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Home grown or imported? Biofuels life cycle GHG emissions in electricity generation and transportation

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HIGHLIGHTS

- LCA methods were used to estimate the contributions of biofuels to GHG emission and energy security goals in Hawaii.
- Counter-factual scenarios related to fuel production location, feedstock crops, and supply chain pathways are examined.
- The study finds crop choice and byproduct credit matter more than distance between fuel production and end-use location.
- Jatropha biofuel was found to have lower GHG emissions than soybean and oil palm biofuel.
- The study shows that biofuels have higher overall GHG emissions than wind and solar PV.

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ABSTRACT

Few previous studies consider the GHG implications of biofuels in electricity generation. Yet, the biofuels have become a key replacement for residual petroleum fuel and LNG in stationary power in Hawai'i. This stems from isolated island grid and heavy dependence on imported oil, characteristics which are shared with many island regions. This study calculates life cycle GHG emissions from biodiesel and renewable fuel oil from soybean, oil palm, and jatropha in electricity production as well as the transportation sector. By using Hawai'i as a case, this study aims to compare biofuels supply chain systems for imported and locally produced. The results indicate that variations in GHG emissions reduction are dictated by the choice of feedstock crops and byproduct credits rather than the distance between the fuel production and end-use location. The study suggests that locally produced biofuels have lower GHG emissions than imported ones but the difference is trivial. This study does not calculate the monetary cost of switching to biofuels; instead, it uses GHG emissions as a unit of measurement to show the trade-offs among different counterfactual scenarios in fuel production location, feedstock crops, and supply chain pathways.

1. Introduction

Biofuels consumption has increased from 0.3 million barrels per day in 2000 to 1.8 million barrels per day in the year 2010 [1]. Policy makers look to subsidizing local biofuels in the hope of alleviating energy security concerns while reducing greenhouse gas (GHG) emissions at the same time. However, the validity of such objectives are not clear.

Local production has the advantage of avoiding transport GHG emissions and giving local control to the availability of the fuel. However, locally produced biofuels may involve higher cost of production than import alternative. Economic theory tells that there are gains from specialization in producing products according to comparative advantage. If local factor prices of producing biofuels are high relative to other competing locations, producing biofuels locally will generally be not efficient [2].

Singh et al. point out that sustainable biofuels are required to be eco-friendly, socially acceptable, and economically viable [6]. In Hawai'i, for example, high labor costs and scarce water resources may raise the price of locally grown biofuels relative to competing growing location such as Malaysia or the Philippines. While the act of transporting biofuels generates additional GHG emissions, the lower cost might also facilitate their use relative to other high GHG fuel alternatives.

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This study addresses the life cycle implications of biofuels in terms of two policy objectives: (1) GHG emissions reduction relative to the baseline; and (2) energy security implications in terms of imported fossil fuel displacement. The motivation for the first policy objective is the reduction of GHG emissions stemming from global concerns over climate change. The motivation for the second policy objective is a desire to minimize the reliance on imported fossil fuels. Imported petroleum has disadvantages of price volatility and security risk due to potential constraints in the supply change.

This study examines life cycle GHG emissions from biofuels used not only in transportation sector but also in electricity production sector. It is rare to consider biofuels in electricity sector. The default assumption for biodiesel usage is in transportation sector and not in the electricity production sector. Muench and Guenther point out that this is because there are other renewable energy sources for electricity production but biofuel is the only alternative energy source to fossil fuel in transportation sector [21].

However, for isolated island locations, biofuels have advantages over other types of renewable energy technologies in electricity production sector. Unlike wind and solar energy, biofuel is not an intermittent energy source. Wind energy and solar photovoltaic (PV) both require backup generation capacity to complement sudden changes in electricity production. Without large energy storage, isolated island electricity grid is a limiting factor to increase deployment of intermittent energy sources such as wind and solar PV. Biofuels, on the other hand, does not face this problem.

In addition to such technical advantages, there are at least two economic advantages. First, biofuels production facilitates rural development [3,4]. Local production of biofuels not only requires feedstock production in agricultural sector but also in bio-oil refining and distribution. Ongoing development in biorefinery technology has a potential to utilize agro-waste to produce biochemicals as well as energy [5]. Hence, biorefinery could have a positive economic spillover effect to increase welfare of the rural community.

