Carbon Pricing Assessment for Hawai‘i

Economic and Greenhouse Gas Impacts

Prepared for the Hawai‘i State Energy Office

FINAL

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Foreword

We are excited to present this study about potential carbon pricing for Hawai‘i. This first-ever Hawaii-specific study was prepared for the Hawai‘i State Energy Office (HSEO) by the University of Hawai‘i's Economic Research Organization (UHERO) as a requirement of Act 122, Session Laws of Hawai‘i 2019. In authorizing the study, the Hawai‘i State Legislature stated that "climate change [was] expected to cost the State at least $19,000,000,000 in losses from sea level rise alone, making the switch to renewable energy and the ultimate reduction of atmospheric carbon a priority."

The study includes an illustrative range of tax amounts to explore options for achieving Hawai‘i's policy goals. The Hawai‘i-specific modeling scenarios are important for deliberations at the Legislature and to further public understanding of how carbon pricing could address the climate crisis, while enhancing Hawai‘i's economy and caring for the most vulnerable among us.

Between the commencement of the study and the release of this draft final *Carbon Pricing Assessment for Hawai‘i: Economic and Greenhouse Gas Impacts*, the global COVID-19 pandemic emerged, bringing with it unprecedented global health and economic crises. Hawai‘i has been one of the hardest economically impacted states in the U.S., with UHERO recently reporting the "statewide unemployment rate remains more than twice the national average." Therefore, there are significant differences between the economic conditions in which this study was first designed and the pandemic-influenced economic circumstances of 2021.

While the study does not speak to economic recovery, the study offers insights at this critical time. The world is grappling with how to ensure no one is left behind in the clean energy revolution. This report demonstrates that a tax on greenhouse gas pollution and a direct payment to Hawai‘i's households, when structured correctly, would help households--especially our most vulnerable--in the move to a clean energy economy.

The next step after this study is the careful consideration of the details of a proposed policy, such as how, when, and to whom a direct payment would be distributed, the timing and amounts, and sufficient notice to everyone to prepare for it.

The HSEO would like to acknowledge and extend a warm thank you to UHERO's Dr. Makena Coffman (Principal Investigator), Dr. Sherilyn Hayashida (Co-Principal Investigator), and their team, for their expertise and diligent development of this groundbreaking study.

Sincerely,

Scott J. Glenn
Chief Energy Officer
February 25, 2021

HOUSE OF REPRESENTATIVES
THIRTIETH LEGISLATURE, 2019
STATE OF HAWAII

H.B. NO. 852
H.D. 1
S.D. 1
C.D. 1

Act 122

(excerpts)

PART I

SECTION 1. …Climate change is expected to cost the State at least $19,000,000,000 in losses from sea level rise alone, making the switch to renewable energy and the ultimate reduction of atmospheric carbon a priority…

[…]

PART V

SECTION 13. There is appropriated out of the energy security special fund the sum of $150,000 or so much thereof as may be necessary for fiscal year 2019-2020 for the purposes of conducting a study of carbon pricing, including whether and how a carbon pricing policy shall be implemented in Hawaii.

The sum appropriated shall be expended by the Hawaii state energy office for this purpose of this Act.

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ACRONYMS

AEO	Annual Energy Outlook
AFOLU	agriculture, forestry and other land use
BLS	Bureau of Labor Statistics
CGE	computable general equilibrium
DBEDT	State of Hawai‘i, Dept. of Business, Economic Development, and Tourism
CAFE	Corporate Average Fuel Economy
EPA	U.S. Environmental Protection Agency
ETS	Emissions Trading Scheme
EV	electric vehicle
GHG	greenhouse gas
GSP	gross state product
IAM	integrated assessment model
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
kWh	kilowatt hour
MMT CO_2 Eq.	million metric tons carbon dioxide equivalent
MT CO_2 Eq.	metric ton carbon dioxide equivalent
MW	megawatt
RGGI	Regional Greenhouse Gas Initiative
RPS	Renewable Portfolio Standard
SAFE	Safer Affordable Fuel Efficient (Vehicle Rule)
SCC	social cost of carbon

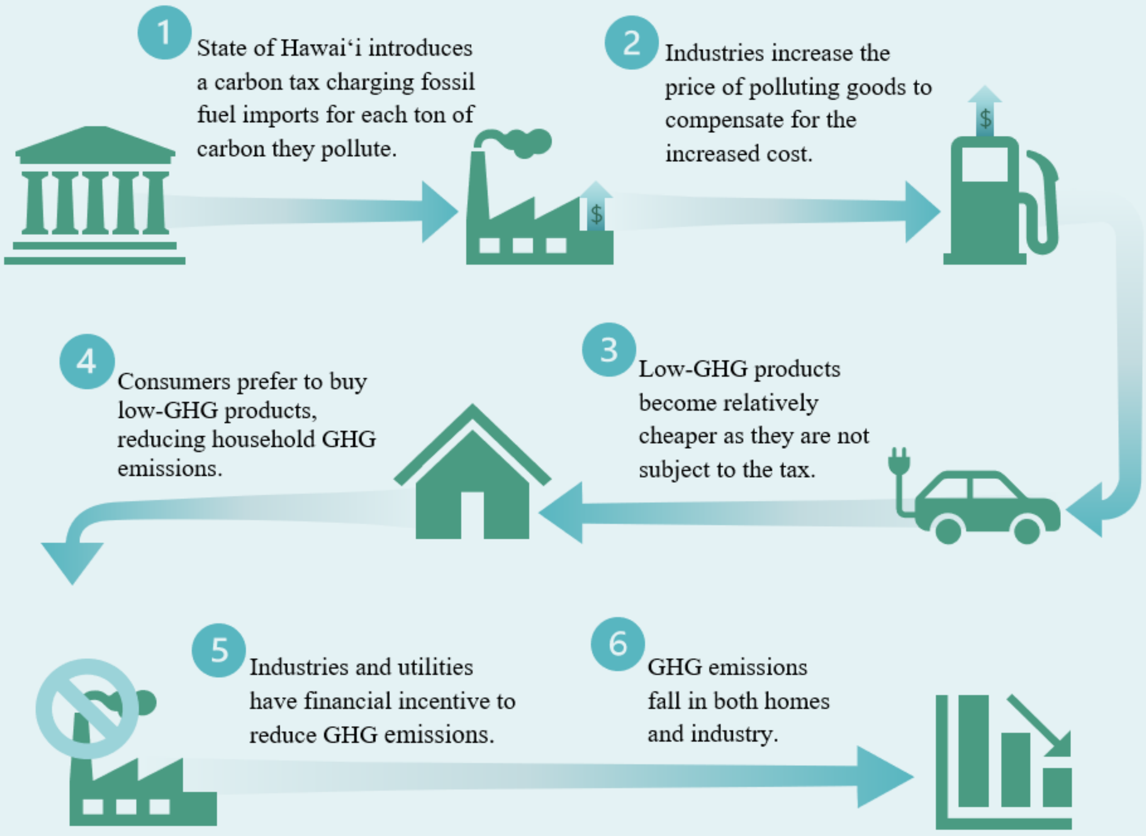
EXECUTIVE SUMMARY

Climate change threatens many of Hawaiʻi's human and natural systems, including coral reefs, beaches, and biodiversity. Sea level rise alone is expected to cost $19 billion in loss of land and structures, in addition to an unknown cost associated with damage to critical infrastructure (Hawaiʻi Climate Change Mitigation and Adaptation Commission, 2017). Minimizing these impacts requires a drastic shift globally from greenhouse gas (GHG) intensive activities to greener technologies and behaviors. Mitigating the causes of climate change is fundamentally a collective action problem. Though Hawaiʻi is a small GHG emitter on a global scale, on a per capita basis Hawaiʻi residents emit more than twice the global average. In 2018 the State of Hawaiʻi passed Act 15, which set a goal of sequestering more GHGs annually than produced. It aims to do so "as quickly as practicable, but no later than 2045" (HRS §225P-5). This study explores the role of a state-level carbon tax in helping to meet this goal. We use a comprehensive model of Hawaiʻi's economy and GHG emissions through the year 2045 to understand the economic and GHG impacts of different carbon tax rates and ways to use the tax revenue.

WHAT IS A CARBON TAX

A carbon tax puts an explicit price on GHG emissions and many prior studies have found it to be the lowest-cost way to reduce GHGs. A carbon tax is most often levied "upstream" where the smallest number of collection points exist. For Hawaiʻi, a carbon tax could be applied on fossil fuels imported to the State and would cover about 80% of GHG emissions. Such an economy-wide policy would charge fossil fuel imports a fee per unit of GHG - measured in metric tons of carbon dioxide equivalent (MT CO_2 Eq.). The price increase encourages industry and consumers to shift towards activities that result in fewer GHGs. Having an economy-wide approach, rather than a set of sector-by-sector policies, lowers the cost of reducing GHGs because it captures a range of GHG reduction opportunities while harmonizing sectoral interactions; for example, between electrification of transportation and renewable energy in the electricity sector. A carbon tax is more efficient than command-and-control approaches to GHG reduction (such as standard setting and other quota mechanisms) and has the added advantage of potentially being more equitable. The revenue feature of a carbon tax is important, as recycling the carbon tax revenues to households can smooth their transition to a low-GHG economy.

Figure ES-1. How would a Hawai‘i State carbon tax work?



Source: Adapted from Spraggon (2013).

There are many different ways to determine an appropriate carbon price. The concept of the social cost of carbon (SCC) is based on an estimate of the economic damages that would result from emitting one additional ton of GHGs into the atmosphere. Because local GHG emissions become a global pollutant, the SCC should be based on an assessment of the damage to the global environment and global economy. Estimating the full extent of damages is difficult, however, and estimates of the SCC vary. A second approach is to estimate the carbon price that leads to a desired level of GHG reduction consistent with science-based targets and government goals.

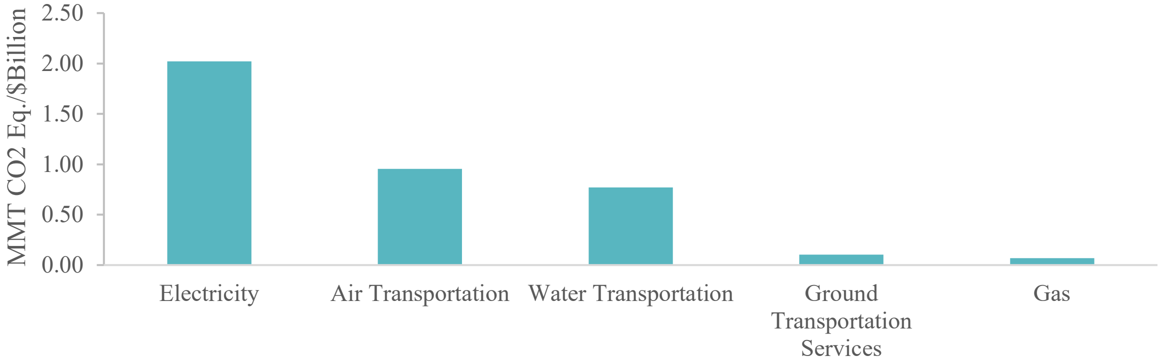
The introduction of a carbon tax generates a new source of government revenues, which can be used for a multitude of purposes – from supporting existing government services to creating new climate-related programs to blunting the impact of higher energy prices on households. Returning the revenues to households has been shown in numerous studies to make taxing carbon a more progressive policy. This means it provides more than proportional benefits to lower-income households. Making the policy progressive can be done through dividend payments of equal shares across households or payments more specifically targeting lower-income households.

HAWAI‘I’S ECONOMY AND GREENHOUSE GAS EMISSIONS

Hawai‘i’s economy produces about $120 billion in annual output ($2012), supporting 860,000 jobs. Because the visitor industry is the largest private sector driver of the economy, the largest employment is in the service sector. Visitor expenditures are about 30% of the value of resident expenditures.

Twenty million metric tons of carbon dioxide equivalent (20 MMT CO_2 Eq.) were emitted in 2016 as a result of economic activity in the State. The vast majority of these emissions came from the combustion of fossil fuels that could be targeted by a carbon tax (16 MMT CO_2 Eq.). Figure ES-2 shows the GHG intensity of Hawai‘i’s energy and transportation services sectors.

Figure ES-2. GHG-Intensity of Energy and Transportation Services Sectors (MMT CO_2 Eq./$Billion)



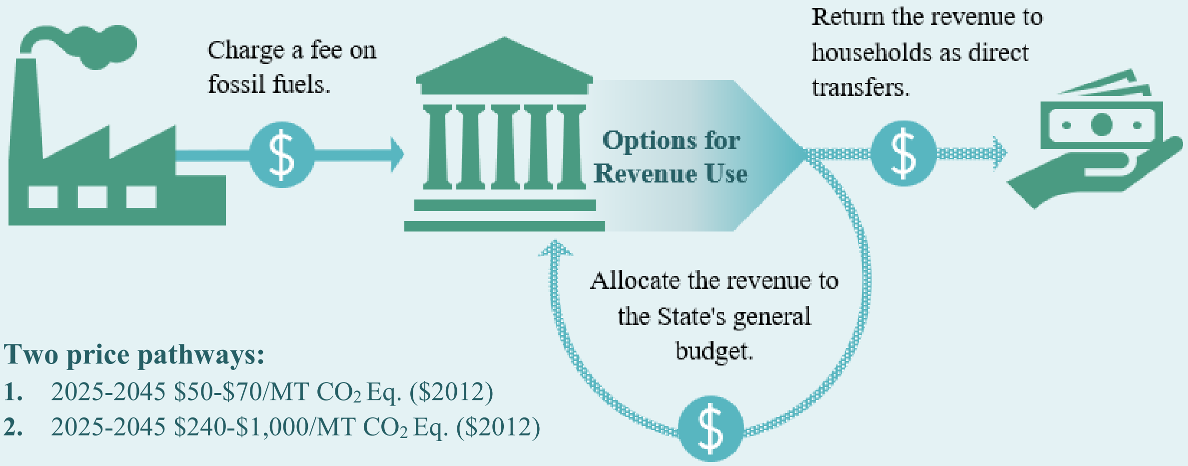
Electricity is Hawai‘i’s most GHG-intensive sector per dollar of output, followed by transportation sectors. Hawai‘i residents expend about 4% of their annual consumption on gasoline for personal vehicle travel, 3% on electricity, 1% on air transportation, 0.4% on water transportation (which includes recreational boating), and 0.1% on gas. These expenditures differ by household income groups. Households in the top income quintile consume twice as much electricity, three times as much ground transportation, and almost 11 times as much air travel as households in the the lowest income quintile. As a percentage of total household expenditures, however, lower-income households spend relatively more on energy sector services. This is most pronounced for electricity, where households in the lowest income quintile spend about 5% of their total expenditures on electricity in comparison to 2% for households in the highest income quintile.

CARBON TAX SCENARIOS

This study uses a state-level economic model that integrates GHG data from fossil fuel usage to assess the economic and GHG impacts of two carbon price pathways and two uses of the revenue. The first price pathway is based on the Obama Administration’s Federal Interagency Working Group on the Social Cost of GHGs – the “federal SCC” (EPA, 2016). Measured in

$2012, this scenario starts at $50/MT CO_2 Eq in 2025, and rises to $70/MT CO_2 Eq, in 2045. The second price pathway investigates a carbon tax level that moves the State substantially towards its goal of deep decarbonization by 2045. This scenario starts at $240/MT CO_2 Eq. in 2025, and increases to $1,000/MT CO_2 Eq. in 2045. We consider two different possible uses of the tax revenues: (1) the state puts the revenues toward existing government services, and (2) the state returns the revenues to Hawai‘i households in equal shares. A baseline scenario, reflecting existing policies and trends, is used for comparison.

Figure ES-3. Carbon Tax and Revenue Recycling Options Considered in this Study



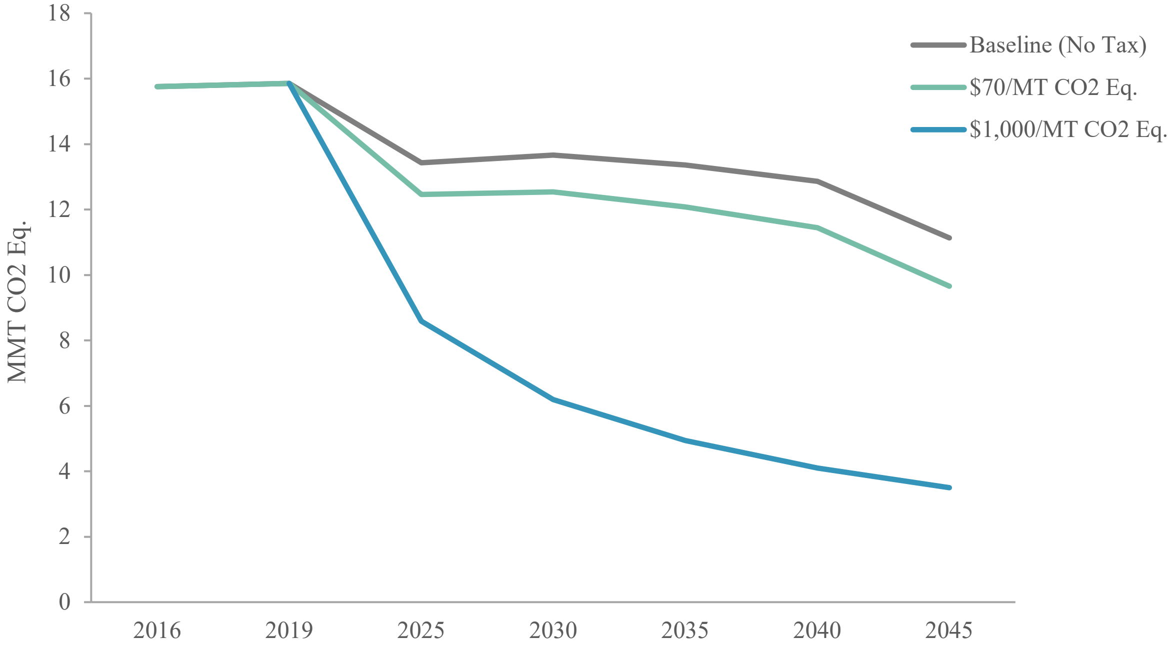
Two price pathways:

1. 2025-2045 $50-$70/MT CO_2 Eq. ($2012)
2. 2025-2045 $240-$1,000/MT CO_2 Eq. ($2012)

KEY FINDINGS

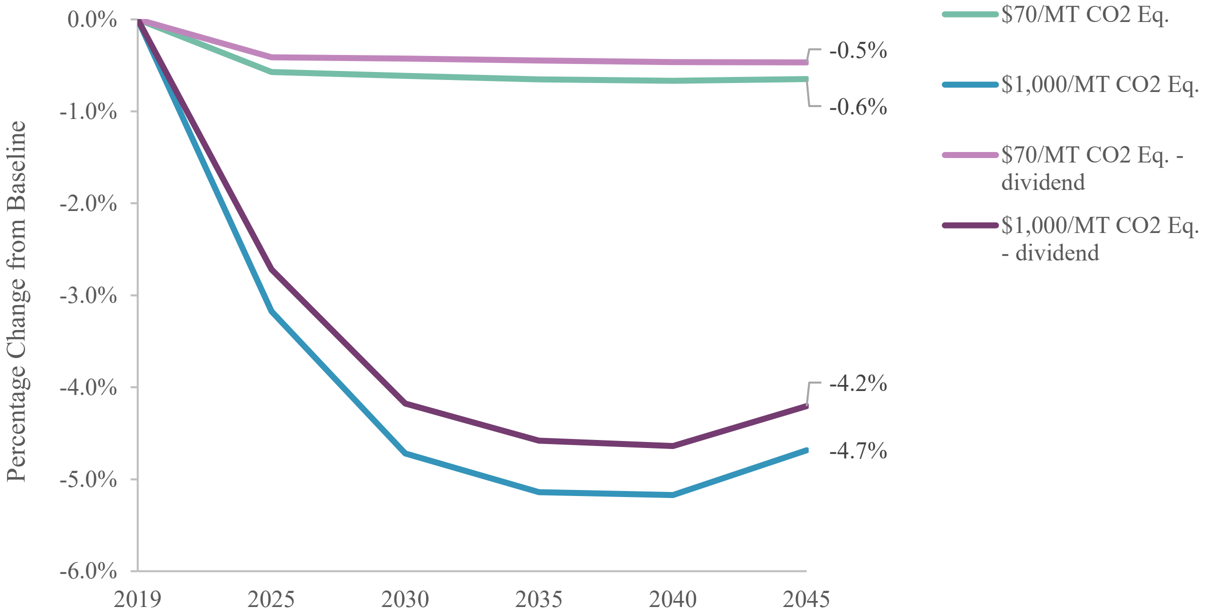
In the baseline scenario without a carbon tax, GHGs are projected to decline over time because of Hawai‘i’s Renewable Portfolio Standard (RPS) and the federal corporate average fuel economy (CAFE) standards. The RPS sets requirements for renewable energy in electricity generation and CAFE sets nationwide targets for increasing light duty vehicle efficiency. A carbon tax that follows the federal SCC reduces cumulative GHG emissions between 2025 and 2045 by 25 MMT CO_2 Eq. In the year 2045, emissions are 13% below 2045 baseline levels and 40% below 2019 levels. A carbon tax that follows the much higher price pathway, reaching $1,000/MT CO_2 Eq. by 2045, reduces cumulative GHG emissions between 2025 and 2045 by 150 MMT CO_2 Eq. In the year 2045, emissions are 70% below 2045 baseline levels and 80% below 2019 levels. As the carbon price approaches $300-$400/MT CO_2 Eq., however, the effectiveness of the carbon tax declines as fewer GHGs are reduced per dollar of tax. Figure ES-4 displays the three GHG pathways: baseline, “$70/MT CO_2 Eq.,” and “$1,000/MT CO_2 Eq.”

Figure ES-4. GHG Emissions in Baseline and Carbon Tax Scenarios, 2016 -2045



A carbon tax set at the federal SCC, i.e., the $70/MT CO_2 Eq. scenario, has small impacts on Hawai‘i’s overall economy. The higher price pathway has large impacts due to a loss of competitiveness for Hawai‘i goods and services. The carbon tax mostly affects exports, but also preferences imports. Visitors pay the carbon tax through the goods and services they consume while in Hawai‘i. The higher costs to visitors leads to a decline in visitor spending; this impact is small in comparison to other export sectors. Figure ES-5 shows the drop in economic output to be around 0.5% in the low price scenarios and over 4% in the high price scenarios. The effects are slightly tempered when revenues are returned to households.

Figure ES-5. Change in Total Output from Baseline under Carbon Tax Scenarios, 2019-2045



For the four scenarios, impacts to household welfare are shown in Figures ES-6 and ES-7 for 2025 and 2045. Under the federal SCC "$70/MT CO_2 Eq." scenario with no dividend, the lowest income household would experience a decrease in spending power of $250 in 2025 and $350 in 2045. For the "$1,000/MT CO_2 Eq." scenario with no dividend this decrease in spending power amounts to $1,700 in 2025 and $3,000 in 2045.

If the revenues are returned to households, the carbon tax becomes much more progressive and benefits all households in the federal SCC "$70/MT CO_2 Eq." scenario. With each household receiving about $1,000 annually, the lowest-income household by quintile sees a $900 and $700 gain in spending power in 2025 and 2045, respectively.

In the higher price pathway, even though households would receive a larger dividend, of about $3,000 annually, this payment is not enough to offset the impacts of the shrinking economy. The dividend still blunts the impact to households, where the lowest income quintile household does see a gain of $1,800 in 2025.

Figure ES-6. Changes in Net Spending Power of Households in 2025 under Carbon Tax Scenarios ($2012)

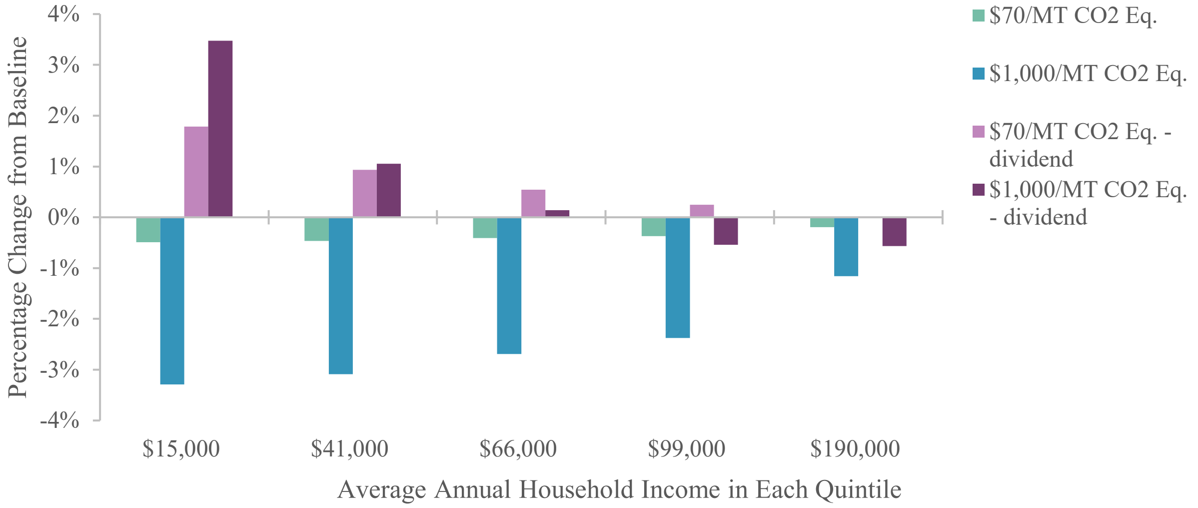


Figure ES-7. Changes in Net Spending Power of Households in 2045 under Carbon Tax Scenarios ($2012)

Placing a carbon tax on fossil fuels will cause energy prices to increase. Figure ES-8 shows these in common metrics. Electricity prices are less affected by a carbon tax than gasoline and gas prices due to the existing RPS policy and the opportunities for cost-effective renewable energy generation. Measured prices reflect “long-run” economic conditions – meaning they are assumed to fully adjust to the carbon tax.

Scenario	Figure ES-8. Changes in Energy Prices		
\$50-\$70/ MT CO_2 Eq.	Gasoline prices will increase by \$0.5/gallon in 2025 and \$0.6/gallon in 2045.	Electricity prices will not increase.	Gas prices will increase by \$0.2/Therm in 2025 and \$0.4/Therm in 2045.
\$240-\$1,000/ MT CO_2 Eq.	Gasoline prices will increase by \$2.2/gallon in 2025 and \$9/gallon in 2045.	Electricity prices will be \$0.08/kWh higher in 2025 and \$0.03/kWh higher in 2045.	Gas prices will increase by \$1.1/Therm in 2025 and \$4.8/Therm in 2045.

MAIN TAKEAWAYS

- If carbon tax revenues are given back to households in equal shares, a carbon tax is progressive – meaning this revenue recycling scheme benefits lower-income households more than proportionately.
- Visitors pay the carbon tax through the goods and services they purchase while in Hawai‘i, and these revenues would be directly transferred to Hawai‘i’s households if a dividend accompanies the carbon tax.
- A high carbon tax that puts Hawai‘i substantially on the path towards achieving deep decarbonization by 2045 (an 80% reduction from 2019 levels) comes at high economic cost. This scenario causes overall declines in household welfare because the high carbon tax causes economic contraction, which dominates other positive effects induced by the tax. This outcome suggests that new technologies must be developed and adopted to cost-effectively meet Hawai‘i’s goal of net negative emissions.
- A carbon tax set at the Obama Administration‘s federal SCC (resulting in a 40% reduction of GHGs from 2019 levels) has small impacts on the overall economy. Moreover, the SCC price represents a commitment to global collective action. Giving revenues back to households in equal shares makes households economically better-off.

I. INTRODUCTION

Human-induced activities are responsible for the majority of greenhouse gas (GHG) emissions that are causing extreme changes in the global climate system (IPCC, 2013). At an increase of approximately 1°C in average global temperature from pre-industrial levels, numerous impacts to natural and human systems can already be observed – from rising sea levels to increasing extreme weather events such as heat, droughts and rainfall. The Intergovernmental Panel on Climate Change (IPCC) predicts that the long-term consequences of warming exceeding 1.5°C will be catastrophic for communities around the world (IPCC, 2018). Moreover, the risks from droughts, temperature extremes and other extreme weather events are expected to be much greater under 2°C of warming. Global mean sea level is predicted to be 0.1 meters lower if the half degree increase can be avoided; which would expose 10 million fewer people to flooding due to sea level rise (IPCC, 2018). As climate change worsens, particularly past the 2°C threshold, there will compounding and potentially runaway effects, such as irreversible glacial melting and loss of the permafrost to the point that methane deposits are released into the atmosphere. In Hawaiʻi, the impacts of sea level rise have been well-studied. A meter of sea level rise is estimated to impact the dwellings of 20,000 people and 40 miles of major roadways (Hawaiʻi Climate Change Mitigation and Adaptation Commission, 2017). The IPCC predicts that, with current global trends, an increase of 1.5°C will be reached between 2030 and 2052 (IPCC, 2018). To stall the global trend at 1.5°C requires achieving net zero GHG emissions by approximately 2050, with rapid decarbonization starting immediately (IPCC, 2018). Despite the efforts made through the United Nations Framework Convention on Climate Change, most recently the 2015 Paris Climate Agreement, global GHG reduction has not achieved the pace demanded by climate science. Even assuming that all countries meet their stated Paris Agreement targets, which aim to limit the rise in global temperature to 2°C at a minimum, the group Climate Action Tracker estimates that the world is on a pathway to reach warming of 2.6°C by 2100 (Climate Action Tracker, 2020).

In its commitments under the Paris Agreement, the U.S. Federal Government pledged to reduce U.S. emissions by about 25% by 2025 compared to 2005 levels. It has not only fallen short on establishing policies to follow-through, but has since changed key policies that allow GHG emissions to increase. For example, lowering the light-duty vehicle fuel-efficiency standards within the updated Corporate Average Fuel Economy (CAFE) standards in the Safer Affordable Fuel Efficient (SAFE) Rule. Though the U.S. officially left the Paris Agreement in November 2020, the withdrawal was short-lived as President Biden immediately re-entered. Without sustained federal leadership to address climate change, however, many U.S. states and cities have moved forward on sub-national climate action. Half of U.S. states, including Hawaiʻi, are members of the U.S. Climate Alliance, committed to implement policies that advance the goals of the Paris Agreement. On a per capita basis Hawaiʻi emits GHGs at more than twice the global average.[1] In 2018 Hawai‘i set the goal of sequestering more GHGs annually than produced. The government was instructed to proceed as quickly as practicable and to meet this goal no later than 2045 (HRS §225P-5). This study explores the role that state-level carbon pricing can play to meet this objective.

