INVESTIGATING THE ECONOMICS OF CURRENT AND FUTURE RECYCLING PROGRAMS IN FLORIDA

2022

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Florida Recycling Partnership Foundation

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EXECUTIVE SUMMARY

The current recycling industry is challenged with higher contamination rates, higher processing costs, lower participation rates, and fluctuating commodity values. Perhaps one of the most common methods of participating in recycling is through residential household curbside programs. This increase in costs and contamination garnered the attention of many local government decision makers looking to optimize or even eliminate their recycling program. In this study, the Department of Environmental Engineering Sciences at the University of Florida (UF) conducted research on the current and potential alternative future states of the household curbside recycling programs in Florida.

One aim of this study was to quantify the influence of commodity market value and degree of contamination on the recycling system. A second aim of the study was to measure the impact on the GHG emissions and costs per household of eliminating the entire recycling program or restricting the types of materials collected. Evaluating the impact of such approaches was done by first using mass composition and disposition for 2020, 2015, and 2011 for Florida. The cost and GHG emissions were estimated using a study-developed model that incorporated various assumptions for recycling and garbage collection, and assumptions used in life cycle assessment waste-based modeling. These years were selected because they provided historical perspective on the worst recycling market (2020) and the best recycling market (2011) since 2005; 2015 provides a middle ground comparison between 2020 and 2011.

In the last 10 years, the average single-family residential recycling rate in Florida remained around 30% (when including yard trash recycling) and most of the waste collected was landfilled 53-58%. Of the total mass recycled, the recycling of paper products (e.g., mixed paper, newspaper, and cardboard) contributed to 20% of the total recycling rate. The total annual household waste management cost increased from 2011 to 2015 to 2020 at $167/ HH-yr. to $188/ HH-yr. to $230/ HH-yr., respectively. We modeled the costs as a function of increasing contamination rates (e.g., 13% for 2011, and 23% for 2020). The largest factor affecting cost was the revenue generated in that year by the sale of recyclables. The impact of high market conditions in 2011 generated a total revenue of $65/ HH-yr, approximately 50% greater than 2020. The average greenhouse gas (GHG) emissions footprint for a Florida single-family household's waste management ranged from -0.02 to -0.09 metric tons of CO_2 equivalents per household annually (tCO_2eq / HH-yr). depending upon the composition of the recyclables stream. There was vast offset potential, approximately 0.30-0.43 tCO_2eq./HH-yr, provided when using recycled materials as production feedstocks instead of virgin resources.

Numerous changes can be made to a local government's recycling program, including changes to the collection frequency, introduction of larger capacity recycling bins, education to promote recycling participation, limiting the types of materials accepted, and even eliminating the program. We evaluated nine different scenarios and present summary results for five in Figure ES-1. Increasing the recycling rate means more materials can be used as secondary feedstocks, this overall reduced costs and significantly reduced GHG emissions. When evaluating the impact of eliminating recycling, we find that there are certain market conditions, recycling stream compositions, and recycling rates which result in only a $1/HH-yr saved but with a tremendous increase in GHG emissions. The removal of historically low commodities, like glass (considered a contaminant in some parts of Florida), result in a slight increase in costs and in GHG emissions.

The most optimized system is one which targets materials for recycling with historically high commodity prices and high GHG emissions offsets when recycled. Such a program will require local governments to educate residents on proper recycling guidelines, and in doing so can help capture materials, like plastics, which are becoming more in demand due to new policies and corporate changes requiring the use of recycled content in product manufacture.