Another economic advantage is that biofuels can replace petroleum with minimal retrofitting with existing power production infrastructure. The major economic advantage of biofuels is that it requires only minor retrofitting to existing infrastructure when replaced with petroleum [7]. While switching to other types of renewable energy incurs large capital investment, biofuels can be introduced without major change in existing infrastructure. This is a great economic advantage because utilities need not abandon existing infrastructure and therefore incur little to no capital expenditures.

Both US and EU policy makers aim to reduce GHG emissions by substituting fossil fuels with biofuels [8]. Hawai'i aims to develop 70% clean energy by 2030. With an isolated grid and great opportunities for solar and wind energy, biofuels are an attractive component of a renewable energy stationary power portfolio.

In Hawai'i, both global warming and energy security concerns are magnified due to its geographic isolation, environmental vulnerability, and island setting as well as a heavy dependence on oil imports. Yergin points out that the recent energy security concerns and motivation to address such concerns stem from high price of energy, political instability of energy exporting countries, and uncertainty in the energy resource reserve [10]. As in Yergin's statement, there are various factors of energy security. According to Winzer, a fundamental element of energy security is the supply chain continuity [11]. In other words, energy security concerns arise at any stage of the fuel production and endues. Given this definition of energy security, imported biofuels may increase energy security.

Unlike other US states, over 75% of the electricity is produced from petroleum in Hawai'i and 57% of petroleum used for electricity production in the US ends up in Hawai'i [1]. High and volatile energy prices are a threat to Hawai'i's economy. To reduce its reliance on imported petroleum, the State signed a Memorandum of Understanding with the US Department of Energy to reduce energy demand by 4300 GW h and introduced a 40% renewable portfolio standard [14].

Hawai'i's natural environment is vulnerable to climate change. In 2007, the State committed to reduce its GHG emissions at 1990 levels by 2020 through Global Warming Solutions Act (Act 234). The motivation behind the State's strong commitment to reduce GHG emissions has economic sense. Tourism being a major income source for Hawai'i, protection of its pristine ecosystem that attracts many tourists, has a direct consequence of future economic gain. Hawai'i already is experiencing signs of sea level rise, ocean acidification, and other deleterious impacts of climate change. While Hawai'i emissions are a trivial component of global GHGs, symbolically the effort to transition to a low-carbon economy is significant to Hawai'i's people.

Findings of this study have direct consequence to other island states where their geographical characteristics and energy supply chain resemble Hawai'i. Weisser states that small developing island states have disadvantage because most of their energy supply is imported and they face higher energy price [23]. In those regions, deployment of renewable energy technologies has potential to be cost effective. However, Increased electricity production from PV and wind can be a threat to island grid by creating sudden change in supply of electricity in the grid which results in frequency in grid to be out of the stable range [22]. In order to take advantage of renewable energy sources, biofuels can potentially play a role as a backup to complement those intermittent renewable energy sources.

In this study, the LCA method is used to calculate overall GHG emission from substituting petroleum with biofuels while tracking energy security concerns. Frontier methodologies of life cycle assessment (LCA) estimate both GHG emission and fossil fuel use reductions. LCA, or also referred to as a well-to-wheel analysis, is a comprehensive measure of calculating GHG emissions that accounts for the entire life cycle, from the production to the consumption, of fuel. LCA allows evaluation of technologies and products by tracking material flows and resulting emissions and resource use.

Many existing models of LCAs are used to evaluate biofuels and GHG emissions in the transportation sector. For example, Delucchi develops the foundation for calculating lifecycle GHG emissions from biofuels, Lifecycle Emission Model (LEM). LEM is the basis for other recent development in LCA models, most notably, Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model [12,13].

The widely used Argonne National Laboratory's GREET model is novel in giving model users flexibility to choose different fuel mix. This facilitates analysis of different fuel mix for electricity generation to be used as input for electric vehicles. The model has been used as a basis to form energy policies such as California's Low Carbon Fuel Standard Program [14]. While this model is popular and flexible, it is not well suited to the case of LCA analysis in Hawai'i where a significant opportunity for biofuels is in the generation of electricity given a heavy reliance on petroleum in stationary power.

In the United States, Environmental Protection Agency (EPA) develops LCA guideline to accompany Renewable Fuels Standard. EPA's methodology is based on The Forest and Agricultural Sector Optimization Model (FASOM) and Food and Agricultural Policy Research Institute-Center for Agricultural and Rural Development (FAPRI-CARD) to supplement LCA. FASOM Economic modeling by Texas A&M University is used to project changes in domestic agriculture sectors and the FAPRI-CARD model by Iowa State