An Analysis of Policies to Promote Agroforestry for Greenhouse Gas Sequestration in Hawaiʻi

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1 Executive Summary

In this report, we analyze policies and make recommendations to promote the intentional planting of trees on agricultural lands in the State of Hawai'i. Agroforestry, a multifunctional land use system that combines trees with crops and/or livestock, has been practiced by indigenous people for centuries and was widespread in Hawai'i prior to European contact. Agroforests provide multiple benefits such as increased food production, improved water quality, diversified revenue streams, protection of livestock from extreme weather, and biodiversity conservation. Additionally, agroforestry sequesters more greenhouse gasses (GHGs) than conventional monoculture agriculture, which makes it an important strategy for meeting the state of Hawai'i's sustainability goals including both becoming carbon neutral by 2045 and doubling local food production by 2030. We recommend that the Greenhouse Gas Sequestration Task Force amend the Forest Stewardship Program, which provides incentives to plant trees on private land, to facilitate the use of these funds to convert conventional and fallow agricultural land into agroforestry systems.

1.1 Summary of Analysis

While a valuable land use for GHG sequestration and multiple co-benefits, agroforestry has low adoption rates in the US including in Hawaii. We reviewed policy instruments that can be used to correct several problems that lead to low agroforestry adoption and then selected five policy alternatives most appropriate for Hawaii to analyze. Next, we assessed how the predicted impacts of each policy would affect five different goals and corresponding impact categories. The four intervention policy alternatives ranked higher than maintaining the current status quo. The top two alternatives were 1) amending the Forest Stewardship Program and 2) amending the Agricultural Loan Program. We recommend making the following amendments to the Forest Stewardship Program: 1) add a definition of agroforestry; 2) reduce the minimum acreage from five acres to one acre for agroforestry systems, and 3) replace the requirement for a management plan with a business plan for agroforestry systems of less than five acres.

1.2 Next Steps

We recommend that the Greenhouse Gas Sequestration Task Force work with stakeholders to adapt an agroforestry definition for state policy. Opening public comment to producers, producer associations and support organizations, funders, and the general public will build consensus around a definition of agroforestry to make implementation of existing and future policies more effective while at the same time building awareness of the land use and its benefits.

2 Introduction

In 2018, House Bill 2182 was signed into law as Act 15 by Governor David Ige. This Act created the Greenhouse Gas Sequestration Task Force, whose members are responsible for identifying nature-based solutions for greenhouse gas (GHG) sequestration in Hawai'i. In this report, we review the GHG sequestration potential of agroforestry and status quo in Hawai'i as well as analyze potential policies to promote the adoption of this land use strategy. In Section III we diagnose the policy issue, provide background on agroforestry and GHG sequestration in agroforestry systems, and present the market and government failures of the agroforestry system in Hawai'i. In Section IV we describe the goals of an agroforestry policy intervention, and in Section V, we describe the methodologies of our study including how we qualified the policy alternatives. In Section VI, we assess and predict each policy alternative's impact on the goals and indicators. In Section VII and VIII, we discuss our recommendations, the limitations of this study, and potential next steps.

3 Diagnosis of the Policy Issue

The United States Department of Agriculture defines agroforestry as the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits (USDA, 2018). Combining trees with agriculture enhances long-term production of food and other useful products while protecting soil and water, diversifying and expanding local economies, providing wildlife habitat, and creating a more pleasant, healthy work environment (USDA, 2018). In terms of climate change adaptation, agroforestry can add a high level of diversity within agricultural lands and increase capacity for supporting various ecological and production services that increase resilience to climate change impacts (Verchot et al., 2007). Agroforestry can be placed into two distinct types: tree-crop coexistence, where trees and agricultural crops are grown together, and tree-crop rotation, where trees and crops are grown in alternation on the same piece of land (Kim, Kirschbaum, & Beedy, 2016). Takimoto, Nair, & Nair (2008) estimated that the total carbon (C) sequestration potential through agroforestry practices in the United States could amount to 90 teragram of carbon per year (Tg C yr^{-1}), with some 630 million hectares (ha) of unproductive croplands and grasslands being converted to agroforestry.

3.1 Types of agroforestry systems and their GHG sequestration potential

There are three main agroforestry systems, agri-silviculture, silvopasture, and agro-silvopasture. *Agri-silviculture* is the combination of crops and trees. Agri-silviculture can take many different forms depending on the arrangement of crops and trees within the system (Table 1). Agro-silvopasture is the combination of trees, animals, and crops. According to the USDA, silvopasture, alley cropping, and forest farming are the most commonly used agroforestry practices with the most potential for GHG sequestration within alley cropping and silvopasture (USDA, 2018).

Table 1. Agri-silviculture methods, potential GHG sequestration rates for the US, and successful implementation examples from around the world.

Method of agri-silviculture	Description	Potential GHG Sequestration in the US ($Tg\ C\ yr^{-1}$)	Successful Implementation Examples
Parklands	Areas where scattered multipurpose trees occur on farmlands as a result of farmer selection and protection.	Not Available (N/A)	Found primarily in the semi-arid and sub-humid zones of West Africa. If mature parklands covered their maximum range, C stocks in Sahelian productive land would be about 1,284 Tg, compared to 725 Tg in a tree-less scenario (1).
Woodlots	Simulate the traditional fallow system in shifting cultivation, in which trees contribute to maintaining soil fertility through nutrient cycling during the fallow phase.	N/A	Research in Kenya found that woodlots were the most successful agroforestry system currently used at sequestering carbon (2).
Alley Cropping	The cultivation of food, forage, or specialty crops between rows of trees.	73.8 (Kim et al., 2016)	The combination of *Leucaena leucoceophala,* a nitrogen-fixing tree, with maize in Central America resulted in an 80% increase in maize yields, reduced soil erosion by 30 times, and also provided abundant fuelwood (3).
Coastal/ Riparian Buffers	The lands and assemblages of plants/trees bordering rivers, streams, bays, coasts and other waterways.	4.7 (Udawatta & Jose, 2011)	Biomass accumulation pattern of a riparian system in Washington USA, showed an increase in C from 9 to 271 Mg ha-1 as the system mature (4).
Windbreaks	A physical obstruction to the passage of wind, usually in the form of a line or copse of tall bushes or trees.	4 (Kim et al., 2016)	The U.S. National Agroforestry Center estimates that protecting the 85 mill. ha of exposed cropland in the North Central US by converting 5% of the field area to windbreaks would sequester over 58 Tg C (215 Tg CO_2) in 20 years. (5).

Contour Hedgerows	Hedgerows involve trees planted along contour lines, on ditches for erosion control, and on cropped bench terraces for stabilization and generation of benefits such as green manure, stakes for climbing crops, fodder, and fuelwood.	N/A	In India, treatments with *Gliricidia* and *Leucaena* hedgerows were 3.8–4.7 % and 3.7–5.3 % more efficient to stock soil organic carbon (SOC) within 40 cm soil profiles than no treatment, and sequestered 1.62 Mg ha^{-1} year−1 SOC, of which 0.93 Mg ha^{-1} $year^{-1}$ was sequestered due to soil reclamation and 0.69 Mg ha^{-1} $year^{-1}$ (5).
Homegardens	A system for the production of subsistence crops for the gardener/home. It may or may not have the additional role of production of cash crops, near the residential area.	N/A	Javanese and Sumatran homegardens accumulated C in the range of 55.8 to 162.7 Mg ha^{-1} which is considerably greater than monocultures of annual crops (6).
Forest Farming / Multi-story cropping	Forest farming operations grow crops under a forest canopy that is managed to provide ideal shade levels as well as other products.	2 (Kim et al., 2016)	The carbon sequestration rate in the Baihe Farm hardwood forest has a potential of 2.98 t C ha−1 year−1, equivalent to 10.93 t CO 2 ha−1 year−1 based on a 20-year growing period (7).

1 (Luedeling & Neufeldt, 2012), 2 (Henry et al., 2009), 3 (Kidd & Pimentel, 1992), 4 (Balian & Naiman, 2005), 5 (Roshetko, Delaney, Hairiah, & Purnomosidhi, 2002), 6 (Jensen, 1993), 7 (Delgado-Baquerizo et al., 2013), 8 (Lin & Lin, 2013)

Silvopasture is the intentional combination of trees and livestock in an agricultural system. Clason and Sharrow (2000) argue that, given the widespread co-occurrence of grazing and forestry across North America, the joint production of livestock and tree products is by far the most prevalent form of agroforestry found in the United States and Canada. The average estimated total soil carbon sequestration potential for U.S. grazing lands is 69.9 Tg C yr^{-1} (Boutton, Liao, Filley, & Archer, 2009). When not managed sustainably, silvopasture systems can result in soil compaction and erosion with losses of carbon (C) and nitrate (N) from soils (Kumar & Nair, 2011; Nair, Rao, & Buck, 2004). Some researchers claim the potential for silvopasture could be around 474 Tg C yr^{-1} worldwide, the most GHG potential of any agroforestry system (Udawatta & Jose, 2011). And the total carbon sequestered by all agroforestry in the US could help offset the US emission rate by up to 34% with the total potential for sequestration at 548.4 Tg per year (Udawatta & Jose, 2011).

