% of new land) under the 10% mandate, and 1600% (land is fixed) and 303% (50% of new land) under the 20% mandate. Although sizable fallow land exists in the State of Hawai‘i, it is unlikely that these areas will immediately become available for expanded use for biofuels production; thus, some form of competition may arise among alternative land uses, particularly in the short-run.

Next, we change assumptions about energy and non-energy substitution parameters $(\sigma_{ENE_i}, \sigma_{NENE_i})$ from the original values to zero. Results indicate that changes in the energy substitution parameters had a negligible impact on energy prices while the quantity demanded changed slightly (Table 6). Assuming that it is possible to substitute electricity and non-electric sources of energy such as gasoline and other petroleum productions, this assumption has led to an increased use of electricity in most cases.

Insert Table 6.

Finally, simulations were implemented by varying the elasticity of the substitution parameters between capital and labor composites, originally assumed as 1 to 0 (Table 7). Allowing for the substitution of capital and labor, an increase in capital cost is estimated to range from 0.19% to 0.27% under the 10% mandate, and 0.52% to 0.71% under the 20% mandate. Assuming that capital and labor are not substitutable, the price of capital goods could increase from 0.66% to 0.78% under the 10% mandate and 1.6% to 1.8% under the 20% mandate. Labor prices are expected to decline further under the no-substitution cases.

Insert Table 7.

6. Discussion

The results highlighted important insights regarding lignocellulosic ethanol development in Hawai'i. The estimated prices of local alternative appear competitive with a conventional ethanol option, with a federal tax credit of $0.27/liter or locally funded subsidies. While this is an encouraging result, it is important to note that techno-economic analyses of advanced fuels typically assume the use of mature technologies and that production incurs no additional cost as a pioneering plant. However, lignocellulosic conversion technologies are still in a state of research development and demonstration (RD&D), and the adoption at a commercial scale will require initial costs of learning (Goldemberg et al., 2004). Once this experience is established, the locally produced alternative fuel will likely be cost competitive, especially if subsidies are extended by the federal government.

Under the existing alternative fuels mandate, economy wide impacts are estimated to be small, confirming the findings of the existing literature (DBEDT 2009). However, because locally produced ethanol is a costlier alternative to an imported source, both resident and visitor welfare declined in all cases. This welfare loss occurred in spite of GSP growth in three out of eight scenarios, and in spite of newly created employment opportunities in the ethanol industry in all scenarios. This asymmetry illustrates how a policy to promote local bioethanol creates both winners and losers. Generally, consumers bear the additional burden of costlier local production, making them worse off, regardless of whether local ethanol leads to an increase in overall economic production.

This study also found that potential GHG reduction resulting from the use of locally produced ethanol will likely be small (the 10% and 20 mandates achieve up to 0.5 and 2.3 % of economy-wide emissions reduction). The limited reduction is due primarily to low mandated levels and a higher price of gasoline which encourages the use of non-gasoline fuel. The subsidy cost per tonne of economy-wide greenhouse gas displaced, ranging from $130 to $2,100/tonnes CO2e, is well above the price of carbon currently being traded, raising serious doubt as to whether lignocellulosic bioethanol should be promoted as a desirable GHG emissions abatement option on economic grounds. Promotion of locally produced biofuels must, therefore, be carefully examined in relation to the cost-effectiveness of alternative GHG mitigation options.

Finally, given the relatively large land-use impacts estimated by this study, it may be beneficial to explore how the local bioethanol industry may be integrated with the local livestock production. Possible avenues for integration include: i) feedstock production: since banagrass is a common cattle feed in other parts of the world, it may be possible to use it as both bioethanol feedstock and fodder depending on their profitability; ii) waste management: the bioethanol plant design adopted for this study includes an anaerobic digestion system, which may process animal manure for biogas production. The use of animal manure for biogas production may reduce the cost of livestock waste management and will mitigate local environmental nuisance associated with poor waste management; and iii) co-product generation: an alternative production design for protein-rich animal feed co-product generation from banagrass-derived bioethanol production is currently being evaluated (Takara and Khanal, 2011). Such a process could prove to be a viable option, as it integrates the bioethanol and livestock industry. The integration of these two industries through these avenues may alleviate direct competition for limited resources.

6. Conclusions

This essay developed a computable general equilibrium model for the State of Hawai‘i, examining the impacts of lignocellulosic ethanol production on the local economy. Our results indicate that the use of banagrass-derived local ethanol to meet the 10% and 20% mandates can lead to both positive and negative impacts to Gross State Product, from -\$63 million to \$49 million, depending on the policy instrument. However, the use of costlier local ethanol leads to a decline in welfare in all scenarios: resident welfare declines from 0.14% to 0.24% under the 10% mandate, and from 0.10% to 0.32% under the 20% mandate. Assuming that agricultural land endowment is fixed, an increase of 0.1% and 0.9% (cropland) 44% and 150% (pasture land), 0.8% and 2.4% (forestland) and 1.5% and 4.4% (miscellaneous land) will occur under the 10% and 20% mandates respectively. Overall, lignocellulosic bioethanol is found to be a costly GHG abatement option as compared to the prices of carbon currently traded: to reduce one tonne of economy-wide GHG emissions, it will cost approximately \$270 to \$2,100/tonnes of subsidies under the 10% mandate depending on alternative scenarios, and \$130 to \$220/tonnes under the 20% mandate. While the overall economic and GHG impacts at the state-level are estimated to be small, it is likely that location-specific impacts will be larger. Hence, further studies evaluating more location-specific cases will be helpful to examine the potential opportunities and risks associated with an advanced bioethanol option in Hawai‘i.

References

Argonne National Laboratory (2012) The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. GREET1 2012. Available at: http://greet.es.anl.gov/ [05.22.2013].

Arndt, C., Pau, K., & Thurlow, J. (2012) Biofuels and economic development: A computable general equilibrium analysis for Tanzania. *Energy Economics* 34 (6): 1922-1930.

Beckman, J., Adaire, J., & Sands, R. (2011) A global general equilibrium analysis of biofuel mandates and greenhouse gas emissions. *American Journal of Agricultural Economics* 93(2):334-341.

Black and Veatch (2010) *The potential for biofuels production in Hawai‘i: a final report*. Jan. B&V Project Number 147375. Available from: Bloomberg Finance L.P. http://energy.Hawai‘i.gov/wp-content/uploads/2011/10/Hawai‘i-Biofuels-Assessment-Report.pdf [03.16.2013].

Bloomberg Finance L.P. (2013) ETHCTOTL Index. Average Ethanol Rack Prices. 01/02/2007 to 12/31/2007. Bloomberg Terminal [02.01.2013].

Bouet, A., Dimaranan, B., & Valin, H. (2010) Modeling the Global Trade and Environmental Impacts of Biofuel Policies. *IFPRI Discussion Paper* 01018. Available at: http://www.ifpri.org/sites/default/files/publications/ifpridp01018.pdf [05.21.2013].

California Air Resources Board (2013) Quarterly Auction 3, May 2013 *Summary Results Report*. Available at: http://www.arb.ca.gov/cc/capandtrade/auction/may-2013/results.pdf [05.22.2013].

Cardno Entrix (2010) *Current State of the U.S. Ethanol Industry.* A document prepared for the US Department of Energy, Fulfillment of Subcontract No. 02-5025 Available at: http://www.nrel.gov/analysis/pdfs/doe-02-5025.pdf [02.12. 2012].

Changsorn, P. (2012) Napier grass to be part of green energy plan, minister says. The nation. December 14. Available: http://www.nationmultimedia.com/business/Napier-grass-to-be-part-of-green-energy-plan-minis-30196080.html [08.14.2013].

Coffman, M. (2010) Oil price shocks in an island economy: an analysis of the oil price-macroeconomy relationship. The Annals of Regional Science. 44 (3): 599-620

Doornbosch R. Steenlik R (2007) *Biofuels: Is the Cure Worse Than The Disease?* Roundtable on Sustainable Development. Organiation for Economic Co-operation and Development. Available at: http://www.oecd.org/sd-roundtable/39411732.pdf. [05.22.2013]

Defense Logistics Agency (2010) *Fact Book Fiscal Year 2010*. Available at: http://www.energy.dla.mil/library/Documents/Publications/Fact%20Book%20FY10.pdf [05.22.2013].

DBEDT [Department of Business, Economic Development & Tourism] (2007) *State of Hawai'i Data Book*. Section 17 Energy. Available at: http://dbedt.Hawai'i.gov/economic/databook/db2007/ [05.22.2013].

DBEDT (2009) *Hawai'i Bioenergy Master Plan.* Available at: http://www.Hawai'ienergypolicy.Hawai'i.edu/EnergyBriefings/BioenergyMP09/BioenergyMP.pdf [03.31.2013].

DBEDT (2011a) *State of Hawai'i Energy Data and Trends*. Available at: http://Hawai'i.gov/dbedt/info/economic/data_reports/reports-studies/energy-data-trend-2011.pdf [04.11.2013].