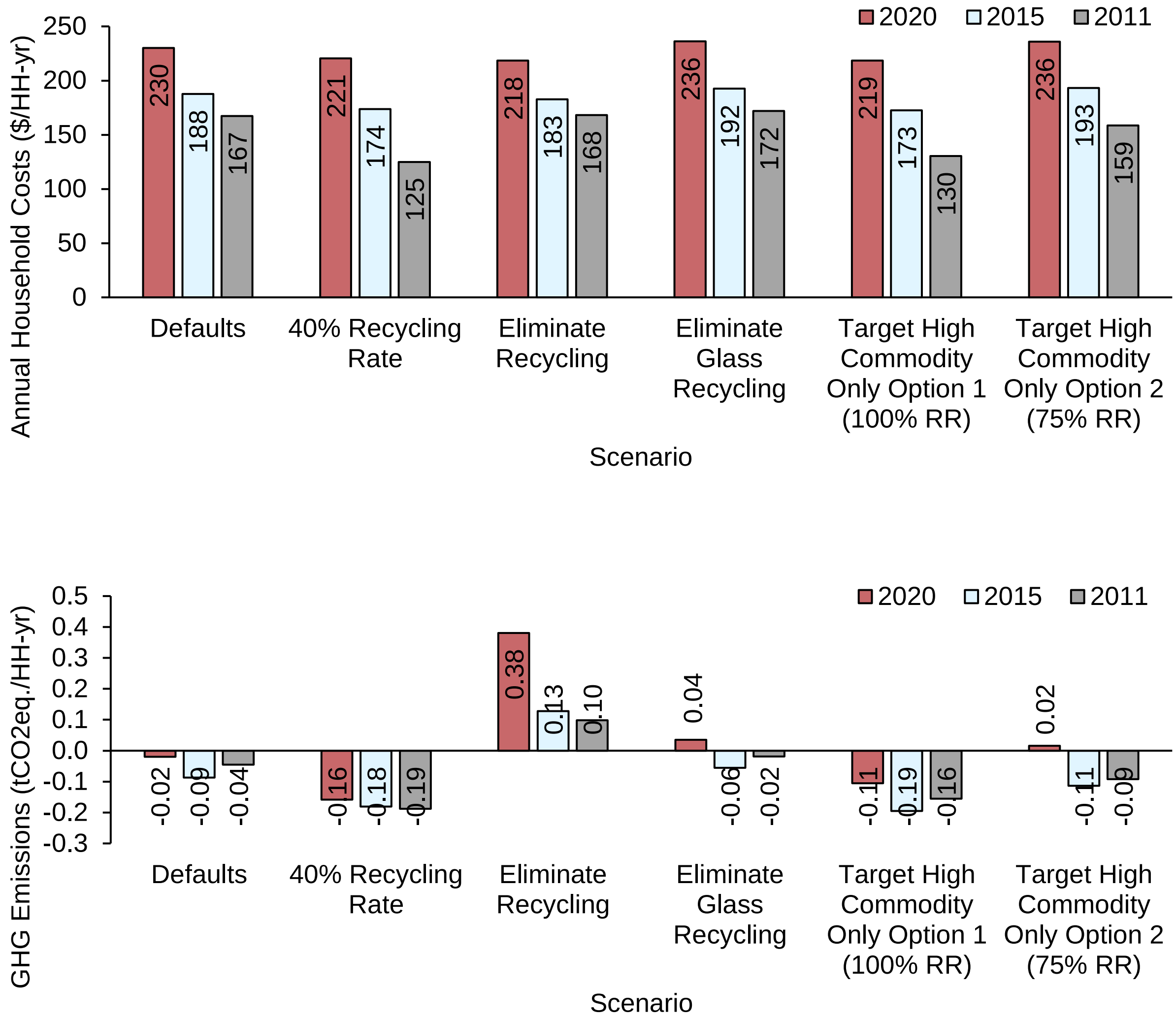

Figure ES-1. Waste management based annual household cost and GHG emissions for the Default scenario and five alternative scenarios. See Figure 8 for all nine scenarios.

Key Findings

- Under most circumstances providing curbside recycling collection does result in a net cost to a local government and residents, but this cost on average is a relatively small percentage of the overall waste management system cost (16-26% of total costs).
- A recyclables program that focuses on targeting a small suite of materials (e.g., newspaper, cardboard, aluminum and steel cans, HDPE and PET bottles) provides local governments and residents a more optimized system to participate in recycling with the goals of lowering costs and mitigating GHG emissions.
- Recycling a target material suite only, even if the total recycling rate is as low as 19%, can achieve the same GHG emissions savings as recycling as much of 40% of the total waste stream.
- The most effective way to control the cost of recycling is to reduce contamination (saving processing time/capacity/labor/energy usage; transportation costs; and disposal costs).

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1 BACKGROUND AND RESEARCH APPROACH

The current recycling industry is challenged with higher contamination rates, higher processing costs, lower participation rates, and fluctuating commodity values. Perhaps one of the most common methods of participating in recycling is through residential household curbside programs. These recycling programs, often managed by local governments (e.g., county or city), provide residents with a recycling container that is placed at the side of their curb, collected once a week, and transported to a recycling facility where the numerous materials are sorted into several marketable categories. A more popular recycling collection scheme, referred to as “single stream” provides convenience for residents to participate in recycling by placing all materials into one bin, as opposed to “dual stream”, where fiber and container materials are separated by residents prior to collection.

Recycling programs, regardless of type, are changing in response to the recycling industry challenges. Where the forefront challenge is an increase in contamination (or non-recyclable garbage in the inbound stream), further defined here as any material entering a recycling facility (better known as a materials recovery facility (MRF)) that cannot be marketed; the material is ultimately sent for disposal. Some research indicated that higher contamination rates, may be due to residents, who have intrinsic motivation (e.g., practice more sustainable behaviors like increasing recycling), but end up placing non-recyclable materials with no market value in their bins (Gundupalli et al., 2017; Lakhan, 2015; Maimoun et al., 2016; Shi et al., 2014; Tonjes et al., 2018) or “wish-cycling”. Other reasons that may result in contamination stems from the common practice in municipal solid waste (MSW) policy of setting sustainability goals, typically in the form of a recycling rate which residents may attempt to meet by recycling the wrong materials. For example, Maimoun et al. (2016) and Shi et al. (2014) both explored single stream recycling and its relationship in Florida to meet the Florida Legislative recycling rate goal of 75% by 2008.

This increase in contamination has disrupted historically steady trade relationships with oversees importers of US (and other nations) recyclable goods. Large portions of the recycling stream, mixed paper and mixed plastics, were rejected from overseas ports, instigating major changes to the cost of recycling in domestic markets. In the last three years, recycling processing costs at MRFs increased from about $50 per ton to over $100 per ton. This sudden increase in costs garnered the attention of many local government decision makers looking to optimize their recycling program, and the attention of decision makers looking to cut costs. In response to these conditions, local governments are limiting certain materials from the recycling stream or eliminating their recycling program altogether. In this study, the Department of Environmental Engineering Sciences at the University of Florida (UF) conducted research on the current and potential alternative future states of the household curbside recycling programs in Florida. The research focused on the economic costs of the current program and future programs (e.g., limiting acceptance of certain materials from the bin, eliminating the program) and the association greenhouse gas (GHG) emissions footprint.

2 RESEARCH APPROACH

One aim of this study is to quantify the influence of commodity market value and degree of contamination on the recycling system. A second aim of this study is to measure the impact on the GHG emissions and costs per household of eliminating the entire recycling program and restricting the types of materials collected. Evaluating the impact of such approaches will be done by first using mass composition and disposition for 2020, 2015, and 2011 for Florida. The cost and GHG emissions will be estimated using a study-specific model that incorporates various assumptions for recycling and garbage collection, and assumptions used in life cycle assessment waste-based modeling. These years were selected because they provide historical perspective on the worst recycling market (2020) and the best recycling market (2011) since 2005; 2015 provides a middle ground comparison between 2020 and 2011. The general categories included in this study are: single stream recycling and garbage curbside collection costs, single stream MRF costs, residual disposal costs, and garbage disposal costs. Demonstrating the potential GHG emissions and economic impacts of eliminating the entire recycling program will be conducted by assuming no recyclables are collected as single stream and instead collected as garbage and only the garbage disposal costs and the GHG emissions impact of landfilling and combustion are included.