Multiple factors play a role in the amount of GHG that can be sequestered in agroforestry systems including soil type, historic land use, plant and animal species in the community, landscape dynamics, hydrology, etc. Making exact estimates of sequestration for a specific system is difficult due to methodological impediments in estimating carbon stock biomass and the extent of soil carbon storage under varying conditions, which are compounded by a lack of reliable estimates of area in agroforestry production (Kumar & Nair, 2011). A compilation of 109 agroforestry assessments and 56 peer-reviewed articles found that on average agroforestry was estimated to mitigate 27 ± 14 tons CO_2 for the first 14 years after establishment (Kim et al., 2016). The number of trees added to a system to increase sequestration benefits ranged from 17 to 44 trees ha^{-1} (Torres et al., 2017).

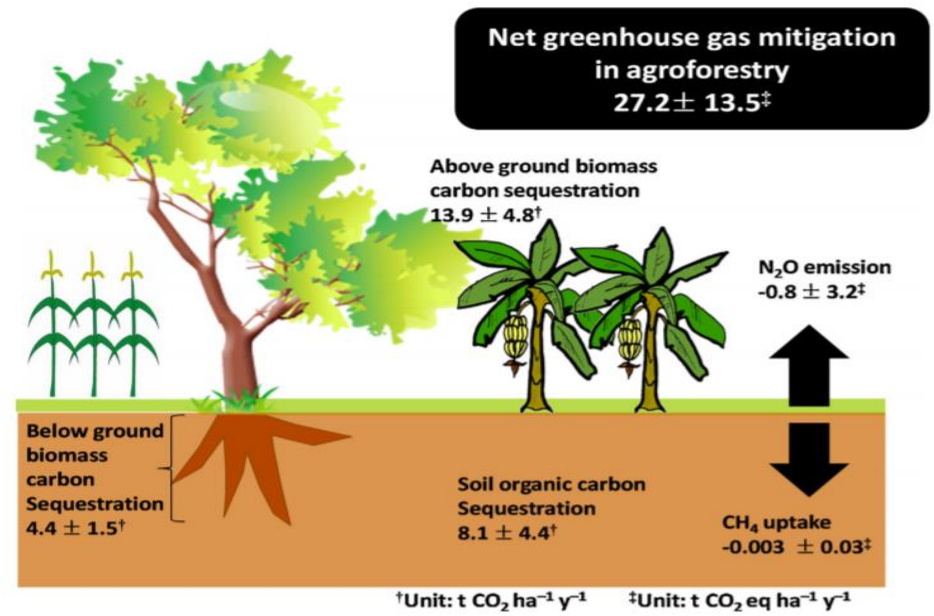

Figure 1. Greenhouse gas sequestration in agroforestry (Kim et al., 2016).

Belowground GHG sequestration, primarily in soils, could be a huge contributing factor to the adoption of agroforestry. Soil organic matter (SOM) is a large and uncertain source of carbon to the atmosphere, and a huge opportunity for sequestration, with the ability of soil to either contribute GHGs or sequester them, depending on how land is managed. Soil organic carbon (SOC) is about 3.2 times the size of the atmospheric pool (i.e. reservoir of carbon that has the capacity to both take in and release carbon) and four times that of the biotic pool (Sommer & Bossio, 2014). The Intergovernmental Panel on Climate Change (IPCC) suggests that specific land management practices, such as agroforestry, can increase soil carbon stocks on agricultural lands (2017). Most cropped soils have lost a large percentage of their pre-cultivation SOC, however, they can re-absorb GHGs through the implementation of agroforestry thus increasing SOC. The US holds a large percentage of global cropped soils and demonstrates the highest total annual potential in sequestration through SOC, with an average increase of 0.62–1.27 t C/ha/yr on over two million km^2 of cropland (Sommer & Bossio, 2014). Estimates suggest that 0.90–1.85 Pg C sequestration in the US could occur in the top 30 cm of cropland soils (Zomer, Bossio, Sommer, & Verchot, 2017).

This could continue over a minimum of 20 years after the adoption of SOC enhancing management, such as agroforestry (Crowther et al., 2016).

In addition to belowground GHG sequestration, agroforestry provides sequestration opportunities with aboveground biomass and roots, which are estimated to hold roughly one-third of the total carbon stored in tree-based land use systems (Lal, 2004). Total carbon storage in the above/below ground biomass of agroforest systems is generally much higher than tree-less croplands under comparable conditions (Toth, Ramachandran Nair, Jacobson, Widyaningsih, & Duffy, 2017). Due to this above and belowground storage capacity, agroforestry systems are believed to have a higher potential to sequester carbon than pastures or field crops growing under similar ecological conditions (Kirby & Potvin, 2007; Roshetko et al., 2002).

3.2 Agroforestry in Hawai'i

3.2.1 History

Agroforestry has been practiced by indigenous people worldwide for centuries and was a common Native Hawaiian land use prior to European contact. Agroforests are used to produce numerous products for subsistence or sale (e.g. fruits, tubers, spices, medicines, wood, and fiber). Historical evidence suggests that native Hawaiians implemented agroforestry practices that used a synergistic approach to the cultivation of trees and food crops (McBride, 1975). Colonization resulted in the alteration of traditional practices of land management and food production to reflect a system that emphasized monoculture and large-scale farming of limited commodity crops.

The movement to large-scale monoculture farming resulted in a loss of woody plants and diversity from the landscape. In addition to sequestering GHGs, agroforestry has the potential to secure food sovereignty in Hawai'i. As of 2018, Hawai'i imports 90% of its food, decreasing food security for residents. Agroforestry allows for more food to be cultivated over less area due to the potential integrated use of trees, crops, and cattle grazing in one system (Steffan-Dewenter et al., 2007). The movement away from traditional Hawaiian farming practices is a lost opportunity to increase food production due to the lack of agroforestry and, in turn, reduction of GHG emissions (Mutuo, Cadisch, Albrecht, Palm, & Verchot, 2005). Multi-tiered approaches of agroforestry allow for additional agricultural production for food, and GHG sequestration due to the increase in plant biomass and soil health through improved ecological interactions. It may be important for Hawai'i to focus on growing fruits and vegetables rather than staple crops, due to the fact that other states and countries will always be able to outcompete producers in Hawai'i on the price of staple crops (e.g. rice) (J.B. Friday, personal communication, May 4, 2017). Traditional Pacific Island agroforestry systems can serve as a model to be adapted to the modern socio-economic contexts (J.B. Friday, personal communication, May 4, 2017). Trees that have an existing market in Hawai'i and integrate well into agricultural systems will be ideal candidates for adoption.

3.2.2 Current Agricultural Context

Understanding current agricultural land use, large landowners, the top agricultural products, and their association with agroforestry in Hawai'i provided us direction in drafting our policy goals and alternatives. In 2015, 83% of Hawaiian agricultural land in production was pasture, 14% was cropland (including sugar, seed production, macadamia nuts, diversified crop, coffee, some tropical fruits, and taro), 3% was commercial forestry, and less than 1% was aquaculture (Table 2 and Figure 2). One must consider what type of land (pasture or cropland) the policy affects. In addition, it is important to understand the potential of the policy to impact both pasture and cropland since the prominent agricultural land use is pasture (Figure 2). According to the State of Hawai'i Department of Agriculture, all sugarcane production became fallow, or not in use, in 2017. This increased the fallow cropland to 227,800 acres (55% of total cropland; USDA major land use). As a result, it is much easier to apply agroforestry practices on fallowed croplands. Also, the agricultural land in production, such as pasture, macadamia nuts farm, coffee farms, and other tropical fruits farm; in total, about 800,000 acres can also be applied with structured agroforestry systems (Table 2). Within all agricultural lands, about 95% are private, and only 5% belong to the government (including federal, state, and county) (Figure 3). Many agricultural leases in Hawai'i have short durations (e.g. less than 5 years). According to USDA National Agricultural Statistics Service (USDA quick stat), the top ten commodities in the State of Hawai'i in 2017 were seed crops, macadamia nuts, cattle, coffee, aquaculture, algae, landscape plant material, papayas, milk, and lettuce. Within the top ten commodities, most of them have the potential to grow in conjunction with an agroforestry system, most specifically, coffee, macadamia nuts, and papayas.

Although the total area of diversified crops has grown, only anecdotal evidence exists for the extent of agroforestry implementation in Hawai'i today. The Hawai'i Department of Agriculture and the USDA National Agriculture Statistic Service collect data on agricultural production including crop types and quantities produced, but this does not include data on the management system in which crops were grown (e.g. monoculture, alley cropping, etc.). The current acreage in agroforestry production in Hawai'i is therefore unknown.