DBEDT (2011b) *The Hawai'i State Input-Output Study: 2007 Benchmark Report.* Available at: http://Hawai'i.gov/dbedt/info/economic/data_reports/2007-io/State2007IO-7-2011.pdf [04.11.2013].

DBEDT (2012) *Biofuels Study Final Report to the Legislature in Accordance with Act 203, Session Laws of Hawai'i, 2011*.Available at: http://files.Hawai'i.gov/dbedt/annuals/2012/2012-biofuels-study-act-203.pdf [05.21.2013].

EIA [Energy Information Administration] (2007) Company Level Imports Archives. Available at: http://www.eia.gov/petroleum/imports/companylevel/archive/ [04.11.2013].

EIA (2012) State Energy Data System (SEDS):1960-2010. Hawai'i. Available at: http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=HI [05.21.2013].

Energy Information Administration [EIA] (2013) The State Energy Data System. Hawai'i State Profile and Energy Estimates. Available at http://www.eia.gov/state/data.cfm?sid=HI#Consumption [03.22.2013].

Gitiaux, X., Paltsev, S., Reilly, J., & Rausch, S. (2009) Biofuels, Climate Policy and the European Vehicle Fleet. Report No. 176. MIT Joint Program on the Science and Policy of Global Change. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Reprint_12-2.pdf [05.22.2013].

Goldemberg, J., Coelho, S.T. Nastari, P.M. Lucon O. (2004) Ethanol learning curve—the Brazilian experience. Biomass and Bioenergy 26(3):301-304.

Gunatilake H., S. Pohit, and G. Sugiyarto. 2011. Economywide Impacts of Biofuel Production and use in India: A CGE Model Assessment. Technical Assistance Report to India for the Study on Cross-Sectoral Implications of Biofuel Production and Use. Asian Development Bank, Manila.

Gurgel, A., Reilly, J. M., & Paltsev, S. (2008) Potential land use implications of a global biofuels industry. Report No. 155 MIT Joint Program on the Science and Policy of Global Change. Available at: http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt155.pdf [05.22.2013].

Hawaii Clean Energy Initiative (2010). Hawai'i is the most fossil fuel dependent state in the nation. Available at: http://www.hawaiicleanenergyinitiative.org/ [28.10.2013]

HECO [Hawai'ian Electric Company] (2012) Average Electricity Prices for Hawai'ian Electric, Maui Electric and Hawai'i Electric Light Company. Available at: http://www.heco.com/portal/site/heco/menuitem.508576f78baa14340b4c0610c510b1ca/?vgnextoid=692e5e658e0fc010VgnVCM1000008119fea9RCRD&vgnextchannel=2c65a51aaabd6110VgnVCM1000005c011bacRCRD&vgnextfmt=default&vgnextrefresh=1&level=0&ct=article [05.29.2012].

Hawai'i County (2012) Hawai'i County Code. Chapter 21. Sewer. Available at: http://www.Hawai'icounty.gov/lb-countycode#countycode [05.29.2012].

Hawai‘i Department of Water Supply (2012) Water Rates. Available at: http://www.Hawai‘idws.org/4%20your%20water%20bill/FinanceWaterRatesBrochure%2020110919ka.pdf [05.29.2012].

Hertel, T. W., Tyner, W. E., & Birur, D. K (2008a) Biofuels for all? Understanding the Global Impacts of Multinational Mandates. *GTAP Working Paper* No. 51. Available at: http://ageconsearch.umn.edu/bitstream/6526/2/469013.pdf [05.22.2013].

Hertel, T. W., Lee, H. L., Rose, S. & Sohngen, B. (2008b) Modeling land-use related greenhouse gas sources and sinks and their mitigation potential. *GTAP working paper* No.44. Available at: https://www.gtap.agecon.purdue.edu/resources/download/3675.pdf [05.22.2013].

Hertel, T. W., Rose, S., & Tol, R. S. J. (2008c) Land Use in Computable General Equilibrium Models: An Overview. *GTAP Working Paper* No. 39. Available at: https://www.gtap.agecon.purdue.edu/resources/download/3659.pdf [05.21.2013].

Holm, C. (2010) Grass could turn toxic waste into energy. ABC Science. http://www.abc.net.au/science/articles/2010/10/29/3050800.htm?site=science&topic=enviro. [06.24 2013].

Huang, M.Y., Alavalapati, J. R. R., & Banerjee, O. (2012) Economy wide impacts of forest bioenergy in Florida: A computable general equilibrium analysis. *Taiwan Journal of Forestry Science* 27(1): 81-93.

Hue, N.V., Uehara, G., Yost, R. S., & Ortiz-Escobar, M. (2007) Distribution of soil orders in Hawai‘i. *Journal of Hawai‘i and Pacific Agriculture* 14:17-28. Available at: http://Hilo.Hawai‘i.edu/academics/cafnrm/research/documents/Hawai‘i_soils706.pdf [05.22.2013].

Internal Revenue Service (2013) Yearly Average Currency Exchange Rates Translating Foreign Currency into U.S. Dollars. http://www.irs.gov/Individuals/International-Taxpayers/Yearly-Average-Currency-Exchange-Rates [05.23.2013].

Jessen, H. (2012) Elephant grass has potential as biofuel crop in southern states. Ethanol Producer Magazine. October 3. http://www.ethanolproducer.com/articles/9166/elephant-grass-has-potential-as-biofuel-crop-in-southern-states. [08.14.2013].

Kinoshita, C. M., Ishimura, D. M., Jakeway, L. A., & Osgood, R. V. (1995) Production of biomass for electricity generation on the Island of Oahu. Honolulu: Hawai‘i Natural Energy Institute.

Koplow, D. (2007) *Biofuels-At What Cost? Government Support for Ethanol and Biodiesel in the United States: 2007 Update.* http://www.iisd.org/gsi/sites/default/files/brochure_-_us_update.pdf [05.22.2013].

Kretschmer, B., Narita, D., & Peterson, S. (2009) The economic effects of the EU biofuel target. *Energy Economics*, 31, p.S285–S294.

Kumar, D., & Murthy, G. S. (2011) Impact of pretreatment and downstream processing technologies on economics, energy and water use in cellulosic ethanol production. *Biotechnology and Biofuels* 4:27.
Manila Times (2011) The green, green grass of hope. November 24.
http://www.manilatimes.net/index.php/opinion/columnist1/11894-the-green-green-grass-of-hope. [06. 24. 2013].

Melrose, J. & Delparte, D. (2012) *Hawai'i county food self-sufficiency baseline*. Hilo: University of Hawai'i. Available from:
http://geodata.sdal.hilo.Hawai'i.edu/techgis/coh/BASELINE_FOOD_SUSTAINABILITY_WEB.pdf [16.03.13].

McCullough, M., Holland, D., Painter, K., Stodick, L., & Yoder, J. (2011) Economic and environmental impacts of Washington state biofuel policy alternatives. *Journal of Agricultural and Resource Economics* 36(3):615-629.

National Research Council (2011) *Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy*. Washington, DC: The National Academies Press.

Ogoshi R. (2013) Unpublished data from Napiergrass irrigation field trials on Maui Island, Hawaii. College of Tropical Agriculture and Human Resources, University of Hawaii.

Painter, K., McCullough, M., Holland, D., Stodick, L., &Yoder, J. (2009) Economic and Environmental Impacts of Policy Alternatives for Promoting Biofuel Usage in Washington State. Available
at: http://www.cals.uidaho.edu/AERS/PDF/AERS/2009/AERS09-01.pdf [02.12. 2012].

Petrides, D. (2012) Bioprocess Design and Economics. INTELLIGEN, INC. Available at: http://intelligen.com/literature.html [06.03.2013].

Point Carbon (2013) Thomson Reuters Point Carbon's OTC Price Assessments EUA Close Date of December 2013. Available at: http://www.pointcarbon.com/ [05.22.2013].

Renewable Fuels Association (2012) Tax Incentives. Available at:
http://www.ethanolrfa.org/pages/tax-incentives [05.22.2013].

Ross, M. T. (2008) Documentation of the Applied Dynamic Analysis of the Global Economy (ADAGE) Model. Working Paper 08_01. Research Triangle Institute.
http://www.rti.org/pubs/adage-model-doc_ross_sep08.pdf [22.03.2013].

Satyakti, Y., Havrland, B., & Pobedischi, V. (2012) Impact of EU biofuel directives policies on developing economies. Engineering for rural development. Engineering for Rural Development.

International Scientific Conference Vol. 11 360-365. Available at: http://tf.llu.lv/conference/proceedings2012/Papers/063_Havrland_B.pdf [05.22.2013].

Schnepf, A. (2004) Energy use in Agriculture: Background and Issues. *CRS Report for Congress*. Order Cde RL32677. 19 November. Available at http://www.nationalaglawcenter.org/assets/crs/RL32677.pdf [03.22.2013].