3 DATA AVAILABILITY AND METHODS

3.1 Model functionality

A spreadsheet-based model was developed to estimate three items: mass flows, costs, and potential GHG emissions footprint associated with a single-family residential home in Florida in 2020, 2011, and 2015. The model was comprised of several sub-models that were used to estimate the three items for each year (e.g., disposal cost model, collection cost model, GHG emissions model, recycling revenue model, economic parameters model, mass flow model). Example of the parameters include in the disposal cost model include the average tipping fees in Florida landfills and combustion facilities. The collection cost model included parameters related to collection schedule, operation times, fuel usage. The GHG emissions modeled housed the GHG emissions factors used to estimate the total potential GHG emissions footprint. The recycling revenue model accounted for average monthly commodity prices of recyclables. The economic parameter accounted for inflation conversions, discount rates, historic diesel/energy prices. The mass flow model estimated disposition flows for 20 material categories collected as garbage and recyclables from Florida’s single-family households. A simplified summary of the key data and their relationships in the model is shown in Figure 1.

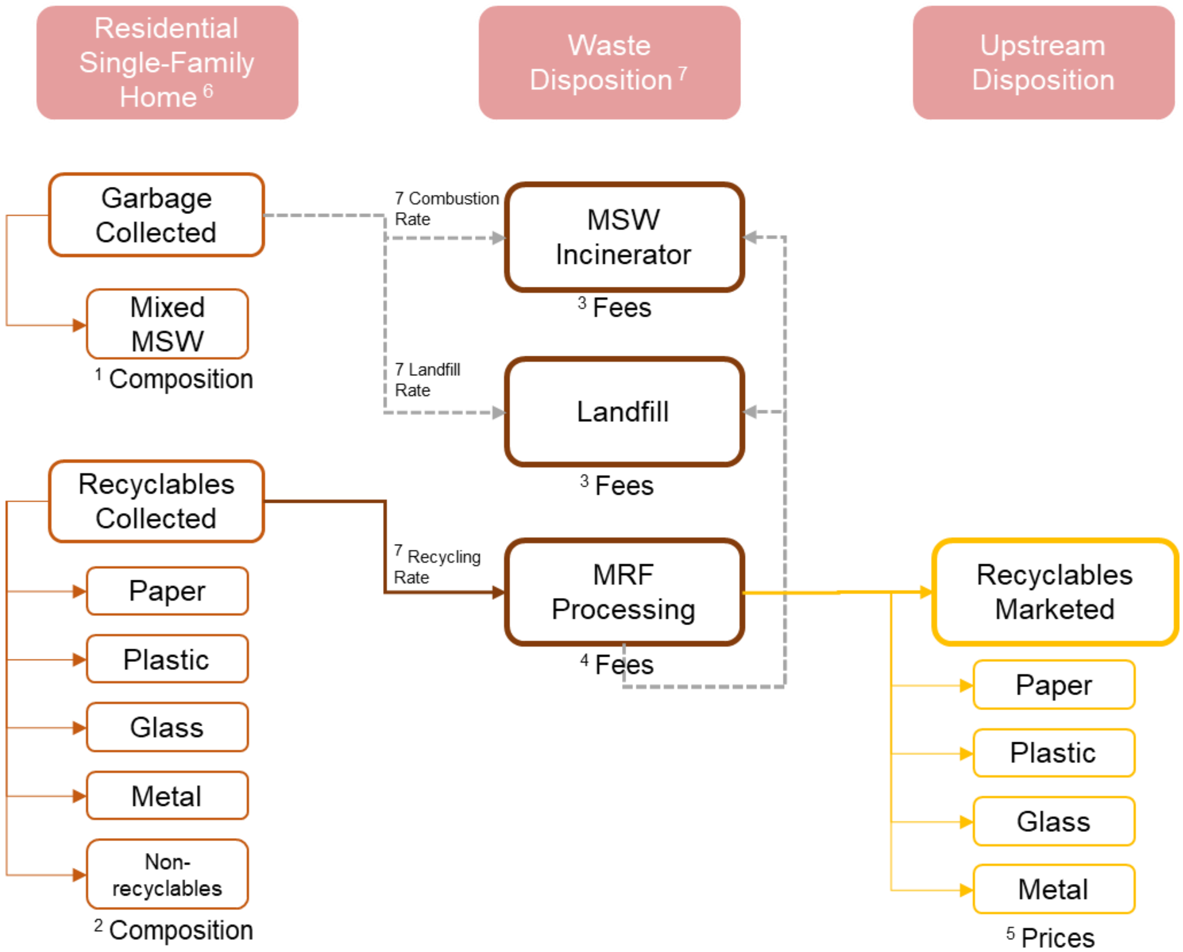

Figure 1. Illustration of key data used and outputs of model. 1) the composition for mixed MSW was determined using single-family disposal-based composition studies from seven Florida counties; 2) the composition used for the recyclables stream are specific to each year; 3) the fees used for combustion and landfilling are specific to each year; 4) the MRF processing fee was assumed to be the same value for all years; 5) the commodity prices were specific to each year (and on a monthly basis); 6) key data used for residentials single-family is not shown; 7) waste disposition data was specific to each year. Also not shown here are the GHG emissions used.

3.2 Data needed and availability

3.2.1 Mass flows

The majority of the data used to estimate the mass flows for each year were retrieved from the Florida Annual Solid Waste Reports published by Florida Department of Environmental Protection (DEP). The total population, single-family population and the mass of mixed MSW collected for garbage and recyclables were retrieved. Data on the recycling rate and recycling participation rate were used to estimate the waste generation rate per household and diversion rate (percent of waste diverted from disposal). Detailed annual data are shown in Table 1, and in the Appendix, Tables A1 The data on the total combusted and landfilled masses were used to determine the combustion and landfill ratio (see Table A2). To get the mass flows of each individual material category, a waste composition for garbage collected and recyclable collected were determined. The waste composition for mixed MSW generated by single-family residents in Florida was determined by taking the average values of seven disposal-based composition studies and this was used for the garbage composition for all years (CH2M Hill Engineers. Inc., 2019; HDR Engineering, Inc. and Kessler Consulting, Inc., 2010; Kessler Consulting, Inc., 2019, 2018, 2015, 2014a, 2014b). Figure 2 shows the composition of garbage used. On the other hand, the composition for recyclables were determined specific to each year, and these were created using data for 2019, 2015, and 2011 reported in (Townsend and Anshassi, 2020). The composition applied to the mass of recyclables collected are shown in Figure 3.