Table 2. The acreage of the agricultural land uses and their proportion to the agricultural land currently in production in the Hawaiian Islands

Agricultural Land Use	Acreage	Proportion
Pasture	761,406	83%
Sugar	38,810	4%
Seed Production	23,728	3%
Commercial Forestry	22,864	3%
Macadamia Nuts	21,545	2%
Diversified Crop	16,904	2%
Coffee	10,149	1%
Pineapple	4,508	0%
Other Tropical Fruits	3,980	0%
Papaya	2,824	0%
Flowers / Foliage / Landscape	2,432	0%
Dairy	1,855	0%
Banana	969	0%
Aquaculture	651	0%
Taro	612	0%

(Data from The University of Hawai'i at Hilo Spatial Data Analysis and Visualization (SDAV) Laboratory in conjunction with the Hawai'i State Department of Agriculture, 2015; downloaded from Hawai'i Statewide GIS program in 2018: http://planning.Hawai'i.gov/gis/download-gis-data-expanded/ *).*

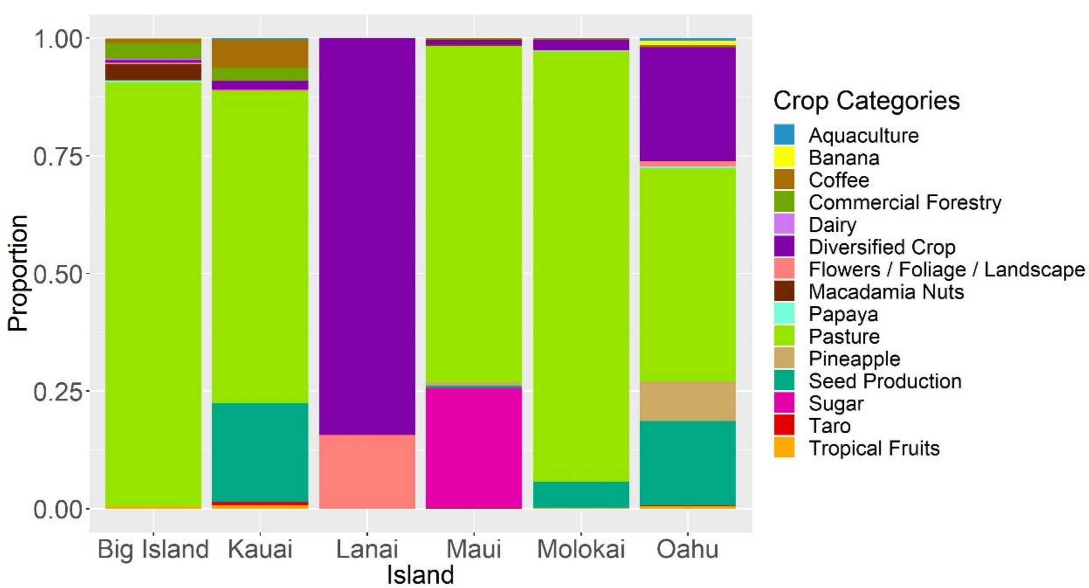

Figure 2. The proportion of agricultural land uses to the entire agricultural land each Hawaiian Island. *(Data from The University of Hawai'i at Hilo Spatial Data Analysis and Visualization (SDAV) Laboratory in conjunction with the Hawai'i State Department of Agriculture, 2015; download from Hawai'i Statewide GIS program in 2018:* *http://planning.Hawai'i.gov/gis/download-gis-data-expanded/* *).*

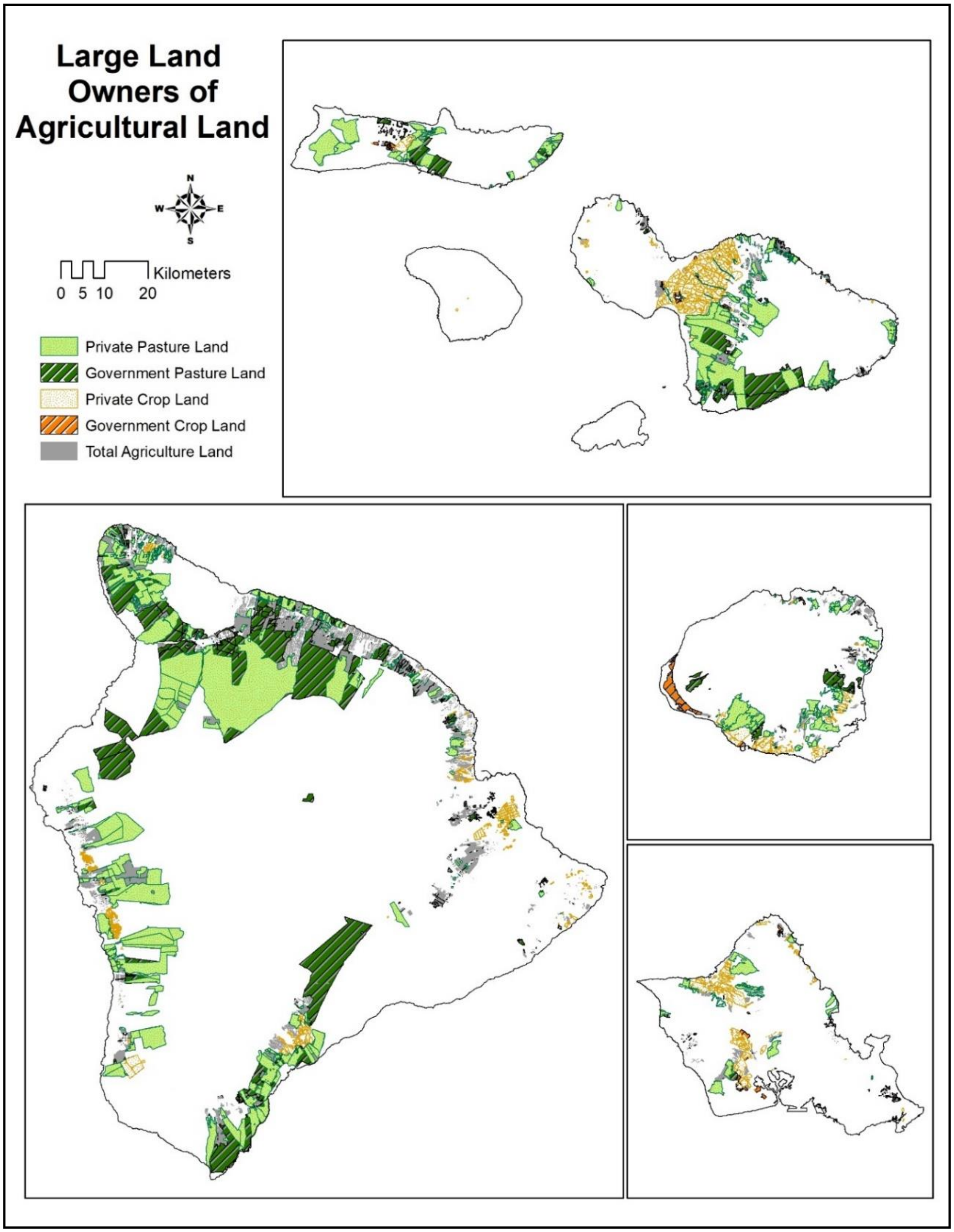

Figure 3 Extent of private and public agricultural land by island
(Data sources: City and County of Honolulu (March 2017), Kauai County (August 2017), Maui County (April 2017), Hawai'i County (April 2017); downloaded and modified from Hawai'i Statewide GIS program in 2018: http://planning.Hawai'i.gov/gis/download-gis-data-expanded/).

3.2.3 Current Policies

Several federal and state policies affect the intentional planting of trees on agricultural lands. These include subsidies at the Federal level, regulations related to food safety, and state-level incentive programs.

One of the most important policies at the federal level is the USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQUIP). This program provides subsidies to producers who meet qualifications for using specific conservation practices on their farms and ranches. Additionally, like other diversified farming systems, agroforestry – particularly small farms - systems are challenged by the administrative burden of complying with food safety regulations that require tracking data at the crop level (e.g. Good Agricultural Practices, GAP). A recent pilot of the GroupGAP program is proving effective at mitigating this burden by allowing small farmers to join together and apply for GAP certification as a collective (USDA AMS, 2015). Similarly, conventional crop insurance, for which one crop is covered per plan, has put monoculture commodity farming systems at an advantage over diversified systems like agroforestry; however, recently the USDA started piloting the Whole Farm Revenue Protection Program to provide insurance to diversified producers (USDA FCIC, 2018). Finally, from 2013-2016 the USDA Departmental Regulation 1073-002 supported the National Agroforestry Strategic Framework (2011-2016), which laid a foundation for education and research initiatives to support agroforestry adoption (USDA, 2013).

At the state level, tree planting on agricultural lands is primarily affected by the Agricultural Loan Program, the Hawai'i Forest Stewardship Program, the Agribusiness Development Corporation, and tax credits associated with organic and Important Agricultural Lands. The Agricultural Loan Program promotes agricultural development by providing credit at reasonable rates through a revolving loan fund (HI Rev. Stat. §155). This program is meant to supplement private lender funds, and, thus, is only accessible to producers who have been denied credit by two private lenders. Producers using agroforestry systems may apply for these funds provided they meet the eligibility requirements, however, unlike aquaculture, agroforestry is not prioritized within the loan program. The Hawai'i Forest Stewardship Program administered by the State of Hawai'i Department of Land and Natural Resources (DLNR) is a cost-share program that supports private landowners to conserve forest systems (HI Rev. Stat. §195F). Although agroforestry is listed in the state statute as a qualified land use for the program, the definition of agroforestry is unclear, and funding is typically directed towards native forest and timber planting projects. Producers growing crops in agroforest systems have had difficulty accessing these funds, in part, because of a lack of understanding within the Program as to what qualifies as agroforestry (D. Shapiro, personal communication, Nov 19, 2018). Furthermore, the minimum planting area needed to qualify for the cost-share program is five acres, which may be a barrier to some smallholders. The Agribusiness Development Corporation was created in 1994 (HI Rev. Stat. §164D) to support the transition to diversified agriculture in Hawai'i by managing lands, directing research, and coordinating agribusiness development. Finally, producers using agroforestry systems may qualify for tax credits for organic agriculture and Important Agricultural Lands, although these instruments do not directly deal with issues specific to agroforestry systems.