Sharma, K. R., Tian, X., Peterson, A., Nakamoto, S., & Leung, P. S. (1997) *The 1992 Hawai'i Input-Output Study.* CTAHR Economic Issue No.1. College of Tropical Agriculture and Human Resources, University of Hawai'i. Honolulu.

State of Hawai'i (1977) *Agricultural Land of Importance to the State of Hawai'i.* Honolulu: Department of Agriculture.

State of Hawai'i (2010) Hawai'i Revised Statue 196-42. State support for achieving alternate fuels standards. Division 1, title 12, subtitle 6, chapter 196, Part III. Honolulu. Available from: http://www.capitol.Hawai'i.gov/hrscurrent/Vol03_Ch0121-0200D/HRS0196/HRS_0196-0042.htm [accessed16.03.13].

Taheripour, F., & Tyner, W. (2012) Welfare assessment of the renewable fuel standard: Economic efficiency, rebound effect, and policy interaction in a general equilibrium framework. 15th Annual Conference on Global Economic Analysis Geneva, Switzerland June 27-29. Available at: https://www.gtap.agecon.purdue.edu/resources/download/6001.pdf [05.24.2013].

Takara, D. (2012) Green Processing of Napier Grass for Generation of Biofuel and Bioproducts. PhD Dissertation. Department of Molecular Biosciences and Bioengineering. University of Hawai'i at Manoa.

Takara. D., & Khanal, S. K. (2011) Green processing of tropical banagrass into biofuel and biobased products: an innovative biorefinery approach. *Bioresources Technology* 102(2); 1587-92.

Tilman, D., Socolow, R ., Foley, J. A. Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J., Searchinger, T., Somerville, C., & Williams, R. (2009) Beneficial Biofuels The Food, Energy, and Environment Trilemma 17 July. *Science* 325(5938): 270-271.

Timilsina, G. R., Beghin, J. C., van de Mensbrugghe, D., & Mevel, S. (2010) The impacts of biofuel targets on land-use change and food supply: A global CGE assessment*. World back Policy Research working paper* 5513.

Timilsina, G. R., & Mevel, S. (2011) Biofuels and climate change mitigation: A CGE analysis incorporating land-use change. *World Bank Policy Research Working Paper* 5672.

Tran, N., Illukpiiya, P., Yanagida, J. F., & Ogoshi, R. (2011) Optimizing biofuel production: An economic analysis of selected biofuel feedstock production in Hawai'i. *Biomass and Bioenergy* 235(5):1756-64.

Turnquist, A. Fortenbery, T.R., & Foltz J. (2008) Progress or devastation? the effects of ethanol location on local land use. American Agricultural Economics Association annual meeting, Orlando, FL, July 27-29. Available at: http://ageconsearch.umn.edu/bitstream/6125/2/469529.pdf [08.14.2013].

United States Bureau of Labor Statistics (2011) May 2011 State Occupational Employment and Wage Estimates
Available at: http://www.bls.gov/oes/current/oes_hi.htm#51-0000 [05.29.2012].

United States Bureau of Labor Statistics (2013) Consumer price index: all urban consumers Honolulu. Available from:http://data.bls.gov/pdq/SurveyOutputServlet?data_tool=dropmap&series_id=CUURA426SA0,CUUSA426SA0 [16.03.2013].

United States Department of Agriculture (2013) Quick Stats. Cash Rent for Cropland and Pastureland. Available at: http://quickstats.nass.usda.gov/ [05.22.2013].

United States Department of Energy (2013) Hawaii Laws and Incentives. Alternative Fuels Data Center. Available at: http://www.afdc.energy.gov/laws/laws/HI [28.10.2013].

Wilsie, C.P. & Takahashi M. (1934) Napier Grass (Pennisetum Purpureum): A Pasture and Green Fodder Crop for Hawaii. Hawaii Agricultural Experiment Station Bulletin No. 72. Available at: http://archive.org/stream/napgrass00unit/napgrass00unit_djvu.txt [30.10.2013]