Table 1. Single-family parameters used to estimate the generation rate (in Table A1), and reported recycling rate, and average recycling curbside participation rates. Data retrieved from DEP solid waste annual reports.

Single family parameter	**2020**	**2015**	**2011**
Total Residential Single Family Units:	6,421,487	5,814,846	6,117,824
Average Residents Per Unit	2.60	2.63	2.63
Residential Single Family Collected Tons:	14,574,848	10,083,674	8,913,528
Residential Single Family Recycled Tons:	4,734,804	3,362,243	2,472,039
*Recycling rate**	32%	33%	28%
Average units participating in curbside collection (based on units with curbside collection service)	72%	66%	61%

Note: Averages for residents per unit and recycling curbside participation rates were estimated using only data reported by counties (e.g., counties not reporting the data were not included in the average).

*The recycling rate includes large amounts of yard trash collected and recycled, we used the values presented here as a conservative estimate (and a more realistic single-family recycling rate for curbside materials would be around 20-25%)

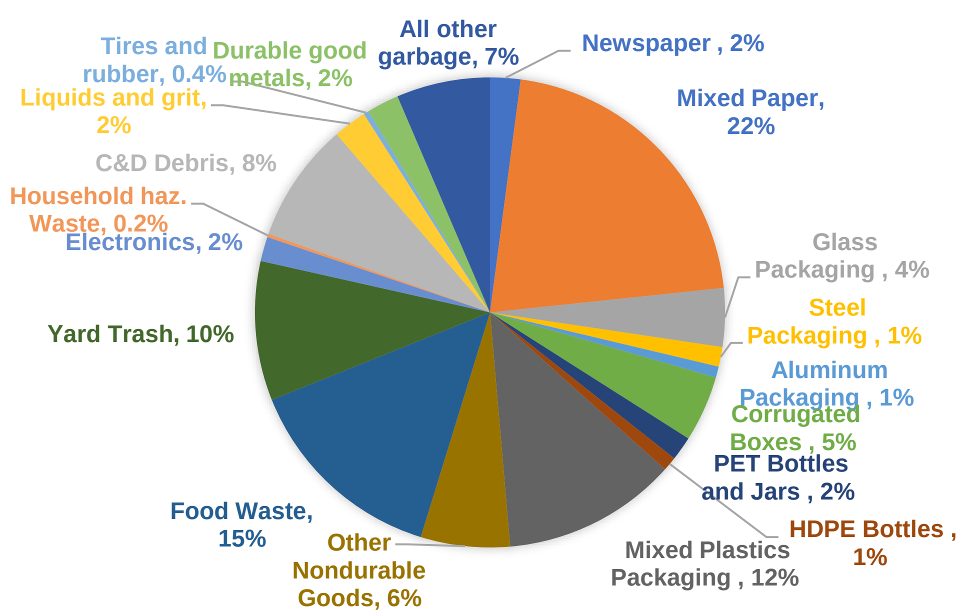

Figure 2. Composition of garbage collected for 2020, 2015, and 2011..