3.3 Symptoms of the Agroforestry Sector Problem

The goal of the State of Hawai'i Greenhouse Gas Sequestration Task Force is to identify strategies for reducing greenhouse gases (GHGs) in Hawai'i through sequestration in the agroforestry, agriculture, urban forestry, and aquaculture sectors. We focused on the agroforestry sector, specifically targeting state and private agricultural lands in Hawai'i. We did not take into consideration the enforcement or monitoring of policy alternatives once implemented.

Climate change is a global issue that significantly impacts Hawai'i. Sea level is rising due to increased melting of the glaciers and ice sheets and the warming of the atmosphere and oceans from GHG emissions. The Intergovernmental Panel on Climate Change predicts a one-meter increase in global sea level rise by the year 2100 if GHG emissions continue at the current rate (Church et al., 2013). This is referred to as the one-meter SLR-XA: the exposure area impacted most by one meter of ocean flooding. Under the one-meter SLR-XA flooding scenario, persistent flooding would render over 25,800 acres of land in Hawai'i unusable (Hawaiʻi Climate Change Mitigation and Adaptation Commission, 2017). An estimated $19 billion across the state in economic losses is predicted generating substantial social, ecological, infrastructure, and economic impacts (Hawaiʻi Climate Change Mitigation and Adaptation Commission, 2017).

Agriculture covers over 40% of land on Earth (Foley et al., 2005), and agricultural intensification and expansion account for as much as 24% of GHG emissions worldwide (Zomer et al., 2017). Land-use change for agricultural production and soil cultivation have contributed 136 ± 55 petagram (Pg) of carbon to the atmosphere from alteration of biomass carbon since the beginning of the Industrial Revolution. In addition, the depletion of soil organic carbon (SOC) accounted for a further contribution of 78 ± 12 Pg carbon (IPCC, 2014). Agriculture is also a large contributor to greenhouse gas emissions in Hawai'i (US EIA, 2018). Thus, it is important to understand the sequestration potential of agriculture as well as best management practices to reduce the impacts agriculture has on the atmosphere.

While modern industrial agriculture, which focuses on growing monocultures of commodity crops, is a major source of GHG emissions, traditional and diversified agricultural systems like agroforestry can be a GHG sink, sequestering more GHGs than they produce. Due to many factors, however, agroforestry is not widely practiced in the US. This lack of adoption of agroforestry, or the limited use of woody plants in diversified farming systems, is a major symptom of the problem in the agroforestry sector that we discuss in this report.

3.4 Framing and Modeling the Problem

Tree planting within an agricultural system has the potential to sequester GHGs, increase food production, and provide various socioeconomic and ecological benefits, but it is often an underutilized land use worldwide, including in Hawai'i. Although agroforestry has been practiced for centuries with success, expansion of this land use has significant hurdles, such as delayed return on investment, underdeveloped markets, emphasis on commercial agriculture, lack of awareness of the co-benefits, adverse regulation, and lack of coordination between sectors (Buttoud, 2013). Other obstacles to agroforestry adoption include land tenure, access to aggregation and processing infrastructure, access to capital and financing, and labor costs (Katie Friday, personal communication, May 4, 2017; Travis Idol, PhD, personal communication, Oct. 18, 2018). Additionally, diverse agroforestry systems are knowledge intensive, unlike conventional monoculture farming systems (J.B. Friday, PhD, personal communication, May 4, 2017). This barrier is corroborated by Kamuela Enos of MA’O Farms - a 40-acre organic farm in Waianae – who is interested in adopting agroforestry, but is deterred by the expertise required to take care of the trees (personal communication, Oct. 30, 2018).

Although low agroforestry adoption rates can be viewed as a symptom of many issues, in this section, we frame and model the problem in the following ways: information asymmetry, influence of mobilized interests, positive production externality, intertemporal, and perception of risk/uncertainty problems. The failure to utilize agroforestry to its fullest potential contributes to increased symptoms of GHG emissions and thus climate change.

3.4.1 Information Asymmetry

Information asymmetry can occur between producers in terms of transaction costs and overall benefits. Large-scale farmers that produce large quantities of consistent quality are able to attract buyers willing to buy their products at true market prices. Transaction cost economics stipulate that information asymmetry is the main reason why agroforestry markets perform poorly and why transaction costs are so high for these systems (Tollens, 2006). Often agroforestry producers are farming at a smaller scale, and smallholder farmers often do not have access to information regarding prices in urban areas that large-scale farmers do; they mostly sell at farm-gate prices to local traders who may have access to price and market information prevailing in other markets (Svensson & Drott, 2010).

3.4.2 Influence of mobilized interests/problems in representative government

In a representative government, concentrated interest groups can sway policies to favor their goals and motives. Farmers in Hawai'i with similar, often large-scale, farming interests (sugar, pineapple, coffee, etc.) come together to create commissions that are capable of paying for firms to lobby for their interests in government. Smallholders, are by definition, left out of this process because they grow a number of different crops and usually do not have the capital to hire lobbyists. Monoculture produced crops provide a large amount of the food we eat, as well as feed for animals, making these crops highly lucrative and backed by multiple organizations that rely on their success. Agroforestry is often constrained by policies and institutions that were created to support more conventional, industrial models of agriculture, forestry, and rural development in spite of agroforestry's potential to sequester GHGs (Kidd & Pimentel, 1992).

3.4.3 Positive production externality

A market failure occurs when the allocation of goods or services is not efficient (Weimer and Vining, 2011). The outcome of these problems can create inefficiency in the market, and result in market and government failures that shift the social benefit from Pareto efficiency. Pareto efficiency is a state where resources cannot be reallocated to make one person better or worse off. We will describe the market and government failures that are addressed in our policy recommendations specifically, and how they relate to agroforestry. These failures include positive production externality, intertemporal problems, and uncertainty/risk perception. The symptoms of GHG emissions and climate change as the inability to maximize GHG sequestration in agricultural systems (through agroforestry) in Hawai'i can be felt through these market and government failures.

Positive production externality is the positive effect an activity imposes on an unrelated third party (Weimer and Vining, 2011). In this context, it is the sequestration of GHGs by farmers adoption of agroforestry, where society receives the benefit of GHG sequestration and reduced climate change symptoms. However, farmers who adopt agroforestry do not gain payments for the ecosystem services they provide – reducing the incentive to provide this social benefit.

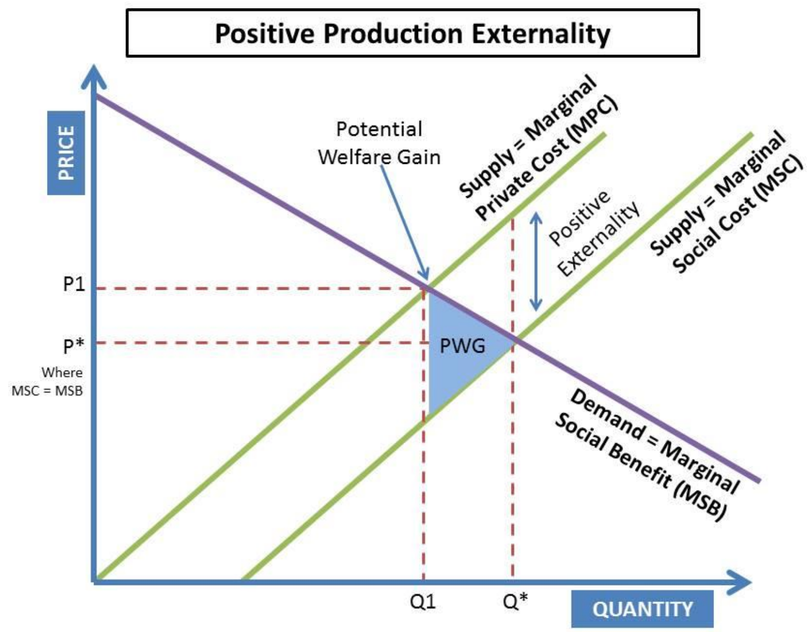

Figure 4. Graph of a positive production externality market failure.

3.4.4 Intertemporal problem

Intertemporal problems represent time as a significant problem in agroforestry. It usually takes years to grow a tree, and many forestry systems can be sources of GHGs during their establishment, with sequestration increasing over time (Dixon, 1995, Feller et al., 2001). The integration of trees into a farming system will often take longer to produce benefits like GHG sequestration, than other forms of agricultural reform (conservation tillage, companion planting etc.). Trees need time to grow, and the areas used for growing trees are often restricted for farming or grazing - activities that are known to turn a faster profit. Many farmers cannot justify the initial start-up costs of tree planting and crop diversifying with future benefits. According to Dr. Idol, coffee (a common agroforestry crop in Hawai'i), takes three years to produce, and trees planted for windbreaks take five years to get to proper size. Trees require a large amount of monetary and temporal capital to plant and often this capital can be difficult to provide upfront as farmers have their funds sunk into their crops and equipment. In conclusion, agroforestry is a long-term investment that can lead to perceptions of risk and uncertainty surrounding the benefits and outcomes.