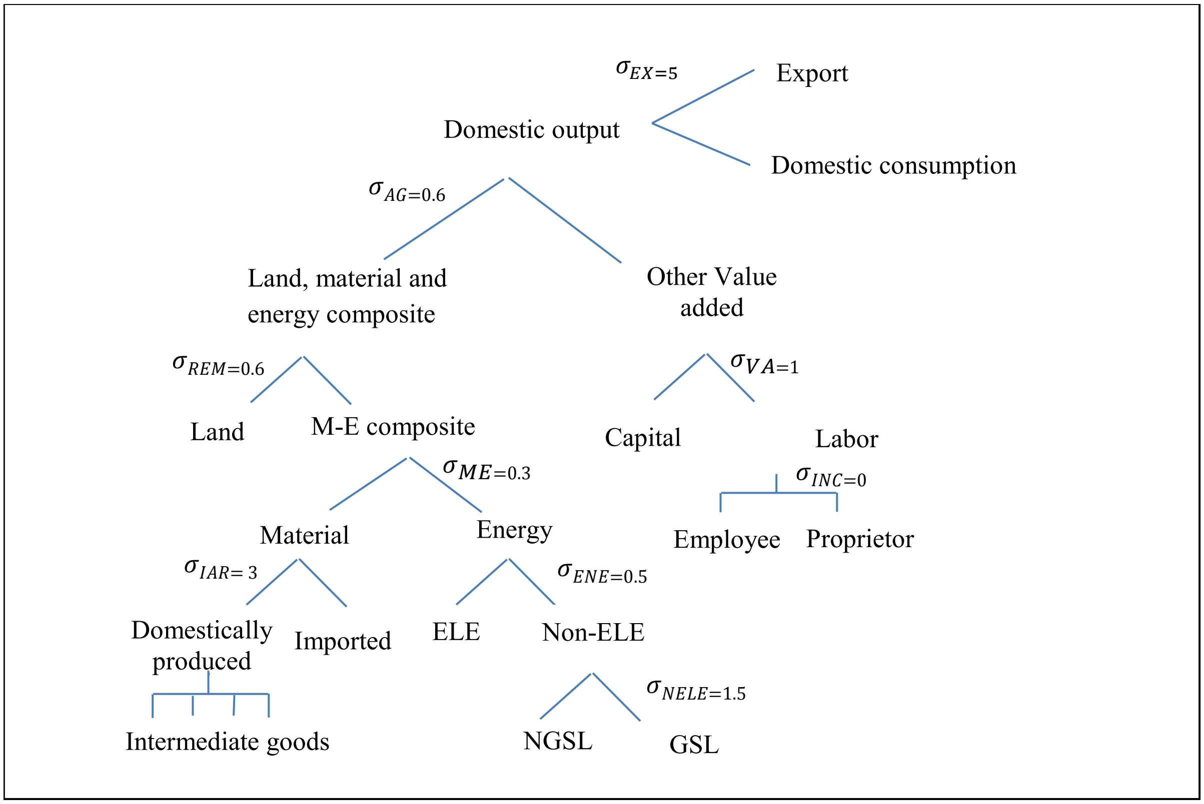


Figure 1: Nested Structure of Agricultural Commodity Production

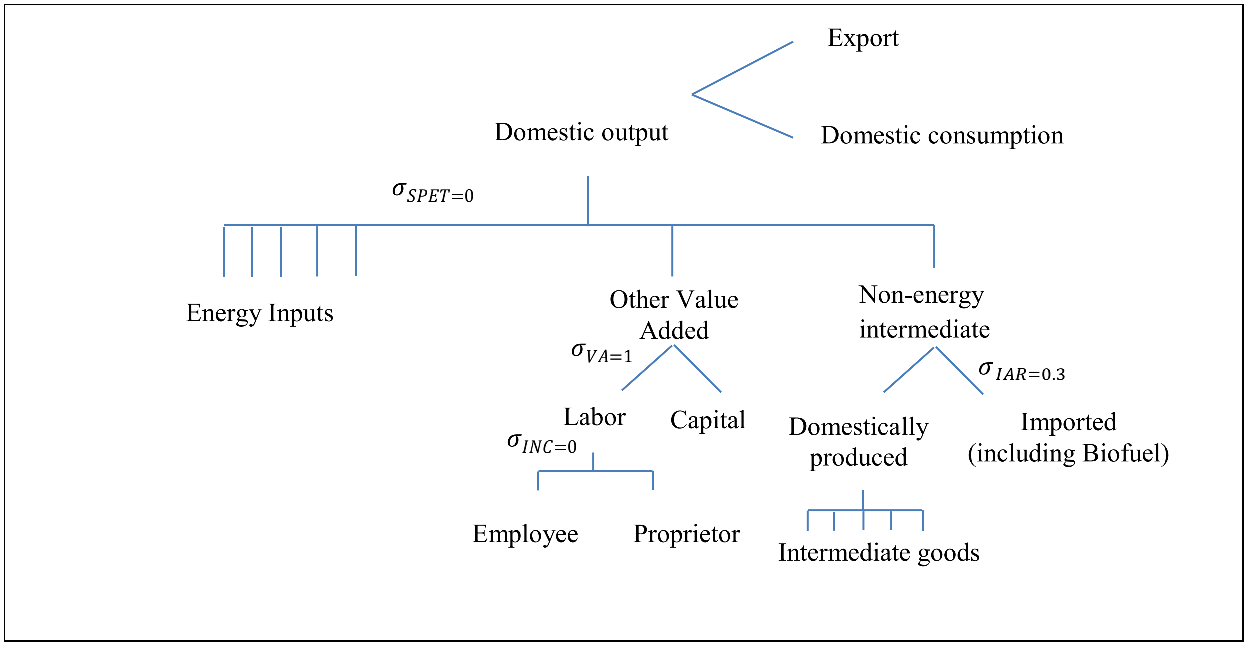


Figure 2: Nested Structure of Gasoline Production

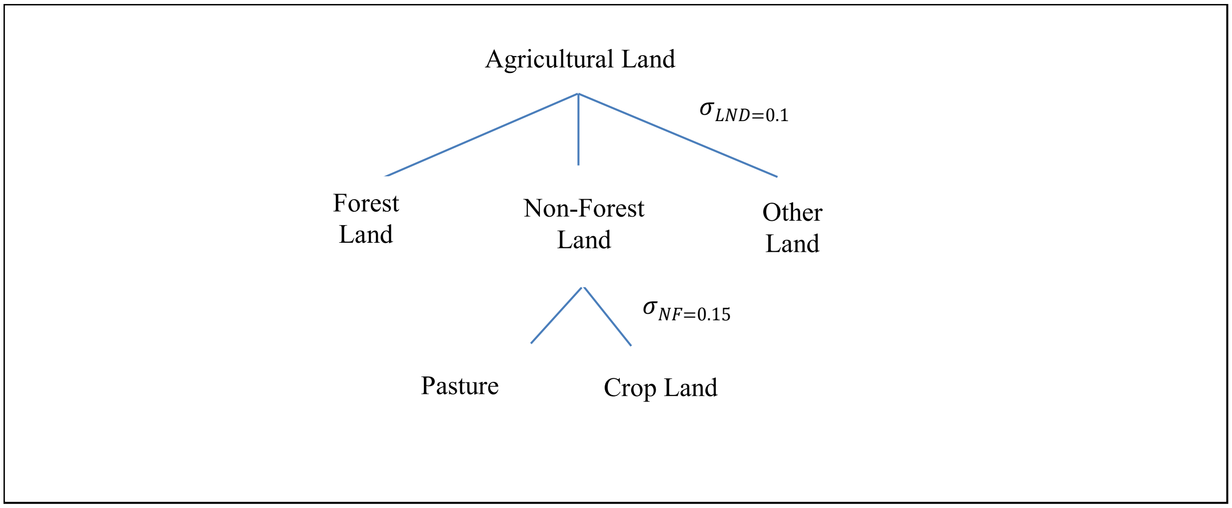


Figure 3: Nested Structure of Agricultural Land Transformation

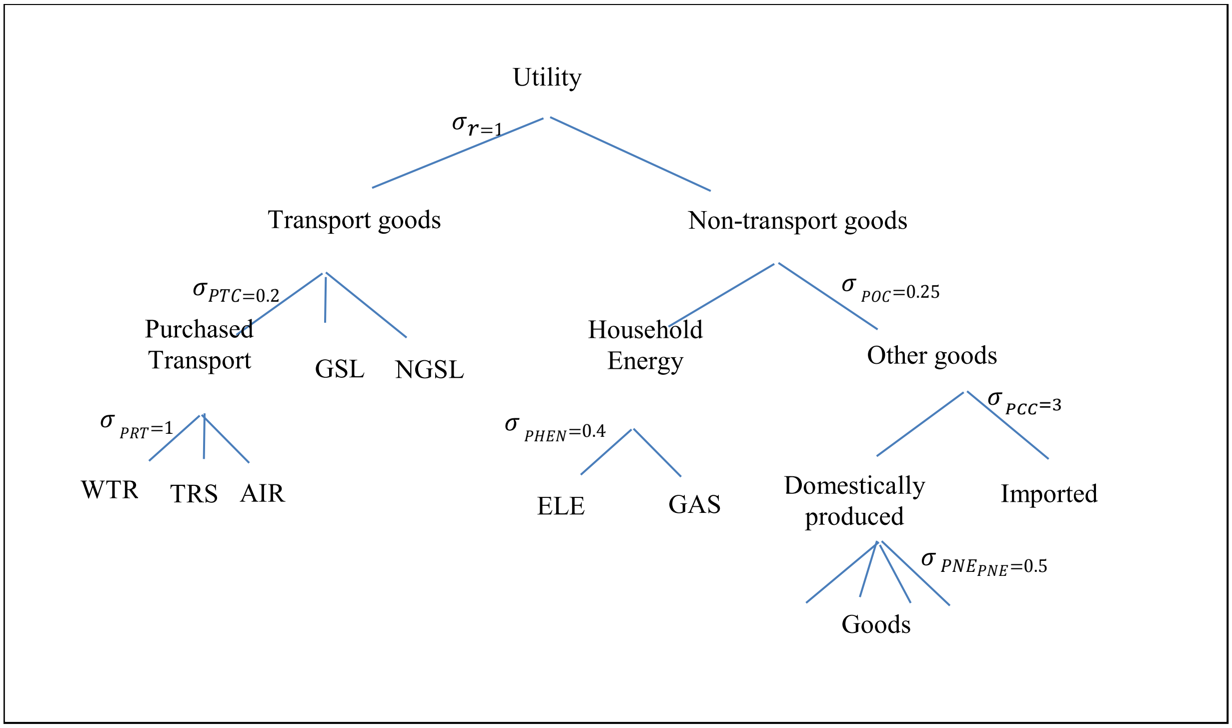


Figure 4: Nested Structure of Consumer Utility