Though commonly referred to as ‘carbon pricing,’ the price could be levied on other GHGs as well.[2] Putting an explicit price on GHG emissions is an efficient means of abating GHGs because it directly discourages GHG-intensive activities (Newell and Pizer, 2003; Nordhaus, 2007; Weitzman, 1974). Carbon pricing promotes substitution to less GHG-intensive production processes and consumer behaviors. A recent report of the U.S. Commodity Futures Trading Commission finds that climate change poses serious risks to the U.S. financial system, and recommends an economy-wide price on carbon as the proper policy instrument to facilitate efficient allocation of resources by financial markets (Climate-Related Market Risk Subcommittee, 2020). Governments generally have a choice between two mechanisms to establish a price on GHG emissions: a carbon tax or cap-and-trade system. The carbon tax is more straightforward, as government levies a predetermined price per unit of GHG. The price is most often reported in dollars per metric ton and reflects the global warming potential of the various GHGs expressed in carbon dioxide equivalence (MT CO_2 Eq.). Carbon taxes can be levied upstream, e.g., at the point of importing a barrel of crude oil, or downstream, e.g., at-the-pump. Because of the much smaller number of entities, it is generally thought to be less administratively burdensome to target upstream sources. While a carbon tax provides price certainty to energy users, a cap-and-trade system provides “quantity certainty” with respect to reaching a specific amount of emissions.[3]

This study analyzes how pricing carbon through an upstream tax would affect Hawai‘i’s GHG emissions and economy. We focus on a tax for two reasons. First, cap-and-trade systems tend to have higher administrative burdens and require a sufficiently large number of participants to avoid manipulation of the allowance market. Hawai‘i’s relatively small market size and small number of market participants pose challenges for a cap-and-trade system; though Hawai‘i could choose to join California in the Western Climate Initiative to overcome administrative and

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[1] Figures based on global emissions estimates from the Climate Watch data explorer (2020), State emissions from ICF & UHERO (2019), global population from the World Bank (2020), and State resident population from DBEDT (2019).

[2] Policies generally concentrate on carbon dioxide or carbon emissions because they comprise the vast majority of GHG emissions and are most relevant to the energy sector.

[3] Some cap-and-trade systems award emission permits to specified users while other systems allocate them via auction. A full auction system, assuming that the prices are harmonized, make cap-and-trade systems more akin to carbon taxes from the perspective of government revenue. Cap-and-trade programs often adopt price constraints which, if reached, mean that the program operates comparably to a carbon tax.

market size hurdles.[4] Second, and more importantly, our study focuses on GHG emissions and economic impacts – not on the details of potential administrative structures. When similarly implemented, the two methods of pricing carbon yield similar results. Thus, the results of this study can be used to understand the high-level economic and GHG impacts of pricing carbon using either a carbon tax or cap-and-trade system.

To better understand the impact of carbon pricing on Hawaiʻi's GHG emissions and economy over the next 25 years, we use a state-level computable general equilibrium (CGE) model. The Hawaiʻi-CGE (H-CGE) model builds on the State of Hawaiʻi's *2012 Input-Output (I-O) Study* and the *Hawaiʻi Greenhouse Gas Emissions Report for 2016* (DBEDT, 2016; ICF & UHERO, 2019). A general equilibrium framework is the best approach to study the impact of carbon pricing because it is designed to incorporate inter-linkages between sectors and consumers with full price feedbacks. We develop an understanding of Hawaiʻi's existing policies and trends in order to project the H-CGE model to the year 2045, providing a reasonable baseline by which to compare carbon tax scenarios. Though there is a wide range of carbon price paths for which we could solve the model, we focus on two. The first is set at the social cost of carbon (SCC) adopted by the Federal Interagency Working Group on the Social Cost of Greenhouse Gases (EPA, 2016). It starts at \$50/MT CO_2 Eq. in 2025 and increases to \$70/MT CO_2 Eq. by 2045 in \$2012 (U.S. GAO, 2020).[5] The argument for the use of SCC is that the carbon price should be set based on the net benefit of mitigating global damages from GHG emissions. An alternative approach to setting carbon prices is based on environmental targeting – meaning setting prices on a path to achieve the stated emissions reductions goal (Metcalf, 2017; Kaufman et al., 2020a). As such, our second price pathway investigates a carbon tax level that moves the State substantially towards its goal of deep decarbonization by 2045. This price pathway starts at \$240/MT CO_2 Eq. in 2025 and increases linearly to \$1,000/MT CO_2 Eq. in 2045.

There is extensive literature showing the efficiency of carbon pricing as a GHG abatement strategy in comparison to command-and-control approaches (referring to standards, prohibition, and other quota mechanisms). However, carbon pricing has faced objections on the grounds that it disproportionately impacts lower-income populations (i.e. is *regressive*). This perspective stems from the notion that excise taxes (including a carbon tax) drive up prices, and since energy goods generally comprise a larger proportion of lower-income households' budgets, carbon pricing will be regressive (Metcalf, 2019a). This perspective only incorporates demand-side

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[4] If Hawaiʻi were to join the Western Climate Initiative and link with California's program, sources covered by the GHG cap would need to be clearly defined along with the annual declines in the cap. Joining the Western Climate Initiative would allow Hawaiʻi to use existing administrative infrastructure provided by the Initiative, such as personnel to run the quarterly auctions and a registry to hold the allowances.

[5] Unless noted otherwise, all dollar figures are in \$2012.

effects and fails to account for the distribution of newly available revenues. If the government returns carbon tax revenues to households, the policy could relatively benefit lower income households (i.e. be *progressive*). To address this for Hawai‘i, we separate available data on expenditures for a representative household in Hawai‘i into five income categories. We run two book-end scenarios on the use of government revenues: 1) where revenues are used for general government expenditures; and 2) where revenues are given back to households in equal shares. This allows us to assess the distributional and welfare impacts of the carbon price contingent on the use of tax revenues. In addition, we estimate the marginal cost of GHG abatement over a range of GHG reduction targets. For all scenarios, we present results for changes in GHGs, impacts to the macroeconomy and household welfare.

II. A PRIMER ON CARBON PRICING

Carbon pricing is a catch-all term for policy mechanisms that create an explicit price for GHG emissions for the purpose of internalizing the negative externalities arising from GHG emissions. In comparison to indirect policies like technology mandates, performance standards or renewable energy subsidies, carbon pricing is more cost effective per unit of GHG reduction (Goulder and Schein, 2013; Fischer et al., 2017). Often regulatory policies are less effective because they fail to address total emissions directly, and instead target a proxy for emissions (e.g., vehicle miles traveled) or the rate of emissions (e.g., emissions per unit of electricity generated). Carbon pricing also addresses both new technologies and the ongoing use of fossil fuels. Moreover, command-and-control regulations can be regressive to households while prior studies on carbon pricing show it can be progressive (Metcalf, 2019a). Carbon pricing can be implemented economy-wide, serving to capture GHG reduction opportunities in multiple sectors and harmonize the marginal cost of abatement among sectors.

Implementation at the national level is more effective than implementation at the state or regional levels (Goulder, 2013; Metcalf, 2009; Newell and Pizer, 2003; Nordhaus, 2007; Stavins, 2008). By covering a broader geographic and political region, a national carbon tax lessens issues of leakage – meaning the transfer of GHG emissions from the regulated jurisdiction to an unregulated or lesser-regulated jurisdiction to avoid the policy. A carbon tax levied at the federal level could also lessen leakage through a trade adjustment mechanism; for example, a border carbon adjustment or output-based rebates (Fowlie and Reguant, 2020; Kaufman et al., 2020b). These mechanisms would also address issues relating to loss of domestic competitiveness.

WHAT PRICE? IN THEORY AND IN PRACTICE

Whereas in cap-and-trade programs the carbon price is determined by the market for permits to emit GHGs, a carbon tax requires the government to set a dollar per ton price on GHG emissions. Imposing a carbon tax rate designed to increase over time sends a price signal to emitters that adopting less GHG-intensive technologies is economically sensible while also allowing time to adjust to the higher tax rate required to achieve targeted emissions reductions.

The SCC is theorized to be the global carbon price that maximizes net benefits to society because it forces market participants to consider both private and social costs associated with burning fossil fuels. Implicit in the idea of the SCC are two market failures associated with climate change: negative pollution externalities and free-riding in the provision of a global public good. A negative pollution externality is a market failure that arises when costs imposed on society are not being fully accounted for within market exchanges. A Pigouvian tax is a per unit tax to correct for the gap between private and societal costs, *internalizing* the externality within the market. Free-riding is a market failure that happens in the provision of a public good, in this case global climate, where individual actors have incentive to shirk on taking action to provide the public good. This market failure makes responding to climate change a collective action problem, where commitments by countries and regions to mitigate GHGs need to be coordinated and monitored.

The Obama Administration's Interagency Working Group on the Social Cost of GHGs combined the results of several different integrated assessment models (IAMs), which are global economic models that incorporate a damage function that increases with the accumulation of GHGs in the atmosphere (U.S. EPA, 2016). The SCC estimates of \$50-\$70/MT CO_2 Eq. between 2025-2045 are based on estimates of global scale damages given that GHGs are a pollutant that knows no national border, i.e., an acknowledgement of global climate as a public good. The damage function includes changes in agricultural productivity, impacts to human health, and property/livelihood damages due to increased flood risk and extreme weather events (U.S. EPA, 2016). It is widely acknowledged though that IAMs tend to underestimate damages, as they do not include a complete assessment of physical, ecological, and human impacts (U.S. EPA, 2016; Nordhaus and Moffat, 2017). IPCC (2014) critiques that damage assessments of climate change used in developing SCC estimates have tended to be too low, thereby rendering existing SCC estimates to also be too low. Developing more precise estimates of global damages is a topic for continued research (IPCC, 2014). Better incorporating uncertainty will also lead to considerably higher estimates of global SCC (Cai et al., 2013; Ricke et al., 2018). SCC estimates are quite sensitive to the chosen discount rate, which can be understood as a rate of time preference. The Interagency Working Group adopted a baseline discount rate of 3%; a larger discount rate would reduce the SCC given that less weight would be put on the benefits of GHG emission reductions that occur far into the future and vice versa.[6] Germany's estimates of the path of the SCC over the next three decades reflect discount rates that change over time based on the level of projected economic growth (U.S. GAO, 2020).

Rather than try to determine damage costs that are inherently uncertain, an alternative approach is to set carbon tax rates to achieve emissions targets. Kaufman et al. (2020a) argue for using the best available science to identify a net-zero GHG emissions target date, selecting an emissions path to reach the net-zero target, and estimating carbon prices consistent with achieving this emissions path in the near-term. As an example, with a 2050 net-zero emissions target for the United States, Kaufman et al.'s approach results in carbon prices ranging from \$34 to \$64/MT CO_2 Eq. in 2025 and \$77 to \$124/MT CO_2 Eq. in 2030, depending on whether complementary policy instruments are in place (see below) and on the future projected path of world oil prices (Kaufman et al., 2020a). For comparison, the IPCC (2018) estimates that to limit global warming to 1.5°C, the marginal abatement cost of GHGs[7] need to be between \$130/MT CO_2 Eq. and

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[6] The Trump Administration re-interpreted the SCC estimates to focus on domestic damages only. It also chose a much higher 7% rate of discount. This brought the federal estimate of the SCC to an incredibly low level, just \$11 in 2020 (\$2018). The U.S. Government Accountability Office criticized the new SCC estimates as being misaligned with the National Academies of Sciences recommendations (U.S. GAO, 2020).

[7] The cost of mitigating one additional MT CO_2 Eq.

approximately \$700/MT CO_2 Eq. by the year 2030.[8] The wide range represents varying pathway assumptions regarding energy prices, technologies, demand, and selected mitigation targets, as well as differences in modelling approaches. In all pathways, achieving the 1.5°C goal requires immediate and large reductions of GHGs (IPPC, 2018).

There are numerous international examples of carbon pricing schemes, and most implement carbon prices at rates lower than calculations of the SCC. The first surge of carbon tax implementations occurred in the early 1990s in Denmark, Finland, Norway and Sweden (Metcalf, 2019b). The mid-2000s saw a second surge in Switzerland, Iceland, Ireland, Japan, Mexico and Portugal as well as in the Canadian provinces of British Columbia and Alberta. The first major cap-and-trade program was the European Emissions Trading System (ETS). As of May 2020, there were 61 carbon pricing programs worldwide implemented or planned that covered roughly 22% of global GHG emissions (World Bank Group, 2020). Twenty-nine are carbon tax programs and 32 cap-and-trade programs. Carbon tax rates vary widely, from less than \$1/MT CO_2 Eq. to Sweden's \$119/MT CO_2 Eq. More than half of emissions covered have carbon prices under \$10/MT CO_2 Eq. (World Bank Group, 2020) and are much lower than the minimum price range needed to reach the country emission targets set by the Paris Agreement (World Bank Group, 2017).

Within North America there are 18 carbon pricing programs, as detailed in Table 1. Mexico has a small \$3/MT CO_2 Eq. carbon tax. In 2018 Canada passed a federal-level carbon tax program for provinces that have not initiated their own program. It sets a minimum standard and is still in implementation. There is no federal-level carbon tax in the United States. Within the United States and Canada, numerous sub-national programs have emerged. The longest standing is the Regional Greenhouse Gas Initiative (RGGI), a cooperative cap-and-trade program for the electric power sector between ten Northeastern U.S. states (RGGI, 2020). It applies to fossil-fuel plants larger than 25 MW and covers roughly 19% of CO_2 emissions in RGGI states (CRS, 2019). Another large program is the Western Climate Initiative, which links California's cap-and-trade program with the Canadian province Quebec.

Table 1. Carbon Pricing Programs in North America

Program	Year Initiated	Sectors and/or fuels covered	Share of jurisdiction's GHG emissions covered	2020 Carbon Price (\$2020)
Carbon Tax Programs				

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[8] Abatement cost estimates are based on figure 2.26 in IPCC (2018) and are translated using Data Thief (Tummers, 2006). The range references the "Below 1.5 °C" scenario with no temperature overshoot and a 5% discount rate to 2020 in \$2010.

British Columbia carbon tax	2008	GHG emissions from all fossil fuels in all sectors with some specific exemptions.	70%	US$30/MT CO_2 Eq.
Canada GHG Pollution Pricing Act - federal fuel charge	2019	GHG emissions from all sectors with some specific exemptions. Includes emissions from waste-to-energy facilities.*	19%	US$22/MT CO_2 Eq.
Mexico carbon tax	2014	CO2 emissions from fossil fuels except natural gas.	46%	Upper: US$3/MT CO_2 Eq. Lower: US$0.38/ MT CO_2 Eq.
New Brunswick carbon tax	2020	GHG emissions from all fossil fuels in all sectors with some specific exemptions.	39%	US$21/MT CO_2 Eq.
Newfoundland and Labrador carbon tax	2019	GHG emissions from all fossil fuels in all sectors with some specific exemptions.	47%	US$15/MT CO_2 Eq.
Northwest Territories carbon tax	2019	CO2 emissions from all fossil fuels.	79%	US$15/MT CO_2 Eq.
Prince Edward Island carbon tax	2019	GHG emissions from all fossil fuels in all sectors with some specific exemptions.	44%	US$22/MT CO_2 Eq.
Cap-and-trade Programs				
Alberta TIER	2007	All GHG emissions from the industry and power sectors except for industrial process emissions.	48%	US$22/MT CO_2 Eq.
California CaT*	2012	GHG emissions from the industry, power, transport and building sectors, including industrial processes.	85%	US$15/MT CO_2 Eq.
Canada GHG Pollution Pricing Act - Output Based Pricing System	2019	GHG emissions of all electricity generation and industrial facilities that emit >50 ktCO2e/year. The price is an excess emissions charge for non-compliant emitters. Compliance can also be met with offset credits and surplus OBPS credits from other facilities.	9%	USD$23/MT CO_2 Eq.*

Massachusetts ETS	2018	CO2 emissions from the power sector.	20%	US$8/MT CO_2 Eq.
Newfoundland and Labrador PSS	2019	GHG emissions from facilities that emit > 10,000 tCO2e/year in the industry and power sectors.	43%	USD$23/MT CO_2 Eq.**
Nova Scotia CaT	2019	GHG emissions from facilities that emit >50,000 tCO2e, produces or distribute >200 l of fuel, distribute natural gas that emits >10,000 tCO2e, or import electricity that emits >10,000 tCO2e in a compliance year, covering the industrial, electricity, transport and heating sectors.	80%	US$18/MT CO_2 Eq. *
Quebec CaT	2013	GHG emissions from the industry, power, transport and building sectors, including industrial process emissions.	85%	US$15/MT CO_2 Eq.
RGGI	2009	CO2 emissions only from the power sector.	18%	US$5/MT CO_2 Eq.

Source: World Bank Carbon Pricing Dashboard 2020. Available at https://carbonpricingdashboard.worldbank.org/

* California's Cap-and-Trade Program is currently linked with that of Quebec through the Western Climate Initiative.

** Price converted to USD assuming a conversion rate of 0.76.

*** The Regional Greenhouse Gas Initiative (RGGI) is a cooperative effort among the states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont. Massachusetts also has a stand-alone ETS program covering portions of the power sector.

Among the existing programs in North America, carbon prices span a broad range, from RGGI's modest $5/MT CO_2 Eq. to British Columbia's $30/MT CO_2 Eq. In addition, some programs focus on specific sectors and therefore cover a narrow proportion of emissions, while others, like British Columbia's program, cover much more of the economy. California's cap-and-trade program has had prices ranging from about $11-$18/MT CO_2 Eq. (CARB, 2020). These auction prices have been criticized as being artificially low due to other sector-focused policies that undercut the carbon price signal (Borenstein et al., 2019). If a carbon tax were to encompass the entire United States, an estimated 75-85% of emissions could be covered by targeting energy sectors (Metcalf, 2017; Metcalf and Weisbach, 2009).

HOW EFFECTIVELY HAVE EXISTING PROGRAMS REDUCED GHG EMISSIONS?

The efficacy of a carbon price depends on the level of the price signal. British Columbia's carbon tax—the only long-standing carbon tax in North America—started at US\$10/MT CO_2 Eq. in 2008 and increased to US\$30/MT CO_2 Eq. by 2012. Metcalf (2019b) finds that the carbon tax resulted in a 5-8% emissions reduction since its implementation compared to Canadian provinces without a carbon tax. Murray and Rivers (2015) find similar results, a 5-15% reduction. Rivers and Schaufele (2015) examine how British Columbia tax affected gasoline consumption, and find emissions fell by 2.4 MMT CO_2 Eq. in the first four years. Moreover, they find that the carbon tax is more salient—meaning consumers respond with a larger change in demand—than equivalent changes in the price of gasoline. At a carbon tax of \$25/MT CO_2 Eq., gasoline consumption falls by four times more compared to an equivalent increase in the price of gasoline. Consumers respond differently to taxes versus supply shocks because taxes have more lasting effects on prices.

In Europe, Boqiang and Xuehui (2011) find that all but one of the early implementing countries, including the Scandinavian countries and the Netherlands, had lower GHG emissions per capita than other European countries where carbon taxes have not been implemented. The exception is Norway, which experienced a slight increase due to a growing oil and gas industry. Only Finland's carbon tax resulted in significant reductions in GHG emissions because the tax covered a broader range of emission sources. Other countries exempted GHG-intensive industries to a greater degree. Two studies also find carbon taxes yielded a modest GHG reduction in Scandinavian countries (Bruvoll and Larsen, 2002; Bohlin and Rosenqvist, 1998; Bjørner and Jensen, 2002). The small impacts identified by these empirical studies is unsurprising given the low carbon tax rates and/or extensive tax exemptions for certain GHG-intensive industries. These studies illustrate the importance of policy design, specifically how it relates to establishing an effective tax rate and appropriate sectoral coverage. Barron et al. (2018) find that an economy-wide carbon tax at US\$50/MT CO_2 Eq. escalating 5% annually over a decade would reduce U.S. emissions by 26-47% compared to 2005 levels.

The overall impact of a sub-national carbon tax also depends on its susceptibility to leakage. Raising the cost of GHGs in one region can result in an increase in emissions from GHG-intensive activities in regions without a carbon pricing program. Leakage occurs in national programs but tends to be amplified in sub-national programs. For example, Bistline et al. (2018) found that with low natural gas prices and no border carbon adjustments, sub-national carbon pricing programs in Canada could result in leakage of 76% of GHG emissions in the electric sector. Leakage of this magnitude is unlikely in Hawaiʻi's electric sector as all generation occurs in Hawaiʻi. However, should a carbon tax shift electricity generation away from oil and towards biofuels there could be substantial leakage related to changes in upstream land use from feedstock production to biofuel production (Murray et al., 2014). There are also opportunities for leakage of GHG emissions from Hawaiʻiʻs transportation sector, discussed in later sections.

CARBON TAX AND HOUSEHOLD IMPACTS

A commonly stated reservation about carbon pricing is that it may result in regressive policy effects (Farrell, 2017; Wang et al., 2016). This means that the burden of the policy intervention increases as income decreases. Conversely, a progressive policy is one where its burden decreases as income decreases. A typical measure of welfare change as a result of a policy intervention that changes prices is "equivalent variation;" this metric is used to understand the distributional impacts of carbon pricing (Goulder et al., 2019). There are two sides of the equivalent variation calculation: "use" and "source" side impacts. "Use-side" impacts focus on increases in the costs of goods and services purchased by households. It is well-documented that carbon pricing is regressive when only "use-side" effects are considered (Burtraw et al., 2009; Hassett et al., 2009; Rausch et al, 2011; Dissou and Siddiqui, 2014; Goulder et al., 2019). "Source-side" impacts include changes in wages, capital and transfer income and are typically progressive because carbon pricing reduces returns to capital, which primarily accrue to higher-income households.[9] Calculations incorporating "source-side" impacts show that carbon pricing can be progressive, even when ignoring how carbon-tax revenues are recycled (Goulder et al., 2019; Williams et al., 2015; Rausch et al., 2011). Sajeewani et al. (2015) finds similar results using a CGE model for Australia with a A$23 carbon tax. Examining ten household income deciles, they find that even without considering impacts of revenue recycling, the carbon tax results in a neutral to mildly progressive tax incidence. Beck et al. (2015) use a CGE model to study British Columbia's carbon tax and also find its overall impact to be progressive.

Lastly, many studies focus on the welfare impacts of carbon pricing schemes in isolation and therefore lack insight on the impacts in comparison to other policy approaches. Several studies show that carbon pricing tends to be more progressive than other GHG and energy policies (Metcalf, 2019a). Borenstein (2017) finds that the benefits of the U.S. federal tax credit for solar photovoltaic installation accrues to high income households in California. Similarly, Borenstein and Davis (2016) find that 60% of federal income tax credits for weatherizing homes, installing solar panels, and buying hybrid and electric vehicles went to households in the top 20% of the U.S. income distribution. For the federal electric vehicle tax credit, 90% of credits were paid to households in the top income quintile. Notable studies have shown that command-and-control type regulation like CAFE standards and energy standards in building codes are regressive (Bruegge et al., 2019; Davis and Knittel, 2019; Jacobsen, 2013; Metcalf, 2019a).

EFFECTS OF REVENUE USE

By explicitly putting a price on carbon, a carbon tax generates a new source of government revenue. The use of the revenues, however, has arisen as a point of contention in policy design

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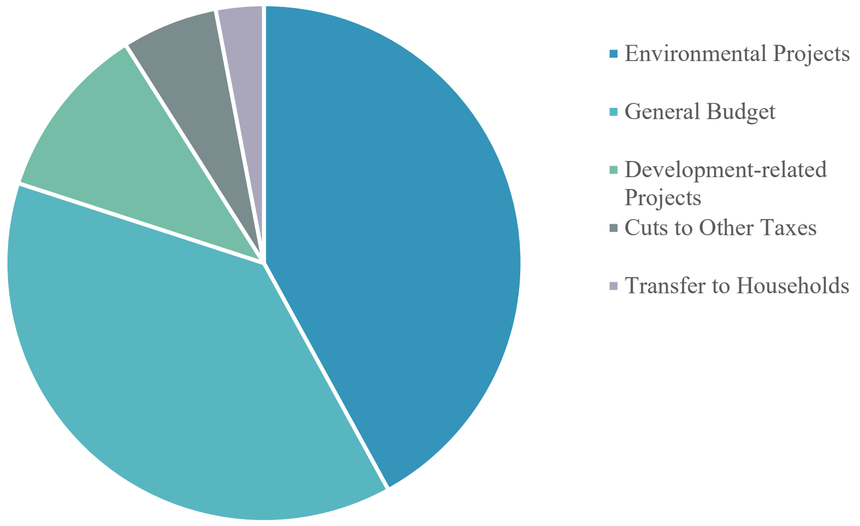
[9] In most cases, the progressive source-side effect only dominates the regressive use-side effect if the cost of the carbon tax falls primarily on capital rather than labor.

(Kotchen et al. 2017, Marron & Morris, 2016). As illustrated in Figure 1, carbon pricing revenues tend to be allocated either to the general budget or specific government programs (World Bank Group, 2019). Like other tax policies outside of the energy sector, the use of revenues is important not only to policy implementation but also to building long-term support for the carbon tax (Rabe, 2018).

Figure 1. 2017/2018 Global Carbon Revenue Use



Source: Adapted from World Bank (2019).

Revenue redistribution towards households makes carbon pricing a more progressive policy (Goulder, 2013, Goulder et al., 2019). Goulder et al. (2019) find that even households with the lowest income (by quintile) on average would experience net welfare gains from a U.S. carbon pricing policy if revenues are returned to households. The revenue portion of the policy can be designed such that household dividends tilt towards low-income households, thereby making it more progressive. Studies show that even equal per-capita redistribution can be a progressive policy (Metcalf, 2019a). This is because higher-income households spend more on energy than they receive as dividend payments. Revenues can be returned to households either in the form of a payout dividend (e.g., proportional shares) or a reduction in other taxes such as income or payroll taxes. Revenue recycling in the form of a reduction of other taxes follows a "double dividend" hypothesis, positing there are efficiency gains from correctly pricing pollution externalities and lowering other distortionary taxes (Goulder, 1995). Assessing a variety of revenue recycling options for a simulated U.S. carbon tax, Goulder et al. (2019) find that policy design is most progressive when all revenues are given back to households in equal-share lump-sum dividends, followed by payroll tax and income tax deductions. The most important feature of any payout mechanism is that the value of the payout be determined independent of household consumption of energy goods and services. Any linkage would distort incentives to reduce consumption of GHG-intensive goods and services.

National surveys have found that how a carbon tax is framed, including revenue uses, is important to public support or opposition (Fitzpatrick et al., 2018; Amur et al., 2014). The University of Michigan and Muhlenberg College have conducted nationally representative biannual surveys on carbon taxes since 2009, with their most recent survey administered in 2017. Though generally the majority of respondents indicate they support a carbon tax (in 2017, 20% "strongly support" and 27% "somewhat support"), 31% were "strongly opposed" (Fitzpatrick et al., 2018). When revenue uses are specified to support renewable energy research and development or payouts to households as an income tax rebate, overall support for a carbon tax increases in comparison to when revenue use is not specified. Support for a carbon tax fell when it was specified that carbon tax revenues will be used to pay down government debt.[10] The Yale Program on Climate Change Communication has found that Hawaiʻi residents are about 8% more likely to support the statement, "Require fossil fuel companies to pay a carbon tax," than the national average (Marlon et al., 2020). The Nature Conservancy Hawaiʻi Chapter conducted a public opinion survey among Hawaiʻi residents in June/July 2020 regarding their views on a carbon tax as a mechanism to address climate change. When asked to choose between revenue uses, a majority, 61%, preferred to invest the revenue in projects to reduce and deal with the effects of climate change in Hawaiʻi, while 26% preferred to refund the money to the public through tax credits or dividend checks (Nature Conservancy Hawaiʻi, 2020).

OVERLAPPING POLICIES – COMPLEMENTARY OR COMPETING?

Layering multiple climate change policies can result in a full spectrum of outcomes, from being complementary to redundant and, at worst, competing. Complementary policies achieve a separate policy objective, enhancing the benefits of carbon pricing. Redundant policies achieve little to no additional GHG emissions reductions and add costs to society compared to using a carbon tax alone. Competing policies undermine the policy objective and the efficacy of carbon pricing. Table 2 orders climate-related policies on a scale of whether they complement, duplicate, or compete with a state-level carbon tax.[11]

Table 2. State Carbon Tax Interaction with Other Climate and Energy-Related Policies

Lessens the societal cost of achieving a GHG emissions	Increases the societal cost of achieving a GHG emissions	Undermines the effect of a state carbon tax

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[10] Similarly, Amur et al. (2014) find in the absence of information about how revenues will be used, over two-thirds of Americans oppose a carbon tax (Amur et al., 2014). However, when asked specifically about how the revenue should be used, 56% support a revenue-neutral carbon tax with a dividend, while 60% support a carbon tax in which revenues are used to fund research and development for renewable energy programs. Only 38% were supportive of using carbon tax revenue to reduce the federal deficit.

[11] In reality, these interacting policies do not fall into discrete categories but are situated on a spectrum. National carbon pricing programs can similarly suffer or benefit from either redundant or complementary policies, as discussed in Gundlach et al. (2019).

reduction target when coupled with a state carbon tax	reduction target when coupled with a state carbon tax	
Complementary	**Redundant**	**Competing**
Regulations of GHG emissions not covered by the carbon tax	Regulations of GHG emissions covered by the carbon tax	Federal Corporate Average Fuel Economy standards*
Public infrastructure supporting low carbon transportation and land use	Federal carbon pricing policies	Federal fossil fuel subsidies
Regulation of local air pollutants	Federal or state renewable or low-carbon fuel standards	
Energy efficiency standards and programs (at a per unit level, e.g. each A/C unit must have a particular efficiency)	Federal or state subsidies for low GHG technologies (purchase or production)	
Funding research and development in low carbon programs and technologies	State renewable or clean electricity standards	
	State or county fuel excise taxes	

Note: This assessment is modified from Gundlach et al.'s (2019) analysis of policy interaction with a U.S. federal-level carbon tax.

**Because CAFE is implemented as a national fleet-wide average.*

Complementary policy mechanisms are needed to reduce GHGs further than what would occur with a price signal alone due to the existence of multiple market failures (Jenkins, 2014; Bataille et al., 2018; IPCC 2018). While a correctly set carbon price would address the market failure stemming from GHG pollution (i.e., correcting the negative pollution externality), it is by itself insufficient to address three other sizeable market failures. First, there is a market failure around energy-related research and development because the resulting outputs—new technologies—are public goods (Gundlach et al., 2019; IPCC, 2018; Metcalf, 2019). Fischer and Newell (2008) show that the optimal policy to reduce emissions entails a portfolio of policy instruments aimed not only at emissions but also complementary technology-related policies that target learning-by-doing, research and development. Second, market failures associated with underinvestment in energy efficiency also merit separate approaches. This market failure is due to the "principal-agent" problem, which in this context describes the difficulty in properly coordinating incentives among developers, landlords, and tenants (Fischer et al., 2017). Lastly, the carbon tax does not necessarily lead to development of new public infrastructure and changes in land use that support less GHG-intensive transportation types, such as high-occupancy transit vehicles and bike infrastructure. Addressing provision of such public goods is an important role for municipal government.

Overlapping, redundant policies add to compliance costs, thereby increasing the overall cost of GHG abatement (Fischer et al., 2017; Metcalf, 2019b). The smaller the additional emissions reductions and the greater the additional cost, the more redundant the policy (Gundlach et al. 2019). While a purely economic argument would point to streamlining policy approaches and eliminating additional costs, Gundlach et al. (2019) argue that policymakers may not want to eliminate certain redundant policies if they serve as "backstops." This means that the policy would ensure a certain amount of emissions reductions are achieved even if there is a "change of political winds" regarding the carbon tax. An example is Australia's carbon tax that was introduced in 2012 and repealed in 2014 (Sajeewani et al., 2015). As legal challenges are settled, however, there may be less need for backstop policies. In addition, whether redundant policies might be kept or omitted depend on their specific interactions with the carbon tax as well as cost burdens. The presence of redundant back-up policies can also reduce incentives for various interest groups to support a carbon pricing policy when they gain more under backstop policies; this can undermine an otherwise durable carbon pricing policy.