3.4.5 Perception of risk/uncertainty problem

The uncertainty surrounding implementation costs, economic return on investment, and the extent of ecosystem benefits (GHG sequestration, pest control, yield increase etc.) can deter farmers from adopting agroforest measures. Farmers can also experience uncertainties in terms of the amount of time they will be cultivating on leased land. Many smallholder farmers are in active leases with landholders that have indefinite leases that can be terminated at any point, making investing in long-term projects a risky endeavor. This is common when the lands farmed are worth more to the leaser in another form (e.g. developed). Agroforestry has the ability to offer greater economic stability and reduced risk under climate change by creating more diversified enterprises with greater income distribution over time. Yet, farmers or ranchers may weigh this against the perceived risk associated with changing practices.

3.5 Stakeholders

Farmers and ranchers (large and small), including landowners and lessees, local communities, policy makers, and researchers are the most prominent stakeholders for agroforestry adoption in Hawai'i. Multiple private organizations (e.g., Hawai'i ‘Ulu Cooperative and Project Lemon Tree) seek to encourage the adoption of agroforestry. Stakeholders may also include all Hawaiian residents as the sequestration of GHGs is a positive production externality that benefits society.

4 Methodology

4.1 Goals of Policy and Impact Categories

To meet the mission of the Greenhouse Gas Sequestration Task Force, we assessed policy alternatives against five policy goals. Table 3 (below) lists our goals with their corresponding impact categories. Our first major goal for this policy analysis was GHG sequestration to meet the mission of Greenhouse Gas Sequestration Task Force. This goal's impact category is increasing GHG sequestration. Second, we considered the economic efficiency of the policy alternatives by assessing the benefits of policy implementation to producer (i.e. reduction in costs to implement agroforestry) and the cost of implementation to the State. Third, we included social equity and we considered the fairness to small producers (ranchers and farmers) as an impact category. Fourth, the policies should also work in concert with the State's goal of doubling local food production by 2030. Here, we evaluated the amount of agricultural land with its production and the existed or potential market. Lastly, we consider the political feasibility of our policy alternatives. Political feasibility relates to the acceptability as well as the capacity to implement the alternative.

Table 3. Policy goals and their impact categories for the assessment analysis.

Goal	**Impact Categories**
1) GHG Sequestration	1.1 Increase in GHG sequestration
2) Efficiency	2.1 Benefits of policy implementation to producer
	2.2 Cost of policy implementation to state
3) Social Equity	3.1 Fairness to small producers
4) Local Food Production	4.1 Amount of converted from fallow into production
5) Political Feasibility	5.1 Acceptability of the policy
	5.2 Capacity to implement the policy

4.2 Policy Alternatives

We considered five policy alternatives drawn from a literature review of proposed and enacted agroforestry policies in the State and around the world. Taking into account that more than 90% of agricultural land in Hawai'i is private (Figure 2), we have given greater consideration to policies that affect agroforestry implementation by private landowners and lessees of private land. Described below are the five policy alternatives that we analyzed, followed by a description of each.

4.2.1 Continue with the current status quo

Without a new policy intervention, agroforestry producers can still access loans through the Agricultural Loan Program and incentives through the Forest Stewardship Program. As the Agricultural Loan Program is a "lender of last resort", and agroforestry is not included in the program priorities, without an intervention, producers utilizing this program to adopt or expand agroforestry systems are often inhibited. Additionally, agroforestry producers have difficulty accessing Forest Stewardship Program funds in part due to a lack of definition of this land use in the statute (D. Shapiro, personal communication, November 19, 2018). Land tenure is a challenge as agricultural leases in the state are generally not long or secure enough to encourage producers to adopt a land management system that has a relatively long return on investment (i.e. 8-20 years).

4.2.2 Amend the Agricultural Loan Program to create an Agroforestry Loan Program

Agroforestry systems have high start-up costs and a long-term return on investment (Buttoud, 2013; Place et al., 2012). With limited access to capital, producers do not make an investment today in a land use practice that will provide a new income stream and co-benefits, including carbon sequestration and other ecosystem services, in the future. Producers value current returns over future returns - an issue with the social marginal rate of time preference, or the rate at which people are indifferent between exchanging current and future consumption. The current Agricultural Loan Program provides the infrastructure to target this intertemporal problem by providing access to additional capital, however, funds are not specifically earmarked for agroforestry. A potential policy alternative, then, is to create an Agroforestry Loan Program modeled after the Aquaculture Loan Program of 2013, which is an economic development measure that allocates $1 million from the Agricultural Loan Program to aquaculture applicants. With access to additional capital, producers are more likely to implement agroforestry systems today and be able to cash flow with existing revenue streams while waiting for returns from agroforestry investments in the future.

4.2.3 Amend the Forest Stewardship Program to prioritize agroforestry

Agroforestry systems produce benefits in addition to food products that cannot be captured by the producer (e.g. carbon sequestration, improved water quality, etc.). In this case, the marginal social benefit of agroforestry production is greater than the marginal private benefit, which causes producers to implement agroforestry at less than socially optimal levels. This positive production externality problem could be addressed by compensating producers for these additional benefits, which would raise the producers' marginal private benefit, triggering an increase in agroforestry adoption. One specific policy alternative to address this issue is to provide incentives to producers using agroforestry systems. Agroforestry currently qualifies for incentives through the Hawai'i Forest Stewardship Program, however, there is not a clear avenue for agroforestry systems to receive approval. This policy could be adjusted to promote agroforestry systems by 1) defining agroforestry in state statutes; 2) reducing the minimum acreage to qualify for funding from five acres to one acre for agroforestry systems; and 3) changing the requirement for a management plan to a business plan for agroforestry projects on less than five acres. This matching grant (supply side subsidy) would contribute much needed start-up capital for agroforestry systems as well as ongoing compensation for additional societal benefits of this land use practice.

4.2.4 Amend the state agricultural land management rules to prioritize long-term leases for agroforestry producers

Many agricultural leases in Hawai'i have short durations (e.g. less than five years) in part to limit the risk born by landowners in the event a producer is not financially successful. This land tenure issue creates significant uncertainty for producers as they do not know how long they will have access to land they steward. In order to recuperate the large start-up investment of planting trees in agroforestry systems, producers need secure, long-term access to land. Without this security, producers are more likely to grow annual crops rather than trees to limit the risk of losing land access and any investment sunk in the land. A policy alternative, therefore, is to amend the state agricultural land management rules to prioritize long-term leases for producers using agroforestry systems (HI Rev. Stat. §166 and §166E). Lessing the uncertainty over land tenure by providing secure long-term land leases to producers would increase the likelihood that producers on State-owned land adopt agroforestry practices that have long-term private and social returns.

4.2.5 Direct the Agricultural Development Corporation (ADC) to provide agroforestry business plan development to meet wholesale market demand

A significant portion of agricultural land in Hawai'i is fallow. Many producers who have access to additional farmland, that is not in production, cite a lack of market for additional products as a reason for not bringing their fallow land into production (D. Kishida, personal communication, August 26, 2018). The uncertainty of not having a market for additional products is a significant barrier to converting more land into agroforestry production. At the same time, institutions such as the Hawai'i Department of Education have identified intent to increase their demand for local agricultural products significantly. In order to reduce uncertainty and risk in adopting agroforestry systems on existing and fallow agricultural lands, one policy alternative is to create an act modeled after Act 194 (2002 - 2005) that would direct the Agricultural Development Corporation (ADC) to provide agroforestry business plan development to meet wholesale market demand. Through this directive, the ADC could also help producers make plans for aggregation and access capital for aggregation infrastructure through public-private partnerships – a need identified by UH Manoa TPSS professor and Hawai'i 'Ulu Cooperative leader Noa Lincoln, PhD (personal communication, November 30, 2018).

4.3 Prediction Methods

Below we describe how we predicted the impacts of each policy alternative for each goal and impact category.

4.3.1 Goal 1 - GHG sequestration

In order to predict the impacts of the policy alternatives on GHG sequestration, we conducted a literature review on the ability of agroforestry systems to sequester GHGs and the potential gains in GHG sequestration from the conversion of conventional farm and pasture land into agroforestry systems. GHG sequestration rates for a given agroforestry system are site-specific; agroforestry systems may sequester different amounts of GHGs depending on the system type and tree density (e.g. alley cropping, silvopasture, etc.), tree species, soil type, use of tillage, climate, and other factors (Krankina & Dixon, 1994; Schroeder, 1993; Winjum, Dixon, & Schroeder, 1992). For example, one study in Oregon, USA documented sequestration rates of 3.4 Mg C /ha/year for alley cropping and 6.1 Mg C /ha/year for silvopasture (Sharrow and Ismail, 2004). Currently, no data on GHG sequestration in agroforestry systems in Hawai'i is available, so we reviewed data from other places to understand the range of sequestration rates of different agroforestry systems and to determine estimates from which to base predictions for Hawai'i.