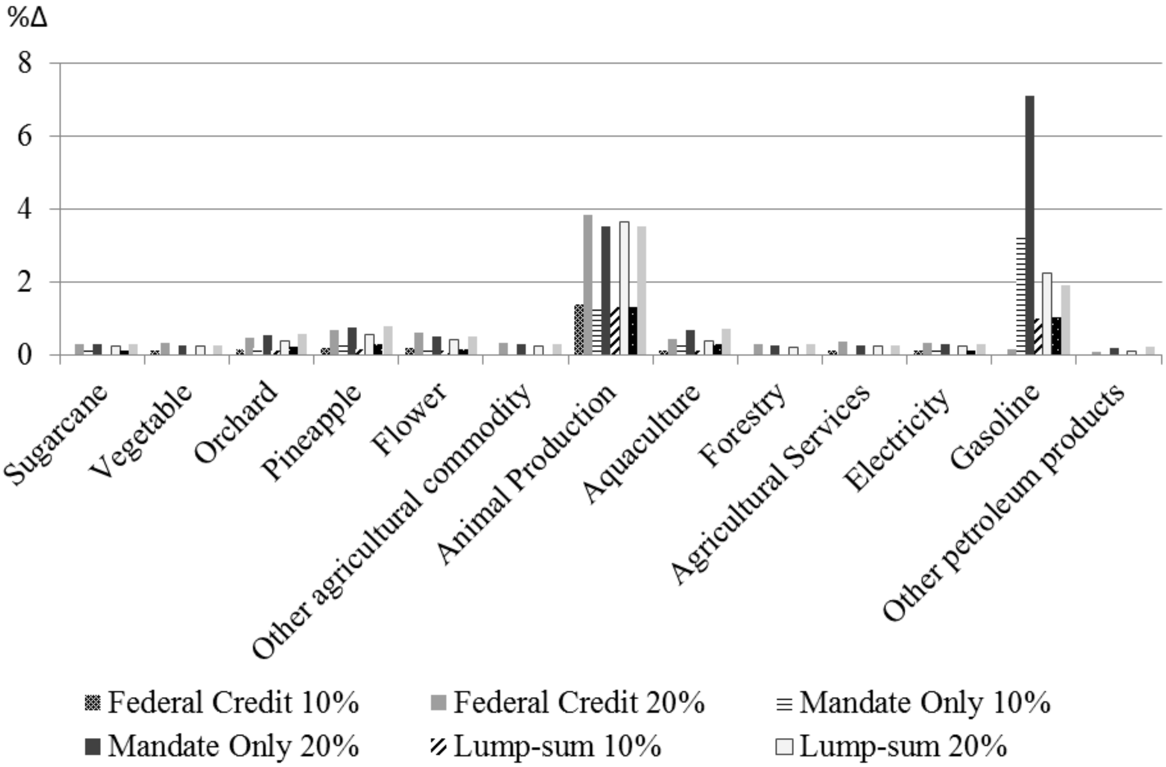


Figure 5: Percentage change in real prices for selected commodities

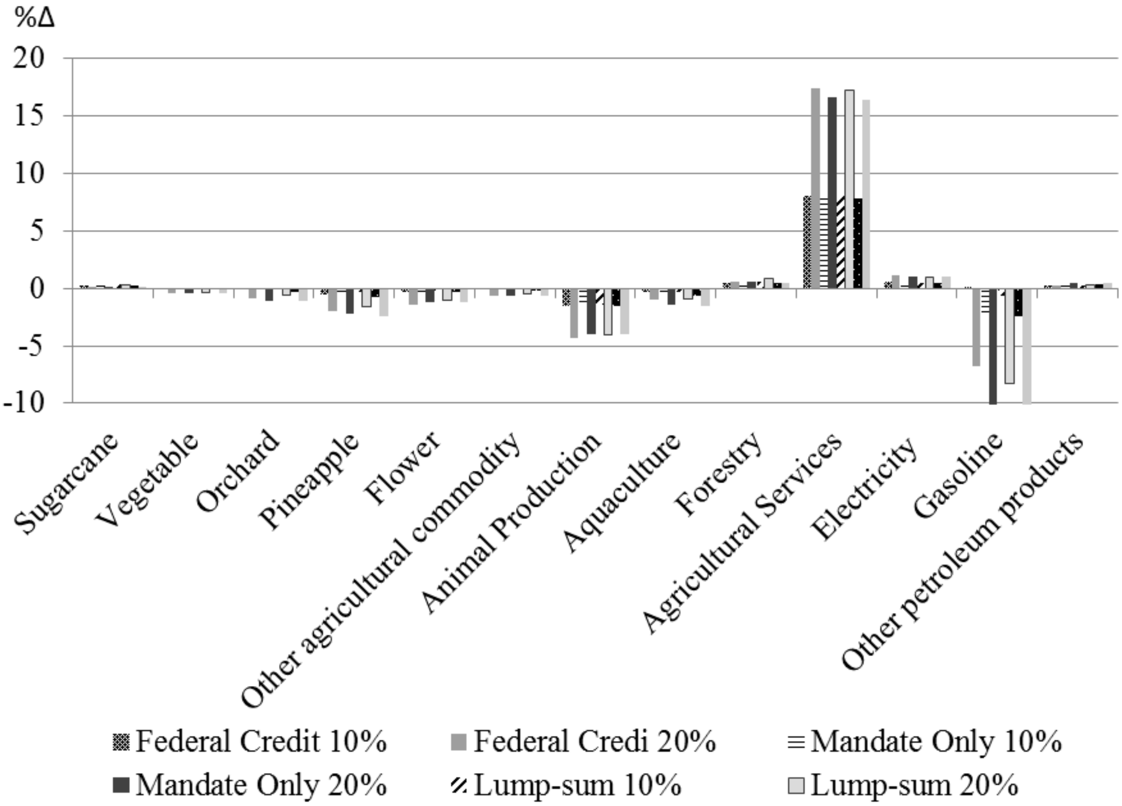


Figure 6: Percentage change in quantity of production for selected commodities

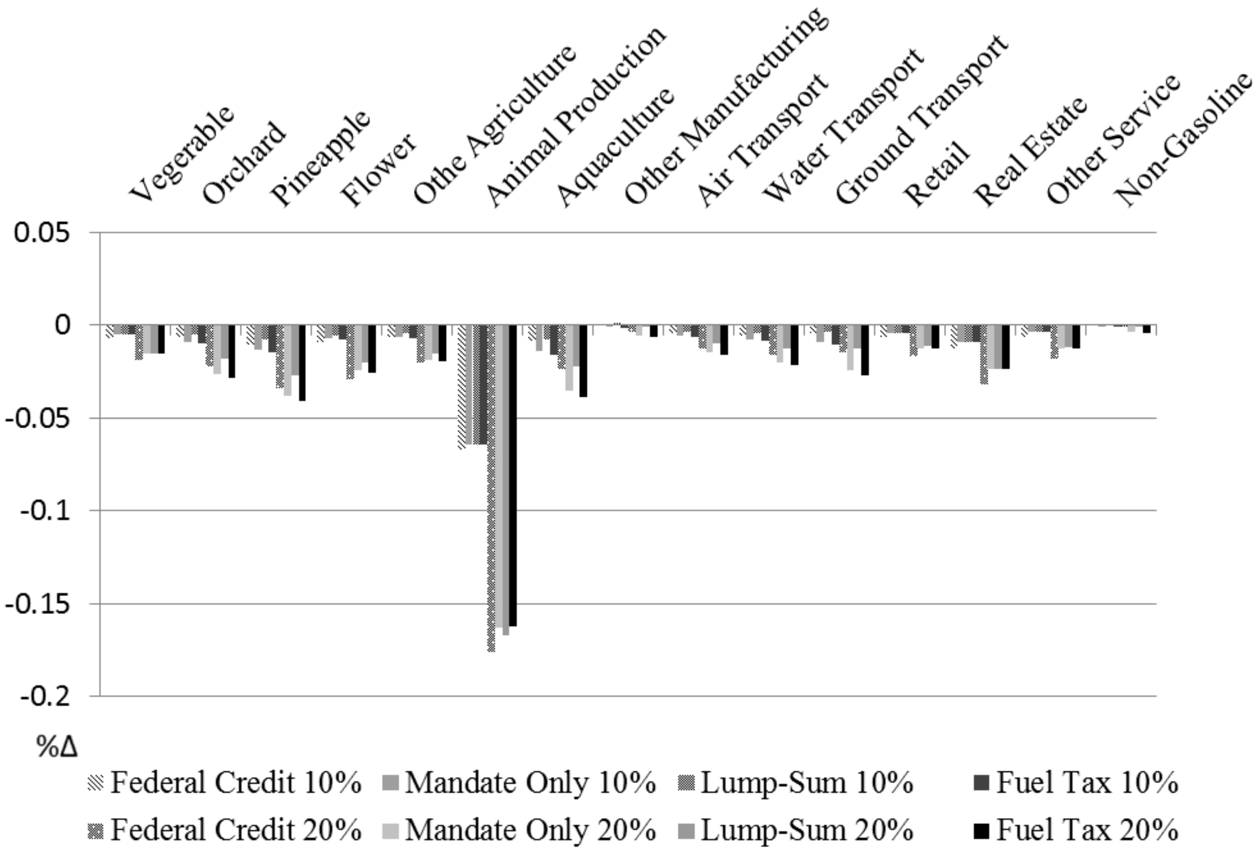


Figure 7: Percentage change in quantity of export

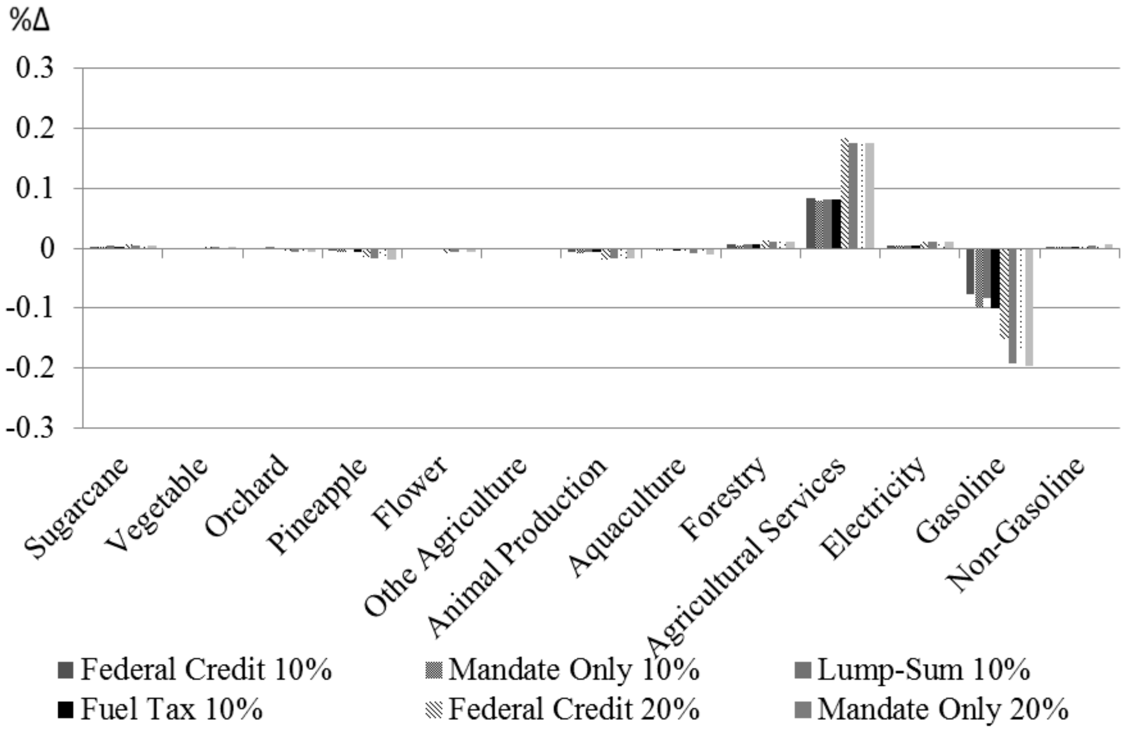


Figure 8: Percentage change in quantity of import for selected commodities