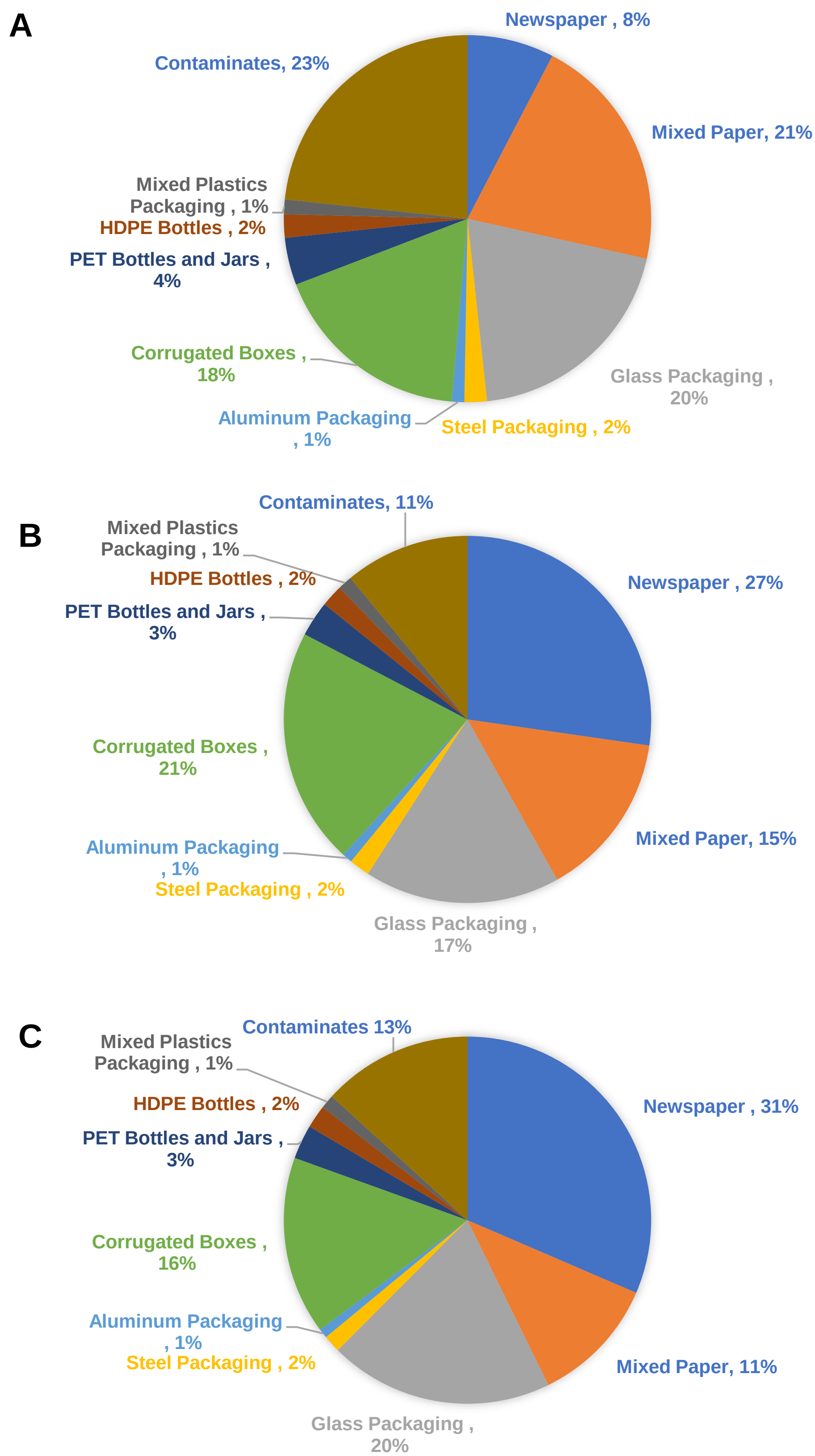

Figure 3. Composition of recyclables collected for A) 2020, B) 2015, and C) 2011.

3.2.2 Cost for solid waste management

Measuring the costs to collect single stream recyclables and garbage is complex because there are many interlinked parameters, and they are region-specific. Minimizing uncertainty when quantifying the collection costs was done by developing a method that considered multiple parameters and by compiling robust data. For example, in the collection schedule parameter the components included are number of households at one stop, participation rate, collection frequency, number of working days a week, and working hours a day per vehicle. The collection costs changed as a function of composition (for both garbage and recyclables stream) and mass. The primary parameters changed were the waste compaction density (in lbs/yd^3), the total masses collected, and the number of households since these were relative to the data used for a given year. Examples of unchanged parameters were collection frequency (1x for recyclables per week, 2x for garbage per week), worker salary, travel speeds, distances between service stops, and the usable vehicle capacity (100% per trip). The cost for disposal (e.g., the landfill and combustion tipping fees) however did change. The average values for Landfill Class I and WTE Facility were retrieved from each DEP annual report (see Table A3). Likewise, the recycling revenue changed as a function of the recycling composition stream and the recycling commodity market. The market value for eight recycling commodities were used for 2020, 2015, and 2011, all retrieved from recyclingmarkets.net for the southeastern region of the US (recyclingmarkets.net, 2020).

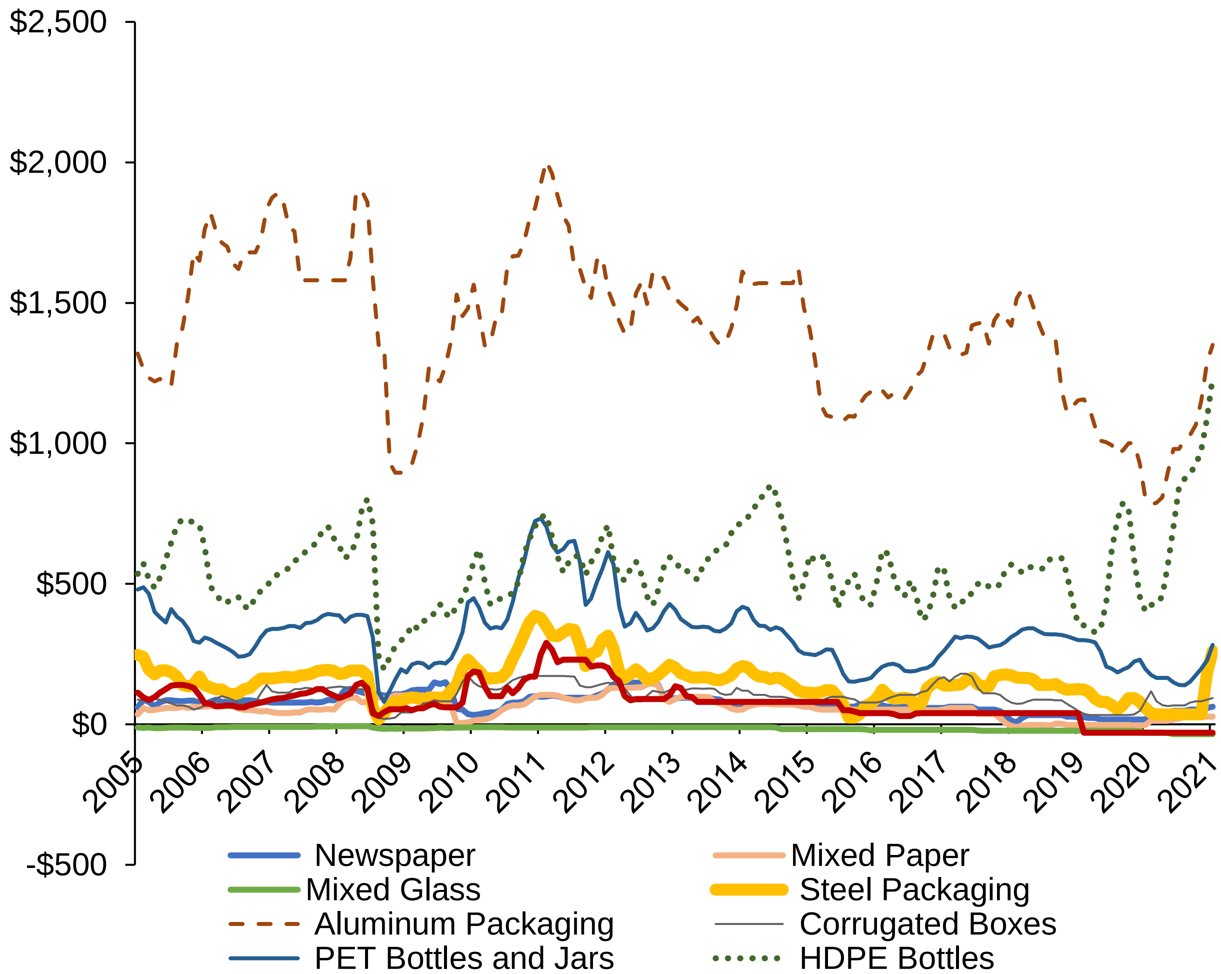

Figure 4. Recycling commodity prices for the 8 common recyclable material categories.