At worst, overlapping policies can compete against each other and are a barrier to achieving GHG reductions. The current federal CAFE standards are the most illustrative example of a federal policy that undermines sub-national efforts to increase low carbon transportation options. CAFE requires manufacturers to achieve a fleetwide average fuel economy of 54.5 miles per gallon by 2025.[12] By its design, "overcompliance" in one state, for example through a zero-emission vehicle mandate or a vehicle purchased as a result of the federal tax credit for EVs, effectively decreases the number of high efficiency vehicles required to be sold elsewhere. As bluntly stated by Metcalf (2019b): "For every Chevrolet Volt bought in Massachusetts in part because of the federal credit, General Motors can now sell a gas-guzzling car to someone else." Having a state waiver to CAFE, like in California, does not change inclusion in the national target. This means that sub-national GHG policies affecting the transportation sector, including a state-level carbon tax, will suffer from almost 100% leakage with respect to the kinds of vehicles purchased (Linn and McConnell, 2019).

Subsidies for low-GHG technologies and overlapping command-and control type policies are redundant at best. At their core, subsidies for low-GHG technologies lower the price of energy rather than raise it. The lower price leads to more energy use and makes investment in efficiency less attractive (Metcalf, 2019b).[13] In extreme cases, subsidies can lead to perverse outcomes that

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[12] CAFE standards have since been rolled back under the Trump Administration‘s Safe Affordable Fuel Efficient (SAFE) Vehicle Rule. States are currently fighting this in courts. The concept of a national averag remains the same.

[13] This is relevant to both the eletrricity and transportation sectors.

increase emissions; for example, with biofuels produced in deforested areas (Murray et al., 2014).

Overlapping command-and-control type mechanisms include mechanisms like an RPS or low carbon fuel standard. These policies add additional compliance costs relative to the carbon price, which can also have regressive distributional effects. Greenstone and Nath (2020) find that U.S. state RPSs have lowered GHG emissions by 10-25% and have increased electricity prices by 11%. The implicit carbon price of the U.S. states' RPS policies range from $60-$300/MT CO_2 Eq. and is most often above $100/MT CO_2 Eq. ($2020). When both a carbon tax and an RPS are implemented, a carbon tax is always binding in the sense that GHG emissions face a price regardless of the RPS level. At high enough carbon prices, the RPS is non-binding and has no impact on GHGs.

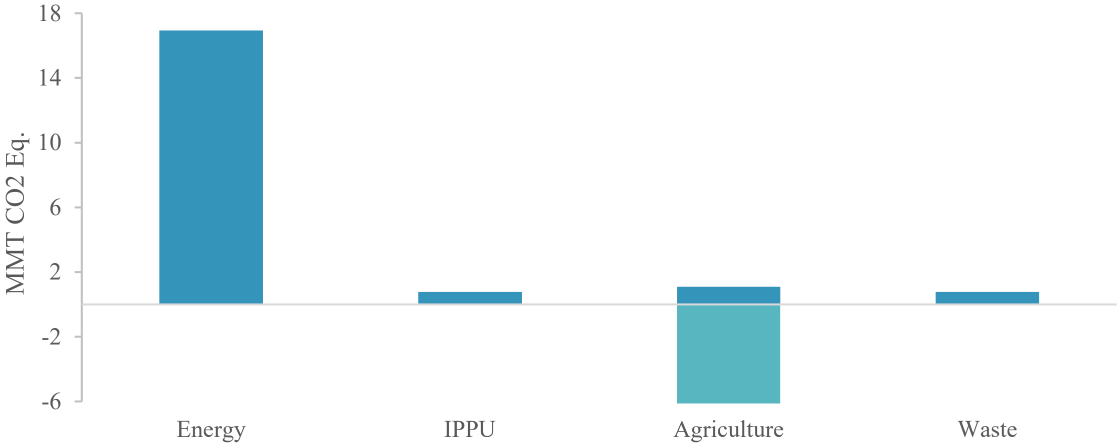
THE ROLE OF CARBON OFFSETS AND SEQUESTRATION

In theory, both carbon taxes and cap-and-trade systems can be designed to include carbon offset activities, but in practice only cap-and-trade programs have actually done so. Carbon offset programs fund GHG mitigation efforts as a way to "offset" activities that generate GHGs. They can range from investment in GHG sequestration projects through reforestation and land use measures to renewable energy projects. The European Union ETS allows entities to offset a limited portion of their emissions by investing in GHG-reducing projects in developing countries (European Union, 2016). Despite the presence of standards to measure and verify offsets, recent studies show that offsets do not always reduce emissions as intended (Cames et al., 2016). For Hawai'i, a report commissioned by the State Office of Planning concludes that it is unlikely the state could generate substantial revenue through the production of offsets. Also, any trading of offset credits produced within Hawai'i would need to be limited because there is an "inherent conflict of interest between these roles as one role provides credibility to offset credits generated, while the other can generate revenue" (AECOM, 2019). Improved and substantially enhanced management of agriculture, forestry and other land use (AFOLU) sinks could be made a policy priority that would complement a carbon tax, even without the offset market mechanisms.

III. HAWAI‘I’S GHG EMISSIONS AND EXISTING POLICIES

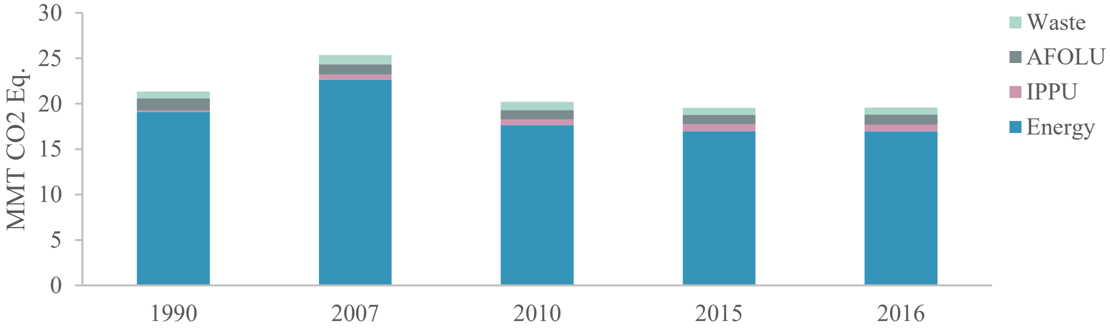
The State of Hawai‘i has adopted goals and policies intended to mitigate Hawai‘i’s contribution to global GHGs. This process began in 2007 with passage of Act 234, which called for reducing GHG emissions to 1990 levels by 2020.[14] The State Department of Health (DOH) was tasked with rulemaking for Act 234 and it emphasized compliance by reducing GHG emissions via the electric sector. The DOH has also maintained GHG inventories for the years 1990, 2007, 2010, 2015 and 2016, as shown in Figures 2 and 3 below (ICF & UHERO, 2019).

Figure 2. Hawai‘i 2016 GHG Emissions by Sector



Source: State of Hawai‘i GHG Emissions Report for 2016 (ICF & UHERO, 2019)

Figure 3. Trends in Hawai‘i GHG Emissions by Sector



Source: State of Hawai‘i GHG Emissions Report for 2016 (ICF & UHERO, 2019)

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[14] HRS §342B-71. The target includes carbon sinks, but excludes emissions from aviation and biogenic sources.

The Energy sector covers GHGs emitted from stationary combustion and transportation.[15] It comprises 87% of GHG emissions, the majority of which is attributable to transportation (51%) and stationary combustion (46%). Industrial Processes and Product Use (IPPU) covers substitution of ozone-depleting substances as well as electricity transmission and distribution, and accounts for 4%. AFOLU are estimated for both sources and sinks of GHGs.[16] As a source, it accounts for 6%. Accounting for sinks creates net negative emissions for this sector. Waste sector emissions covering landfill, composting and wastewater treatment account for 4%.

Projections of the GHG inventory to the year 2020 show that the goals of Act 234 have likely been accomplished (ICF & UHERO, 2019), particularly if we include the impact of the COVID-19 pandemic and economic crisis on GHG emissions. In a follow-up to Act 234, in 2018 the State passed legislation setting a goal to be carbon net negative, meaning that more GHGs are sequestered than emitted, as soon as practicable and no later than 2045 (HRS §225P-5).

Moving beyond goal setting and towards policy mechanisms, the State has adopted a series of sector-focused policies that affect GHG emissions. In the electricity sector, the main policy instrument is the RPS. It requires Hawaiʻi to reach 100% of net electricity sales from renewable sources by 2045 (HRS §269-92).[17] There are interim targets of 30% by 2020, 40% by 2030, and 70% by 2040. At nearly 30% of net electricity sales from renewable energy in 2019, Hawaiʻi is on track to reach the 30% RPS target in 2020. Future attainment depends on the development of renewable energy resources which are subject to cost and siting considerations, community acceptance as well as the ability of the grid to accommodate increasing levels of variable utility-scale and distributed generation (PUC, 2018). As discussed above, the RPS is redundant to a carbon tax. An advantage of the carbon tax is that it would influence the operational efficiency (i.e., the amount of fossil fuel to produce a kWh of electricity) of existing fossil fuel electricity generation whereas the RPS guides the relative amount of generation from fossil and renewable energy sources. To support customer-sited renewable energy adoption, the state established a 35% renewable energy income tax credit in 2009 (HRS §235-12.5). Similar to the federal renewable energy tax credit, benefits from the state tax credit tend to be realized by higher-income households (Coffman et al. 2016a). Subsidies to renewable energy are somewhat redundant but also additive to the carbon tax.

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[15] Stationary emissions include electricity generation, petroleum refinery emissions, on-site energy use in the residential, commercial, and industrial sectors, oil and natural gas emissions, and incineration of waste.

[16] Sources include enteric fermentation, manure management, agricultural soil management, field burning of agricultural residues, agricultural soil carbon, and forest fires. Sinks include landfill trimmings and food scraps, urban trees, and forest carbon (ICF & UHERO, 2019).

[17] The calculation of the RPS allows for double-counting behind-the-meter renewable energy, mainly solar photovoltaic. It is included in the numerator, but not in the denominator. This results in 100% of net sales of electricity not equating to 100% of generation from renewable energy.

There is also an Energy Efficiency Portfolio Standard (EEPS) that requires electricity demand to decline by 4,300 GWh by 2030 (HRS §269-96). The EEPS is primarily governed by a ratepayer-funded program serving Honolulu, Maui and Hawaiʻi counties. There is still a strong role for energy efficiency programs as they can be complementary to a carbon tax, in particular when they address the principal-agent problem.[18]

In the transportation sector, the State of Hawaiʻi has implemented a patchwork of policies aimed at increasing the adoption of electric vehicles (EVs). EVs have lower emissions compared to internal combustion engine vehicles in Hawaiʻi given the current mix of electricity generation, but do not yet have lower emissions than many hybrid vehicles (U.S. DOE, 2019). Coffman et al. (2017) estimate that EVs will be GHG reducing compared to hybrid vehicles in Hawaiʻi once the 2030 RPS requirement is met, though this will happen sooner with the shuttering of the state's coal-fired power plant. Several EV policies have been introduced and sunsetted, including a brief EV purchase subsidy and home charger subsidy as well as free parking at state airports and other public parking spaces. Remaining state-level policies include passenger count exemptions for use of high-occupancy vehicle lanes and a mandate that parking lots with 100 stalls or more be equipped with a charging station (HRS §291C-222 and §291-71). There is also a rebate program for Level 2 and 3 charging stations in multi-dwelling units and commercial facilities (HRS §269-72). Overall, a state carbon tax would serve to reduce the GHG-intensity of miles traveled. There would be leakage with the types of vehicles purchased through the federal CAFE – at least under its current configuration through 2026. This means that policies targeting EV adoption will be undermined. Policies that focus on the provision of EV charging infrastructure in multi-unit and public spaces are complementary.

There are several existing taxes on fossil fuels. The Environmental Response, Energy, and Food Security Tax imposes a modest tax of $1.05 on each barrel of petroleum, and a 19 cent/MMBtu tax on non-petroleum fossil fuels (HRS §243-3.5). While coal, the most GHG-intensive fossil fuel, has been exempt, more recent legislation (Act 23, 2020) prohibits the use of coal beginning in 2023. As with the fuel tax, it was established primarily as a funding source rather than to capture the externality cost associated with GHG-intensive fuels and is scheduled to sunset in 2030. The barrel tax is separate from state and county fuel taxes on gasoline and diesel oil, liquefied petroleum gas, ethanol, methanol, biodiesel, compressed natural gas, and liquefied natural gas. Gasoline and diesel are subject to a 16 cent per gallon state fuel tax; county fuel taxes range from 16.5 cents per gallon on Oʻahu to 23 cents per gallon on Maui (DoTax, 2019). State taxes also apply to naphtha for power-generating facilities (2 cents/gallon) and gasoline used for agricultural equipment off highways, aviation fuel, and diesel oil used off highways (1 cent/gallon). With respect to aviation fuel, the 1 cent per gallon tax is deposited into the airport

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[18] The disconnect between who makes the investment decision, who pays the bills, and who consumes the energy, results in greater energy consumption and less investment in energy efficiency.

revenue special fund to be used in the airport zone (HRS §261-5a), except for bonded fuel that is imported under federal customs. Bonded aviation fuel is only sold to air carriers arriving from or going to a foreign port (HRS §243-7). In 2018, an estimated 27% of the aviation fuel was bonded (DoTax, 2019). This portion of aviation fuel sold would not be subject to a state carbon tax. Existing taxes on fossil fuels are generally redundant to a carbon tax as GHG abatement policies. However, existing taxes are levied for a number of reasons, for example to pay for roads.[19]

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[19] Fuel taxes are not the most efficient or effective means of capturing revenues for the provision of roads. Other mechanisms, like vehicle miles taxes, more directly capture a "user pays" principle.

IV. ASSESSING HAWAI‘I’S IMPLEMENTATION OF A CARBON TAX: DATA, METHODS, AND SCENARIOS

We use a CGE model of Hawai‘i’s economy to assess the economic and GHG impacts of adopting a state-level carbon tax. CGE models are well suited to assess the economy-wide impacts of policy interventions as they are designed to incorporate linkages between sectors of the economy, including elements of production, consumption, and trade. The concept of equilibrium means that prices are computed such that all markets clear and presumes that prices are flexible. By definition CGE models represent a long-run view of economic conditions. Their ability to incorporate full price effects makes CGE models a more comprehensive tool of analysis than a standard Input-Output model. Several previous studies have used CGE models to assess economic impacts of energy sectors in Hawai‘i (Coffman et al., 2007; Coffman, 2010; Coffman and Bernstein, 2015; Coffman et al., 2016b) as well as the economic and environmental impacts of the visitor industry (R.M. Towill et al., 2005). Here we build on prior models, updating the H-CGE model to the most recent data and calibrating it more specifically to sector-level GHG emissions to analyze the economic and environmental impacts of a state-level carbon tax.

BASELINE DATA AND CALIBRATION

H-CGE is a model of Hawai‘i’s overall economy. It is built upon a Social Accounting Matrix (SAM) of macro-economic and sector-level activity for a baseline year. The 2012 State of Hawai‘i Input-Output (I-O) Study is the most recent I-O table available for Hawai‘i (DBEDT, 2016). Developed by the State of Hawai‘i Department of Business, Economic Development and Tourism, this dataset represents Hawai‘i’s production from sixty-eight sectors including GHG-intensive sectors like petroleum manufacturing, electricity, ground transportation services, water transportation, and aviation. The I-O table also represents agents of final demand including households, visitors, federal and state governments, and the value of exports from Hawai‘i. For tractability, we aggregate the I-O sectors and agents into sixteen sectors and five agents. We augment the economic dataset from the I-O table, which provides the basis for the SAM, to represent different levels of household expenditures based on income cagetory and sector-based GHG emissions by fossil fuel. This report’s technical appendix provides a detailed description of the adapted H-CGE model used in this study, information on assumptions and model structure, and documentation of additional data sources. This section provides a high-level overview.

Table 3 shows Hawai‘i’s production sectors for the baseline year 2012, with data on total output by sector, inter-industry demand (i.e. outputs from other industries used as inputs by the sector), the value of imports, labor income, proprietor income,[20] other value added, and the number of jobs in each sector.

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[20] Proprietors' income is the excess of revenue over explicit production cost of owner-operated businesses and includes payments for labor, capital, land, and entrepreneurship.

Table 3. Overview of Hawai'i's Production Economy

	Total Output*	Inter-Industry Demand	Imports	Labor Income	Proprietor Income	Other Value-Added	Jobs**
	$ 2012 Billion						
Total	**$120**	**$31**	**$18**	**$40**	**$4.5**	**$25**	**860,000**
Petroleum	4.8%	8.8%	27%	0.2%	0.8%	1.2%	0.1%
Electricity	2.8%	5.5%	1.4%	1.0%	1.4%	3.6%	0.4%
Gas (e.g. propane)	0.2%	0.3%	0.2%	0.1%	0.0%	0.2%	0.0%
Water Transportation	0.6%	0.3%	0.9%	0.4%	0.01%	0.3%	0.2%
Air Transportation	2.6%	0.6%	2.5%	1.5%	0.04%	3.9%	0.9%
Ground Transportation Services	1.6%	2.6%	0.9%	1.8%	2.3%	1.0%	2.2%
Water & Other Utilities	0.1%	0.3%	0.1%	0.0%	0.0%	0.1%	0.1%
Waste Management	0.3%	1.0%	0.1%	0.3%	0.1%	0.2%	0.2%
Agriculture & Forestry	0.8%	1.1%	0.9%	0.7%	0.3%	0.4%	1.8%
Construction	5.3%	0.0%	5.8%	5.0%	12%	2.5%	3.9%
Wholesale and Retail Trade	11%	9.4%	9.5%	9.0%	7.2%	13%	13%
Real Estate and Rentals	14%	16%	10%	1.6%	25%	44%	5.4%
Other Manufacturing	4.9%	9.9%	9.9%	2.8%	3.5%	1.5%	2.9%
Other Services	35%	38%	24%	40%	47%	20%	48%
Federal Government	8.8%	2.3%	4.1%	21%	0.0%	4.1%	11%
State & Local Government	7.0%	3.5%	2.9%	15%	0.0%	3.4%	11%
Sum	100%	100%	100%	100%	100%	100%	100%

** The value of total output is equal to the summed value of inter-industry demand, imports, labor income, proprietor income and other value-added. These components provide a "production function" for each sector.*
*** "Jobs" represents both the quantity of employee labor and proprietor labor.*
May not add to 100 % due to rounding.

Hawai'i's economy in 2012 produced $120 billion of total output. There were 860,000 jobs, with the largest employment in the service sector, including wholesale and retail trade (13% of jobs), and other services (48%). State and local governments were large employers, accounting for nearly 11% of jobs and 15% of wages paid. Regarding GHG-intensive sectors, petroleum (manufacturing and imports) accounted for 5% of output while the electricity accounted for 3% and gas (meaning propane and synthetic gas, i.e. *not* gasoline) accounted for 0.2% of economic activity. Transportation sectors combined accounted for 5% of economic activity.

Table 4 provides a summary of Hawai‘i’s demand-side economy: consumption, investment, and exports (defined as demand by agents outside Hawai‘i).

Table 4. Overview of Hawai‘i’s Final Demand

	Resident Demand	Visitor Demand	State and Local Gov*	Federal Gov**	Private Investment	Exports
$ 2012 Billion						
Total	**$51**	**$16**	**$8.7**	**$11**	**$11**	**$5.3**
Petroleum	3.9%	0.1%	0.4%	3.1%	0.1%	12%
Electricity	2.8%	0.0%	1.5%	0.1%	0.0%	0.0%
Gas (e.g. propane)	0.2%	0.0%	0.0%	0.1%	0.0%	0.0%
Water Transportation	0.4%	1.2%	0.2%	0.0%	0.7%	2.4%
Air Transportation	1.1%	13%	0.2%	0.0%	0.1%	1.8%
Ground Transportation Services	0.7%	3.4%	0.3%	0.1%	0.2%	2.1%
Water & Other Utilities	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
Waste Management	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%
Agriculture & Forestry	0.6%	0.1%	0.0%	0.0%	0.0%	4.4%
Construction	0.0%	0.0%	17%	3.6%	40%	0.0%
Wholesale and Retail Trade	13%	13%	1.2%	0.2%	7.2%	3.2%
Real Estate and Rentals	20%	8.7%	0.9%	0.0%	0.4%	6.4%
Other Manufacturing	1.9%	0.6%	0.2%	3.7%	1.6%	21%
Other Services	36%	52%	1.7%	4.1%	4.9%	33%
Federal Government	1.6%	0.5%	0.0%	81%	0.0%	0.0%
State & Local Government	1.8%	0.0%	73%	0.0%	0.0%	0.0%
Imports	16%	6.6%	3.8%	3.5%	45%	15%
Sum	100%	100%	100%	100%	100%	100%

Source: Department of Business, Economic Development, and Tourism, State of Hawaii (2016). The 2012 State Input-Output Study for Hawaii.
** State and Local Government includes both investment and consumption*
*** Federal Government includes both civilian and military, investment and consumption.*
May not add to 100 % due to rounding.

In 2012 there were 450,000 households in Hawai‘i (ACS, 2013). Residents consumed $51 billion of goods and services, the largest portions being services (36%), real estate (20%), imported products (16%), and wholesale/retail trade (13%). Residents spent $1.4 billion on electricity (3%) and $2.0 billion on petroleum (primarily gasoline for private vehicle transportation) (4%). In the I-O table, residents also spent a total of $1.8 billion on government services – federal, state and local. The $940 million on state and local government expenditures represent items like vehicle registration fees and other fees for service. The expenditures on federal government represent items like the postal service.[21] Visitors to Hawai‘i spent $16 billion in 2012. Other services, which includes accommodations and restaurants, comprised 52% of visitor spending, air transportation, 13%, and wholesale/retail trade, 13%. Visitors do not consume utilities directly but rather indirectly through their consumption of services. The benefit of a CGE framework is that it accounts for indirect and induced consumption within the model.

The I-O table provides the baseline data for the consumption patterns of the representative household. To better understand the welfare implications of a carbon tax across income groups requires representing different household types. To do this, we merge Hawai‘i-specific consumer expenditure data with the national Consumer Expenditure Surveys conducted by U.S. Bureau of Labor Statistics that provide expenditures by income groups, broken into quintiles, for a range of goods and services (BLS, 2019). Similar to Goulder et al. (2019), we undertake a process of matching the BLS Consumer Expenditures Survey data with the I-O sectors to develop a parameter for expenditure shares across income quintiles by sector. The assumptions embedded in this process mean that we are taking Hawai‘i-specifc data on total consumer expenditures across sectors but imposing a national representation of the distribution of expenditures across income quintiles. Importantly, the data reflect, for example, Hawai‘i’s higher than average expenditures on goods like housing as well as differential housing expenditures by households in each income quintile.

Table 5 provides a description of the proportion of each sector's expenditure share by each household income quintile, based on matching the BLS data to the aggregated I-O sectors. Due to a lack of data, we assume that all households devote an equal share of their expenditures to consumption of government goods and services.[22]

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[21] Obtained through correspondence with Dr. Eugene Tian, DBEDT.

[22] We had concern that this assumption would unduly influence our results, so we conducted sensitivity analysis of this assumption, where we assumed higher income quintiles consumed more government goods and services. We find that changes in this assumption do not meaningfully change the results of our analysis.

Table 5. Sector Demand by Household Income Group

	Lowest 20 percent	Second 20 percent	Middle 20 percent	Fourth 20 percent	Highest 20 percent	Sum
Average Annual Household Income in Each Quintile (ACS, 2013)	**$15,000**	**$41,000**	**$66,000**	**$98,000**	**$190,000**	
Petroleum	9.6%	15%	19%	24%	32%	100%
Electricity	14%	18%	20%	22%	26%	100%
Gas	12%	16%	19%	22%	31%	100%
Water Transportation	0.9%	1.7%	4.8%	34%	58%	100%
Air Transportation	4.8%	9.8%	13%	21%	52%	100%
Ground Transportation Services	10%	14%	17%	20%	39%	100%
Water & Other Utilities	11%	17%	19%	23%	30%	100%
Waste Management	11%	17%	19%	23%	30%	100%
Agriculture & Forestry	12%	16%	18%	23%	31%	100%
Construction	7.1%	11%	16%	23%	43%	100%
Wholesale and Retail Trade	7.8%	14%	17%	22%	39%	100%
Real Estate and Rentals	11%	14%	17%	22%	36%	100%
Other Manufacturing	9.0%	17%	18%	22%	33%	100%
Other Services	7.1%	11%	16%	23%	43%	100%
Federal Government	20%	20%	20%	20%	20%	100%
State & Local Government	20%	20%	20%	20%	20%	100%
Imports	7.8%	14%	17%	22%	39%	100%

Note: The rows add to 100 %, meaning the percentages show the relative consumption of a sector by quintile. May not add to 100 % due to rounding.

The highest income quintile consumes 32% of all household expenditures of petroleum (i.e., gasoline), 26% of electricity, 31% of gas, 58% of water transportation, 52% of air transportation and 39% of ground transportation services. In contrast, the lowest income quintile consumes 10% of all household expenditures of petroleum, 14% of electricity, 12% of gas, 1% of water transportation, 5% of air transportation, and 10% of ground transportation services.

Table 6 shows the same household expenditures data another way, based on how each household income quintile distributes its expenditures across sectors, such that the columns add to 100%.

Table 6. Household Expenditures by Sector by Income Group

	Lowest 20 percent	Second 20 percent	Middle 20 percent	Fourth 20 percent	Highest 20 percent
Average Annual Household Income in Each Quintile (ACS, 2013)	**$15,000**	**$41,000**	**$66,000**	**$98,000**	**$190,000**
Petroleum	4.3%	4.5%	4.5%	4.2%	3.1%
Electricity	4.6%	4.0%	3.3%	2.7%	1.9%
Gas	0.3%	0.3%	0.2%	0.2%	0.2%
Water Transportation	0.0%	0.1%	0.1%	0.7%	0.6%
Air Transportation	0.6%	0.8%	0.8%	1.0%	1.4%
Ground Transportation Services	0.8%	0.8%	0.7%	0.6%	0.7%
Water & Other Utilities	0.0%	0.0%	0.0%	0.0%	0.0%
Waste Management	0.0%	0.0%	0.0%	0.0%	0.0%
Agriculture & Forestry	0.9%	0.8%	0.7%	0.7%	0.5%
Construction	0.0%	0.0%	0.0%	0.0%	0.0%
Wholesale and Retail Trade	11%	14%	13%	13%	13%
Real Estate and Rentals	25%	22%	21%	20%	18%
Other Manufacturing	1.9%	2.5%	2.1%	1.9%	1.6%
Other Services	29%	31%	34%	36%	39%
Federal Government	3.8%	2.5%	2.0%	1.5%	0.8%
State & Local Government	4.2%	2.8%	2.2%	1.6%	0.9%
Imports	13%	14%	16%	16%	18%
Sum	100%	100%	100%	100%	100%

May not add to 100 % due to rounding.

In general, the largest proportion of household expenditures, across all quintiles, are on housing (real estate and rentals), services, and other goods (wholesale and retail trade). The first four quintile households spend approximatley 4% of their income on petroleum (i.e. gasoline), in comparison to the highest-quintile that spends closer to 3%. The lowest-quintile household spends 5% of its expenditures on electricity, in comparison to the highest-quintile household that spends 2%. Other notable differences are relative expenditures on air and water transportation. The lowest income quintile household spends less than 1% of its income on air transportation, while the highest income quintile household spends about 1.4%. The lowest income quintile household spends a neglible amount on water transportation while the highest income quintile household spends about 0.6%. Direct expenditures on water transportation are highly skewed towards upper-income groups because they include goods like recreational boating.[23]

The last major data step to calibrate H-CGE is to link the State‘s most recent GHG inventory to the economic sectors of the I-O table (ICF & UHERO, 2019). Based on the structure of carbon tax programs elsewhere, we focus on energy sector emissions which come from the burning and processing of oil, coal, and gas.[24] Due to issues of federal preemption, direct military and federal consumption of fossil fuels in Hawai‘i, i.e. military aviation and non-aviation emissions, are excluded from the carbon tax. In total, the carbon tax is assumed to cover 81% of total statewide GHG emissions.[25] Table 7 displays the state's 2016 energy sector emissions included in H-CGE.

Table 7. State of Hawai‘i 2010, 2015 and 2016 Energy Sector GHG Emissions

Sector	2010	2015	2016	Percentage of 2016 Total
Included Sectors				
Energy Industries	7.79	6.88	6.83	35%
Residential	0.09	0.06	0.08	0%
Commercial	0.37	0.47	0.45	2%
Industrial	0.57	0.52	0.43	2%
Ground	4.15	4.04	4.05	21%
Marine	0.60	0.56	0.64	3%
Aviation	2.67	3.33	3.20	16%
Oil and Natural Gas	0.20	0.19	0.19	1%
Subtotal	**16.45**	**16.06**	**15.87**	**81%**

Source: State of Hawai'i GHG Emissions Report for 2016 (ICF & UHERO, 2019)

To operationalize GHG emissions in H-CGE requires dividing them into their fossil fuel source (oil, coal and gas), back-casting to 2012 and mapping fossil fuel quantities to economic sectors as described in the technical appendix. Most connections between sectors and GHGs are straightforward – like the mapping of energy industries as stationary sources to electricity and

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[23] As a double check to the household spending disaggregation, a comparison of the above estimates is made to Goulder et al. (2019), who also used national BLS data. Though the sector aggregation in the E3 model differs from H-CGE, several key sectors can be compared. In particular, electricity, air transportation, and motor vehicle fuels (matching "petroleum"). Each of the three sectors has similar relative differences among quintile groups. For example, Goulder et al. (2019) estimate that the lowest income quintile spends 2.4% on electricity, in comparison to the highest income quintile at 1.3%. In comparison, we find a range of 4.6% to 1.9%. In addition, Goulder et al. (2019) find that the lowest quintile spends 0.1% of their income on air transportation in comparison to the highest quintile at 0.8%. In comparison, we range from 0.6% to 1.4%. Goulder et al. (2019) find that the a range of 3.9% to 3.4% for expenditures on motor vehicle fuels in comparison to our 4.3% to 3.1% - all reasonably in the ball park. Lastly, we compare the lowest income quintiles relative expenditures on electricity with the U.S. Department of Energy's estimate of low income energy cost burdens (i.e. electricity costs for those making 80% of the Area Median Income). Our estimate of 4.6% (Table 3) falls within their estimated range of 4-6% (U.S. DOE, 2018).

[24] Levied in the model on CO_2 emissions.

[25] It could be extended to IPPU and AFOLU sectors to capture the non-biogenic portion of waste incineration.

petroleum manufacturing. Some, however, require sharing over multiple sectors and sources. An example is mapping ground transportation emissions to ground transportation services and resident demand for gasoline (which serves as our proxy for resident light duty vehicle travel). Table 8 presents the baseline 2012 GHG-intensity of Hawai‘i’s sectors, normalized by billions of dollars.