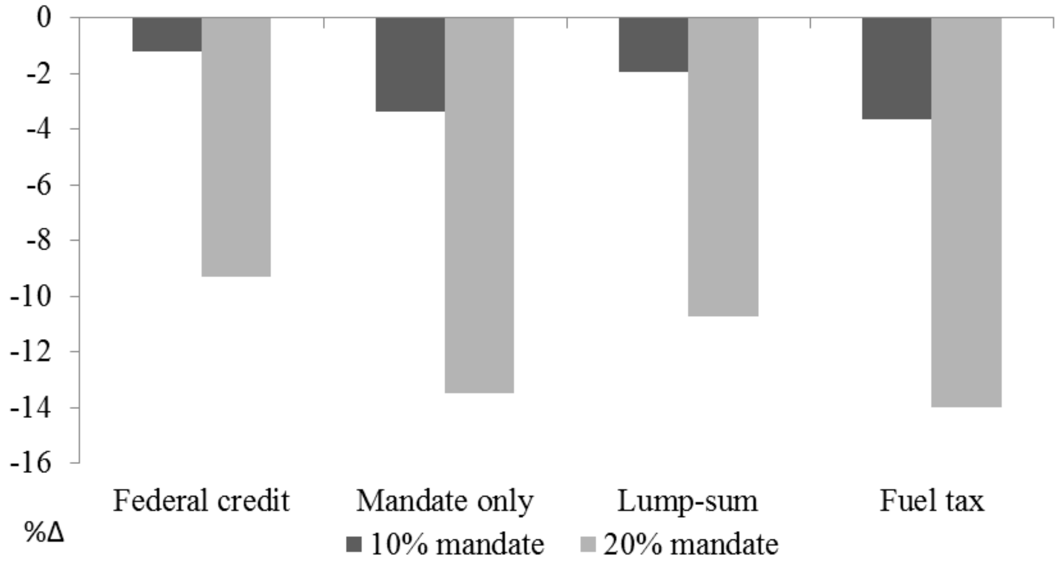


Figure 9: GHG emission reduction in the petroleum sector

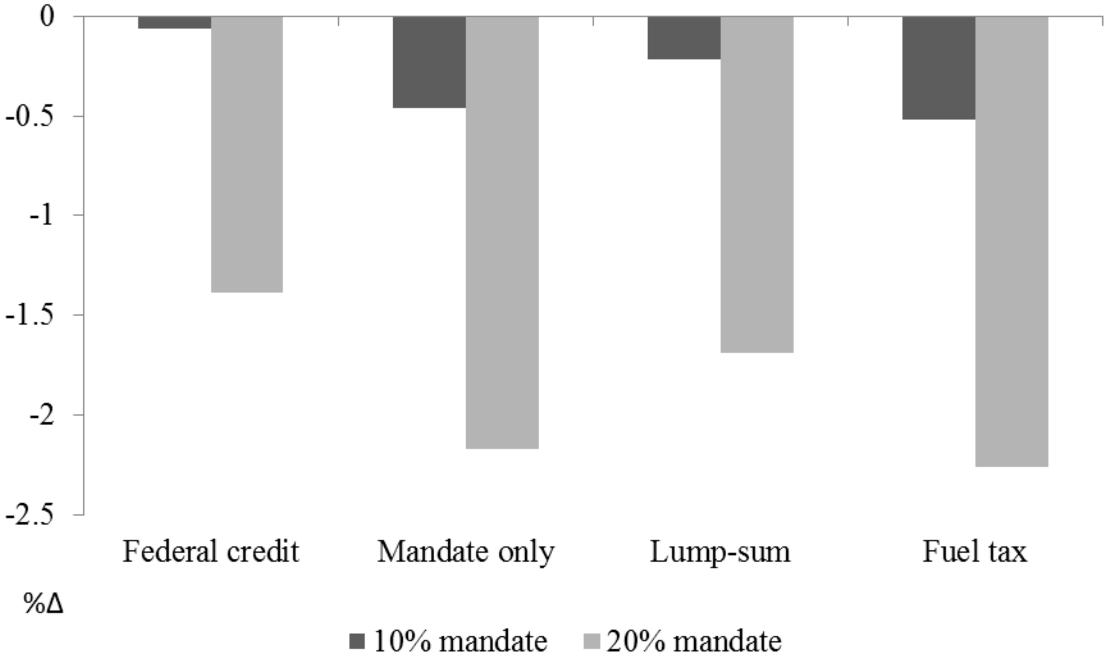
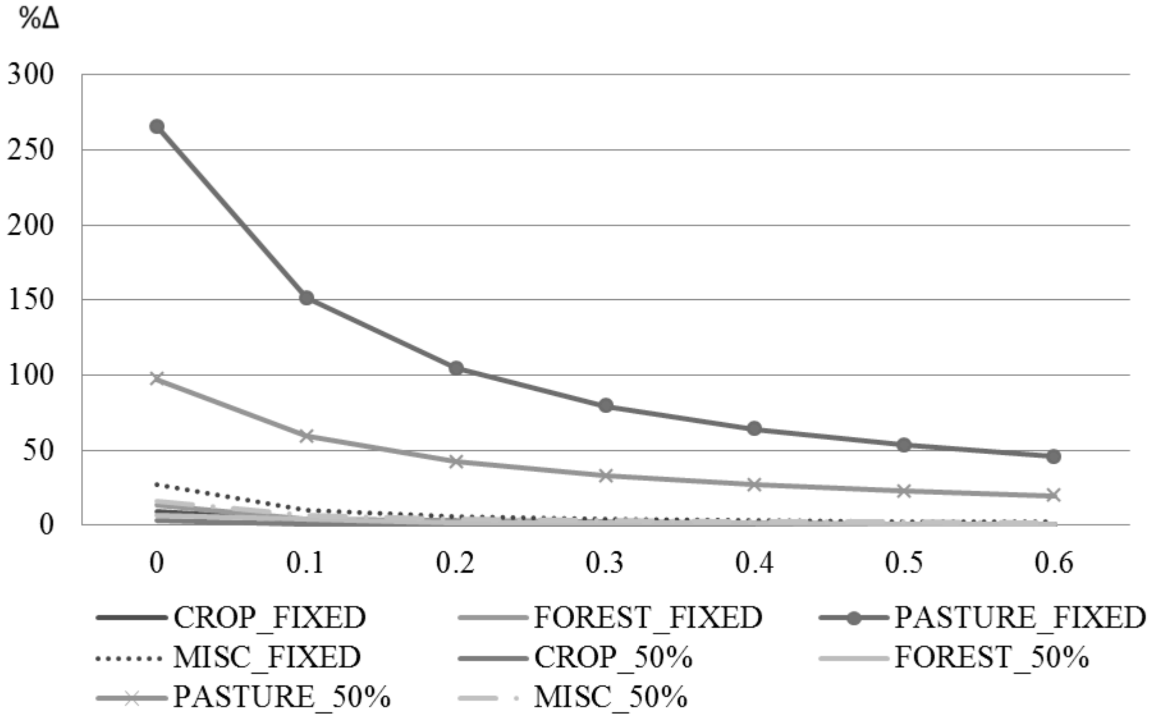
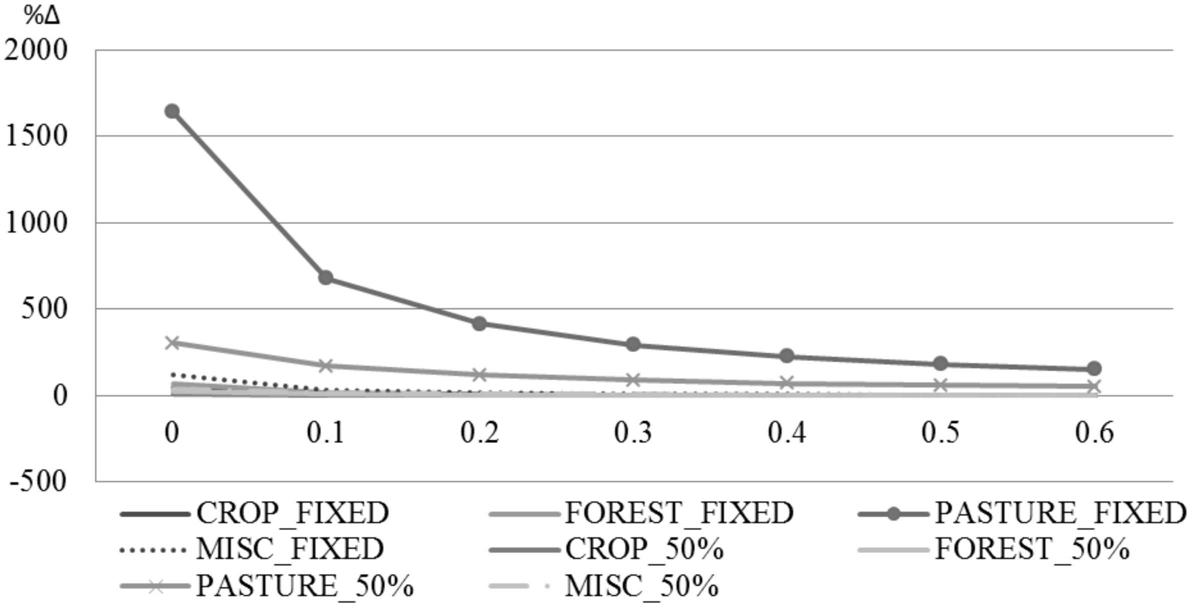


Figure 10: Changes in Overall GHG emissions



Note: ‘_Fixed’ denotes fixed land endowments whereas ‘_50%’ denotes 50% of new areas become avaialble.