Ideally, to predict the outcomes of each policy alternative on GHG sequestration, we would multiply the estimated sequestration rate for each type of agroforestry system by the amount of land we predict would be converted to that system by each policy alternative. However, due to limited data, we used modified methods to make our predictions. In order to simplify the extensive potential variability in sequestration rates by site and system explained above, we assumed that, on average, each policy alternative will result in the adoption of the same proportion of alley cropping, silvopasture, and multi-strata cropping systems over a range of site conditions since none of the policy alternatives target only one type of agroforestry system. This assumption allowed us to hold the sequestration rate constant for all policy alternatives. Then, we estimated the maximum extent of land impacted by each policy alternative using data from impact reports of existing programs (e.g. Forest Stewardship Program's report to the legislature) and our understanding of the maximum potential land that could be affected by agroforestry in Hawai'i (Figure 3). Since we held the sequestration rate constant, the predicted amount of land impacted by each policy alternative served as a proxy for GHG sequestration.

4.3.2 Goal 2 - Efficiency

While sequestering a high level of GHGs is an important goal for the policy alternative, the efficiency of dollars spent to implement the policy is also a necessary consideration; the benefit of GHG sequestration can be outweighed if implementation costs are high. We predicted the efficiency of each policy alternative by comparing the estimated cost of implementing the policy alternative to the government to the estimated cost of implementing agroforestry to the producer. We used a literature review to qualitatively predict the relative costs of implementing the policy alternative to the government. We also compared the relative costs of agroforestry implementation to the producer for each policy alternative as an indicator of the alternative's benefit.

4.3.3 Goal 3 - Social Equity

Social equity compels the policy to not disadvantage certain groups, especially those that are vulnerable economically or socially. Ensuring that our policy alternatives meet the goal of being socially equitable we have designed a valuing technique that assesses how many stakeholders benefit positively from the alternative. The stakeholders of our policy issue include farmers (large and small), ranchers (large and small) both landowners and lessees; landowners, land managers, local communities, policy makers, and researchers. For the sake of our analysis, we will include farmers (small) and ranchers (small) both landowners and lessees; and local communities in our policy valuation. We will evaluate policies' predicted effect on the differently sized producers, based on annual sales. Our baseline information for social equity is from the 2012 Statistics Overview from the USDA in Hawai'i. There are 7,000 farms in operation across the Hawaiian Islands, the median value of annual sales is between $5,000 ~ $9,999 (Figure 4). Small producers are considered as farms and pastures not listed in the larger private landowner list (Appendix A, B) or the value of their annual sales is under the median (e.g. < $9999 for farmers).

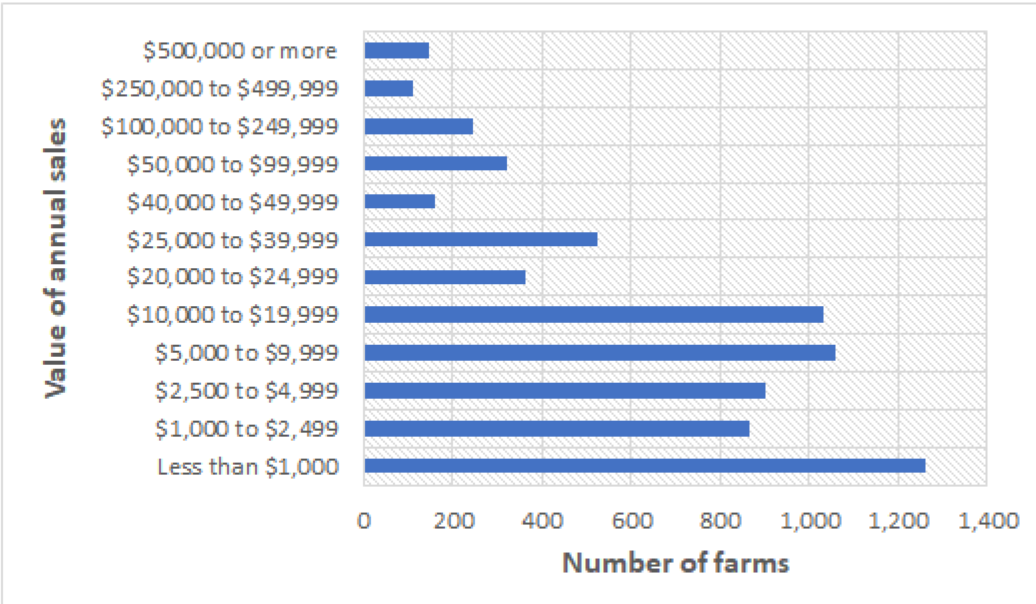

Figure 5. Number of crop and livestock farms by value of sales. Data from USDA NASS 2012.

4.3.4 Goal 4 - Local Food Production

Like GHG sequestration, the impact each policy alternative has on local food production is related to the amount of land converted to agroforestry. Fallow agricultural land converted to agroforestry is assumed to increase local food production. The change in local food production resulting from the conversion of row crops or livestock pasture, however, is more nuanced due to variability in management practices and productivity before and after conversion. When managed effectively, though, agroforestry systems often increase productivity (Ponisio et al., 2015). For the purposes of this analysis, we assumed that an increase in land converted to agroforestry will increase food production, and thus we compared the amount of land predicted to be converted by each policy alternative.

4.3.5 Goal 5 - Political Feasibility

A politically feasible policy certifies its adoption by the legislature and voters. The analysis of political feasibility predicts how probable a proposed solution to a policy failure may be through the examination of actors, events, and environment. In this analysis, we will examine the acceptability in the legislative process. The acceptability of the policy alternatives will be assessed based on the policies potential to appeal to legislators, stakeholders, and voters. Not only will we look for the acceptability of these policy alternatives but also their capacity to be implemented in the State of Hawai'i, meaning the time, labor, money, and other resources needed to take action on a policy. Hawai'i is a unique system and many federal and State policies may not be applicable. We will also use professional judgement informed by experience and validated through interviews, to judge the possibility of local acceptance of these policies by landowners and farmers.

4.3.6 Valuation Methods

After predicting the impacts of each policy alternative, we qualitatively assessed how the impacts contribute to each goal using a multi-goal solution analysis. We assigned the impact of each policy alternative to one of three levels: low, medium, or high impact on each goal. For GHG sequestration, *low* corresponds to the status quo and *medium* and *high* are represent predicted increases in sequestration based on the amount of land converted to agroforestry relative to the status quo.

For efficiency, we rated the impact on reduction in the cost of agroforestry implementation to producers (a benefit) as *low* if the cost of implementation to the producer stays the same – at a not socially optimal level – and *high* if the alternative reduces costs to a more socially optimal level. We ranked the impacts on the cost of policy implementation to the state (a cost) as *high* if there will be no increase in funding requirements (low cost) and *low* if there is significantly more funding required to implement the policy (high cost). Combining these two efficiency impact categories, we found a qualitative cost/benefit ratio where the most efficient ration of reduced cost to the producer to cost to the state is equal to *high/high*.

For social equity, we ranked policies *low* if we predicted no stakeholder benefit from the policy alternative, *medium* if some stakeholders benefit, and *high* if all stakeholders benefit and are positively impacted. We ranked the impacts of a policy alternative on food production as *low* if we predicted they will result in little land conversion to agroforestry and *high* if we predicted it would lead to significantly more land being converted to agroforestry.

Finally, if a policy alternative is new (requires education on the proposed bill and lacks initial support), we ranked it as having *low* political feasibility. If a policy is familiar to the stakeholders, yet requires a substantial change in order to work in favor of agroforestry, it was scored as a *medium*. A policy alternative receiving a *high* score requires a small change to existing legislation and already maintains significant stakeholder support. For the political feasibility goal, we assume that policy alternatives will be most accepted if they are less impactful and new.

4.3.7 Assessment Methods

We then performed an assessment of the alternatives by evaluating the impacts of each policy alternative on the goals and impact categories. We then considered tradeoffs to identify the policy alternative that best suits all goals and impact categories. We added impact category rankings for each policy alternative giving equal weight to each category to come up with a total score for each alternative. We then based our recommendations on the highest scoring policy alternative.

5 Assessment (Analysis/Results)

In this section we discuss our assessment. Because of limited data and the qualitative nature of our analysis, we made several assumptions that are discussed by goal in the following sections.

5.1 GHG Sequestration

Without a new policy intervention, the status quo alternative will have little impact on GHG sequestration by agroforestry systems. State and Federal agricultural statistics surveys do not collect data on the type of cropping system farmers use, only the types of crops that they grow. Thus, no data on the current acreage in agroforestry exists for the State; however, from personal communication with both producers and extension agents, we understand there to be very little land in agroforestry production today (T. Idol, personal communication, October 18, 2018). As described in the policy alternative methodology section above (4.2), State and Federal incentive programs do apply to agroforestry systems, however, the funds are not easily used for this purpose (D. Shapiro, personal communication, November 19, 2018). Therefore, we predict that any increases in GHG sequestration because of conversion of agricultural land to agroforestry systems without new policy intervention will be *low*.