3.2.3 Life cycle waste-based greenhouse gas emissions

Life cycle assessment (LCA) is a tool that quantifies the environmental benefits or burdens associated with a material throughout its life cycle. The life cycle stages included in LCA begin at the extraction of raw materials, then extend to processing, manufacturing, use, and end-of-life management. All processes prior to end-of-life management are referred to as upstream processes. For the purposes of applying LCA for a waste management system only the end-of-life management stages are included (e.g., collection of waste, processing at a facility, landfill, incineration), however when materials are assumed to offset virgin feedstocks, as is the case for recycling or for when electricity is generated from combustion or landfill gas, then upstream processes are accounted for in the LCA.

We provide the GHG emissions factors used in the study in Table 2, which correspond to the average GHG emissions footprint based on results from the three models. These factors were created using the US EPA WARM Model, NC State SWOLF Model, and RTI International MSW-DST Model (Levis et al., 2014a; Thorneloe et al., 2007; US EPA, 2020). For example, the recycling impact factor for newspaper was calculated as the average of the three recycling newspaper impact factors estimated using WARM, MSW-DST, and SWOLF.

Table 2. Simplified life cycle assessment GHG emissions factors for individual materials managed through collection, MRF processing, recycling (remanufacturing processes), combustion at a WTE facility, and typical Florida landfill.

Material	Collecting Garbage Factor (in tCO_2eq./ton)	Collecting Recyclables Factor (in tCO_2eq./ton)	MRF Processing Factor (in tCO_2eq./ton)	Recycling Factor (in tCO_2eq./ton)	Combusting Factor (in tCO_2eq./ton)	Landfilling Factor (in tCO_2eq./ton)
Newspaper	0.01	0.01	0.03	-0.84	-0.80	-0.81
Mixed Paper	0.01	0.01	0.03	-0.27	-0.69	0.15
Glass	0.01	0.01	0.03	-0.29	0.03	0.04
Steel	0.01	0.01	0.03	-1.55	-1.69	0.04
Aluminum	0.01	0.01	0.03	-11.59	0.03	0.04
Cardboard	0.01	0.01	0.03	0.06	-0.70	0.43
PET Bottles and Jars	0.01	0.01	0.03	-1.52	0.97	0.04
HDPE Bottles	0.01	0.01	0.03	-1.31	1.65	0.04
Mixed Plastics	0.01	0.01	0.03	-1.10	1.33	0.04
Food Waste	0.01				-0.21	0.59
Yard Trash	0.01				-0.34	-0.13
Mixed MSW	0.01				-0.14	0.46

Note: Only SWOLF was used to find the MRF processing factor; and negative values represent an avoidance or offset of GHG emissions (e.g., a savings).

3.3 Modeling alternative recycling programs in Florida

As local governments begin changing their recycling systems to optimize these environmental benefits and reduce costs associated with recycling several questions about what options exist come into play. The first option is to leave the recycling program as is, where currently about 8-10 different recyclable categories are sorted from the incoming dozens and dozens of products placed in the recycling bin. A second option is to attempt to capture more products. Although many products may make their way into a recycling bin, many are not recyclable because of their material composition and lack of markets. Achieving a hypothetical recycling rate of, for example, 40% would require capture of products with low and high commodity values, and for some communities may be approaching their theoretical maximum recycling rate since much of their waste stream are materials that are not recyclable. There are many other alternatives to the current recycling system. In this study, we evaluate nine scenarios, as seen in Table 3 for each year. The recyclables curbside participation rate, diversion rate, and recycling rate for each scenario (including the default, which uses direct reported data from FDEP) used for 2020, 2015, and 2011 are summarized in Tables A4-A6.

Table 3. The recycling collection frequency and types of material recycled for the nine alternative scenarios and the default scenario.

Scenario	Recycling Collection Frequency (Per Week)	Materials Recycled
Defaults	1	All
Biweekly	biweekly	All
80% Participation Rate	1	All
40% Recycling Rate	1	All
Eliminate Recycling	1	None
Eliminate Mixed Plastic Recycling	1	All except for mixed plastic
Eliminate Glass Recycling	1	All except for glass
Eliminate Mixed Paper Recycling	1	All except for mixed paper
Target High Commodity Only Option 1	1	Newspaper, cardboard, steel, aluminum, PET, HDPE at each 100% RR
Target High Commodity Only Option 2	1	Newspaper, cardboard, steel, aluminum, PET, HDPE at each 75% RR

**All= newspaper, mixed paper, glass packaging, steel packaging, aluminum packaging, PET packaging, HDPE packaging, mixed plastic packaging*

4 MODELED CURRENT RECYCLING PROGRAMS IN FLORIDA

4.1 Mass Flow, Costs, and GHG emissions for Florida recycling programs

In Florida, when waste is collected at the residential curb it is hauled to be disposed of at a landfill and/or a MSW incineration facility. Also collected at the curb are recyclables which are transported to a MRF to be sorted and marketed to be used as secondary feedstocks in product manufacturer. In the last 10 years the average single-family residential recycling rate in Florida remained around 30% and most of the waste collected was landfilled 53-58%. The mass disposition and recycling composition are shown in Figure 5. The portion of garbage combusted is shown to decrease from 18% to 14% to 11%, this decrease is due to changes in accounting methods since the capacity and operation of MSW incineration facilities has not dramatically changed in the last 10 years. Of the total mass recycled the recycling of paper products (e.g., mixed paper, newspaper, and cardboard) contributed to about 20% of the total recycling rate. The second largest contributor to the recycling rate was recycling of glass (~7%), and the least was metals (aluminum and steel cans) at 1%. The recycling rate is based on a mass; therefore, the heaviest materials contribute the greatest portion to the overall rate.