Figure 11: Percentage change in real prices of rent (Federal Credit 10%)



Note: '_Fixed' denotes fixed land endowments whereas '_50%' denotes 50% of new areas become avaialble.

Figure 12: Percentage change in real prices of rent (Federal Credit 20%)

Table 1: Policy Scenarios

Scenarios	Descriptions
Scenario 1A (Federal credit-10%) **1B** (Federal credit-20%)	• Local bioethanol production replaces imported sources currently used to meet 10% of ethanol use in 85% of gasoline demand. The federal government subsidizes lignocellulosic biofuel through a tax credit of $0.27/liter. • Local bioethanol production replaces imported sources currently used to meet 20% of all gasoline demand. All other assumptions remain the same as scenario 1A.
Scenario 2A (Mandate only -10%) **2B** (mandate only-10%)	• Local bioethanol production replaces imported sources currently used to meet 10% of ethanol use in 85% of gasoline demand. A blender adopts a long-term contract with a local ethanol producer, which drives the consumption of local ethanol. It is assumed that neither federal nor state-level subsidies are extended for an ethanol blender, ethanol producer, or banagrass producer. • Local bioethanol production replaces imported sources currently used to meet 20% of all gasoline demand. All other assumptions remain the same as scenario 2A.
Scenario3A: (Lump-sum 10%) **3B** (Lump-sum 20%)	• Local bioethanol production replaces imported sources currently used to meet 10% of ethanol use in 85% of gasoline demand. There is no federal tax credit. Instead, the state government subsidizes 30% of ethanol production cost. This subsidy is financed through a lump-sum tax on a representative household. • Local bioethanol production replaces imported sources currently used to meet 20% of all gasoline demand. All other assumptions remain the same as scenario 3A.
Scenario 4A (Fuel tax-10%) **4B** (Fuel tax-20%)	• Local bioethanol production replaces imported sources currently used to meet 10% of ethanol use in 85% of gasoline demand. There is no federal tax credit. Instead, the state government subsidizes 30% of ethanol production cost. This subsidy is financed through an endogenously determined ad-valorem tax on gasoline consumption. • Local bioethanol production replaces imported sources currently used to meet 20% of all gasoline demand. All other assumptions remain the same as scenario 4A.

Table 2: Summary of Economic Impacts

	Federal		Mandate only		Lump-sum		Fuel tax	
	10%	20%	10%	20%	10%	20%	10%	20%
Nominal GSP change (in million $)	75	240	73	220	43	170	56	180
%Δ	0.1	0.4	0.1	0.3	0.1	0.3	0.1	0.3
Real GSP change (in million $)	13	49	-10	-5.0	-1.4	15	-36	-63
%Δ	0.0	0.1	0.0	0.0	0.0	0.0	-0.1	-0.1
Ethanol Job[a]	750	1600	730	1600	740	1600	730	1600
Real Effective Ethanol Price ($/liter)[b]	0.57	0.58	0.84	0.84	0.64	0.65	0.64	0.65
Real Motor Fuel Price* (%Δ)	0.02	0.13	3.21	7.12	0.98	2.23	1.03	1.90
CPI (%Δ)	0.10	0.29	0.13	0.36	0.07	0.23	0.14	0.38

Source: results from the Hawaii biofuel CGE model
Note:

[a] includes jobs in the banagrass production and ethanol processing sectors. To estimate these figures, it was assumed that labor wage in the banarass sector was equivalent to an endogenously determined wage in the sugarcane sector, while that of ethanol processing is assumed be the same as the other manufacturing sector.
[b] the price of gasoline and ethanol blend.

Table 3: Impact on agricultural land prices (% change in real prices)

	Federal		Mandate only		Lump-sum		Fuel tax	
	10%	20%	10%	20%	10%	20%	10%	20%
Crop (%)	0.2	0.6	0.2	0.4	0.4	0.9	0.1	0.3
Forest (%)	0.8	2.2	1.0	1.9	1.0	2.4	0.9	1.8
Pasture (%)	46	153	44	140	45	150	44	140
Miscellaneous (%)	1.9	4.4	1.6	3.6	1.9	4.4	1.5	3.5

Source: results from the Hawaii biofuel CGE model

Table 4: unit GHG abatement costs

	Federal credit		Mandate only		Lump-sum		Fuel tax	
Cost of CO2 mitigation ($/ton)	10%	20%	10%	20%	10%	20%	10%	20%
Gasoline sector only								
subsidy cost per ton	590	170	n.a.	n.a.	380	150	200	110
real expenditure decline per ton	850	82	520	170	910	220	590	230
Economy-Wide Emissions								
subsidy cost per ton	2100	220	n.a.	n.a.	660	180	270	130
real expenditure decline per ton	3020	104	710	202	1600	270	780	270

Source: results from the Hawaii biofuel CGE model

Table 5: Subsidy per tonne of CO2e displaced based on existing literature

Cost of CO2 mitigation ($/ton)	Low	High
United States conventional ethanol*	295	-585
United States cellulosic*	110	195
European union conventional ethanol	590	4520
Australia conventional ethanol	244	1679
EU allowance (EUA)	4.15**	
California C&T, price floor	10.71	

Source: Koplow (2007), Doornbosch and Steenlik (2007), Point Carbon (2013) and California Air Resources Board (2013)

Note: *average costs from 2006-2012. **exchange rate of €1= $1. 24 based on annual average in 2012 (IRS 2013)