Table 8. GHG Intensity of Economic Sectors (MMT CO_2 Eq./$2012 Billion)

Source	MMT CO_2 Eq./$ Billion
Petroleum Manufacturing	0.03
Electricity	2.52
Gas	0.04
Water Transportation	0.78
Air Transportation	0.95
Ground Transportation Services	0.11
Other Light Duty Vehicle Transportation (Resident)	0.08
Water & Other Utilities	0.01
Waste Management	0.02
Agriculture & Forestry	0.01
Construction	0.00
Wholesale and Retail Trade	0.00
Real Estate and Rentals	0.00
Other Manufacturing	0.09
Other Services	0.00
Federal Government	0.00
State & Local Government	0.01

Electricity is the most GHG-intensive sector in Hawai‘i as measured by GHGs per dollar of output. Other GHG-intensive sectors are air transportation and water transportation. With a notable drop, ground transportation services and other manufacturing are also GHG-intensive. Petroleum manufacturing itself is not particularly GHG-intensive because oil-related GHG emissions are attributed to the sectors in which they are burned. Direct emissions from petroleum manufacturing represent emissions in refining and processing. Gas is a relatively low GHG-intensive fossil fuel when considering direct burning; upstream emissions, however, can be substantial (Coffman et al., 2016b) . After initial calibration, the model is re-solved for 2016 as a double check against the official GHG inventory.

Though the I-O table provides a comprehensive view of Hawai‘i’s economy, data gaps exist. Of particular importance is the limited detail on imports to Hawai‘i. The data on imports in the I-O table are compiled into a single vector, meaning the total value of imports per sector and agent of final demand cannot be disaggregated into different goods. We take this as a block of imports into the production of a sector, with the exception of sources of fossil fuels. Imports of coal, for example, are identified as imports into the electricity sector and treated separately. Crude oil is identified as imports into the petroleum sector and treated separately, as detailed in the technical appendix. Lastly, taxes in the I-O table are shown as a single vector covering economic sectors – meaning that the I-O table shows all sector taxes together and lacks income taxes.

BASELINE FORECAST TO 2045

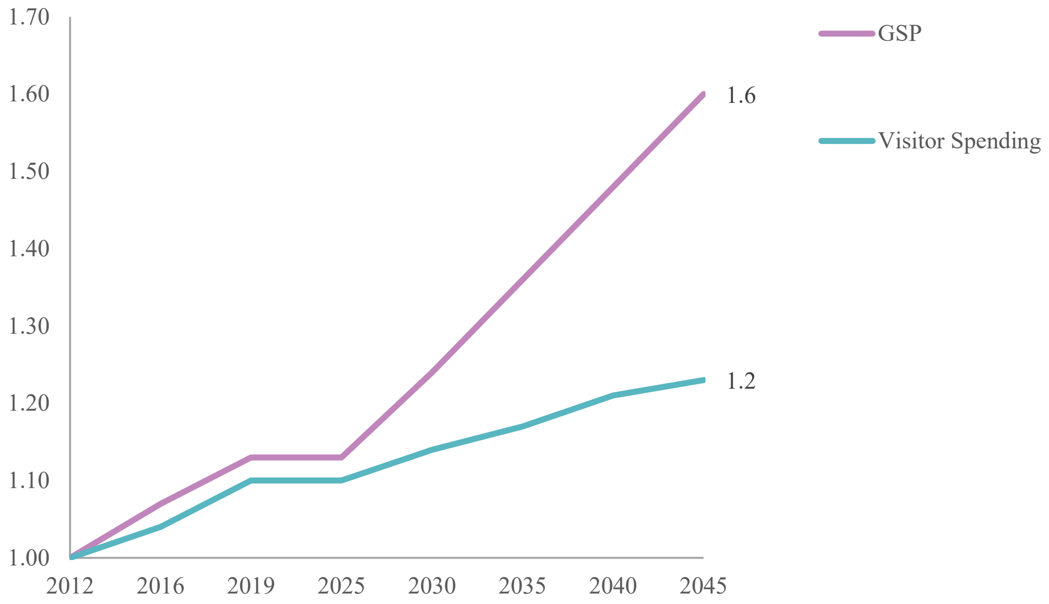
H-CGE is a recursive-dynamic model: it solves for one period at a time, where the prior year‘s conditions influence the following year. It is calibrated to 2012 data, solved for 2016 and 2019, and then projected at five-year intervals between 2025 and 2045. The model solution for 2016 is an additional calibration against the State's GHG inventory. Similarly, the model solution for 2019 is done as a check with respect to the most recent economic conditions for which there are sufficient data. In general, data from earlier years are used for calibration purposes, while results from model simulations are presented for future years.

While there is always uncertainty in forecasting future conditions, the global pandemic creates unprecedented levels of uncertainty. The pandemic has led to a dramatic decline in economic activities, with a particularly heavy impact on transportation and services-related sectors, especially tourism. To the extent possible, we account for the pandemic in our baseline forecast of economic recovery and growth. However, we do not account for any structural changes in economic conditions that might impact GHG emissions. We do not explicitly solve for the year 2020, as the dramatic decline in economic activities makes it a difficult year to calibrate.

Most important for this analysis is to create a reasonable representation of "baseline" economic conditions, including a representation of existing policies and trends, against which to assess scenarios of different carbon tax levels and ways to recycle revenue. The baseline macroeconomic forecast adopted for this analysis simply assumes that Hawai‘i's economy returns to 2019 levels by 2025. This is informed by a combination of several short-term macroeconomic outlooks. Notable sources for economic forecasts for Hawai‘i include the official state report issued by the State Department of Business, Economic Development and Tourism (DBEDT) and reports issued by the University of Hawai‘i Economic Research Organization (UHERO). DBEDT's third quarter 2020 report estimates that by 2023, which is the end of the forecast period, Hawai‘i's real gross state product (GSP) will be 8% lower than 2019 levels (DBEDT, 2020). UHERO's third quarter 2020 report finds that by 2023, real GSP will be 4% lower than 2019 levels (UHERO, 2020). To reach 2019 levels by 2025 requires that we assume an approximate 2% annual growth rate over 2023-2025 based on UHERO‘s forecast. After 2025, we assume that the economy gets back on track to a more steady-state representation of growth as estimated by DBEDT‘s long-run forecast to 2045 (DBEDT, 2018). Because the DBEDT report was issued prior to the pandemic, we make an adjustment such that the 1.8% annual growth rate initially projected from 2020 to 2025 now kicks in at 2025, and this forecast guides growth through 2045. Between 2012 and 2019, the change in GSP is based on observed levels (DBEDT, 2019).

There are several additional parameters that influence economic growth conditions in H-CGE. The most important is the forecast of visitor spending. As shown in Table 4, visitor spending comprises 24% of consumer spending in Hawai‘i. From an economic perspective, this is akin to an export good – though it accrues GHG and other environmental impacts within Hawai‘i. Historic data are used between 2012 and 2019 (UHERO, 2020). We similarly assume that visitor spending will return to the 2019 level by 2025 and return to DBEDT’s long-term growth rate as is done with the GSP forecast. This is shown in Figure 4.

Figure 4. Baseline Gross State Product and Visitor Spending Forecast, Normalized to 2012



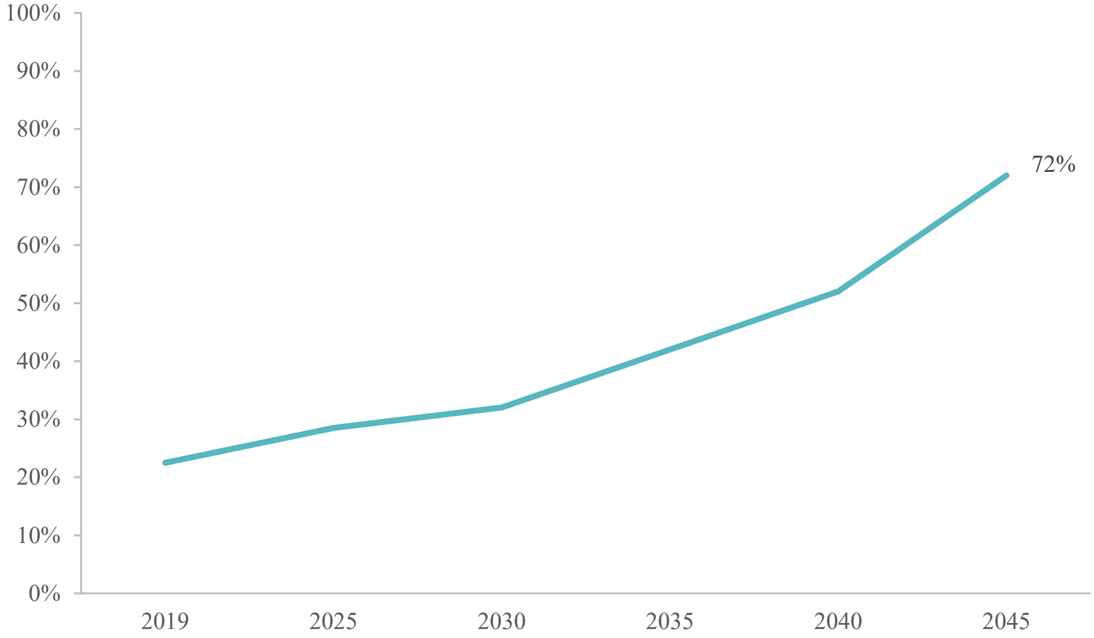
EXISTING ENERGY POLICIES AND TRENDS

To create a baseline forecast, we model the major existing policy mechanisms that directly influence GHG emissions. We build into H-CGE Hawai‘i’s RPS, federal CAFE standards, and a forecast for EV adoption.

By design, Hawai‘i’s RPS does not specify the share of electricity generation from renewable sources. The State’s law requires 30% of net sales of electricity be met through renewable sources in 2020, 40% by 2030, 70% by 2040 and 100% by 2045. The calculation of “net sales” allows for the double-counting of behind-the-meter renewable energy, mainly distributed solar photovoltaic. Thus the actual amount of renewable energy generation needed to comply with the

RPS changes based on how much distributed solar photovoltaic energy is adopted over time. To estimate this for H-CGE, we build an excel spreadsheet model that uses Hawaiian Electric's Power Supply Improvement Plan demand projections updated with the utility's most recent projection for distributed renewable energy and total electricity generation (Hawaiian Electric, 2020a, PUC, 2016).[26] For this estimation, H-CGE incorporates an "RPS constraint" as represented in Figure 5. We estimate that realizing the targets of the RPS law will result in 72% of electricity generated through renewable sources by the year 2045.

Figure 5. Renewable Sources of Electricity Generation as % of Total



The current federal CAFE requires that light duty cars and trucks have an EPA-rated efficiency of 204 g CO_2 Eq./mile and 284 g CO_2 Eq./mile, respectively, by 2026. This is a national standard and will not be met uniformly across states. H-CGE incorporates two types of light duty vehicles, gasoline-powered and EVs. Existing forecasts for the future adoption of EVs vary widely, and we rely on two very different perspectives. The first is Hawaiian Electric's most recent EV adoption forecast developed in their Integrated Grid Planning (Hawaiian Electric, 2020b). This forecast estimates the share of vehicles that are EVs over time, predicting that approximately 50% of light duty vehicles on the road by 2045 are electric-powered. The second perspective that we consider is the U.S. Energy Information Administration's Annual Energy Outlook (AEO) 2020 reference forecast (U.S. EIA, 2020). It projects only 4% of light duty vehicles will be electric by 2045. These dramatic differences, stemming from uncertainty in

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[26] Though this does not include the electricity service area for Kaua‘i, we would expect this to change very little with inclusion of KIUC. This is because KIUC relies less heavily on rooftop solar photovoltaic and more on utility-scale projects.

federal CAFE standards after 2026 as well as interpretations of how the national standard will be realized by regions, make choosing a forecast challenging. Whereas the Hawaiian Electric forecast is optimistic, the AEO forecast is in our view overly pessimistic. Lacking perfect insight to the path forward, we create a forecast that sits in-between, reaching 34% of of light duty vehicles as EVs by 2045 (shown as the baseline in Figure 18). This is similar to earlier forecast work done by members of our research team, presented in Coffman et al. (2015). While this assumption substantially impacts our baseline forecast of GHG emissions, it has little impact on the qualitative relationship among the different scenarios. Its importance is to serve as a basis for assessment of the carbon tax scenarios.

Lastly, we make assumptions about exogenous improvements in energy efficiency of major sectors over time. We base these parameters on the U.S. AEO 2020. This is particularly important for our baseline assessment of air transportation emissions due to the size of the sector, and is described in the technical appendix.

SCENARIOS

The four core scenarios of this analysis consider two different levels of carbon taxes and two different methods of recycling the carbon tax revenues. The carbon tax is assumed to be levied on fossil fuels within Hawai‘i's economy: oil, coal, and gas. It excludes direct military fossil fuel consumption and in total covers 81% of total statewide GHG emissions. Table 9 presents the two carbon tax scenarios. From now on, we refer to these by their ending tax value; for example "\$70/MT CO_2 Eq." and "\$1,000/MT CO_2 Eq." scenarios.

Table 9. Carbon Tax Scenarios ($2012)

Year	"$70/MT CO₂ Eq."	"$1,000/MT CO₂ Eq."
2025	$50	$240
2030	$54	$430
2035	$60	$620
2040	$65	$810
2045	$70	$1,000

Two book-end assumptions are made to specify scenarios regarding the use of carbon tax revenues. In the first, all revenues go to state government which determines their best use based on existing government spending as described in the technical appendix. In the second, most revenues are equally distributed back to Hawai‘i's households. Revenues from the taxation of aviation fuel are kept by the state, consistent with the current 1 cent per gallon aviation fuel tax. This is due to federal limitations on the use of tax revenues from the aviation industry, which is predominantly federally regulated.[27]

In addition to these four scenarios, we illustrate the GHG reduction opportunities from a wider range of carbon taxes. This provides insights into the marginal cost of GHG abatement.

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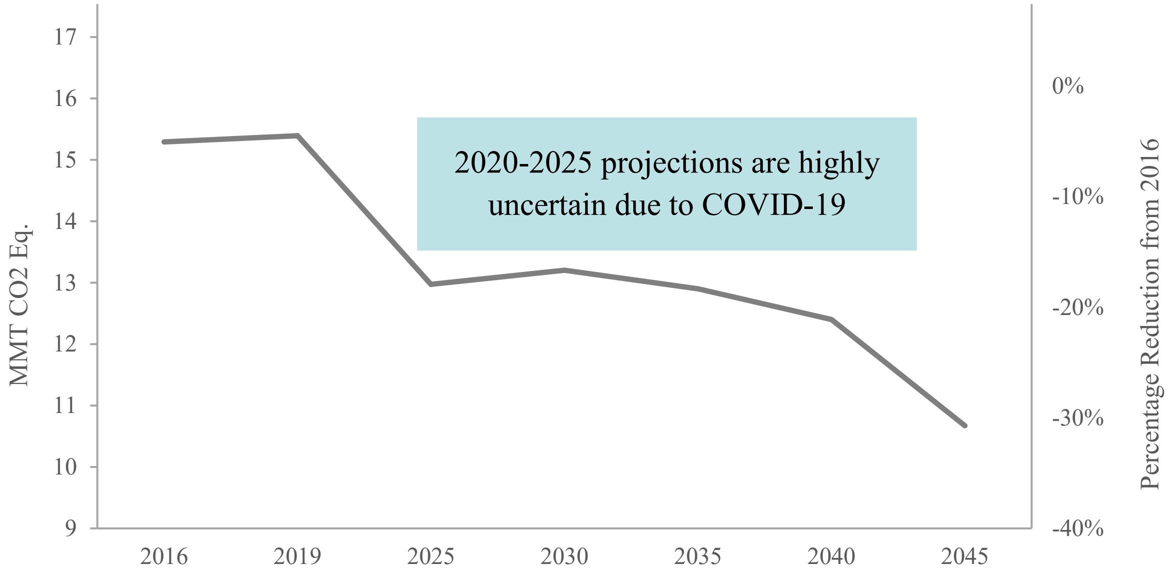
[27] This is due to the Anti-Head Tax Act, a federal statute regulating state taxation of the airline industry. Whether such a high tax rate would be upheld is a legal question outside the scope of this analysis. California's cap-and-trade program, as a point of comparison, currently excludes aviation fuels.

V. RESULTS

GHG EMISSIONS

In the baseline, targeted GHG emissions amount to 15.8 MMT CO_2 Eq. in 2016. For the first year that GHGs are estimated without an inventory benchmark, 2019, we estimate that baseline emissions will be 15.9 MMT CO_2 Eq. under current policies and trends. We expect this to fall to 13.4 MMT CO_2 Eq. by 2025. Besides the assumption of zero economic growth in this time period, the decline in GHG emissions is mainly attributed to the closure of the exisiting coal-fired power plant. This alone accounts for 1.5 MMT CO_2 Eq. The remainder reflects a combination of increasing renewable energy adoption for electricity and more fuel efficient vehicles. We estimate a slight increase in baseline GHG emissions from 2025 to 2030, reflecting increases in emissions from economic growth outpacing the increase in the RPS. Between 2030 and 2045 there is a smoother trend downward as the RPS targets increase more rapidly and transportation becomes more electrified. In 2045, we estimate that GHG emissions will reach 11.1 MMT CO_2 Eq. This amounts to a 30% decrease from 2016. The H-CGE baseline forecast of GHG emissions is shown in Figure 6.[28]

Figure 6. Baseline GHG Emissions, 2016-2045



2020-2025 projections are highly uncertain due to COVID-19

Figure 7 shows the estimate for baseline GHG emissions by major emitting sectors: Electricity, Water Transportation, Air Transportation, and Ground Transportation (including both

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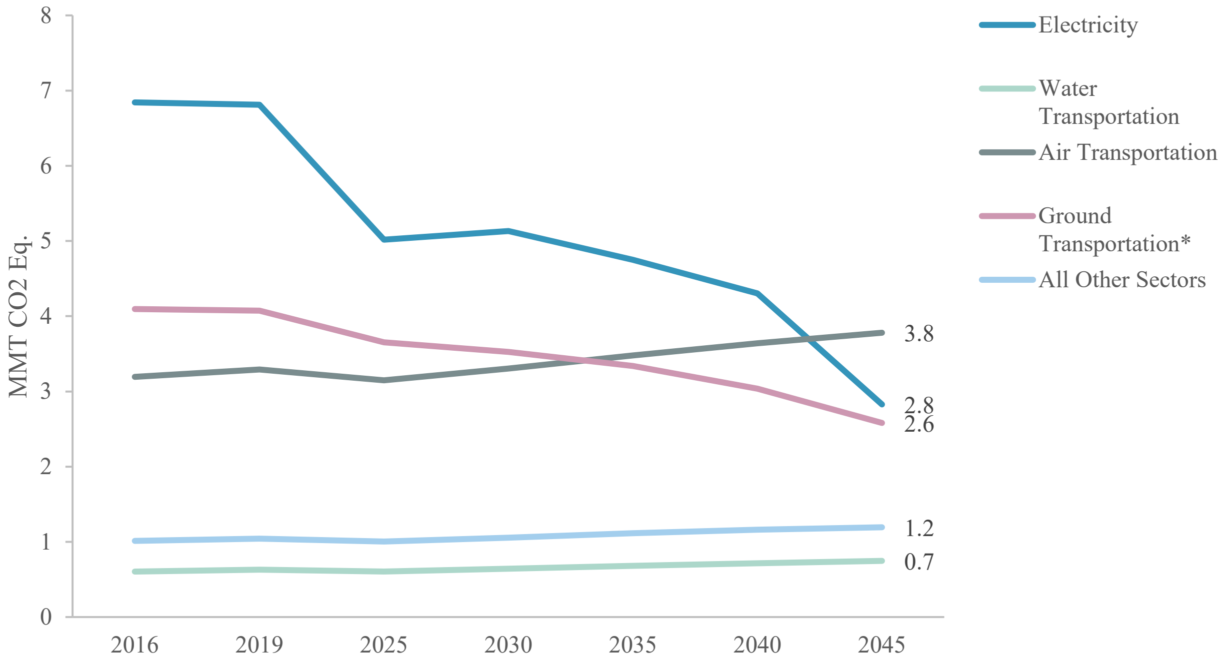
[28] To reiterate, we do not solve for GHG emissions in the COVID-19 pandemic time period. We expect a large drop in GHG emissions in 2020 and for several years following, such that it reaches our estimated 2025 levels. The figure shows this as a smooth curve.

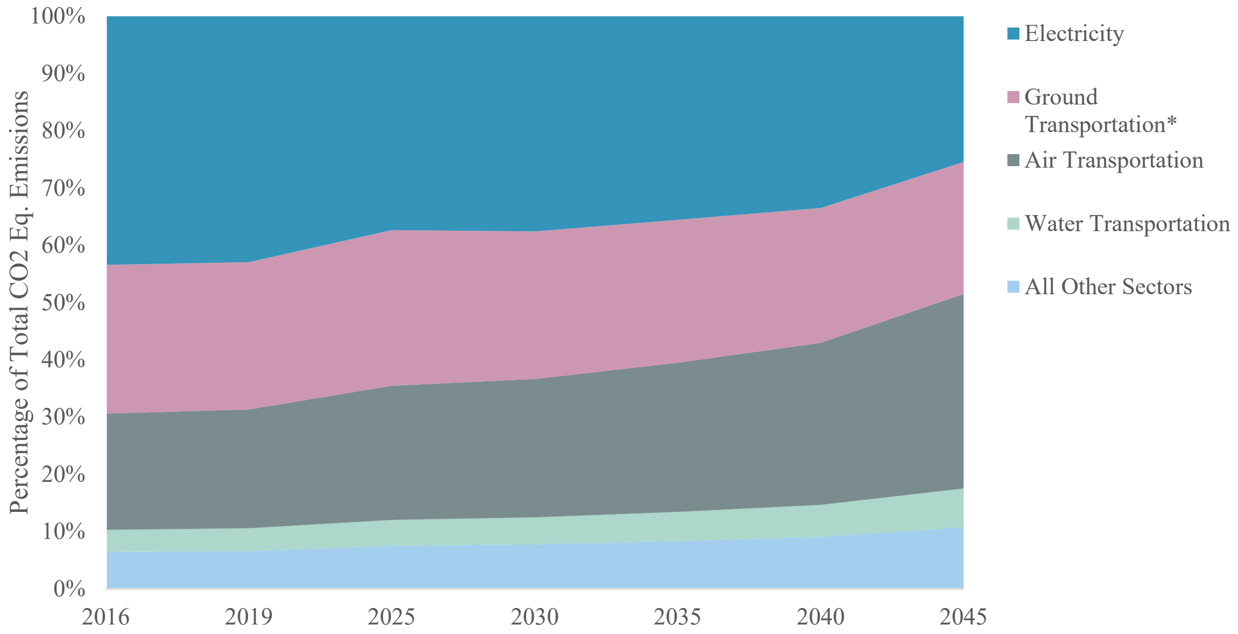
commercial ground transportation services and personal vehicle travel). Figure 8 below provides the same data expressed as their proportion of GHG emissions.

Figure 7. Baseline GHG Emissions by Major Emitting Sector, 2016-2045



**Includes Ground Transportation Services and Personal Vehicle Travel*

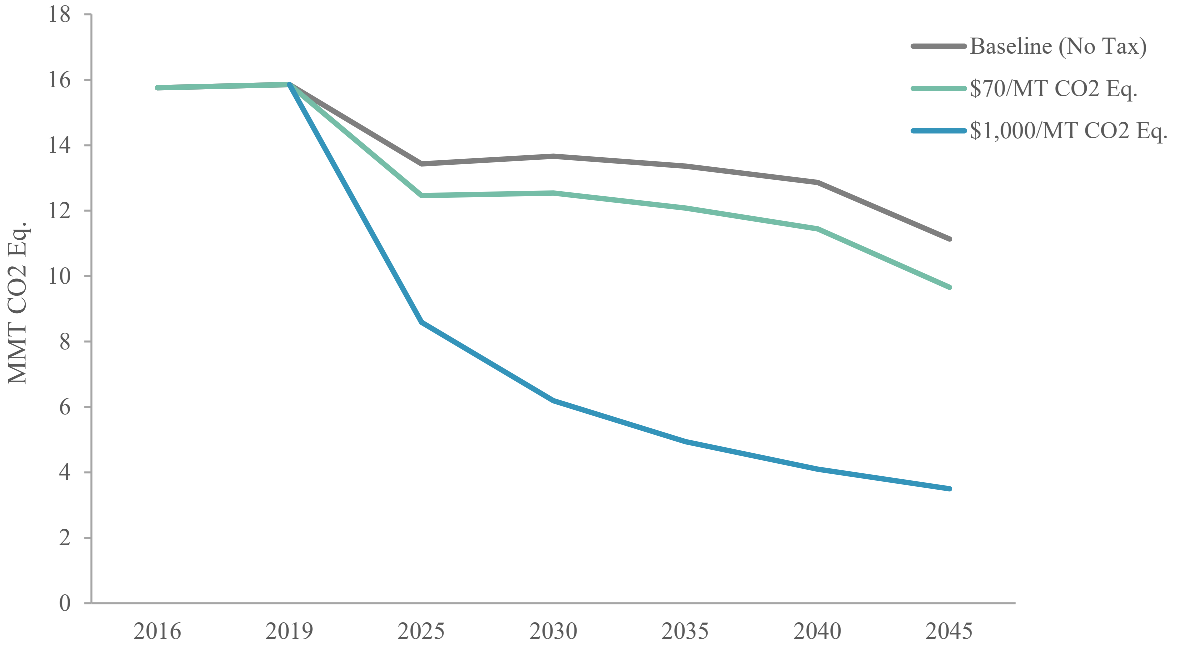
Figure 8. Composition of Baseline GHG Emissions, 2016-2045



**Includes Ground Transportation Services and Personal Vehicle Travel*

Compliance with the RPS continues to reduce GHG emissions in the electricity sector. In addition, with our assumptions about EV adoption and overall vehicle fuel efficiency gains, we estimate a downward trend in ground transportation emissions. Aviation emissions, on the other hand, are estimated to rise: with 2045 emissions being 0.5 MMT CO_2 Eq. higher than 2019 levels. As electricity and ground transportation become a smaller proportion of Hawaiʻi's total emissions over time, emissions from air and water transportation as well as the aggregate of other small fossil fuel consuming sectors become increasingly important.

Figure 9. GHG Emissions in Baseline and Carbon Tax Scenarios, 2016-2045



Note: GHG emissions for the scenarios are shown for the case where government keeps the carbon tax revenue, as the differences between this scenario and one with revenue recycling to household are extremely small.

The adoption of the lower price carbon tax in 2025 shows a reduction of 1 MMT CO_2 Eq.[29] As the carbon tax increases only slightly over time (going from \$50 to \$70/MT CO_2 Eq. from 2025 to 2045), the annual decrease in GHG emissions relative to the baseline also increases slightly over time. In the year 2045, emissions decline by 1.5 MMT CO_2 Eq. from the baseline. More important to the global climate than any single year's impact, however, is the cumulative emissions reductions achieved – estimated to be 25 MMT CO_2 Eq. We find that under the "\$70/MT CO_2 Eq." scenario that the RPS remains a binding constraint, determining levels of

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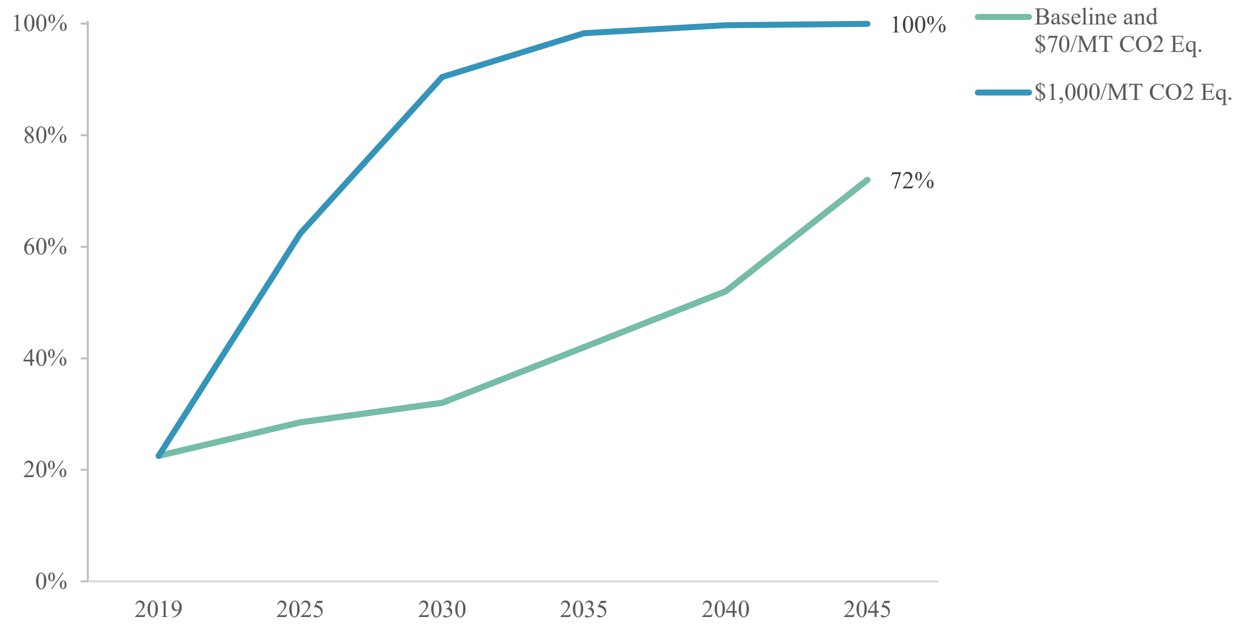
[29] When carbon tax revenues are returned to households, with the exception of those collected from aviation fuels, there is a slight rebound effect to GHG emissions due to improved economic conditions (an income effect). The GHG impacts are nearly negligible, amounting to 0.4% increase in cumulative emissions between 2025-2045 in the "\$70/MT CO_2 Eq." scenario and about 1% increase in the "\$1,000/MT CO_2 Eq." scenario. For this reason, only the cases where revenues are kept by the government are shown.

renewable energy adoption and being the primary driver of GHG emission reductions for the electricity sector. Concurrently, the carbon tax should influence the efficiency of oil-fired electricity generation.

For the higher price pathway, the \$240/MT CO_2 Eq. tax levied in the year 2025 results in a dramatic reduction of almost 5 MMT CO_2 Eq. from the baseline. The RPS constraint immediately ceases to be binding. By 2045, this amounts to cumulative GHG abatement totalling 150 MMT CO_2 Eq. Nearly 90% of electricity is provided through renewable energy sources by the year 2030, and 100% by 2040. Electricity sector GHG emissions are driven to zero in the model.[30] The amount of electricity from renewable sources is shown in Figure 10 for the baseline and two carbon tax scenarios. The percentages in the baseline and the "\$70/MT CO_2 Eq." scenario are identical because the baseline RPS constraint remains the more stringent policy.

Figure 10. % of Electricity Generation from Renewable Energy, 2019-2045



Figures 11 and 12 show the composition of sector GHG emissions under "\$70/MT CO_2 Eq." and "\$1,000/MT CO_2 Eq." scenarios.