Creating an Agroforestry Loan Program modeled after the Aquaculture Loan Program will have a *medium* impact on GHG sequestration. The state's current Agricultural Loan Program has a goal to preserve or expand 250 acres of agricultural land and approve 25-30 loans per year (DOA, 2017). By earmarking one million dollars of the current funding to agroforestry related ventures, significantly more of these loans can be used to implement agroforestry projects. Assuming that more land in agroforestry production, converted from either fallow agricultural land, annual crops, or pasture, will increase GHG sequestration, this policy alternative will have a *medium* impact on GHG sequestration.

We also predict that productively defining agroforestry in the Forest Stewardship Program, prioritizing long-term leases for agroforestry producers in State agricultural land rules, and providing business development services to new agroforestry producers and collectives will all have a *medium* impact on GHG sequestration based on the amount of land we predict them to impact. The Forest Stewardship Program funds approximately six new projects per year on average (DOFAW, 2017). Amending the State agricultural land rules can only directly impact 4% of agricultural lands in the State since most are privately owned. This alternative, though, may indirectly increase the use of long-term leases on private lands by setting a precedent for this being an acceptable type of contract and providing a model for other landowners to follow. Then, directing the ADC to provide technical assistance in creating agroforestry-based business plans will reduce risk resulting in increased adoption of agroforestry. All of the alternatives, except the status quo, will also increase public awareness of agroforestry, which may indirectly increase the conversion of agricultural land to agroforestry, thus increasing GHG sequestration.

5.2 Efficiency

Amending the Forest Stewardship Program to promote the use of these funds for agroforestry implementation is the most efficient policy alternative. Under this alternative, the cost of implementation to the producer is reduced by the incentive amount which provides a *high* benefit, while at the same time the cost of policy implementation to the State is *low* because no new funds need to be allocated to the program. The other policy alternatives also have a *low* cost to the State as this was a constraint we used in selecting policy alternatives. The reduction in cost to producers, however, varies between the remaining four alternatives. We predict both the status quo and amending the State agriculture land rules to prioritize long-term leases will have a *low* impact on the cost of agroforestry implementation to the producer. In continuing with the status quo without the ease of access to incentive and loan programs, producers who want to switch to agroforestry bare the cost of the marginal societal benefit provided by agroforestry, and for the long-term lease alternative, producers have more secure land tenure, but no direct change in their costs of agroforestry implementation. Slightly better, amending the agricultural loan program would provide access to start-up capital, but over the long-term the producers still bear the same cost. We assessed this impact to have a *medium* effect on policy benefit to producers. Similarly, directing the ADC to provide technical assistance on aggregation may make producers and/or groups of producers more efficient, indirectly reducing their marketing costs. Assistance with locating capital for infrastructure may also indirectly reduce start-up costs. We thus ranked the impacts of this policy alternative as *medium*.

5.3 Social Equity

Ensuring that our policy alternatives meet the goal of being socially equitable we have designed a valuing technique that assesses how many stakeholders benefit positively from the alternative. For the sake of our analysis, we included farmers (small) and ranchers (small) both landowners and lessees; and local communities in our policy valuation. Smallholders are the most at-risk in policy change as they typically deal with less land and lower income. The status quo ensures that nothing new happens in these systems, so no changes need to be made, but also does not currently assist the smallholder population. As a result, this alternative is scored *low*. A loan program offers these farmers the opportunity, providing the capital, to plant trees on their farms. Due to the financial support of this alternative, it has been ranked *high*. Through the amendment of the Forest Stewardship Program, the cost of planting these trees is reduced for smallholder farmers - via incentives - helping them to adopt agroforestry systems on their land. However, due to the competitive nature of this project, not benefiting all interested parties, it has been scored as *medium*. Long-term leases help to ensure that adopted agroforestry benefits, such a food production or shade for cattle, are felt by farmers due to the time it takes for these trees to grow. The security promoted in this alternative has granted it a *high* score. Lastly, the development of an Agroforestry Business Plan will help smallholders to understand the best management practices for trees. However, this alternative does provide any financial assistance, and may take a long time to develop, receiving a *medium* score.

5.4 Local Food Production

Following the status quo, increases in local food production will be minimal due to the multiple challenges described in the diagnosis of the policy issue section (3.4). Although the governor set a goal of doubling local food production from 10% of food consumed in Hawai'i to 20% by 2030, without a policy intervention, producers are unlikely to bring the 40% of currently fallow agricultural land into production (State Ag Land Use Baseline 2015). Similarly, we predict that amending the state agricultural lands rules to prioritize long-term leases will have a *low* impact of local food production because this alternative will only affect state-owned lands which do not make up a majority of fallow lands.

Alternatively, all of the proposed policies would increase local food production compared to the status quo. We predict both amending the agricultural loan program and amending the forest stewardship program to have a *medium* impact on local food production. Amending the loan program will provide access to capital that can help producers with the start-up costs of converting land to agroforestry. Also, compensation for private costs that provide greater social benefit encourages agroforestry adoption, thus moving land into production. Finally, creating a directive for the ADC to provide wholesale market development assistance has a *high* impact on local food production because producers with a clearly defined plan for aggregation and wholesale marketing have less risk, and therefore may be more likely to secure access to privately owned land that is now fallow.

5.5 Political Feasibility

A politically feasible policy certifies the adoption by the legislature and voters. The analysis of political feasibility predicts how probable a proposed solution to a policy failure may be through the examination of actors, events, and environment. In this analysis, we examined the acceptability in the legislative process. Policy alternatives scored higher on the scale if they were less impactful and new. Our policy alternatives of this goal were scored by two impact categories, the acceptability of the policy and the capacity to implement the policy.

For the acceptability of the policy, the status quo scored *high* because no new changes will need to be made in the legislation. Earmarking funds from the aquaculture loan program may receive pushback from legislators that help direct this bill as well as aquaculturists. When scoring the acceptability of this alternative it earned a *medium* score. A long-term lease program will call for an amendment of a current bill. As this bill has already been approved, it is understood that this amendment would require new education of the amendment as to why this bill has been changed. Due to this, the alternative was scored as a *medium*. Due to the lack of a current Agroforestry Business Plan, this alternative earning a score of *low*.

In analyzing the capacity to implement the alternative, the status quo alternative scored *high* because no new capacity needs to be created in order to implement this policy. The agroforestry loan program will require the movement of funds from the aquaculture loan program, potentially reducing the capacity of that program as well as requiring an in-depth review of the percentage of funds that will need to be moved. As a result of this, this alternative scored a *medium*. The Forest Stewardship Program must pivot in order to properly support the adoption of agroforest practices, a section it currently does not effectively address. This causes its capacity to be implemented to be scored as *medium*. The long-term lease program helps with issues of land tenure, but first an up-to-date study must be performed to assess the current status of leases and lease duration. Due to this, this policy alternative received a score of *medium*. Finally, the Agroforestry Business Plan is a new model, which will require time and money in its research and development phases, reducing its potential to impact in the near future. This shortcoming causes it to receive a *low* score.

Table 3. Agroforestry (AF) Policy Evaluation Matrix (Score scale: low is orange with 1 point; medium is yellow with 2 points; high is green with 3 points)

		Policy Alternatives				
Goals	**Impact Category**	**Status Quo**	**Amend Agriculture Loan Program**	**Amend Forest Stewardship Program**	**Amend State Agricultural Lands rules to prioritize long-term leases**	**Create a directive for ADC to provide technical assistance**
GHG sequestration	GHG sequestered	Low – *Incentive and loan programs that apply to AF exist, but are under-utilized for this purpose*	Medium – *Program goal is to impact 250 acres/yr and approve 15-30 loans*	Medium – *FSP awards approximately 6 new projects/yr*	Medium - *Directly impacts sequestration on 4% of ag. lands - long-term lease model may indirectly impact all leased private lands*	Medium –*Assistance with aggregation reduces risk, increasing adoption of agroforestry*
Efficiency	Benefit of policy to producers (reduction in cost of agroforestry implementation to producer)	Low – *Access to incentive and loan programs is difficult, so producers bare the cost of marginal societal benefit provided by AF*	Medium – *Over long-term, producers have the same costs as status quo, but have access to start-up capital when it is most needed*	High – *The cost of implementation is directly reduced by the incentive amount*	Low – *No change in cost, only more secure land tenure to be able to make return on investment*	Medium – *Assistance with aggregation may make producers more efficient, reducing marketing costs; assistance locating capital may reduce start-up costs*
	Cost of policy implementation to state	High – *It does not require any additional funding*	High – It *does not require any additional funding*	High – It *does not require any additional funding*	High – *It does not require any additional funding*	High – It *does not require any additional funding*
Social equity	Fairness to small producers	Low - *Status Quo does not currently do anything to assist smallholder producers*	High - *Loan program provides financial assistance to smallholders*	Medium – *Only serves around 6 producers per year, not all producers*	High - *Helps to ensure return on investment, allowing farmers to reap benefits long term*	Medium - *Business plans help to explain risk, but do not help financially, nor immediately*
Local food production	Amount of agricultural land converted from fallow to agroforestry	Low – *40% of ag land is fallow and producers are not motivated to bring land into production*	Medium –*Access to capital helps producers with start-up costs of converting land*	Medium – *Compensation for private costs that provide greater social benefit encourages agroforestry adoption*	Low – *Only affects state owned lands which do not make up a majority of fallow lands*	High – *Producers with an aggregation plan have less risk, may be more likely to secure access to privately owned fallow land*
Political feasibility	Acceptability of the policy	High - *No new changes need to be made and no new information needs to be shared in order to adopt this policy alternative*	Medium - *This is already an accepted program but will require more education on agroforestry*	High - *The development of a definition for agroforestry should remain quite simple, as long as it is easily agreed upon*	Medium - *The long-term lease program requires amendment to a current bill which requires a new vote on the amended bill and voter knowledge of what has been changed and why*	Low - *This plan would require timely research and development in order to be politically feasible, and education once completed*
	Capacity to implement	High – *already implemented*	Medium – *money needs to be earmarked*	Medium – *program is already implemented, only requires changes to writing and monitoring*	Medium - *requires an assessment of current status of leases in the state*	Low– *requires staff time for program development*
Total Score:		**13**	**16**	**17**	**14**	**15**