Appendix A: Product nests for other sectors

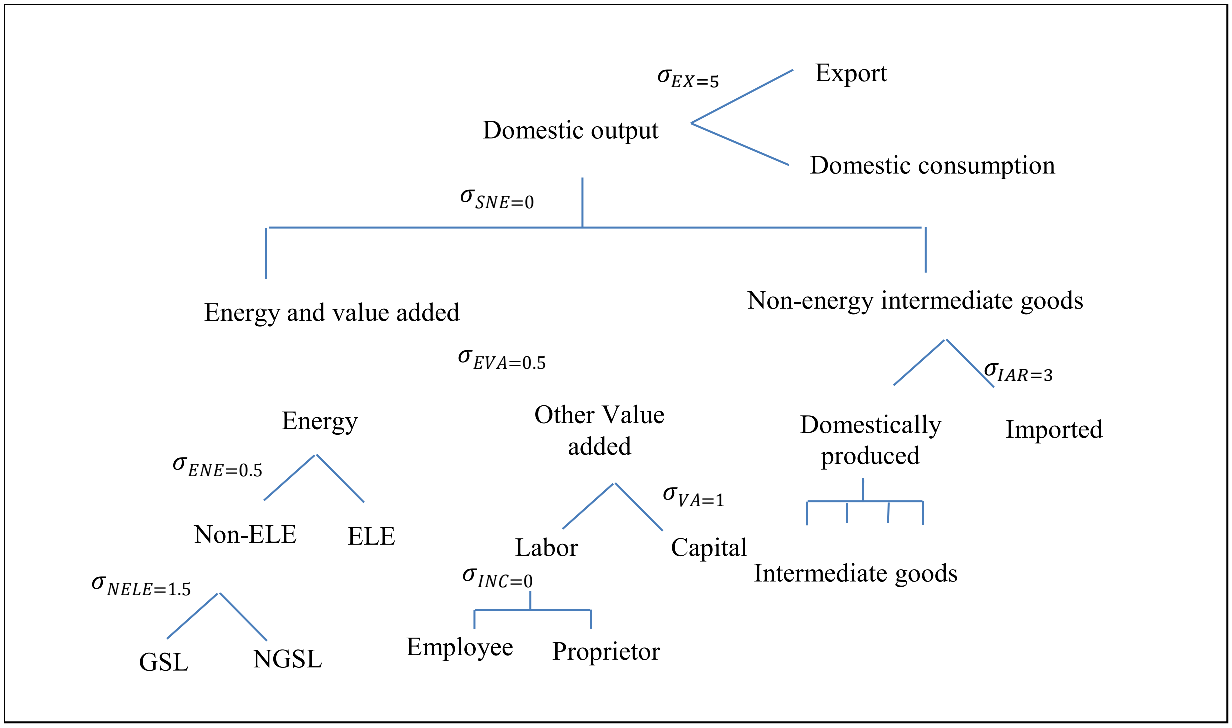


Fig A.1. Nested Structure of Non-Agricultural Non-Energy Commodity Production

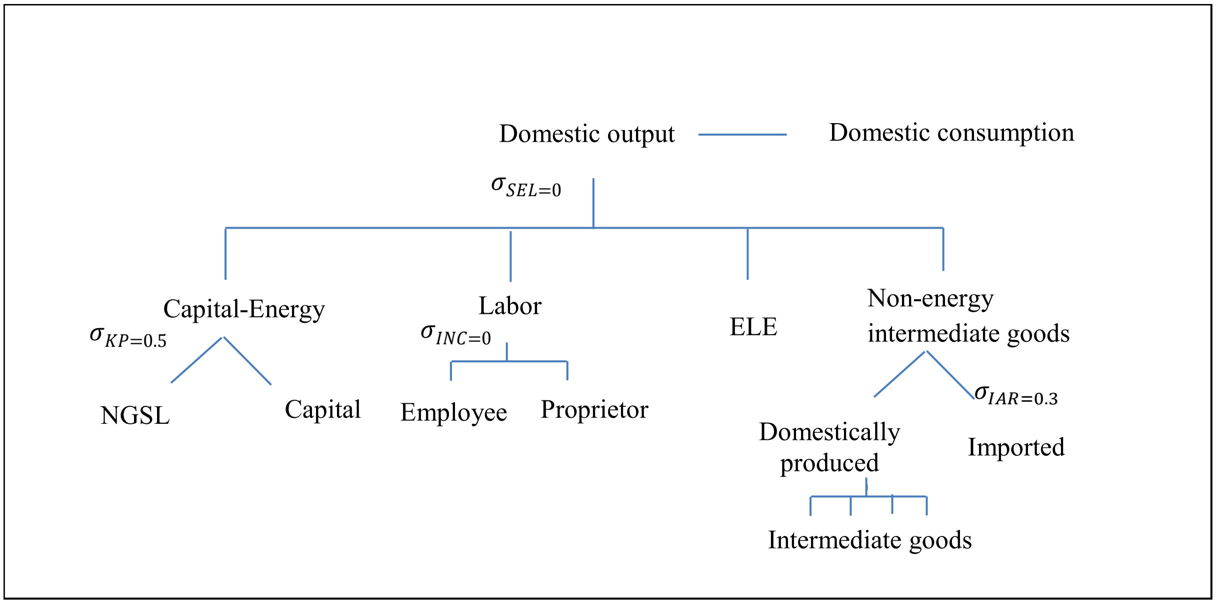


Figure A.2: Nested Structure of Electricity Production

Appendix B: Estimated production functions for banagrass and ethanol production

Table B.1: **Estimated Banagrass Production Cost Per Acre (in 2007 $)**

	Sugarcane[*]	Banagrass
Agricultural services	222.7	114.4
Other manufacturing	90.0	43.9
Non-gasoline petroleum products	238.5	122.5
Ground transportation	4.5	2.3
Water transportation	2.2	1.2
Electricity	322.4	165.6
Rental service	29.2	15.03
Real estate[**]	215.9	111.0
Other services	40.5	20.8
Total intermediate	1166.0	596.8
Value added	2339.4	1202.0
Labor income	1691.6	869.2
Capital payment	647.8	332.9
Imports	202.5	104.0
Total input	3707.9	1902.8

Note:[*] Sector inputs based on Sharma et al. (1997) was divided by the acreage in production based on USDA (2013). Prices of electricity and petroleum products are adjusted based on DBEDT (2011a).
[**] Used as a proxy for agricultural land rent.[***]may not add up due to rounding

Table B.2: **Estimated Ethanol Processing Industry Inputs to Meet 10% and 20% Mandates (in Million 2007$)**

	10% mandate	20% mandate
Banagrass production	45.7	107.6
Other manufacturing	21.5	50.6
Gasoline manufacturing	0.9	2.1
Electricity	8.8	20.7
Sewage and waste management services*	0.1	0.3
Water provision*	1.1	2.6
Water transportation	0.7	1.8
Ground transportation	1.1	2.7
Real estate	1.5	3.4
Other services	1.0	2.3
Total intermediate demand	82.5	194.1
Value added	44.3	104.3
Labor income	6.9	16.3
Capital payment	37.4	88.1
Imports	-	-
Total input	126.8	298.4

Source: Authors estimate based on Kumar and Murthy (2011) with modification and DBEDT (2011b).Note: *reported as 'other utilities' sector according to the 2007 IO table.
***may not add up due to rounding

Appendix C: Estimating Gasoline and Non-Gasoline consumption by sectors.

The U.S. Energy Information Administration (EIA) publishes annually the breakdown of fuel expenditure in each state. The fuel expenditure for petroleum resources in Hawai‘i in 2007 was recorded at $4,800 million (total) with $1,400 million spent on gasoline with bioethanol and $3,400 million spent on non-gasoline petroleum products. According to the 2007 Hawai‘i IO table, however, petroleum expenditure is recorded as $4,700 million, thus a small discrepancy exists. Because of this discrepancy, the following steps were taken to estimate the gasoline and non-gasoline portions of expenditure by sector.

First, using the EIA breakdown and the total petroleum sector expenditure based on Hawai‘i’s 2007 IO table, the portions of total gasoline (including bioethanol) vs. non-gasoline consumption were estimated. Second, for the agricultural sectors (excluding animal/fish and the forestry industry), it was assumed that the fuel breakdown corresponds to Schnepf (2004). The expenditure share for gasoline reported by Schnepf (2004) was multiplied by the total petroleum spending for each agricultural sector. Third, for personal consumption by resident households, a small portion of liquefied petroleum gas (LPG) is used while the rest of petroleum expenditure is used for gasoline consumption. The gasoline expenditure is estimated by subtracting the petroleum product expenditure from the expenditure on LPG. Fourth, for visitor expenditure, all petroleum expenditures were assumed to be used for gasoline consumption. Fifth, for military consumption, the fuel composition was estimated based on the average figure of all military fuel spending available from the Defense Logistics Agency (2010). Sixth, the air, water transport and power generation sectors were assumed to consume no gasoline. Finally, for the remaining sectors, this study first subtracted the sum of steps (2) to (6) above from the total gasoline expenditure as estimated in step (1). This difference is then allocated across all remaining sectors, based on their respective petroleum expenditure share. (i.e., all the remaining sectors have the same proportions of gasoline vs. non-gasoline consumption).

Appendix D: Life-Cycle GHG Emissions Calculation.

For this study, the changes in life-cycle GHG emissions as a result of the mandates were calculated in the following manner. First, the changes in the quantity of fuel used are estimated based on the changes in the quantity of each sector output. To avoid double-counting, the changes in GHG emissions (GHG′) were estimated as follows:

$$GHG' = \sum \alpha * GSL' + \beta * ELE' + \gamma * AIR' + \delta * OTHER' + \varepsilon * BIO + \eta * COAL' + \theta * NG'$$
…(D.1)

Where
α = unit life-cycle GHG emissions of gasoline
β = unit life-cycle GHG emissions of electricity
γ = unit life-cycle GHG emissions of aviation fuel
δ = unit life-cycle GHG emissions of other petroleum fuel
ε = difference in unit life-cycle GHG emissions between imported and locally produced bioethanol (10% mandate); plus additional GHG difference between locally produced bioethanol and gasoline (20% mandate)
η = unit life-cycle GHG emissions of industrial coal use
θ = unit life-cycle GHG emissions of natural gas
GSL′ = changes in gasoline demand (in BTU) estimated based on the gasoline sector output
ELE′ = changes in electricity demand (in BTU) estimated using the electricity sector output
AIR′ = changes in aviation fuel demand (in BTU) estimated using the air transport sector output
OTHER′ = changes in other petroleum fuel demand (in BTU) estimated based on the non-gasoline petroleum sector output (subtracting demand for gasoline, electricity and the air transportation sector).
BIO = quantity of biofuels used (constant in the case of the 10% mandate, increases in the case of the 20% mandate)
COAL′ = changes in industrial coal demand (in BTU) estimated based on the other manufacturing sector output
NG′ = changes in natural gas demand (in BTU) estimated based on the gas sector output

The unit life-cycle GHG emissions factors were estimated using the 2012 version of the GREET model (Table D1):

Table D.1: Unit life-cycle GHG emissions factors

Parameter	GHG emissions (g of CO2e/btu)
α: Gasoline	0.094
β: Electricity	0.099
γ: Jet Fuel	0.097
δ: Other Petroleum	0.096
ε:	
Imported Biofuel	0.057
Lignocellulosic Biofuel	0.033

η: Coal	0.106
Θ: Natural Gas	0.079

Source: Argonne National Laboratory, 2012