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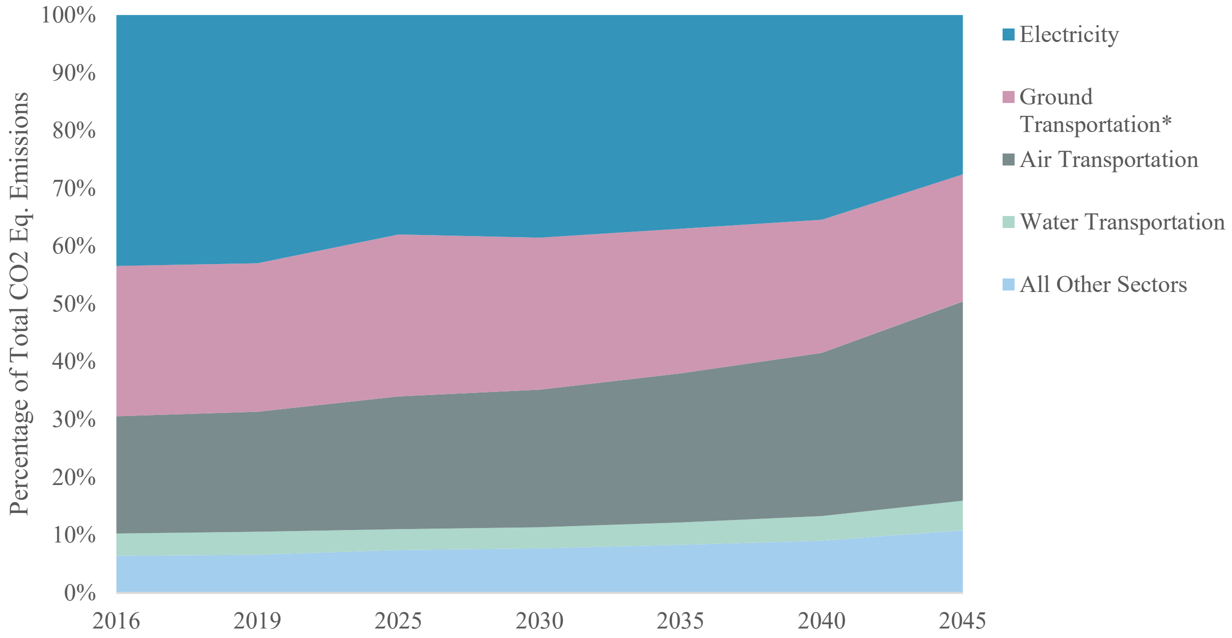
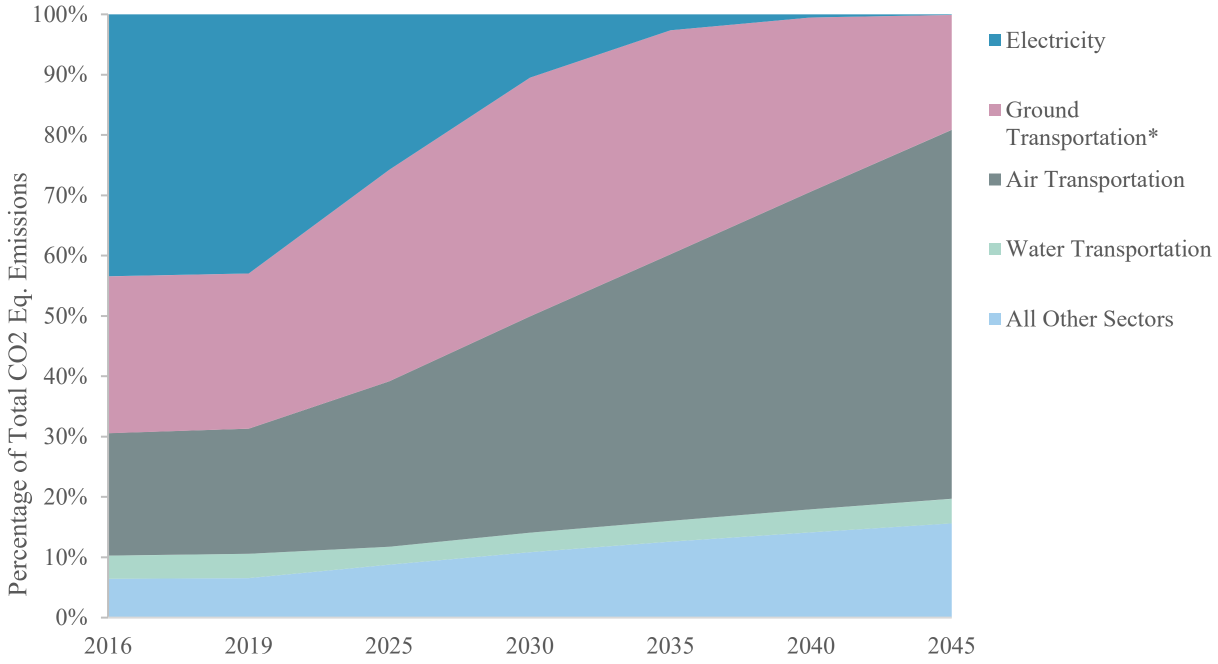
[30] This does not account for sources of GHG emissions from waste-to-energy, as this feedstock is not represented in the baseline I-O table. In addition, sources of GHG emissions from biofuels are not addressed.

Figure 11. Composition of "$70/MT CO$_2$ Eq." Scenario's GHG Emissions, 2016-2045



**Includes Ground Transportation Services and Personal Vehicle Travel*

Figure 12. Composition of "$1,000/MT CO$_2$ Eq." Scenario's GHG Emissions, 2016-2045



**Includes Ground Transportation Services and Personal Vehicle Travel*

The composition of GHG emissions under the high carbon price scenario, “$1,000/MT CO_2 Eq.,” shows that electricity sector emissions are driven to zero, causing air transport to become a considerably more important share of total emissions.

Figure 13 shows the change in GHG emissions for each carbon tax scenario based on each source of fossil fuel: oil, gas, and coal.

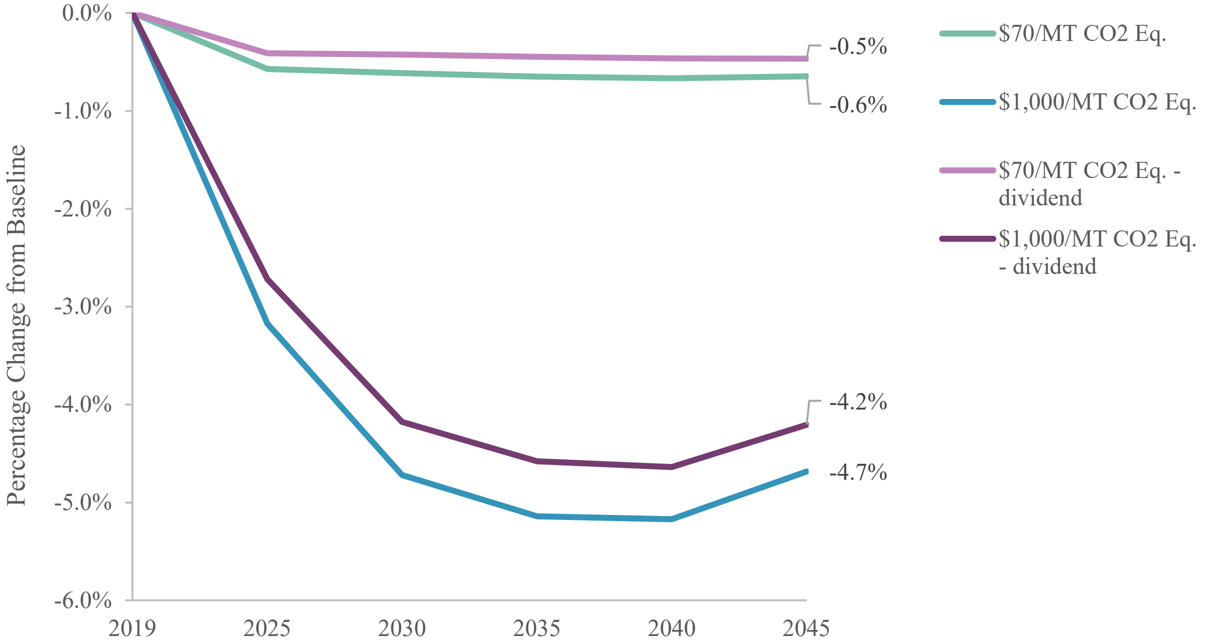
Figure 13. Baseline GHG Emissions by Fuel, 2019-2045

Per state law, coal is assumed to phase out prior to 2025. Though small, the GHG emissions from gas decline with the level of the carbon tax. Oil is by far the largest fossil fuel source of GHG emissions, and the most notable changes are from the tax impact on oil demand.

MACROECONOMIC AND SECTOR IMPACTS

The introduction of a carbon tax reduces Hawai‘i’s overall economic productivity because it increases the cost of production for domestically produced goods and services. The introduction of a carbon tax at the level of the Interagency Working Group Social Cost of GHGs recommendation, the “$70/MT CO_2 Eq.” scenario, results in a reduction of total economic output of 0.6% in 2045. Some of this effect can be mitigated by giving tax monies back to households, leaving the reduction at 0.5% in 2045. This is denoted by the scenario name with “dividend” afterwards, as shown in Figure 14.

Figure 14. Change in Total Output from Baseline under Carbon Tax and Revenue Scenarios, 2019-2045



The higher carbon tax scenario, "$1,000/MT CO_2 Eq.," leads to a much bigger drop in total output than the lower tax scenario. The shape of the impact, which bottoms out in 2040, is due to the electricity sector having already reached 100% renewable energy generation by that time. Therefore by 2045 input costs relative to the baseline do not rise like they had previously. By 2045, though, there is still a 4.7% difference in total output from the baseline. Giving revenues back to households mitigates this negative impact by half a percentage point in 2045. Note that these declines are relative to a baseline of growing GSP, as shown in Figure 4. Thus it is not a decline from the 2019 economy, but rather represents a slower growth pathway.

Figure 15 shows the impact of the carbon tax and revenue scenarios on demand for imports.

Figure 15. Change in Imports from Baseline under Carbon Tax and Revenue Scenarios, 2019-2045

The impact on imports is determined by two competing effects. The first and largest effect is the trend of decreasing productivity which leads to a decline in the demand for imports as an intermediate input. On the other hand, because U.S. states cannot impose carbon-adjustment taxes at their borders, the relative price of imported final goods and services declines in comparison to Hawai‘i-produced goods and services.[31] Therefore, imports become preferred to Hawai‘i produced goods, and the demand for imports falls less than the demand for Hawai‘i's goods. We see this effect particularly after 2030 in the high carbon price “$1,000/MT CO_2 Eq.” scenario. If carbon tax revenues are returned to households, then the trade-off between imports and domestically produced goods is large enough to cause net imports to return to baseline levels by 2045.

The main finding is that there is a loss of economic productivity, as seen by the effect on exports from Hawai‘i in Figure 16.

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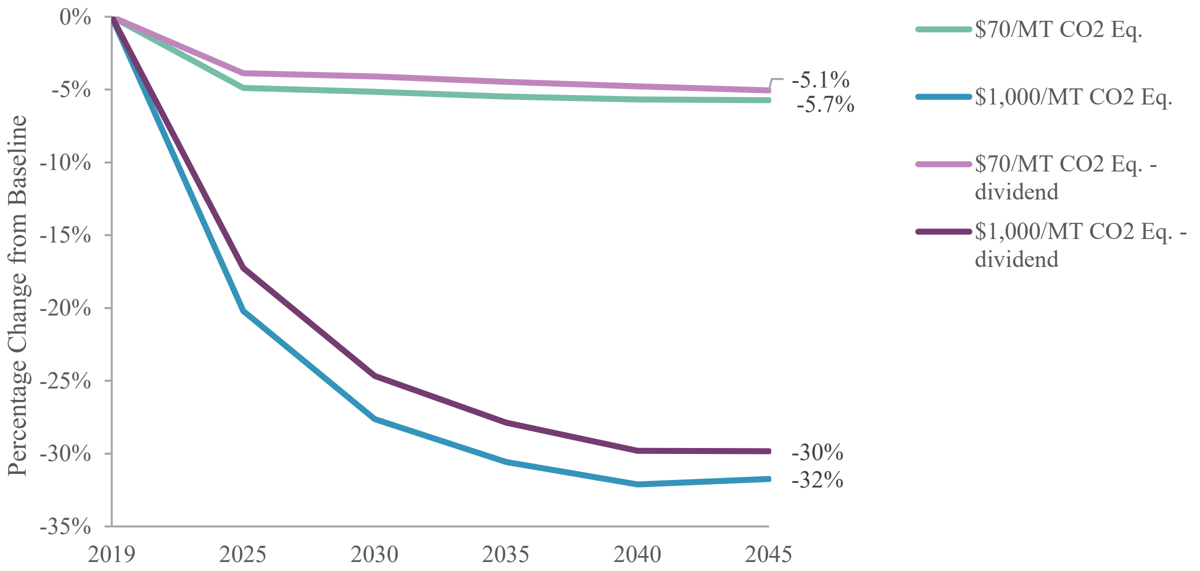
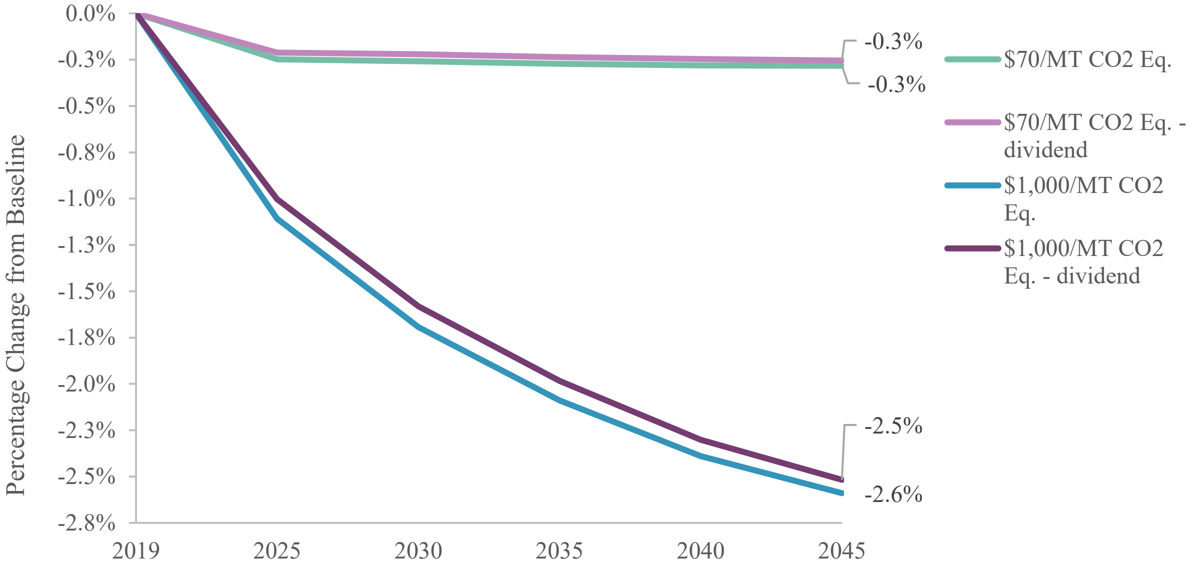
[31] The extent to which Hawai‘i has trading partners that have adopted or will adopt carbon pricing would lessen this effect.

Figure 16. Change in Exports from Baseline under Carbon Tax and Revenue Scenarios, 2019-2045



The changes in the value of exports are much more dramatic than imports as their price rises relative to the price of goods produced outside of Hawai‘i. In the “$70/MT CO_2 Eq.” scenario, there is an approximate decline of 5% by 2045, with small differences in the case where tax revenues are returned to households. In the “$1,000/MT CO_2 Eq.” scenario there is a much larger decline of 30% by 2045. This reflects a loss of competitiveness for Hawai‘i’s non-tourism exports. There is, however, much less of an impact on the state’s major export, tourism. Relative changes in visitor spending are shown in Figure 17.

Figure 17. Change in Visitor Spending from Baseline under Carbon Tax and Revenue Scenarios, 2019-2045



Total visitor spending is estimated to decline by 0.3% in the "$70/MT CO_2 Eq." scenario and 2.5% to 2.6% in the "$1,000/MT CO_2 Eq." scenario. This is driven by our assumption that tourist demand for Hawai'i vacations is relatively insensitive to changes in air travel cost per Fuleky et al. (2013).[32] Though visitor spending is impacted only modestly, a carbon tax means that a share of their spending goes to indirectly paying the tax, through the goods and services they consume while in Hawai'i. This is accounted for in our measure of total output and sectoral impacts. If revenues are returned to households, the proportion of revenues gained through visitor spending would accrue more directly to households.

Tables 10 and 11 present results by sector. We show results for the revenue scenario in which the state government retains carbon tax revenues to allow additional state and local government spending. Other than for the State and Local Government sector, results are quite similar to the case where revenues are returned to households. For each sector, results are presented as a percentage change from the baseline value.

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[32] Assuming a constant elasticity of substitution for travel to Hawai'i versus all other goods of 0.25. This is based on Fuleky et al. (2013)'s estimate of the own-price elasticity of demand of visitor arrivals to Hawai'i from the continental U.S. to changes in airfare. Operationalizing this parameter in the model means equating arrivals and spending. Because tourism is Hawai'i's largest private sector industry, we ran sensitivity analysis of this parameter. Doubling it, meaning an elasticity of 0.5, reduces visitor spending and total output by about 1% and 0.5% by 2045 in the "$70/MT CO_2 Eq." scenario in comparison to the baseline. It reduces visitor spending and total output by 6% and 4% by 2045 in the "$1,000/MT CO_2 Eq." scenario. The central result that visitor spending impacts are substantially muted in comparison to other export goods and services remains.

Table 10. Sector Output for the "$70/MT CO_2 Eq." Scenario – % Change from Baseline

	2025	2030	2035	2040	2045
Petroleum Manufacturing	-5.0%	-5.8%	-6.9%	-8.1%	-9.6%
Electricity	0.1%	0.3%	0.8%	1.3%	1.8%
Gas	-4.9%	-5.5%	-6.2%	-6.9%	-7.6%
Water Transportation	-16%	-16%	-17%	-17%	-17%
Air Transportation	-5.7%	-6.0%	-6.3%	-6.6%	-6.8%
Ground Transportation Services	-1.8%	-1.9%	-2.0%	-2.0%	-2.0%
Water & Other Utilities	-0.9%	-0.9%	-0.8%	-0.6%	-0.3%
Waste Management	-0.4%	-0.5%	-0.6%	-0.6%	-0.6%
Agriculture & Forestry	-2.8%	-2.8%	-3.0%	-3.0%	-2.9%
Construction	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
Wholesale and Retail Trade	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
Real Estate and Rentals	0.3%	0.2%	0.1%	0.1%	0.1%
Other Manufacturing	-2.3%	-2.3%	-2.5%	-2.5%	-2.5%
Other Services	-0.4%	-0.4%	-0.4%	-0.4%	-0.3%
Federal Government	-0.5%	-0.5%	-0.5%	-0.5%	-0.4%
State & Local Government	3.2%	3.1%	3.1%	2.9%	2.8%

Table 11. Sector Output for the "$1,000/MT CO_2 Eq." Scenario – % Change from Baseline

	2025	2030	2035	2040	2045
Petroleum Manufacturing	-26%	-41%	-49%	-55%	-56%
Electricity	-9.5%	-10%	-4.0%	4.3%	11%
Gas	-18%	-28%	-36%	-42%	-47%
Water Transportation	-42%	-52%	-57%	-60%	-61%
Air Transportation	-17%	-22%	-25%	-27%	-28%
Ground Transportation Services	-7.3%	-10%	-12%	-13%	-14%
Water & Other Utilities	3.1%	12%	15%	16%	11%
Waste Management	-2.9%	-5.3%	-6.7%	-7.6%	-7.7%
Agriculture & Forestry	-14%	-19%	-21%	-23%	-23%
Construction	-1.2%	-1.7%	-1.6%	-1.3%	-0.9%
Wholesale and Retail Trade	-2.6%	-3.5%	-3.6%	-3.4%	-3.1%
Real Estate and Rentals	0.9%	-0.3%	-1.4%	-2.0%	-1.7%
Other Manufacturing	-10%	-14%	-16%	-17%	-17%
Other Services	-3.1%	-4.1%	-4.1%	-4.0%	-3.8%
Federal Government	-2.3%	-2.9%	-3.1%	-3.1%	-2.9%
State & Local Government	15%	17%	17%	16%	16%

The most negatively affected sectors include petroleum manufacturing, gas, and water transportation. Petroleum manufacturing and gas sectors are taxed by design. Petroleum is the most prevalent fossil fuel in Hawaiʻi; in the "$70/MT CO_2 Eq." scenario it declines by 9.6% by 2045; in the "$1,000/MT CO_2 Eq." it declines by over 50%.[33] Water transportation encompasses interisland shipping as well as recreational/commercial activities – the large decline coming from the latter. Other heavily-impacted sectors include air transportation, ground transportation, agriculture and forestry,[34] and other manufacturing. A few sectors, notably electricity, increase output due to new sources of demand from EVs, as shown in Figure 18.

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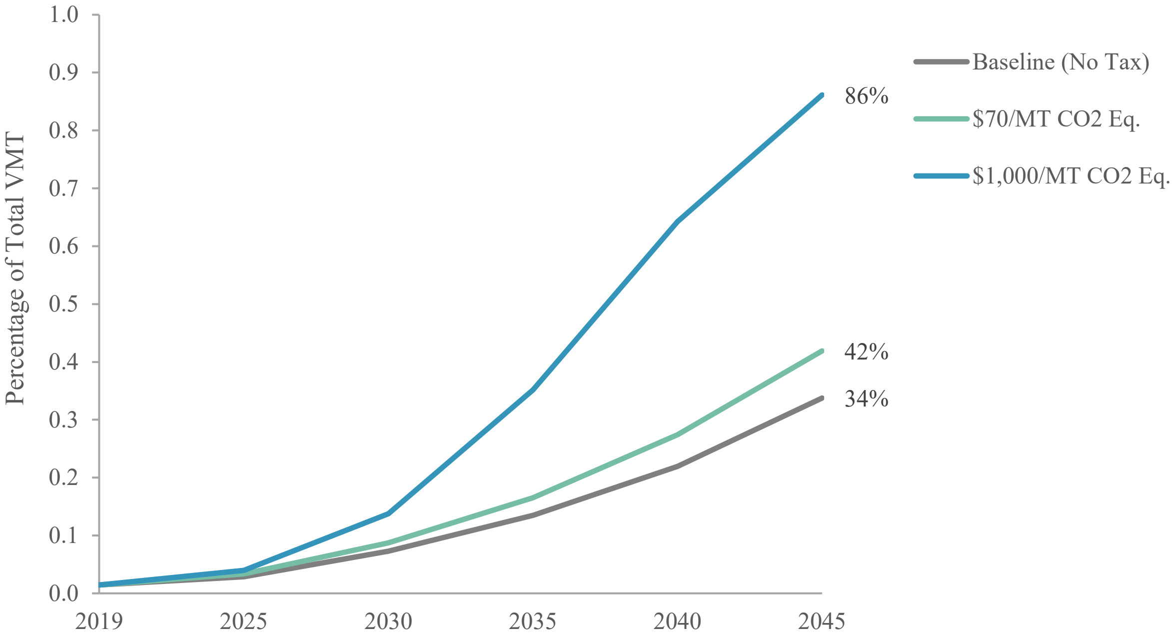
[33] A decline of this magnitude could cause Hawaiʻi's only refinery to shutter and transition to an import terminal. This shift would lead to no change in global emissions.

[34] Impacts to sectors like agriculture and forestry show the challenges of integrating GHG reduction goals with other stated goals like increasing local food production. Making transparent the existing connection between agriculture and forestry with fossil fuel usage is an important step in finding technological and practice-oriented solutions; for example, in targeted renewable energy investments or carbon sequestration through agricultural practices.

Figure 18. Share of Vehicle Miles Travelled by Electric Vehicles



The carbon tax has a large impact on EV adoption and overall vehicle miles travelled. In comparison to the baseline, the EV share of miles travelled increases by 8 percentage points (or an over 20% increase from the baseline) under the "\$70/MT CO_2 Eq." scenario, and an additional 52 percentage points (or a more than 100% increase from the baseline) under the "\$1,000/MT CO_2 Eq." scenario.

To transform sector results into metrics that are more easily relatable, Table 12 reports the impact of the carbon tax to a gallon of gasoline,[35] kWh of electricity,[36] and therm of gas.

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[35] Because the model has multiple uses for petroleum, this is calculated as a straight price pass-through, converting the carbon price into the gasoline price.

[36] The current electricity rate setting mechanism allows almost perfect pass-through of energy cost changes – 98% in-between rate cases. This implies a perfectly inelastic supply curve in the short-run such that the consumer takes the full burden of the price change. Assuming that there is regulation of electricity contracts such that costs are minimized in the long-run, there would be shared burden determined by the relative elasticities of supply and demand.

Table 12. Change in the Price of a Gallon of Gasoline, kWh of Electricity and therm of Gas

	2025	2030	2035	2040	2045
“$70/MT CO_2 Eq.” Scenario					
Increase in Gasoline Price ($2012/Gallon)	$0.45	$0.49	$0.54	$0.59	$0.63
Increase in Electricity Price ($2012/kWh)	$0.00	$0.00	$0.00	$0.00	$0.00
Increase in Gas Price ($2012/therm)	$0.25	$0.27	$0.30	$0.33	$0.35
“$1,000/MT CO_2 Eq.” Scenario					
Increase in Gasoline Price ($2012/Gallon)	$2.20	$3.90	$5.60	$7.30	$9.00
Increase in Electricity Price ($2012/kWh)	$0.08	$0.11	$0.08	$0.06	$0.03
Increase in Gas Price ($2012/therm)	$1.10	$2.00	$2.90	$3.90	$4.90

There is effectively no increase in the price of electricity in the “$70/MT CO_2 Eq.” scenario because the RPS remains the dominant policy. Under the “$1,000/MT CO_2 Eq.” scenario, the price of electricity increases by $0.08/kWh in 2025 because of the high carbon tax on oil-fired generation – a 25% increase from 2012 prices. The increase in electricity decreases over time to $0.03/kWh in 2045 because of the switching away from fossil fuel generation. The price of a gallon in the “$70/MT CO_2 Eq.” scenario increases by $0.45 per gallon in 2025 and increases by $0.63 per gallon in 2045. This jumps considerably in the “$1,000/MT CO_2 Eq.” scenario – reaching an increase of $9 per gallon by 2045 about three times 2012 prices. This price change, coupled with the tempered price effects in electricity, motivate the large shift towards EVs. In the “$70/MT CO_2 Eq.” scenario, gas prices increase by $0.35/therm in 2045. For the “$1,000/MT CO_2 Eq.” scenario, the increase is by $4.90/therm, about double compared to 2012 prices, by 2045.

HOUSEHOLD IMPACTS

We find that the carbon tax scenarios have very different outcomes for households depending on whether carbon tax revenues (with the exception of aviation-related revenues) are returned to them. Figure 19 displays the change in household welfare, by quintile, relative to the baseline under the different carbon tax and revenue sharing scenarios for 2025. Figure 20 displays the same information for 2045.

Figure 19. Change in Household Welfare from Baseline under Carbon Tax and Revenue Scenarios, 2025

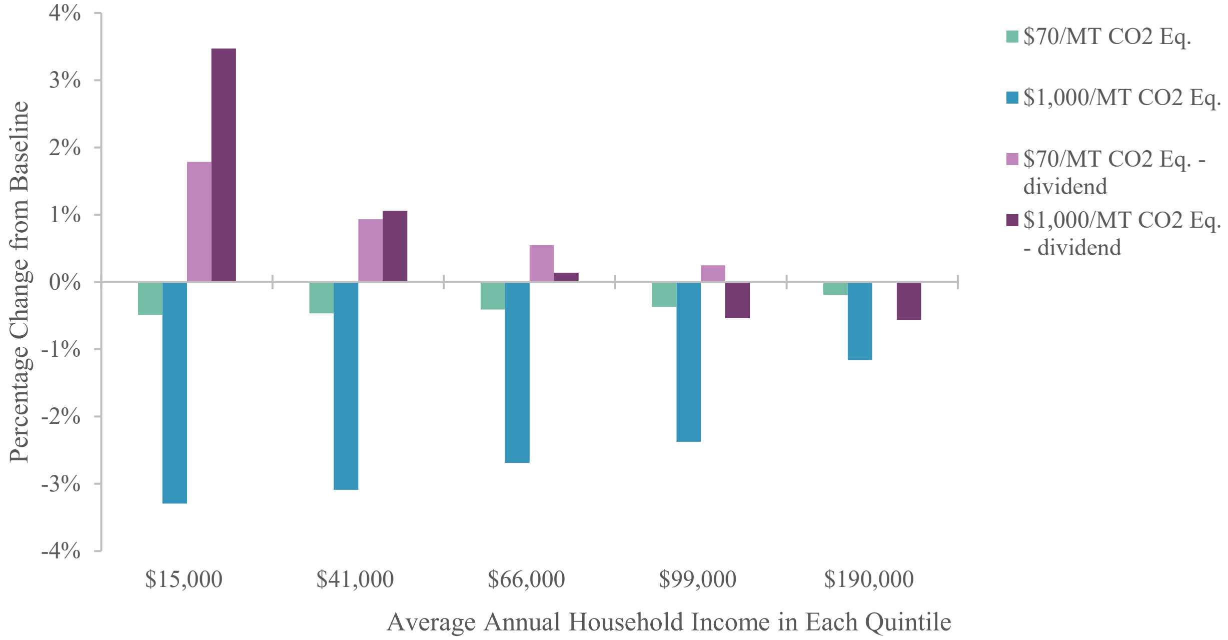
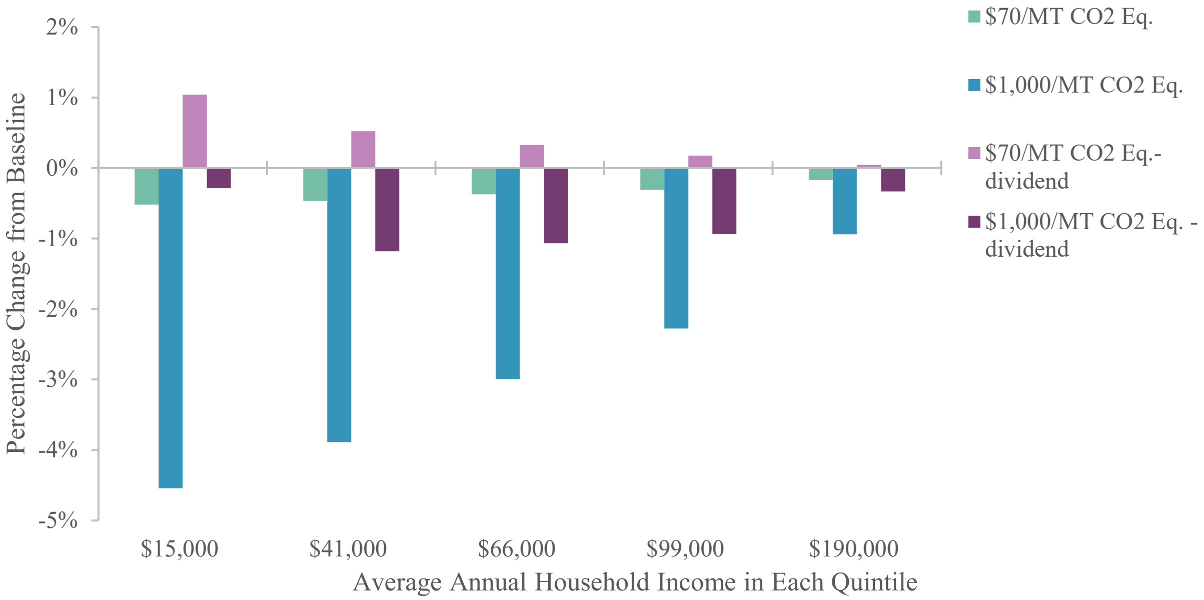


Figure 20. Change in Household Welfare from Baseline under Carbon Tax and Revenue Scenarios, 2045



Overall the impacts on households are relatively modest under the “\$70/MT CO_2 Eq.” scenario; however, even a small change in income for lower-income quintiles is meaningful. To translate this into monetary terms, under the “\$70/MT CO_2 Eq.” scenario with no dividend, the lowest income household would experience a decrease in spending power of \$250 in 2025 and \$350 in 2045. For the “\$1,000/MT CO_2 Eq.” scenario with no dividend this amounts to \$1,700 in 2025 and \$3,000 in 2045.[37] If the revenues are returned to households, the carbon tax becomes much more progressive. It also becomes positive for each income quintile in the “\$70/MT CO_2 Eq.” scenario. The average lowest income quintile household sees a \$900 and \$700 gain in spending power in 2025 and 2045 respectively. The dividend serves as a wealth transfer from the production to consumption side of the economy, helping to offset decreasing economic productivity. Under the high price pathway, “\$1,000/MT CO_2 Eq.,” the overall shrinking of the economy is not offset; however, the dividend still blunts the impact to low-income households who see a \$1,800 gain in 2025 and a \$190 loss in 2045.