Figure 6 breaks down the 2020, 2015, and 2011 annual cost and GHG emissions footprint per Florida single-family household estimated using the study-developed model. The total annual household waste management cost increased from 2011 to 2015 to 2020 at $167/ HH-yr. to $188/ HH-yr. to $230/ HH-yr., respectively. The costs ranged for garbage collection ($89-92/ HH-yr), recyclables collection ($54-68/ HH-yr), landfill and MSW incineration disposal ($51-73/ HH-yr), and recyclables processing ($37/ HH-yr). The largest factor affecting cost is the revenue generated in that year by the sale of recyclables. As previously mentioned, the worst recycling market was in 2020 and the best in 2011 (relative to the markets from 2005 to 2020). We see the impact of high market conditions in 2011 where the total revenue generated was $65/ HH-yr, approximately 50% greater than 2020. These market comparisons do not even consider the price paid to recycle mixed glass, which in 2020 cost a household $6/ yr (as opposed to the $1/ yr in 2011). Since a constant recycling processing cost was used for all three years ($115/ton) and we know that processing costs were as low as $50/ton in 2011, it can be assumed that the recyclables MRF processing cost in 2011 would be lower than the estimated $37/ HH-yr. Although we did not model a difference in the costs of recycling processing as a function of contamination rate, we did model the costs with an increasing contamination rates (e.g., 13% for 2011, and 23% for 2020). Our cost analysis finds that under most circumstances providing curbside recycling collection does result in a net cost to a local government and residents, but this cost on average may be a relatively small percentage of the overall waste management system cost (16-26% of total costs).

The average GHG emissions footprint for a Florida single-family household's waste management ranged from -0.02 to -0.09 metric tons of CO_2 equivalents per household annually (tCO_2eq / HH-yr). depending upon the composition of the recyclables stream. Notably, the resulting net GHG emissions offset was due to recycling. There is vast offset potential, approximately 0.30-0.43 tCO_2eq./HH-yr, provided by the use of recycled materials as production feedstocks instead of virgin resources (Christensen et al., 2020; Levis et al., 2014b).The GHG emissions offset potential varies among the different recyclable material types; it depends upon the embodied carbon footprint of each material. The method of virgin material extraction or harvesting, as well as the amount of recyclable material used in the manufacture of a product explains the contrasting offset potentials shown in Figure 6 among glass, plastic, metal, and paper products recycling. Even though metal products (e.g., aluminum and steel cans) comprise less than 1% of the recyclables stream, they have the either the largest emissions offset or second largest at -0.06 to -0.15 tCO_2eq./HH-yr, indicating the importance of prioritizing their recycling collection. The smallest GHG emissions contributor comes from the collection of recyclables and garbage, and the processing of recyclables at a combined total of 0.035-0.058 tCO_2eq./HH-yr. Unlike most landfills, combustion of waste components with high energy contents can be used to generate electricity and offset the use of local fossil fuels (Christensen et al., 2020; Istrate et al., 2020). In some cases, landfilling can also generate an emissions avoidance when the methane produced is collected at high efficiencies, when that gas is used to generate electricity to offset fossil fuel energy, or when biogenic carbon containing materials are considered to sequester carbon in the landfill (Levis et al., 2014b; Manfredi and Christensen, 2009).