6 Recommendations

Based on our qualitative assessment of the predicted impacts of each policy alternative we recommend amending the Forest Stewardship Program. All four intervention alternatives rated higher that the status quo, with the top two highest-ranking alternatives being amending the Agricultural Loan Program and amending the Forest Stewardship Program. We predict the loan program will have lower acceptability because it requires earmarking funds for agroforestry, which reduces funding for conventional producers, thus affecting those stakeholders. We predict amending the Forest Stewardship Program will be more efficient because the direct benefit of incentives to the producer is higher than a loan and the cost to the government is the same for both alternatives. Neither of these alternatives requires new revenue, although they impact mores producers if additional funding were allocated to them.

We recommend taking action on amendments to the Forest Stewardship Program policy alternative in two phases to provide time to create awareness of agroforestry and build consensus over the need to prioritize this land use in the existing incentive program. First, in year one, we recommend defining agroforestry in the state statute. This will require working with stakeholders to identify an agreed upon, policy-relevant definition of agroforestry that includes both crop and animal integrated systems including alley cropping, multi-story cropping, and silvopasture. Then in year two, we recommend reducing the minimum acreage required to qualify for the program from five acres to one acre for agroforestry systems and replacing the requirement for a management plan with a business plan for agroforestry systems of less than five acres. This reduction in regulatory burden will require more consensus building than defining agroforestry, but will further promote agroforestry adoption.

6.1 Next Steps

For immediate next steps, we recommend that the Greenhouse Gas Sequestration Task Force work with stakeholders to build consensus on an agroforestry definition for state policy. Producer associations (e.g. Farm Union, Hawai'i Cattleman's Council, Hawai'i 'Ulu Cooperative, etc.), producer support organizations (e.g. O'ahu Resource Conservation and Development Council, GoFarm, Hawai'i Agriculture Research Corporation, etc.), (Ulupono Initiative, Hawai'i Agriculture Foundation, etc.), as well as community members and other interested individuals should be invited to give public comment on considerations for the definition. Not only will this process clarify agroforestry for the implementation of the Forest Stewardship Program, it will also build awareness of agroforestry and its importance around the state.

Additionally, before taking action on legislation, the task force can take action to build awareness of the benefits of agroforestry and existing technical resources for implementation by leveraging existing resources. Creating awareness and sharing technical knowledge are critical in the agroforestry adoption process. Awareness can be furthered through education of farmers on why agroforestry is a key climate-smart practice, as well as how to best plant and manage agroforestry systems (Place et al., 2012). Education and community outreach will need to be available to all farm sizes and types to ensure the equitable education of all stakeholders.

Engaging the University of Hawai'i College of Tropical Agriculture and Human Resources (CTAHR) and the Hawai'i Agriculture Research Center (HARC) in research and education will further leverage existing resources. CTAHR operates thirteen research stations across the Hawaiian Islands where agroforestry could be further integrated to provide demonstration to producers. Based on interviews with local farmers, having sample plots would assist in the adoption and education of farmers on agroforestry practices (K. Enos, personal communication, October 30, 2018). HARC could be a key player in the advancement of agroforestry knowledge, potentially partnering with the State, to conduct assessments of successful tree species in different agriculture systems as well as sequestration potential.

6.1.1 Possible Funding Schemes

As currently outlined, none of our policy recommendations require new funding appropriations. All of the existing programs that the policy alternatives affect, however, could have a larger impact if additional funding were allocated to them. The Forest Stewardship Program specifically could use additional funding, so we have outlined various funding opportunities below that can be utilized to promote agroforestry practices in Hawai'i. Once it is better understood what frameworks work best in Hawai'i, we recommend that the GHG Sequestration Task Force consider the following funding strategies to encourage agroforestry adoption.

Table 4. Funding Scheme Pros and Cons

Funding Scheme	Pros	Cons	Source
Carbon Tax	-Will cause people to pay for polluting while also gaining funding for trees -Will create more carbon smart consumers -Encourages firms and consumers to look for smart alternatives -Can be adjusted over time -Can be phased out	-Will increase cost of living in Hawai'i. -Some costs may be borne by consumers -May be hard to measure pollution and collect tax	(Bauman & Komanoff, 2017)

Tourist Environmental Fee	-Around 9 million tourists visit the islands annually -Steadily increasing annually -Hawai'i's beauty is the reason for visiting, in line with reason for tourism fee -Incorporates the costs of environmental services and damages -Environmental behavioral change	-May impact the tourism industry -Need framework of determining who 'should' be paying the fee	(Sustainable Tourism, 2018)
Carbon Offsets of Flights	-Can be voluntary -Can fluctuate based on distance and duration of flight -Can be ensured that funds stay in Hawai'i -Flights are one of the largest contributors to GHG emissions -Can be made cheap -Can be progressive over time	-Mayimpact the tourism industry. -Maylead to travelers choosing different airlines -If mandatory, can be financially impactful	Current Price: $13.12 per mT ("Terrapass," 2018)
Carbon Offsets of Shipping	-One of the largest polluters in Hawai'i -Can promote shift to more self-sustaining Hawai'i -Can be progressive over time -Can be voluntary at consumer level or mandatory at the larger container level	-Increased cost could impact the consumer	(Gallucci, 2018)
Barrel Tax Expansion	-Will account for jet fuel, a large emitter in HI -Already very low in cost (~$1) -Room to increase -Will put a more accurate price on petroleum -Already a current policy, just needs renovation	-Increased tax could fall upon the consumer -May lead to less refinement of jet fuel in HI and more shipping of fuel (increased emissions)	

7 Conclusions

Based on our problem and solution analysis outlined in the methods section (4), we recommend that the Greenhouse Gas Sequestration Task Force consider amending the Forest Stewardship Program to increase the adoption of trees on agricultural lands. An actionable first step is working with stakeholders to adapt a definition of agroforestry that is appropriate for the unique socio-cultural, ecological, economic, and policy contexts of Hawai'i. Additionally, further research, education, and outreach on the benefits of agroforestry including GHG sequestration rates of specific systems in the State of Hawai'i will help producers take advantage of existing resources and help planners identify best systems to promote for sequestration.

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Appendix A. The top 20 private cropland owners across the state of Hawai'i.

Private large landowners	**Acreage**	**Proportion**
Alexander & Baldwin	40,394	45%
Kamehameha Schools	7,024	8%
Dole Food Company	4,857	5%
Robinson Family	4,537	5%
Macfarms	3,938	4%
Royal Hawaiian Orchards	3,765	4%
Monsanto Company	2,898	3%
E.C. Olson	2,090	2%
Pioneer Hi-Bred International	1,900	2%
W.H. Shipman	1,868	2%
Grove Farm	1,792	2%
Robinson Kunia Land LLC	1,599	2%
Island Palm Communities	1,518	2%
Maui Land & Pine	1,119	1%
D.R. Horton Schuler Homes	1,106	1%
Purdyco	1,020	1%
Molokai Ranch	1,004	1%
Mahaulepu Farm LLC	926	1%
Castle & Cooke	665	1%
Mauna Loa Macadamia Nut Corp.	627	1%

Appendix B. The top 20 private pasture landowners across the state of Hawai'i.

Private large landowners	Acreage	Proportion
Parker Ranch	96,720	23%
Kamehameha Schools	50,887	12%
Haleakala Ranch	21,045	5%
Molokai Ranch	17,373	4%
Ulupalakua Ranch	16,945	4%
Robinson Family	11,983	3%
Kealakekua Heritage Ranch	11,450	3%
McCandless Ranch	10,213	2%
Queen Emma Foundation	8,494	2%
E.C. Olson	8,231	2%
Kukaiau Ranch	8,151	2%
Waikoloa Mauka	6,699	2%
E.M. Stack	6,698	2%
The Nature Conservancy	6,377	2%
Kaonoulu Ranch	6,353	2%
Grove Farm	5,509	1%
Waikoloa Village Ass.	5,159	1%
Alexander & Baldwin	5,059	1%
Lanihau	4,878	1%
Yee Hop	4,703	1%

Appendix C. Hawai'i Agricultural Land Utilization (2015)