CARBON TAX REVENUES AND HOUSEHOLD DIVIDENDS

The four carbon tax and revenue scenarios generate a new source of government revenue as well as dividends to households, as shown in Table 13.

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[37] This finding differs from other studies. For example Goulder et al. (2019) that find the carbon tax can be progressive even without the dividend to households. Though we find very similar results in terms of regressive use-side impacts and progressive supply-side impacts, estimated supply-side impacts do not offset the use-side impacts. This is likely because higher income Hawai‘i residents hold much less GHG-intensive capital than higher income U.S. residents more broadly; for example, because Hawai‘i has little manufacturing.

Table 13. Carbon Tax Revenues to Government and Households by Scenario

	2025	2030	2035	2040	2045
State Government Revenue ($2012 Million)					
$70/MT CO_2 Eq.	$580	$630	$670	$690	$610
$1,000/MT CO_2 Eq.	$1,900	$2,400	$2,600	$2,800	$2,800
$70/MT CO_2 Eq. - dividend	$110	$120	$140	$150	$170
$1,000/MT CO_2 Eq. - dividend	$410	$690	$980	$1,300	$1,600
Household Revenue ($2012/household)					
$70/MT CO_2 Eq. - dividend	$980	$1,000	$1,100	$1,000	$850
$1,000/MT CO_2 Eq. - dividend	$3,000	$3,400	$3,300	$2,900	$2,400

In the case where the government allocates revenues based on its existing services, there is an estimated $610 million in carbon tax revenues in 2045 in the "$70/MT CO_2 Eq." scenario. This jumps to $2.8 billion under the "$1,000/MT CO_2 Eq." scenario. If only revenue from air transportation fuels remain with the government, in the case that there are dividends to households, the total revenue from the carbon tax is nearly the same, but revenues retained by the government are much lower: in 2045 revenues are $170 million and $1.6 billion for the "$70/MT CO_2 Eq." scenario and "$1,000/MT CO_2 Eq." scenario, respectively.[38] In this case where households are returned a dividend, they would receive on average a check of approximately $1,000 annually in the "$70/MT CO_2 Eq." scenario from 2025 through 2045. Under the "$1,000/MT CO_2 Eq." scenario, the annual dividend would start at $3,000 in 2025, increase to about $3,400 in 2030, and then trend lower to $2,400 by 2045.[39] The household dividend goes down as emissions go down and an increasing portion of revenues are from air transportation.

MARGINAL COST OF GHG ABATEMENT

Figure 21 shows levels of GHG emissions abatement from a wider range of carbon tax levels in 2045. This figure provides insight into the marginal cost of GHG abatement under the model assumptions.

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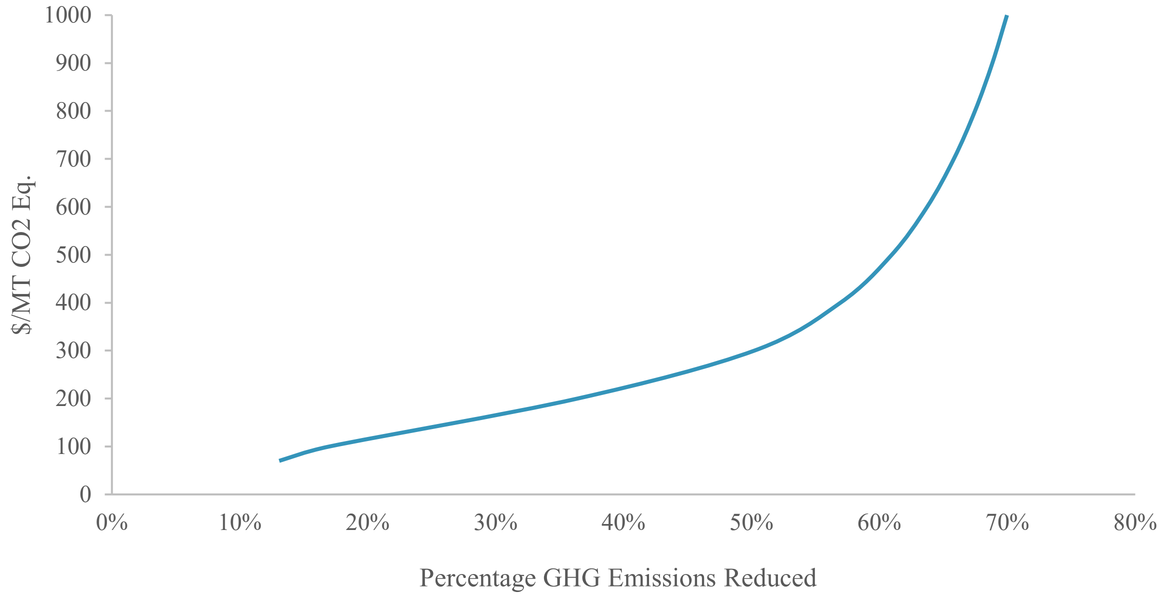
[38] Though these revenues must be put towards the air transportation sector, presumably this would allow for reallocation.

[39] These do not equal net change in government revenues as there will be a reduction in income tax and GET receipts with the imposition of the carbon tax. See Kaufman et al. (2019).

Figure 21. Marginal Cost of GHG Abatement in 2045



The cost of reducing GHGs is increasing in levels of GHG emissions; its concave shape means that there are flatter and steeper parts of the curve. There will be greater returns to GHG abatement along the flatter parts of the curve – meaning more GHG emissions abated for every dollar spent. There will be diminishing returns to GHG abatement along the steeper parts of the curve – meaning fewer GHG emissions abated for every dollar spent. We find that there starts to be increasingly diminishing returns around \$400/MT CO_2 Eq. in 2045.[40] In earlier years, it is closer to \$300/MT CO_2 Eq. This illustration highlights that the level of a state carbon tax should consider the issue of increasing marginal cost of abatement (in addition to levels of leakage as a result of the carbon tax). Lastly, the cost of a “backstop technology” serves as a theoretical maximum for the cost curve. For Hawai‘i, the backstop per the language of Act 15 (2018) means investment in Hawai‘i-focused sequestration; though estimating its cost is outside the scope of this analysis.

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[40] Our selected scenario of \$1,000/MT CO_2 Eq. by 2045 was in part chosen because it is on the relatively steep part of the abatement cost curve, showing higher economic tradeoffs. In addition the scope of work motivated a very high carbon tax to see its potential contribution to achieve the net negative GHG emissions target set for 2045.

VI. CONCLUSION

This study presents the economic and GHG implications of adoption of a carbon tax by the State of Hawai‘i. Using a CGE model representing flows of GHGs and economic activities across different sectors of Hawai‘i’s economy, we estimate these impacts under four scenarios that consider the combination of two carbon tax price pathways and two revenue use schemes. The key findings are as follows:

- A carbon tax at the level of the Federal Interagency Working Group on the Social Cost of GHGs, which rises from \$50/MT CO_2 Eq. in 2025 to \$70/MT CO_2 Eq. in 2045, reduces Hawai‘i’s cumulative GHG emissions between 2025 and 2045 by 25 MMT CO_2 Eq. In the year 2045, GHG emissions are 13% below 2045 baseline levels and 40% below 2019 levels.
- A carbon tax on a much higher price pathway, starting at \$240/MT CO_2 Eq. in 2025 and rising linearly to \$1,000/MT CO_2 Eq. in 2045, reduces Hawai‘i’s cumulative GHG emissions between 2025 and 2045 by 150 MMT CO_2 Eq. In the year 2045, emissions are 70% below 2045 baseline levels and 80% below 2019 levels.
- If tax revenues are given back to households in equal shares, the carbon tax is progressive, meaning the carbon tax’s overall operation more than proportionally benefits lower-income households. This finding would be strengthened if larger shares of revenues are returned to lower-income households. The very high carbon tax scenario produces overall declines in welfare even when tax revenues are returned to households because the high carbon tax results in economic contraction, which dominates other positive effects from the tax.
- A carbon tax induces an increase in electricity demand through electrification of transportation. By 2045 the share of vehicle miles travelled by EVs increases by 8 percentage points in the “\$70/MT CO_2 Eq.” scenario and by 52 percentage points in the “\$1,000/MT CO_2 Eq.” scenario. The impact of an increase in gasoline prices of approximately \$9 per gallon above baseline levels results in nearly 90% of personal vehicles on the road being electric by 2045.
- A high carbon tax that puts Hawai‘i substantially on the path towards achieving deep decarbonization by 2045 (an 80% reduction from 2019 levels) comes at high economic cost. This suggests that new technologies must be developed and adopted to cost-effectively meet Hawai‘i’s goal of net negative emissions (Act 15, 2018). There are decreasing gains in GHG abatement around \$300-400/MT CO_2 Eq. as the marginal cost of abatement increases rapidly at these carbon prices.
- There is an overall loss of competitiveness for Hawai‘i goods and services, mostly affecting exports but also preferencing imports. Sectors most negatively impacted by a carbon tax are petroleum manufacturing, gas (e.g., propane), air transportation, water

transportation (mainly via reduced resident and visitor recreational demand), manufacturing, and agriculture.

- Visitors pay for the carbon tax through the goods and services they purchase while in Hawaiʻi, and these revenues would be directly transferred to Hawaiʻi's households if a dividend accompanies the carbon tax. This represents a transfer from Hawaiʻi visitors to Hawaiʻi residents.

To address issues of regional competitiveness and to minimize leakage of GHG emissions from one sub-national region to another, the Federal government should be the one to put a price on carbon.[41] Without strong federal leadership, the path forward for individual states is difficult. Our results show a loss of competitiveness for Hawaiʻi's export products, as well as a shift towards more imports. The largest private sector industry, tourism, is less impacted than other export sectors. Moreover, visitors would pay the carbon tax, proceeds from which would be returned to residents in some schemes.

One consideration is whether Hawaiʻi has a first-mover advantage from being among the first states to adopt a price on carbon. Though it could be argued that getting the prices right on carbon could spur Hawaiʻi-based technology development and deployment, a carbon price would be far from sufficient to achieve this outcome, particularly given the small size of Hawaiʻi's market for technology. Other policies that enable energy sector innovation would have to be in place – from dynamic electricity rates to venture capital to rapid technology transfer.[42] In addition, decisions by individual states to adopt carbon taxes also depends on expectations about future federal carbon policies. Consider, for example, if the U.S. should adopt a decentralized approach to carbon taxation like Canada, where minimum GHG reduction standards would be set nationally but with flexibility for implementation aross states. Then Hawaiʻi's early adoption of a carbon tax could provide some first-mover advantages because adjustments by firms, governments, and households to the carbon tax would become investments towards adherence to the new federal carbon policies.

There is little economic argument for Hawaiʻi, or any other state, to unilaterally adopt a very high carbon price given issues of leakage. Our assessment of overlapping policies shows that the current construct of federal CAFE standards leads to almost perfect leakage of light duty vehicle ground transportation emissions in terms of the types of new vehicles purchased. Nonetheless, a carbon tax would suffer from less leakage, for example, than command-and-control policies targeting vehicle purchases because it would give an incentive to reduce vehicle miles travelled –

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[41] If a sufficiently high price signal was set, Hawaiʻi should repeal its own state-level carbon tax; however, they would also layer onto one another such that a low federal tax rate could be supplemented with an additional state-level price signal. This is very different for the layering of a federal carbon price with a regional cap-and-trade. The price signal would compete rather than "layer."

[42] For a discussion of the potential for Hawaiʻi to have a thriving energy innovation sector see Bonham and Coffman (2017).

also enabling conditions supportive of alternative transportation infrastructure which would complement carbon pricing. In addition, Hawai‘i is likely to suffer less leakage of GHG emissions as a result of carbon pricing in comparison to continental states due to its bounded electricity grid. As islands, there is extremely limited transfer of GHG emissions from electricity in Hawai‘i to other regions.[43]

As more countries and states, particularly Hawai‘i’s main trading partners, adopt carbon policies, the impacts to competitiveness and leakage decline. This fundamentally points to the issue that mitigating global climate change is a collective action problem. Hawai‘i’s per capita emissions are double the global average – motivating a responsibility to play a role in global GHG mitigation. A carbon price in line with the Obama Administration SCC assessment, that would incentivize renewable energy deployment as well as dissuade fossil fuel burning in power plants and vehicles, would go a long way to reducing Hawai‘i’s contributions to global GHGs – regardless of whether Hawai‘i is a leader or a follower in enacting the tax. The transfer of carbon tax revenues to Hawai‘i households is an important component in making such a policy progressive. At the federal SCC price, returning revenues in equal shares to households would benefit lower-income households relatively more as well as make all of Hawai‘i’s households economically better-off.

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[43] Because the RPS does not distinguish between renewable energy based on GHG emissions, leakage can still occur through importation of irresponsibly produced biofuels. Overall, fuels that have distinctly different emissions from a lifecycle perspective pose leakage problems. Natural gas is an example, as it burns relatively clearly but has considerable upstream GHG emissions. On the other hand, biofuels are treated as zero-GHG emissions fuels based on Act 234 even though they may have considerable emissions from a lifecycle perspective. More recently, the Public Utilities Commission is considering lifecycle GHG emissions per HRS §269-6(b). This complementary approach will serve to scrutinize more (and less) responsible sources of biofuels. Lastly there may be leakage from the air transportation sector related to airlines changing their refueling to areas outside Hawai‘i.

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VIII. TECHNICAL APPENDIX. HAWAIʻI COMPUTABLE GENERAL EQUILIBRIUM MODEL (H-CGE)

A-I. INTRODUCTION

The Hawaiʻi Computable General Equilibrium Model (H-CGE) is a regional representation of Hawaiʻi's economy. It is built upon a Social Accounting Matrix (SAM) of macro-economic and sector-level activity for a baseline year. H-CGE is a recursive dynamic model, projecting in five-year intervals from 2025 to 2045. This appendix provides a detailed overview of the H-CGE model developed to assess the impacts of a carbon tax on Hawaiʻi's economy. It includes a description of the data used, an exposition of the model structure and other key assumptions.

A-II. SOCIAL ACCOUNTING MATRIX: BASELINE ECONOMIC DATA

The main economic data input into the baseline calibration of H-CGE is the 2012 State of Hawaiʻi Input-Output Table (DBEDT, 2016). This detailed I-O table represents a total of sixty-eight sectors including GHG-intensive sectors like petroleum manufacturing, electricity, ground transportation services, water transportation, and aviation. In addition, there are eleven agents of final demand including households, visitors, federal and state governments. The I-O sectors and agents are aggregated within H-CGE, based on relevance to key energy sectors.

Representing Hawaiʻi's Economic Sectors

We begin by listing the sectors within the 2012 I-O table and the aggregation used for baseline calibration and reporting purposes. The aggregation scheme is determined at three levels. The first identifies GHG-intensive sectors, based in energy and transportation, which either produce energy or directly burn large amounts of fossil fuel (oil, gas (e.g. propane) and coal). The second level identifies other GHG sectors highlighted within the State of Hawai'i's GHG inventory. These sectors are identified either by their methane generation from waste decomposition and wastewater treatment or by their linkage to the GHG category of Agriculture, Forestry and Other Land Use (AFOLU). These emissions are not explicitly modeled in H-CGE because they are not subject to the carbon tax; however, we tease out their sectors to establish the model for future GHG emissions scenarios that could incorporate these sources of emissions. The third set of sectors simply represent important and remaining sectors in Hawaiʻiʻs economy. These sectors emit small levels of GHGs, but are indirectly responsible for GHG emissions because of the emissions associated with the inputs into their production.

The full list of 68 sectors and the aggregated list of sectors are presented in the order they appear within the I-O Table:

I-O Table Sector List

1 Sugarcane
2 Vegetables
3 Macadamia nuts
4 Pineapples
5 Flowers and Nursery Products
6 Other Crops
7 Animal Production
8 Aquaculture
9 Commercial Fishing
10 Forestry and Logging
11 Support Activities for Agriculture
12 Mining
13 Single Family Construction
14 Construction of Other Buildings
15 Heavy and Civil Engineering Construction
16 Maintenance & Repairs
17 Food Processing
18 Beverage Manufacturing
19 Apparel and Textile Manufacturing
20 Petroleum Manufacturing
21 Other Manufacturing
22 Air Transportation
23 Water Transportation
24 Truck and Rail Transportation
25 Transit and Ground Passenger Transportation
26 Scenic and Support Activities for Transportation
27 Couriers and Messengers
28 Warehousing and Storage
29 Publishing including internet
30 Motion Picture and Sound Recording Industries
31 Broadcasting
32 Telecommunications
33 Internet providers, web, and data processing
34 Other Information Services
35 Electricity
36 Other Utilities
37 Wholesale Trade
38 Retail Trade
39 Credit Intermediation and Related Activities
40 Insurance Carriers and Related Activities
41 Other Finance and Insurance
42 Owner-Occupied Dwellings
43 Real Estate
44 Rental & Leasing and Others
45 Legal Services
46 Architectural and Engineering Services
47 Computer Systems Design Services
48 R&D in the Physical, Engineering & Life Sciences
49 Other Professional Services
50 Management of Companies and Enterprises
51 Travel Arrangement and Reservation Services
52 Administrative and Support Services
53 Waste Management and Remediation Services
54 Colleges Universities and Professional Schools
55 Other Educational Services
56 Ambulatory Health Care Services
57 Hospitals
58 Nursing and Residential Care Facilities
59 Social Assistance
60 Arts and Entertainment
61 Accommodation
62 Eating and Drinking
63 Repair and Maintenance
64 Personal and Laundry Services
65 Organizations
66 Federal Government Military
67 Federal Government Civilian
68 State and Local Government

16-Sector Aggregation

Energy and Transport Sectors
20 Petroleum Manufacturing
35 Electricity
36 Gas (Adjusted, see below)
23 Water Transportation
22 Air Transportation
(24*27) Ground Transportation Services

Other GHG-Intensive Sectors
36 Other Utilities (Water and Wastewater, Adjusted, see below)
53 Waste Management
(1*11) Agriculture and Forestry

Other Sectors
(13*15) Construction
(37,38) Wholesale and Retail Trade
(42*44) Real Estate and Rentals
(28*34,39*41,45*52,54*65) Other Services
(12,16*19,21) Other Manufacturing
(66,67) Federal Government
68 State and Local Government

In the 2012 I-O table, the gas, water, and wastewater utilities comprise one sector. To better represent flows of GHGs, we separate the gas sector (i.e. primarily propane and synthetic gas) from the water and wastewater utilities, which remain together.

The Gas Sector – e.g. Propane and Synthetic Gas

The Other Utilities sector (sector 36 in the original 68 sector I-O table, see above) is disaggregated into the water and wastewater utilities and gas sectors, using the production and consumption shares represented in the more detailed 1997 State of Hawai‘i Input-Output Study that separately lists these sectors. This prior I-O table is the only one that shows all utilities separately. It shows the value of gas that is demanded by the other sectors and the value of inputs from the other sectors into the gas sector. To determine how to disaggregate the Other Utilities sector in the 2012 I-O table, we first aggregate the 1997 I-O‘s 131 sectors into the same sectors 16 sectors presented above.

Energy and Transport Sectors
42 Petroleum Manufacturing
64 Electricity
65 Gas Utility
51 Water Transportation
52 Air Transportation
(49*50,53*56,126) Ground Transportation

Other GHG-Intensive Sectors
125 Other Utilities (Water and Wastewater)
102 Waste Management
(1*17) Agriculture and Forestry

Other Sectors
(18*25) Construction
(26*41,43*48) Other Manufacturing
(66*79) Wholesale and Retail Trade
84 Real Estate and Rentals
(57*63,80*83,85*101,103*123) Other Services
(127*130) Federal Government
(124,131) State and Local Government

Next we separate the relative value of the 2012 I-O gas sector from the other sectors. When we look at the U.S. EIA data on Hawai‘i gas sector prices and quantities for 2012, multiplying them together gives a value of the aggregated sector. As such, we look to the 1997 I-O table for comparison. We similarly find that when we multiply U.S. EIA data for 1997 gas sector prices and quantities in Hawai‘i, the numbers exceed the gas sector value in the 1997 I-O data. As such, we take the ratio of U.S. EIA gas sector values in 1997 over the I-O value, which gives a factor of 70%. Using this, we take U.S. EIA data on the quantity of gas used in Hawai‘i as certain, as it is the data that aligns with the GHG inventory. It is 6,212,000 Mcf in 2012 (U.S. EIA 2020b). Taking the January 2012 U.S. EIA price of $50/Mcf, we adjust this by the estimated factor, giving $35/Mcf. Together this gives the estimated value for the gas sector in 2012. Isolating the value of the gas sector in 2012 leaves the remainder of the I-O utilities value for the water/wastewater utility.

To estimate the production of gas using intermediate inputs, as well as the consumption of gas across the sectors, we run a routine to find its least squares fit. As a first step, the “targets” for the Gas sector’s 2012 production and consumption vectors are computed based on the 1997 I-O values.

$$Target\ (Gas, sectors) = IO_{2012}(Other\ utilities, sectors) * Ratio_{1997}(Gas, sectors) \tag{1}$$

$$Target\ (sectors, Gas) = IO_{2012}(sectors, Other\ utilities) * Ratio_{1997}(sectors, Gas) \tag{2}$$

Where in the first equation $Target\ (Gas, sectors)$ is the least-squares distance for the estimated production of Gas in 2012, using $Ratio_{1997}(Gas, sectors)$ as the value of Gas from the 1997 utility relative to other sectors. The second equation is identical in structure and represents how Gas is consumed across sectors. Lastly, the least-squares routine solves to find the values for Gas into each sector and the input values of other sectors into the Gas sector that minimize the sum of squares of the differences with the targets:

$$Sum\ of\ Squares = Sum(sector, \left(Target(sector, Gas) - IO_{2012}(sector, Gas)\right)^2 + \left(Target(Gas, sector) - IO_{2012}(Gas, sector)\right)^2) \tag{3}$$

The 2012 I-O values for Other Utilities are then adjusted by subtracting the new production and consumption vectors for Gas. In sum, using these values allows for the gas sector to be disaggregated from Water and Wastewater Utilities, denoted as Other Utilities.

Representing Hawai‘i’s Households

The I-O table shows the aggregate final demand of Hawai‘i’s households by sector and including imports. An objective of this study is to estimate the incidence of a carbon tax on residents from multiple income groups. There is, however, no Hawai‘i-specific data on consumer spending patterns by income group. In lieu of this, we use data on U.S. household expenditures by income quintiles as a proxy for the distribution of Hawai‘i’s household expenditures. We rely on the U.S. Bureau of Labor Statistics (BLS) Consumer Expenditure Survey (BLS, 2019) as the most comprehensive publicly available data source that allows consumers to be sorted by quintiles of before-tax income. Expenditure categories in the U.S. Consumer Expenditure Survey data were matched to the 16 aggregated Hawai‘i I-O sectors as described in Table A-1. Because “Public and Other Transportation in the Consumer Expenditure Data” represents the aggregate expenditure of air transportation, water transportation and ground transportation, a more in-depth survey of expenditures on transportation conducted by BLS in 1999 was used to distribute expenditures from our database’s transportation sectors among the quintiles. Consumer expenditures on Federal, State and Local government are not represented in the Consumer Expenditure Survey data and were assumed to be shared equally among income groups. The Hawai’i resident total expenditures is disaggregated based on the U.S. Consumer Expenditure Survey data on the relative shares of before tax income in each quintile.

Table A-1. Overview of Consumer Expenditure Survey Mapping to I-O Categories

I-O Category	Consumer Expenditure Survey Category
Petroleum Manufacturing	Fuel Oil and Other Fuels (in Utilities, Fuels, and Public Services); Gasoline Other Fuels, and Motor Oil (in Transportation)
Electricity	Electricity
Gas	Natural Gas
Water Transportation	Public and Other Transportation (shared out to water transportation using BLS 1999)
Air Transportation	Public and Other Transportation (shared out to air transportation using BLS 1999)
Ground Transportation	Public and Other Transportation (shared out to ground transportation using BLS 1999)
Water & Other Utilities	Water and Other Public Services
Waste Management	Water and Other Public Services
Agriculture & Forestry	Food at Home (in Food)
Construction	NA
Wholesale and Retail Trade	Housekeeping Supplies (in Housing); Household Furnishing and Equipment (in Housing); Apparel and Services; Vehicle Purchases (in Transportation); Pets, Toys, Hobbies, and Playground Equipment (in Entertainment); Other Entertainment Supplies, Equipment, and Services (in Entertainment; Tobacco Products and Smoking Supplies
Real Estate and Rentals	Shelter (in Housing)
Other Manufacturing (Including Maintenance and Repairs)	Maintenance and Repairs (in Other Vehicle Expenses)
Other Services	Vehicle Finance Charges, Vehicle Insurance, Vehicle Rental, Leases, Licenses, and Other Charges (in Other Vehicle Expenses); Healthcare; Fees and Admissions, and Audio and Visual Equipment and Services (in Entertainment); Personal Care Products and Services; Reading; Education; Personal Insurance and Pensions; Miscellaneous.
Federal Government	Not mapped, equal shares assumed
State & Local Government	Not mapped, equal shares assumed

The national data on the relative spending patterns across income quintiles are used to create sector spending shares by quintile that are applied to Hawaiʻi's aggregate household. This means that the relative spending of Hawaiʻi's residents across sectors are based on Hawaiʻi-specific data, but the relative spending by income groups is based on national data. As discussed in the body of the report, the constructed data reflects, for example, Hawaiʻi's higher than average expenditures on goods like housing. We also conduct a number of efforts to compare our estimates with a similar study, Goulder et al. (2019) and other sources of Hawaiʻi data like the distribution of income based on the census, as described in the report.

Due to a lack of data, we assume that there are equal shares of expenditures on government goods and services. There is a substantial amount of resident spending on government goods and services in the 2012 I-O table, amounting to $1.8 billion. The $940 million on state and local government expenditures represent items like vehicle registration fees and other fees for service. The expenditures on federal government represent items like the postal service. To test the assumption of equal shares, we run a sensitivity check to see if our results remain robust when we assume that higher income households consume a larger proportion of government goods and services (which brings relative spending closer to proportional). The results did not meaningfully change.

In addition, to fully represent the income groups by quintile, we also develop the SAM such that each household income quintile is endowed with labor, capital and transfer income. To do this, we rely on Goulder et al. (2019) – who obtain data on U.S. before-tax income by quintile from the 2013 Survey of Consumer Finances (SCF). The data are summarized as percentage of income from labor, capital and transfer income for each quintile in Table A-2.

Table A-2. U.S. Average After-Tax Income Shares by Source by Quintile (Goulder et al. 2019)

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Labor	53%	71%	76%	80%	50%
Capital	9%	8%	12%	13%	47%
Transfer	38%	21%	12%	6%	3%
Total	100%	100%	100%	100%	100%

The SAM is constructed such that the sum of resident expenditures and investment equals total endowment of labor, capital and transfers. To operationalize the targets presented in Table A-2 per quintile, we run a least squares routine (similar to what was done for the the gas sector utility) to find the least distance “fit” of the SCF data and Hawai‘i‘s households. The objective function Y is the sum of the squares of differences between the desired variables and the targets from Table 2 (described as “share”):

$$\mathit{Minimize}\ Y = (\mathit{Labor}(H) - \mathit{Share}(\mathit{Labor}, H) * \mathit{IOEndowmentLabor})^2 + (\mathit{Capital}(H) - \mathit{Share}(\mathit{Capital}, H) * \mathit{IOEndowmentCapital})^2 + (\mathit{Transfers}(H) - \mathit{Share}(\mathit{Transfer}, H) * \mathit{IOEndowmentTransfers})^2 \qquad (4)$$

Where $\mathit{Labor}(H)$, $\mathit{Capital}(H)$, and $\mathit{Transfers}(H)$ are the identified values of labor, capital and income transfers for each household by quintile. The Share parameters are the targets given by the SCF data in Goulder et al. 2019, and $\mathit{IOEndowmentLabor}$, $\mathit{IOEndowmentCapital}$, and $\mathit{IOEndowmentTransfers}$ are the endowments of labor, capital and transfers in the 2012 I-O table. Transfers are approximated by the amount of government spending necessary to balance income and expenditures. Running this routine results in the shares reported in Table A-3.

Table A-3. Resulting Income Shares for H-CGE from Solving Least Squares Routine

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Labor	69%	81%	84%	86%	52%
Capital	11%	9.0%	13%	14%	47%

Transfer	21%	10%	3.7%	0.5%	0.4%
Total	100%	100%	100%	100%	100%

Lastly, we use the ACS data on average income per quintile to share out household investment per quintile. Each household quintile‘s share of investment is given by the product of the average household income and the after-tax shares of capital, divided by the total value of income and capital.

Adjusting Negative Flows

Within the I-O data, several sectors present with negative proprietor income and taxes. The SAM must have zero or positive values to meet the parameter criteria of the equilibrium model. As such, sectors with negative proprietor income (Agriculture and Forestry, and Water/Wastewater Utilities) are adjusted to zero and the imbalance is taken instead from wages. For sectors with negative taxes, meaning subsidies (Agriculture, Federal and State/Local Government), these are also converted to zero and the imbalance is placed in capital.

Dynamic Calibration

Though the I-O Table is “balanced” for the year 2012, meaning that the total value of demand exactly equals the total value of supply, it is not dynamically balanced. This means that the flow of investment must reflect year-to-year annual capital accumulation. Capital is re-estimated within the I-O table to be consistent with the following equation:

$$Capital_0 = {(\delta + r)Investment_0}\Big/{(\delta + g)} \tag{5}$$

where δ is the depreciation rate of capital, g is the historic steady-state growth rate of Hawai‘i’s economy, and r is the rate of return on investment (Paltsev, 2004).

Consistent with the dynamic baseline in U.S. Environmental Protection Agency‘s CGE model, called SAGE, the depreciation rate of capital is assumed to be 5% annually. This is the average U.S. capital depreciation rate from 1950 to 2014 (U.S. EPA, 2019) and estimated by Feenstra et al. (2015). The annual rate of return on investment is 4.5%, which is the average after-tax rate of return on private capital (U.S. EPA, 2019). Hawai‘i’s steady-state growth rate is taken based on the average annual growth rate of real Gross State Product (GSP) from 2010 to 2019, 1.9% (UHERO, 2020).

As a result of this dynamic calibration (and to a much lesser extent the adjustment of negative taxes discussed above), initial capital is decreased by 14.3% - from $21.7 billion to $18.6 billion in the baseline year. To offset this imbalance, the SAM is adjusted such that the loss of capital is transferred to the value of imports. Imports are chosen because they are a large sector with high flexibility in the modeling assumption between consuming imported and domestically produced goods and services (see below).

A-III LINKING TO GHG EMISSIONS

We link the economic data to GHG emissions based on the State of Hawaiʻi's most recent inventories for 2010, 2015 and 2016 (ICF & UHERO, 2019). Based on our review of common ways to construct a carbon tax, we levy the carbon tax on major sources of fossil fuels within the stateʻs jurisdiction. This means focusing on the GHG sectors within the Energy Sector (based on the GHG inventory accounting), excluding military and international sources. This accounts for 81% of total statewide GHG emissions. The quantity of these emissions is based on a fixed relationship between the economic output of these sectors and GHG emissions produced by these sectors. This means that non-federal/international energy sector GHG emissions are solved endogenously within H-CGE. GHG sinks and offsets are outside the scope to this analysis. Table A-4 give the 2010, 2015 and 2016 values of GHG emissions by energy and non-energy sectors (at the most detailed level provided), in MMT CO_2 Eq.

Table A-4: State of Hawai‘i 2010, 2015, and 2016 Energy Sector GHG Emissions, MMT CO_2 Eq.

Sector	2010	2015	2016	Percentage of 2016 Total
Included Sectors				
Energy Industries	7.79	6.88	6.83	35%
Residential	0.09	0.06	0.08	0%
Commercial	0.37	0.47	0.45	2%
Industrial	0.57	0.52	0.43	2%
Ground	4.15	4.04	4.05	21%
Marine	0.60	0.56	0.64	3%
Aviation	2.67	3.33	3.20	16%
Oil and Natural Gas	0.20	0.19	0.19	1%
Subtotal	**16.45**	**16.06**	**15.87**	**81%**
All Other Sectors				
Military Aviation	0.49	0.66	0.64	3%
Military Non-Aviation	0.50	0.05	0.16	1%
Incineration of Waste	0.19	0.20	0.27	1%
Cement Production	0.00	0.00	0.00	0%
Electrical Transmission and Distribution	0.02	0.01	0.01	0%
Substitution of Ozone Depleting Substances	0.65	0.76	0.77	4%
Landfills	0.84	0.69	0.69	4%
Composting	0.01	0.02	0.02	0%
Wastewater Treatment	0.07	0.07	0.07	0%
Enteric Fermentation	0.27	0.24	0.25	1%
Manure Management	0.04	0.04	0.04	0%
Agricultural Soil Management	0.16	0.16	0.16	1%
Field Burning of Agricultural Residues	0.01	0.01	0.01	0%
Urea Application	0.00	0.00	0.00	0%
Agricultural Soil Carbon	0.53	0.56	0.55	3%
Forest Fires	0.01	0.02	0.07	0%
Subtotal	**3.78**	**3.48**	**3.71**	**19%**
Total	**20.22**	**19.54**	**19.58**	**100%**

Source: State of Hawai'i GHG Emissions Report for 2016 (ICF & UHERO, 2019)

* *International bunker fuels are excluded from emissions totals in the State GHG Inventory and similarly for this study.*

** *CO_2 from Wood Biomass and Biofuels Consumption is assumed to be biogenic and not an anthropogenic source of emissions.*

To line up the economic and GHG data for initial calibration, first an interpolation of 2012 GHGs is made by assuming a constant annual change in emissions from the 2010 to 2015 estimates of GHGs for each category.[44] Emissions from the three fossil fuels - oil, coal and gas - are disaggregated within the estimated 2012 GHG inventory. GHGs associated with coal and gas are the product of the annual quantity of each fuel consumed given in the U.S. Energy Information data SEDS database for Hawaiʻi and their emissions factor from the U.S. Environmental Protection Agency (U.S. EIA, 2020b; U.S. EPA, 2020c). Total emissions in each category associated with the combustion of crude oil and refined petroleum products are the difference between total emissions from all fuels less emissions associated with coal and gas.

The next step is to map the emissions of each fuel from the above sources to the sectors in the H-CGE model. The process starts with assigning emissions from coal, then gas and finally oil. Assigning emissions from coal is straightforward as all emissions from coal come from the electricity sector, which is represented by energy industries in the Hawaiʻi GHG emissions data. Assigning emissions from gas and oil is more complicated, as they need to be mapped from GHG inventory sectors to the H-CGE model sectors. Table A-5 shows the mapping of the GHG sectors to the H-CGE model sectors for gas and oil.

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[44] Residential sources of GHGs in 2012 are interpolated between 2010 and 2016 emissions so as to not have a decrease in emissions, due to the dip in 2015 and rise in 2016.

Table A-5: Mapping of GHG Emission Sources to Sectors in the H-CGE Model

Mapping for Gas		Mapping for Oil	
GHG Source	**H-CGE Sectors**	**GHG Source**	**H-CGE Sectors**
Energy Industries	Electricity	Energy Industries	Electricity
Residential	Resident Consumption	Residential	Resident Consumption
Commercial	Agriculture and Forestry, Construction, Wholesale and Retail Trade, Real Estate and Rentals, Other Utilities, Waste Management, Other Services, Federal Government, State and Local Government, Visitor Consumption	Commercial	Agriculture and Forestry, Construction, Wholesale and Retail Trade, Real Estate and Rentals, Other Utilities, Waste Management, Other Services, Federal Government, State and Local Government, Visitor Consumption
Industry	Other Manufacturing	Industry	Other Manufacturing
Ground Transportation Services	Ground Transportation Services	Ground Transportation Services	Resident Petroleum Consumption, Ground Transportation Services
Marine	Water Transportation	Marine	Water Transportation
Aviation	Air Transportation	Aviation	Air Transportation
Military	Federal Government	Military	Federal Government
Oil and Natural Gas Systems	Gas, Petroleum Manufacturing	Oil and Natural Gas Systems	Gas, Petroleum Manufacturing

The share of total gas emissions going to each GHG sector equals the value share of gas consumed by the corresponding H-CGE sectors (and is one if the mapping is from one GHG sector to one H-CGE sector). The residential share is adjusted to account for the higer price in residential gas than the other sectors. The commercial sector equals the residual share after accounting for all other gas-related GHG sector categories. The GHG emissions from gas for each sector equals the product of its share of gas emissions and the total GHG emissions from the combustion of gas (U.S. EPA, 2020c).

The share of total oil emissions going to each GHG sector equals the value share of oil consumed by the corresponding H-CGE sectors (and is one if the mapping is from one GHG sector to one H-CGE sector). Overall, each category’s GHG emissions from the combustion of oil equals the category’s total GHG emissions less those from the combustion of coal and gas.

A-IV. H-CGE MODEL STRUCTURE

H-CGE represents Hawaiʻi as a small open economy: it engages in international trade and is a world price-taker. Prices are calibrated to clear markets where supply equals demand. The model assumes that goods are produced under perfect competition and constant returns to scale using intermediate commodities, imports, labor provided by residents, and capital.

CGE models rely on a series of nested constant elasticity of substitution (CES) production functions (U.S EPA, 2019). The generalized framework for nesting assumptions and elasticities is adopted from SAGE, which builds on prior work including Rutherford (1999), Rutherford et al. (1999), Paltsev et al. (2005), Rausch et al. (2011), Capros et al. (2013) and Cai et al. (2015).

Production of Non-Energy, Non-Transportation Sectors

The production function for non-energy, non-transportation sectors is a multi-level, nested CES function. Following the notation of the SAGE model, *cs* represents the relative cost shares in the benchmark year and *se* denotes a substitution elasticity.

The first level of the nest is a CES function that trades off Materials (in an Armington nest, given by ARM) and Energy/Value-Added (EVA) to produce final output (Y_s) in sector (non-energy and non-transportation) *s*:

$$Y_s = [cs_{ARM,s} ARM_s^{(se\_klem-1)/se\_klem} + cs_{EVA,s} EVA_s^{(se\_klem-1)/se\_klem}]^{se\_klem/(se\_klem-1)} \tag{6}$$

At the second level, the Armington nest (Armington, 1969) represents domestically produced intermediate inputs, materials (MAT_s) that trade off against importable commodities (XM_s). Distinct from other CGE models, the I-O table is limited in its detail on imports and lumps their value entirely together per sector. As such, the Armington nest is quite aggregated, at the level of all imports, rather than by each type of import.[45]

$$ARM_s = [cs_{D_s} MAT_s{}^{(se\_ARM-1)/se\_ARM} + cs_{XM} XM_s{}^{(se\_ARM-1)/se\_ARM}]^{se\_ARM/(se\_ARM-1)} \tag{7}$$

At the third level, the production of materials is represented by a Leontief relationship, meaning the substitution elasticity is zero.

$$MAT_s = \min \left[\frac{id_{i,s}}{id0_{i,s}}, \dots, \frac{id_{n,s}}{id0_{n,s}}\right] \tag{8}$$

Where $id_{i,s}$ represents intermediate demand for good *s*, for intermediate inputs *i*= 1,....,*n;* and $id0_{i,s}$ represents intermediate demand for good *s*, for intermediate inputs *i*=1,.....n in the benchmark year.

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[45] This high level of aggregation most likely leads to imports being more substitutable for domestically produced goods in the model than in reality. However, this is a data hurdle that we are not able to overcome with the I-O table.

For the energy/value-added nest, energy sectors (E_s) are represented as substitutable with value-added (VA_s):

$$EVA_s = [cs_{E_s} E_s^{(se\_kle-1)/se\_kle} + cs_{VA,s} VA_s^{(se\_kle-1)/se\_kle}]^{se\_kle/(se\_kle-1)} \tag{9}$$

Value-added consists of capital (K_s) and labor (L_s), where labor is a composite of wage labor (W_s) and proprietor income (which is taken as a Leontief relationship):

$$VA_s = [cs_{K,S} K_s^{(se\_kl-1)/se\_kl} + cs_{L,S} L_s^{(se\_kl-1)/se\_kl}]^{se\_kl/(se\_kl-1)} \tag{10}$$

The energy nest has two levels. At the first level, petroleum manufacturing (Oil_s) substitutes against final energy, which consists of electricity and gas. At the second level, electricity (Ele_s) and gas (Gas_s) substitute against each other.

$$E_s = [cs_{Oil,S} Oil_s^{(se\_e-1)/se\_e} + cs_{FE,S} FE_s^{(se\_e-1)/se\_e}]^{se\_e/(se\_e-1)} \tag{11}$$

$$FE_s = [cs_{Gas,S} Gas_s^{(se\_ge-1)/se\_ge} + cs_{Ele,S} Ele_s^{(se\_ge-1)/se\_ge}]^{se\_ge/(se\_ge-1)} \tag{12}$$

GHG is represented in a Leontief relationship to Oil_s and to Gas_s. It is at this lowest level of nesting that the carbon tax is levied.

The initial endowment of wage labor, proprietor income, and capital (W_0, R_0, K_0) are given within the baseline dataset. In calibration, the value of the initial endowment of wage labor, proprietor income and other value-added must equal the sum of each factor over all *s* sectors.

Output commodity (Y_s) can be either domestically consumed or exported. Output is differentiated for those markets using a constant elasticity of transformation (CET) function between domestic sales (D_s) and exports (X_s):

$$Y_s = [cs_{D,S} D_s^{(se\_cet-1)/se\_cet} + cs_{X,S} X_s^{(se\_cet-1)/se\_cet}]^{se\_cet/(se\_cet-1)} \tag{13}$$

Figure A-1 provides a graphical representation of the described production function for non-energy sectors.[46]

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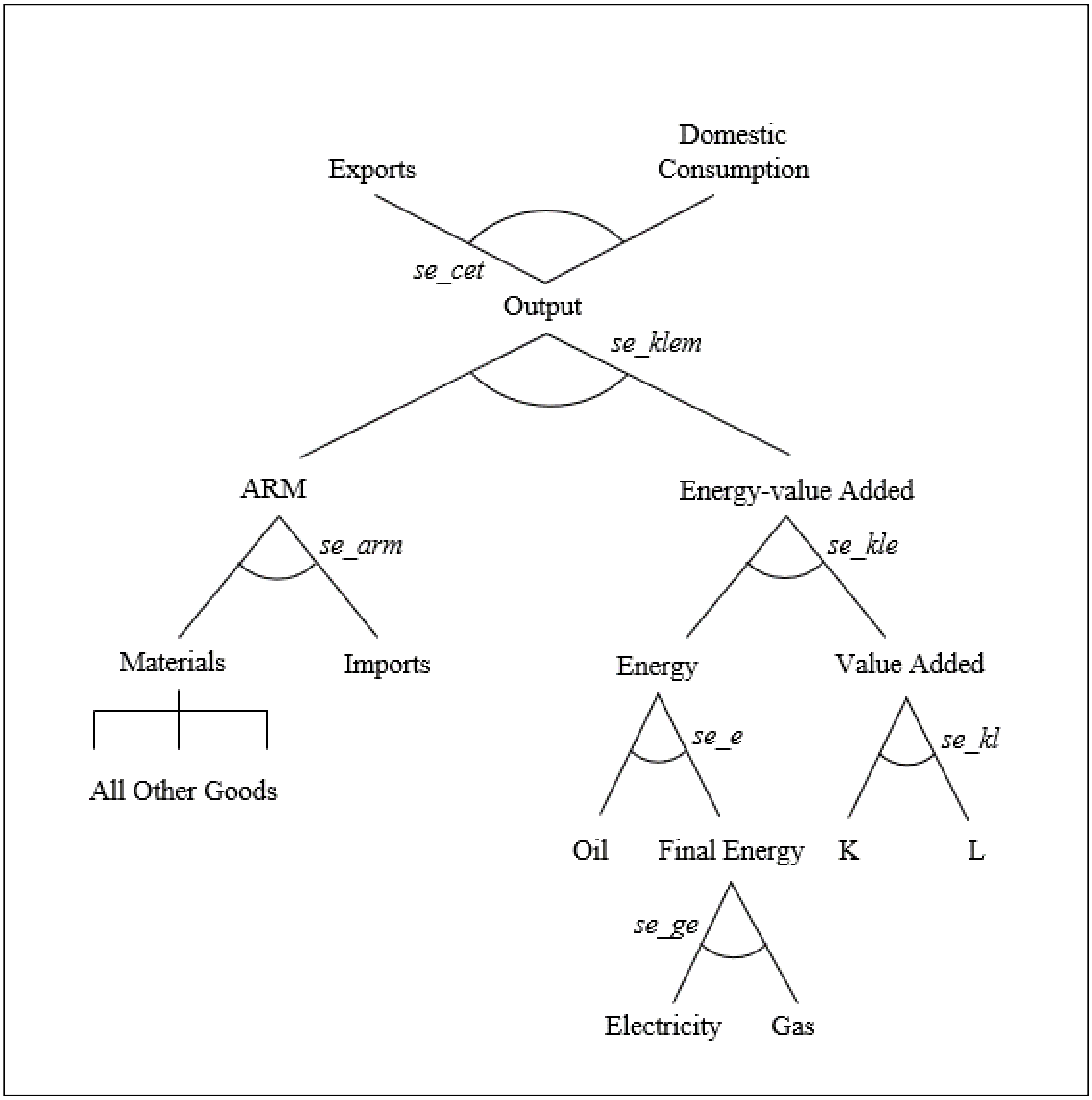
[46] Any nest with right angles (e.g., the Materials nest) indicates a Leontief production function (i.e., an elasticity of substitution of zero).

Figure A-1. Non-Energy, Non-Transport Sector Production Structure

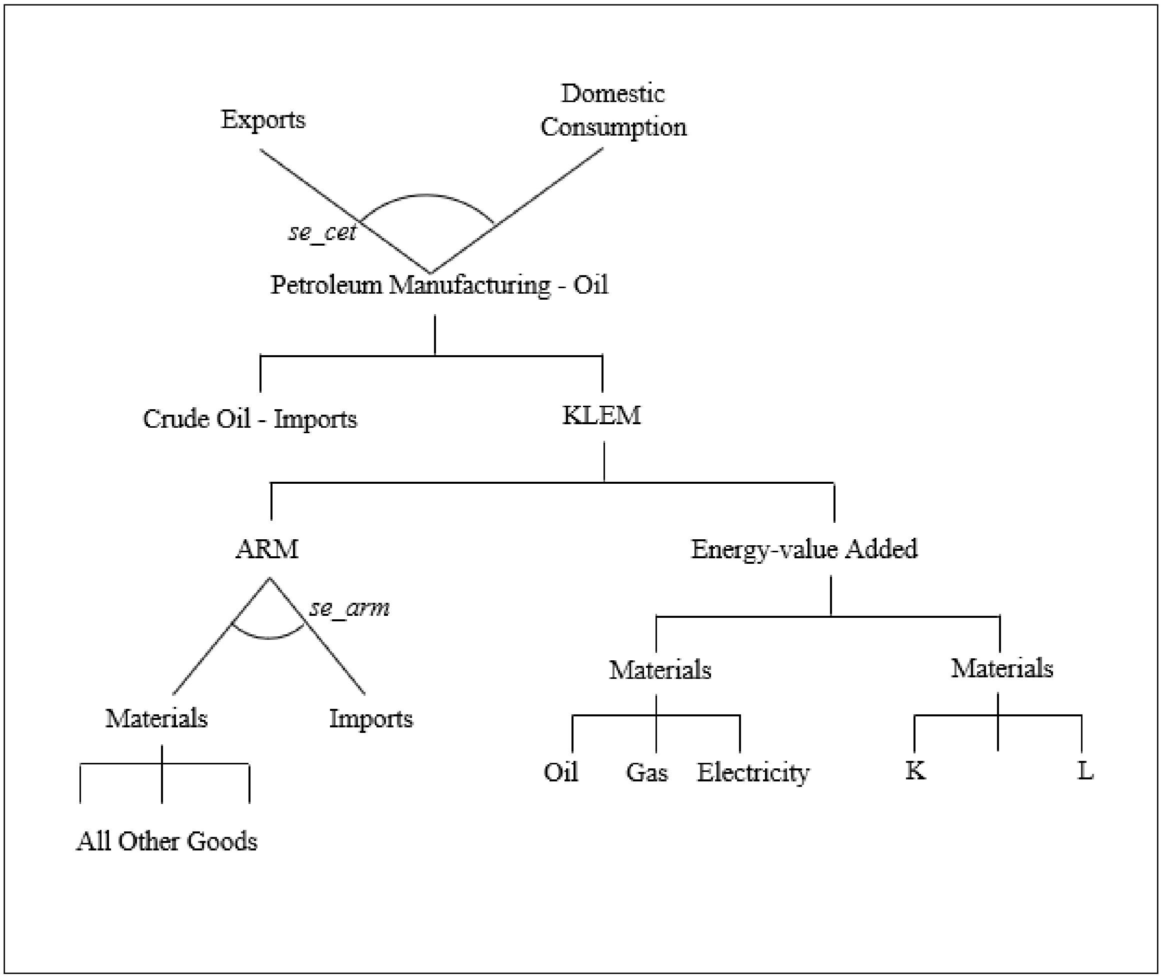


With the CES functions introduced mathematically and graphically (including the CES of zero elasticity known as the Leontief function), energy and transport sectors are described in graphical terms for brevity.

Production of Petroleum Manufacturing

The production of petroleum manufacturing output (i.e. refined petroleum products) is assumed to be a nested Leontief structure. It mainly follows the SAGE model for manufacturing production with extant capital; however, it modifies crude oil (whose value is separated from other imports) to the first level of the nest. As such, petroleum manufacturing is a Leontief production function between the value of crude oil imports and the capital-labor-energy-materials (KLEM) nest. At the second level, KLEM is a Leontief production function between domestic materials and imports (ARM), and energy-value added (EVA). ARM is a CES function between domestically produced materials (MAT) and imports, where materials are produced as a Leontief function of domestic intermediate inputs. EVA is a Leontief function between Energy and Value Added, where Energy is comprised of Oil, Gas and Electricity. Value added is comprised of capital and labor (where labor is a Leontief function between wage labor and proprietor income). GHG emissions are assumed to be directly tied to Oil and Gas, represented by a Leontief production function.

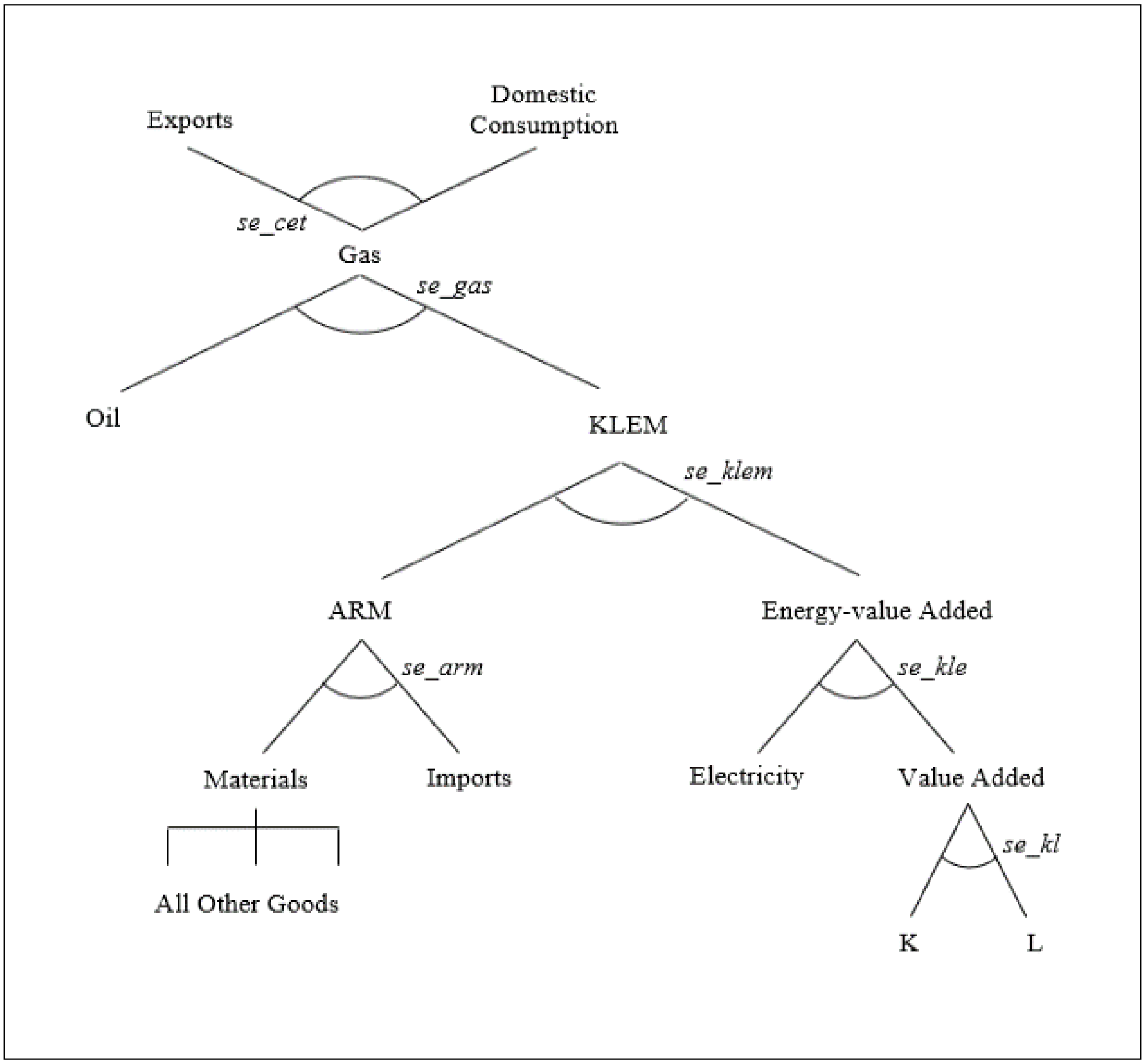
Figure A-2. Petroleum Manufacturing Production Structure



Production of Gas

The production of gas follows a similar structure, though there is slightly more flexibility allowed between oil and other inputs. At the first level, gas production is represented in a CES function between petroleum and the capital-labor-energy-materials (KLEM) nest. At the second level, KLEM is a CES function between domestic materials and imports (ARM), and energy-value added (EVA). ARM is a CES function between domestically produced materials (MAT) and imports, where materials are produced as a Leontief function of domestic intermediate inputs. EVA is a CES function between Electricity and Value Added. Value added is comprised of capital and labor (where labor is a Leontief function between wage labor and proprietor income). GHG emissions are assumed to be directly tied to Oil and Gas, represented by a Leontief production function. It is at this lowest nest that the carbon tax is levied.

Figure A-3. Gas Production Structure



Production of Electricity

At the highest level, the electric sector is represented by a CES function between fossil-based and renewable sources of electricity. Fossil-based electricity is represented as a Leontief function between domestic materials and imports (ARM), labor and a composite of energy and capital. Energy and capital are represented by a CES function, with an additional nest between oil and coal. GHG emissions are assumed to be directly tied to Oil, Coal and Gas, represented by Leontief functions. It is within these nests that the carbon tax is levied. Renewable-based electricity is represented by a Leontief function between domestic materials and imports (ARM), labor and capital.

Figure A-4. Electricity Production Structure

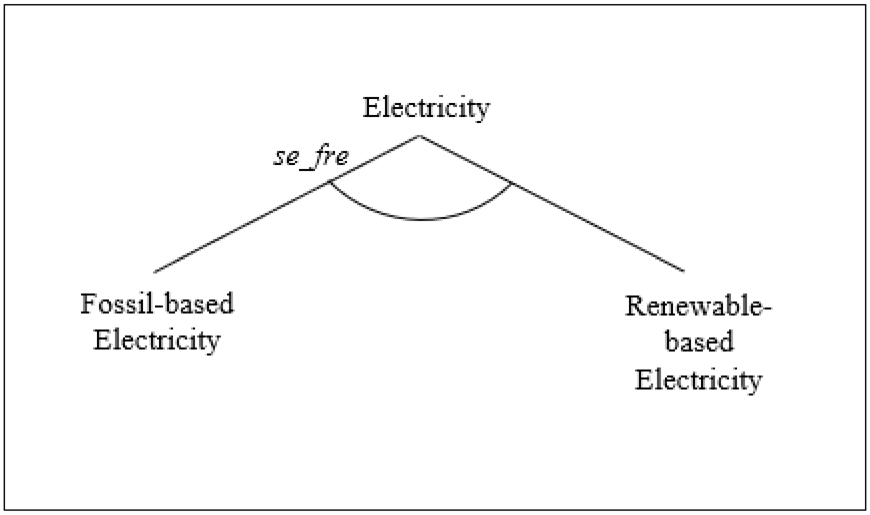


Figure A- 5. Fossil-based Electricity Production Structure

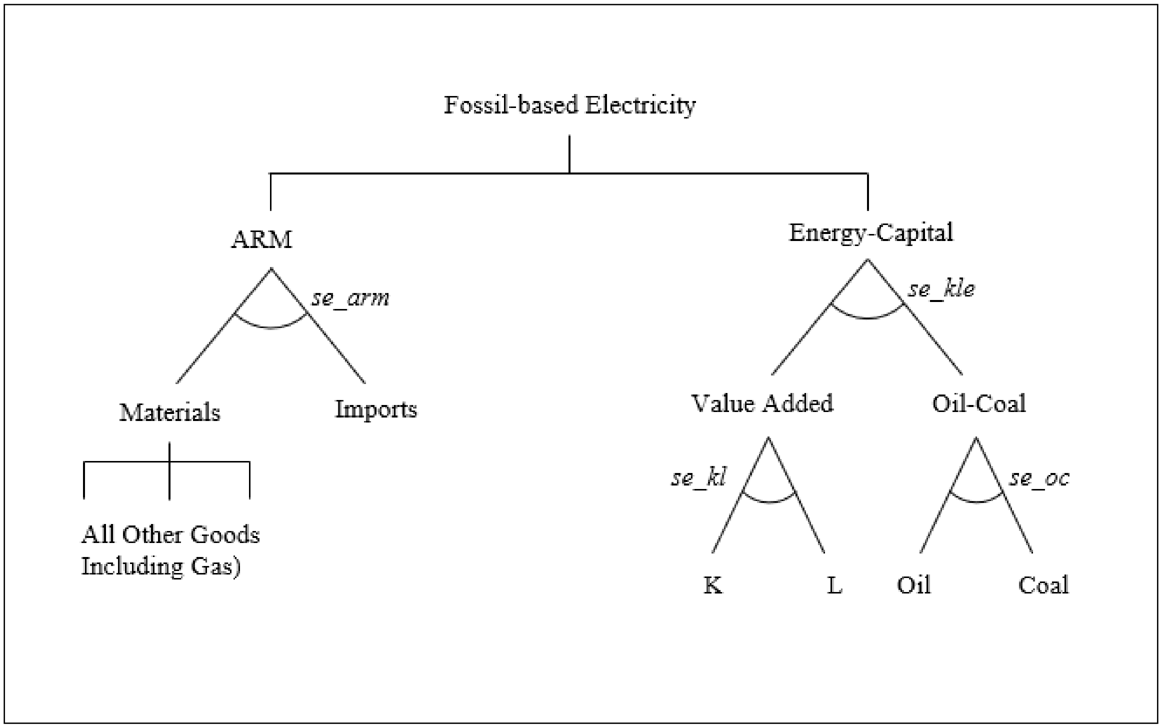
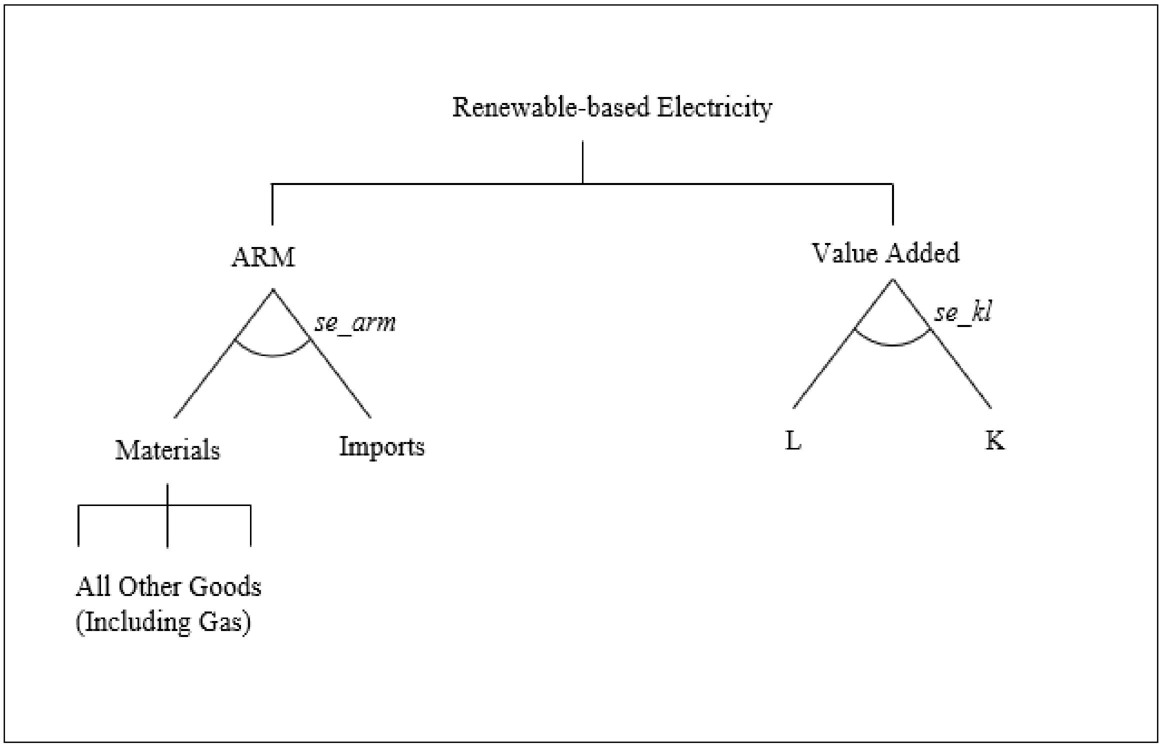


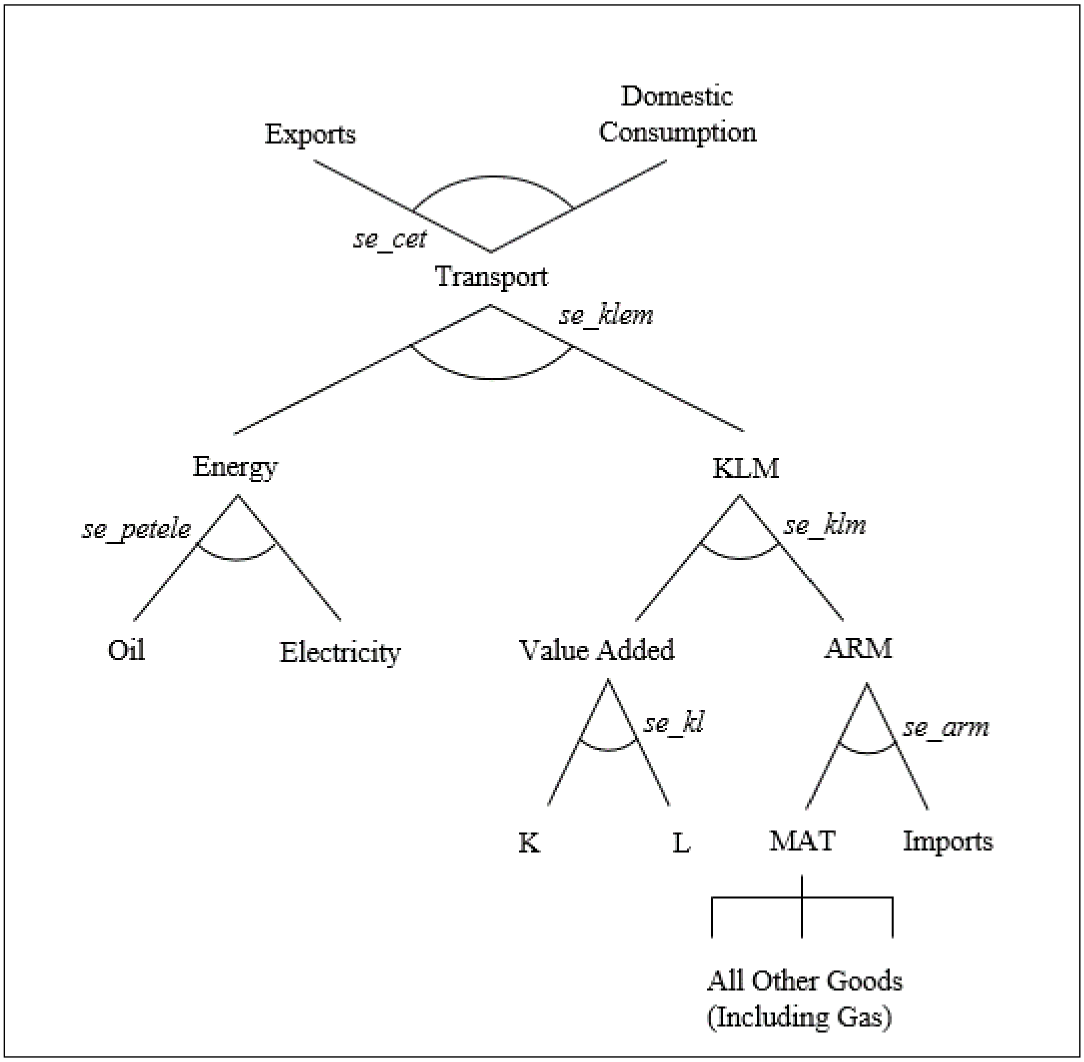
Figure A-6. Renewable-based Electricity Production Structure



Production of Transportation Sectors

The production of transportation sectors (Water, Air and Ground Transportation) are represented at the first level by a CES function between an energy and the capital-labor-materials nest (KLM). Energy is represented as a CES function between Oil and Electricity. GHG emissions are related to Oil by a Leontief function and this is where the carbon tax is levied. KLM is represented as a CES function between value added (VA) and domestic materials and imports (ARM). Value added is comprised of capital and labor (where labor is a Leontief function between wage labor and proprietor income). ARM is a CES function between domestically produced materials (MAT) and imports, where materials are produced as a Leontief function of domestic intermediate inputs. MAT includes Gas, which is related to GHG emissions by a Leontief function and this is where the carbon tax is levied.

Figure A-7. Production Function for Transportation Sectors



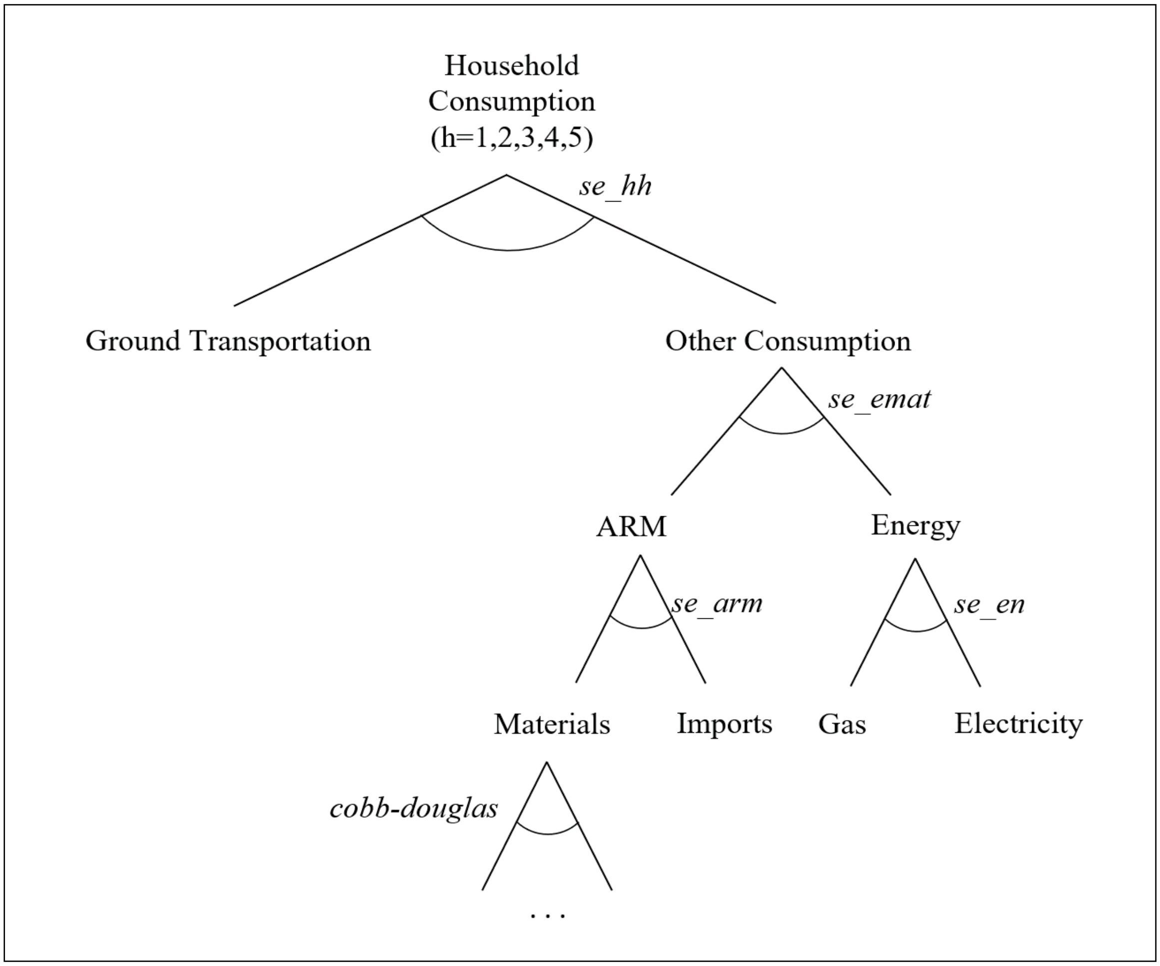
Household Consumption

Each representative household (h=1,2,3,4,5) seeks to maximize its utility, a measure of well-being. Household utility, at the first level, is represented by a CES function between ground transportation (GT) and other consumption (OC).

$$U_h = [es_{GT}GT_h{}^{(se\_hh-1)/se\_hh} + es_{OC}OC_h{}^{(se\_hh-1)/se\_hh}]^{se\_hh/(se\_hh-1)} \tag{14}$$

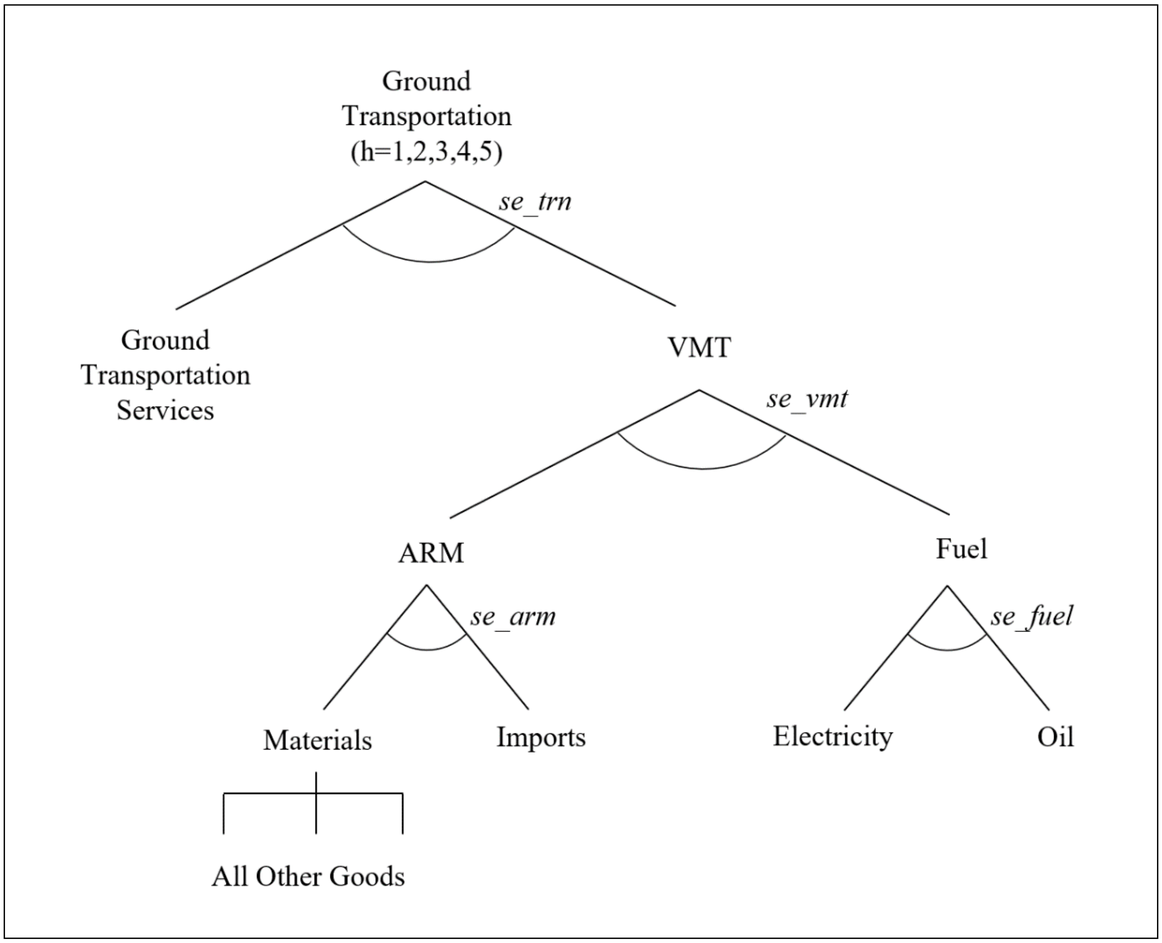
U_h is the utility level of each representative household (by quintiles), *GT* is the consumption of ground transportation and *OC* is the consumption of other goods and services. The relative expenditure shares are denoted by *es*. *OC* is represented by a CES function between domestic materials and imports (ARM) and energy. Domestically produced materials are represented by a Cobb-Douglas consumption function, meaning a CES equal to one. Energy is a composite between gas and electricity. Gas is represented to GHG emissions in a Leontief function, and is another point where the carbon tax is levied.

Figure A-8. Household Consumption



Ground Transportation (*GT*) is represented by a CES function between private vehicle miles traveled (VMT) and purchased ground transportation services. VMT is a CES function between fuel and all other domestically produced and imported imputs (ARM). Fuel can come from either oil (i.e. gasoline) or electricity (i.e. representing the substitutability between internal combustine engine gasoline powered and electric-powered vehicles). Oil is related to GHG emissions in a Leontief function and this is where the carbon tax is levied.

Figure A-9. Household Transportation



The household welfare impact is measured in equivalent variation, which is the change in consumption (here identifical to an expenditure function) between new levels of utility (after intervention) and initial prices, and initial utility and initial prices. In other words, the change in welfare from getting to a new level of utility, all else equal, as shown in the following equation:

$$Welfare = EX(U_1, P_0) - EX(U_0, P_0) \tag{15}$$

where EX is the expenditure (consumption) function, U_1 represents aggregate household utility after the carbon tax intervention, U_0represents initial aggregate household utility, and P_0 represents the initial vector of prices. The measure of EX includes both "use" and "source" side effects.

Household Budget Constraint

Households derive income from factors of production including household wage labor W_h, proprietor income R_h, capital K, where p_w, p_R, and p_k are the market prices of the respective factors. In addition, the households derive income from the imposed carbon tax under the carbon tax scenarios that return some dividends to households (excluding air transportation-related GHG revenues). The household budget constraint is:

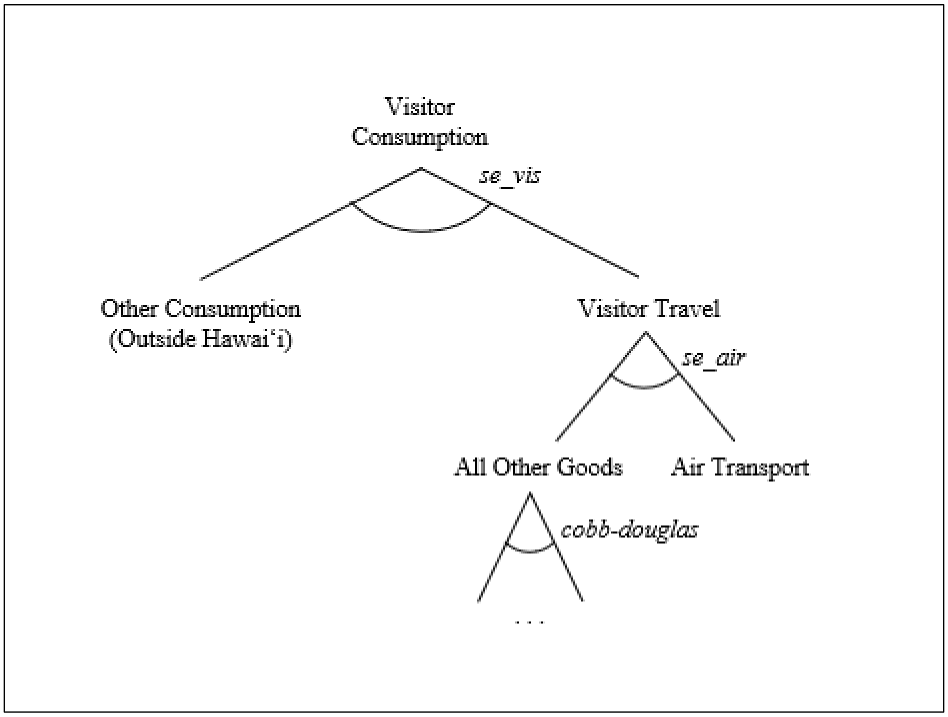
$$\Sigma_h(\Sigma_s p_s C_{h,s} + p_M C_{h,M}) + I_h = \Sigma_h(p_w W_h + p_R R_h) + p_k K + p_{fx} TR + \tau_{GHG}\left(GHG(Oil, Coal, Gas) - GHG(Oil_{AirTransport})\right) \$HHRevScen \tag{16}$$

where prices p_s represent the market prices for sectors s = 1,.., n and p_M is the price of imports. $C_{h,s}$ is household h=*1,2,3,4,5* consumption of sector s and $C_{h,M}$ is household h consumption of imported goods. I_h are household investments and $p_{fx}TR$ represent transfers, where p_{fx} is the numeraire. τ_{GHG} is the carbon tax levied on Oil, Coal and Gas, where revenues are returned to households when the $\$HHRevScen$ is flagged, net air transportation carbon tax revenues.

Visitors

Visitor consumption is represented by a nested CES utility function. At the first level, a CES function trades off between choosing to take a vacation and an exogenous endowment (consumption) of all other goods (external to Hawai‘i). At the second level, visitor travel is comprised of air travel and all other goods (internal to Hawai‘i). Visitor preferences between air transport, as well as in the third level of the nest between all other goods, are represented by a Cobb-Douglas function.

Figure A-10. Visitor Consumption



Because visitors do not provide labor or earn income within Hawai‘i, a representative visitor’s income (I_v) is taken to be exogenous:

$$I_v = I_{v0} = \Sigma_i p_i C_{v,i} + p_M C_{v,M} \tag{17}$$

where I_{v0} is the initial visitor expenditure, $C_{v,s}$ is visitor consumption of good *s* and $C_{v,M}$ is visitor consumption of imported goods.

Government

State and Local Government (*SG*) and the Federal Government (*FG*) each purchase domestic produced materials and imports represented by a CES utility function.

The State and Local Government expenditures are constrained by collected taxes, including the carbon tax, such that it maintains a balance budget:

$$\Sigma_s p_s SG_s + p_M SG_M = \Sigma_s p_s Y_s \tau_s + \tau_{GHG} GHG(Oil, Coal, Gas)\text{-}\ \tau_{GHG}\left(GHG(Oil, Coal, Gas) - GHG\left(Oil_{AirTransport}\right)\right) \$HHRevScen \tag{18}$$

where prices p_s represent the market prices for sectors *s* = 1,..*n* and p_M is the price of imports. SG_s is State and Local Government consumption of sector *s* and SG_M is State and Local Government consumption of imported goods. Y_s is total output of each domestically produced sector *s* = 1,..*n* and the relevant tax rate, given in the baseline SAM, τ_s. The carbon tax, τ_{GHG}, is levied on GHGs from Oil, Gas and Coal at the most upstream level. In the scenario where households are returned the revenues, this is shown net air transportation GHG-related revenues.

The level of Federal Government (FG) expenditures is taken to be exogenous and grows at the rate of the overall economy (discussed below).

Balance of Payments & Market Clearance

As a small open economy, a balance of external payments (*BP*) is maintained under the assumption of a fixed exchange rate (p_{fx}) with the “rest of the world” which includes the continental United States. The exchange rate serves as the numeraire for prices within the model. The quantity of imports (*M*) is constrained by the inflow of dollars obtained from visitor expenditures (I_v), Federal Government expenditures (I_{FG}), and Hawai‘i exports (X_s).

$$p_{fx} BP = p_M M - I_v - I_{FG} - \Sigma_s p_{x,s} X_s \tag{19}$$

Lastly, given sector production, and household, visitor and government consumption, it is assumed that prices equal marginal cost. In equilibrium, the total value of economic output equals producer costs, including labor, proprietor income and capital costs.

Dynamic Calibration

Capital accumulation is endogenous within the model, meaning that investment in one period leads to new capital stock in the next:

$$p_k K_{t+1} = (1-\delta)(p_k K_{t-1} + p_k K_t) \tag{20}$$

$$p_k K_t = (r+\delta)(p_{INV} INV_{t-1}) \tag{21}$$

Other drivers of economic growth, such as labor (both wage labor W and proprietors income R) and the balance of payments, are assumed to grow at the GSP growth rate *g(t)*:

$$p_w W_{t+1} = g(t) p_w W_t \tag{22}$$

$$p_R R_{t+1} = g(t) p_R R_t \tag{23}$$

$$p_{fx} BP_{t+1} = g(t) p_{fx} BP_t \tag{24}$$

Elasticity Values

Table A-6 provides the elasticity values used within H-CGE. Most are time invariant; however, in cases where there is reasonable expectation of substantial technological progress, we assume that they become more elastic to represent the increased malleability of capital over time for energy-related sectors. This is done to approximate the "putt-clay" structure of SAGE. The sources and/or underlying logic underlying the values are also given.

Table A-6: Model Elasticity Values and Source

Elasticity	Between	Value	Source/Logic
se_cet	Domestic & international consumption (i.e. exports)	5	Beck et al. (2015) uses 4; SAGE (2019) uses 2
se_klem (non-energy, non-transport sectors)	ARM & energy-value added	0.2-0.6	SAGE (2019), average se_klem for sectors non-energy and non-transport is 0.6
se_klem (gas sector)	ARM & energy-value added	0.2	SAGE (2019) se_klem for gas
se_klem (ground transport services)	Energy & value-added/imports	0.2-0.5	SAGE (2019) uses 0.2, increases with technological advances for electrification of heavy duty vehicles
se_klem (air)	Energy & value-added/imports	0.1-0.15	SAGE (2019) lumps all non-truck transport together; lowered substantially from ground transport services because air currently has fewer technological substitutes
se_klem (marine)	Energy & value-added/imports	0.15-.3	SAGE (2019) lumps all non-truck transport together; lowered substantially from ground transport services and placed as mid-point to air
se_kle (non-energy sectors)	Energy & value-added	0.2-0.6	SAGE (2019) has an average of 0.4
se_kle (petroleum manufacturing)	Energy & value-added	0	Leontief selected to represent Hawai‘i‘s aging refineries

se_kle (gas sector)	Energy & value-added	0.2	SAGE (2019) has 0.4, adjusted downward because limited gas market in Hawaiʻi compared to U.S. as a whole
se_kle (electricity)	Energy & value-added	0.7	SAGE (2019) has 0.46, adjusted upward
se_e	Energy & Oil	0.7	SAGE (2019), average se_ene for non-energy, non-transport sectors
se_kl (gas)	Capital & labor	0	Leontief
se_kl (refineries)	Capital & labor	0	Leontief
se_kl (non-energy, non-transport)	Capital & labor	0.8	For petroleum, 0 aging refineries, gas is 0
se_ge	Electricity & gas	0.5	SAGE (2019) average se_ene for energy sectors
se_fre	Fossil & renewable electricity	2-8	High elasticity chosen to represent high substitutability between types of electricity
se_oc	Oil & coal	8	High elasticity to ensure phase-out of coal per State law
se_arm	Domestic materials & imports	5	SAGE (2019), average se_dn for non-energy, non-transport sectors
se_petele (ground transport)	Petroleum & electricity	0.1-0.4	SAGE (2019) uses 0.25
se_petele (air)	Petroleum & electricity	0.05	No source; Small, to represent potential switching for tarmac operations
se_petele (water)	Petroleum & electricity	0.1	No source; Small, to represent difficulty of fuel switching for lon-distance marine travel
se_hh	Household ground transport & all other goods	0.25	SAGE (2019), se_c
se_emat	Household ARM & Energy	0.25-0.75	SAGE (2019), se_c is 0.25; Beck et al. (2015) use 0.5
se_en	Household Gas & Electricity	0.3-0.6	SAGE (2019) uses 0.7, se_cene between electricity and primary energy consumption; Beck et al. (2015) use 0.25
se_VMT	Household VMT Fuel & ARM	0.25-0.75	Own-price elasticity of demand for gasoline is inelastic, estimated to be -0.3 (Hossinger et al. 2017). When inelastic, the absolute value of own price elasticity is an approximation to the value of a substitution elasticity; Asumes it will become more elastic over time
se_fuel	VMT Electricity & Oil	0.4-2.4	Calibrated to target the EV adoption forecast, discussed below
se_vis	Visitor travel & other consumption	0.2	Fuleky et al. (2013) estimate an own price elasticity for air transportation and visitor arrivals to Hawaiʻi of -0.2; When inelastic, the absolute value of own price elasticity is an approximation to the value of a substitution elasticity
se_air	Visitor air transportation & all other goods	0.1	Low elasticity selected to represent minimal substitution opportunities once committed to the trip; for example, switching to coach or flying on a discount ticket.

	consumed in Hawaiʻi		

As shown in Table A-6, the compilation of elasticity parameters for CGE models are both important but also tend to be quite ad hoc. The documentation of the SAGE model is one of the most comprehensive in showing the selection of elasticity parameters; however, not all parameters translate from the U.S. to Hawaiʻi context. Though elasticity parameters are important in calibrating the model to reasonable relationships among sectors and consumers, what is most important is that they remain the same between model runs, from baseline to scenarios. This allows us to tease out the impacts of the intervention.

Exogenous Energy Efficiency

Webster et al. (2008) demonstrate in the MIT Emissions Prediction and Policy Analysis (EPPA) model, a global CGE model, the importance of representing exogenous energy efficiency trends independent of changes in income. To do this, we adopt energy efficiency parameters for petroleum, gas, electricity and vehicles from the U.S. Annual Energy Outlook 2020, using the Low Oil Price Forecast. This particular forecast is chosen because energy prices remain nearly constant throughout the 2020-2045 time horizon – both more likely the pathway that global prices are on since the COVID-19 recession as well as more consistent with our internal modeling assumptions that fixes relative prices to 2012 relationships, excluding the carbon price intervention.[47] Table A-7 shows the annual energy efficiency improvement parameters incorporated into H-CGE sectors.

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[47] The AEO energy efficiency parameters are quite similar in their Reference Case.

Table A-7: Annual autonomous energy efficiency improvement parameters

	Commercial	*Industrial*	*Light Duty Vehicles*	*Ground Transportion Services (Heavy Duty Vehicles)*	*Water Transportation*	*Air Transportation*
Petroleum	-0.5%	-0.6%	-1.0%	-0.7%	-0.6%	-0.9%
Gas	-0.5%	-0.6%				
Electricity	-2.5%					
VMT			-0.9%			

Source: Tables 4, 5, 6 and 7 U.S. AEO (2020).

Notes: Table 4 – Delivered and total energy consumption (Light Duty Vehicles, VMT); Table 5 – Thousand Btu per sq ft (energy consumption) (Commercial, Petroleu, Gas, Electricity); Table 6 – Energy consumption per dollar (Industry, Petroleum and Gas); Table 7 – Freight Truck Fuel Efficiency (mpg) (Ground Transportation Services, Petroleum), Seat Miles Per Gallon (Air Transportation, Petroleum), Shipping (Water Transportation, Petroleum). Industrial sectors are mapped to Other Manufacturing. Commercial sectors are mapped to all other sectors not specifically identified.

Renewable Portfolio Standard (RPS) Constraint

As discussed in the body of the report, the State‘s RPS sets targets for renewable sources of electricity is based on "net sales," which effectively double-counts behind-the-meter renewable energy. To represent the RPS in H-CGE, we must estimate the effective renewable energy generation target. Using data made available through the utility‘s Power Supply Improvement Plan (PUC, 2016), we calculate the proportion of generation from renewables by taking the MWh of renewable generation over MWh of total generation. We also calculate the implied percentage of renewable energy generation presented in the plan, based on the RPS accounting (subtracting distributed generation from the denominator). By taking the ratio of these two parameters, we develop a share parameter that is used to adjust the RPS targets, solving for effective renewable energy. Because the RPS has compliance years in 2020, 2030, 2040 and 2045, mid-points are taken for 2025 and 2035 such that each year of H-CGE‘s model solve has a renewable energy generation constraint, which is operationalized in the production of electricity. If the marginal value of this constraint in H-CGE is positive, then the value of the marginal is applied to the cost of fossil-fired generation such that the price of fossil-fired generation increases to a level that this constraint is met.

Table A-8: Renewable sources of electricity generation levels imposed in the H-CGE model

Year	Renewable Energy Generation (%)
2025	29
2030	32
2035	42
2040	52
2045	72

Electric Vehicle Adoption

H-CGE incorporates two types of light duty vehicles, gasoline-powered and EVs. The model targets an exogenous forecast of the share of total travel by EVs and share of total EV travel by quintile.

To begin we must make assumptions about how household income quintiles adopt EVs. Borenstein and Davis (2015) find that the top income quintile in the U.S. has accrued 90% of the federal tax credit for EVs. For 2019, we start with the percentage of EVs on the road in Hawai‘i and split it among household quintiles knowing that the vast majority are in the top quintile. From there we assume that the distribution of EVs among quintiles increases over time, as EV costs decline and more enter the used car market. Our baseline assumption for the share of travel by electic vehicles by household quintile and over time is shown in Table A-9.

Table A-9: Forecast of each quintile's VMT from EVs (%)

Quintile	2019	2025	2030	2035	2040	2045
hh1	0%	0%	0%	2%	6%	12%
hh2	0%	0%	1%	5%	12%	22%
hh3	0%	1%	4%	8%	20%	35%
hh4	1%	3%	10%	18%	30%	50%
hh5	4%	8%	18%	34%	50%	70%

Taking this as our main calibration, we solve for the total baseline EV adoption forecast to ensure that it lies roughly half way between the Hawaiian Electric electrification of transportation forecast and the U.S. EIA's Annual Energy Outlook EV adoption forecast (AEO, 2020; Hawaiian Electric, 2020b). Hawaiian Electric forecasts 50% of light duty vehicles in 2045 will be EVs while the EIA forecasts only about 5% of travel will be from EVs in 2045. The final EV forecast is shown in Table A-10.

Table A-10: Forecast of share of EVs on the road relative to light duty vehicles

2019	2025	2030	2035	2040	2045
1.4%	2.9%	7.3%	13%	22%	34%

We did considerable testing of these assumptions and, though the overall adoption of EVs of course impacts our baseline estimates of GHGs, the qualitative results of the carbon tax scenarios are robust to our assumptions about the baseline distribution of these vehicles.

H-CGE is solved using GAMS (General Algebraic Modeling System) and MPSGE (Mathematical Programming for General Equilibrium Analysis). For more information on these modeling platforms, refer to Brooke et al., 1988, and Rutherford, 1987 and 1999, respectively.

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