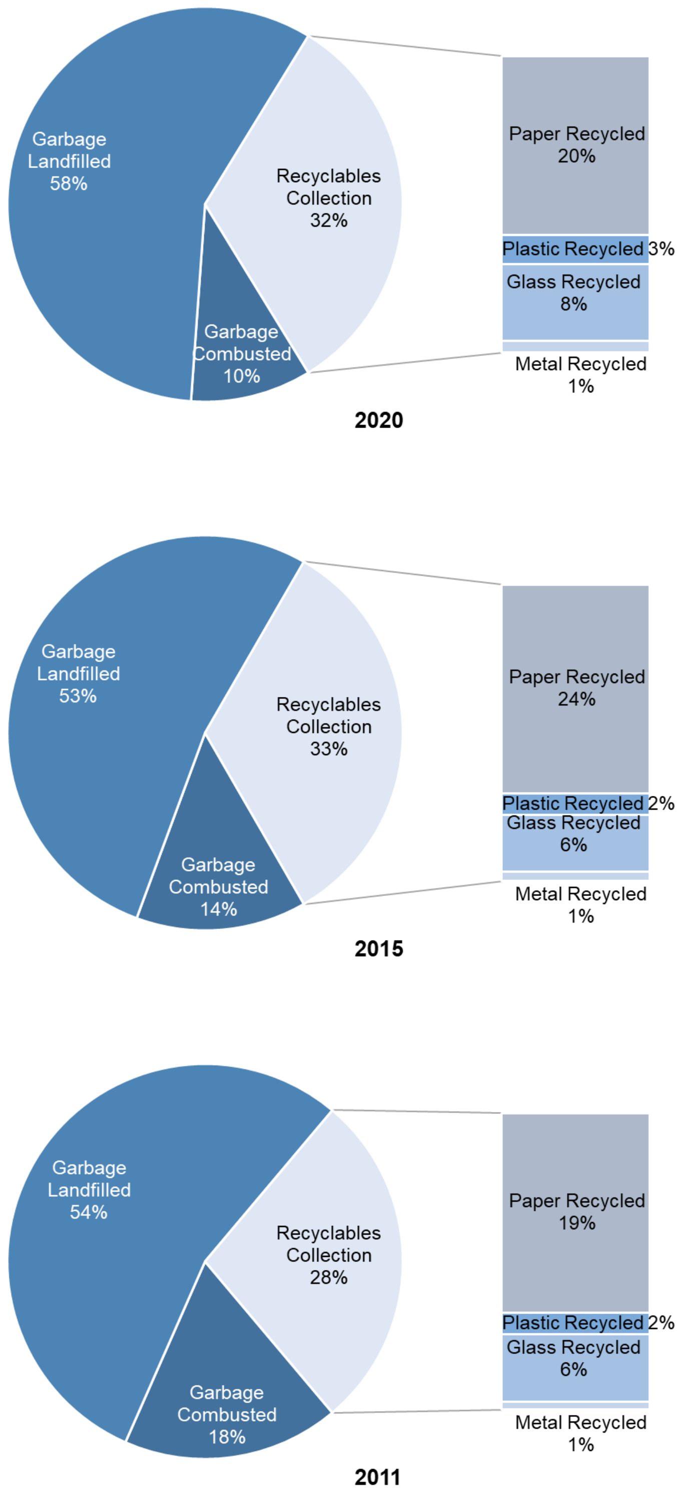

Figure 5. Results for the mass disposition of garbage (plus any residual from MRF processing) collected that is landfilled or combusted, and recyclables collected (and the composition of materials recycled at the MRF).

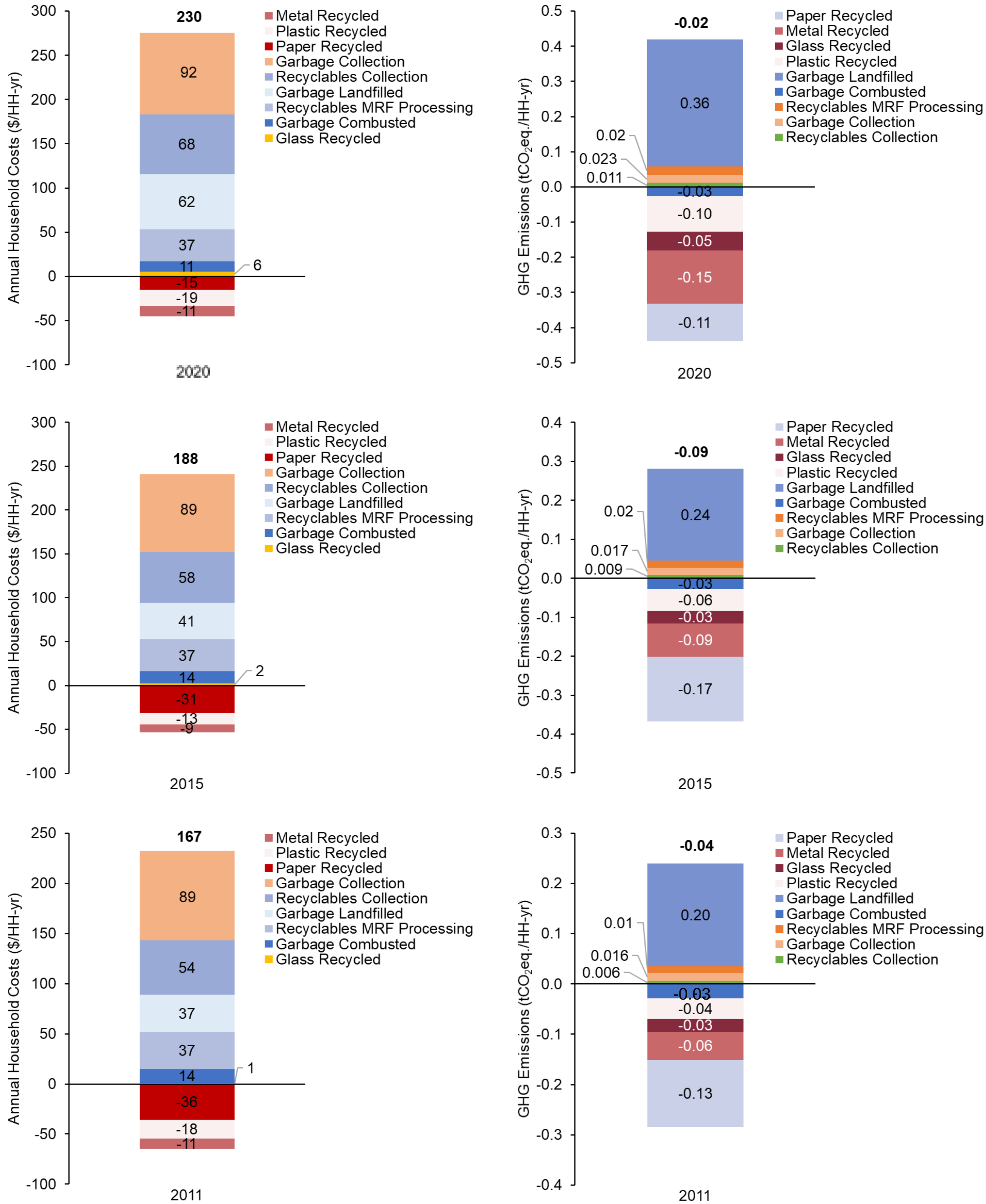

Figure 6. Results for the waste management based annual household costs and GHG emissions for Florida single-family households in 2020, 2015, and 2011.

4.2 Comparison with actual Florida recycling program costs

The model developed for the study relies on robust datasets, therefore we compiled solid waste management cost data from across Florida and compared the actual costs incurred by residents to those estimated by the model. Of the data collected, there were many cases where the annual household single-family costs for solid waste management were provided on a total basis. In some cases, the total costs were further broken down into the costs of annual garbage collection, recyclables collection, disposal costs, recyclables processing costs, administration costs, and revenue from marketed recyclables. A general map showing the counties where data were collected per year (2020, 2015, and 2011) is presented in Figure 7. Th exact data that was used to determine the average actual annual solid waste management costs for each year is provided in the Appendix, Tables A7-A9. The total annual average costs for 2020, 2015, and 2011 were $244, $196, and $191, respectively. The data trend generally follows the modeled estimates for these years where 2020 is the greatest annual cost of the three and 2011 is the least.

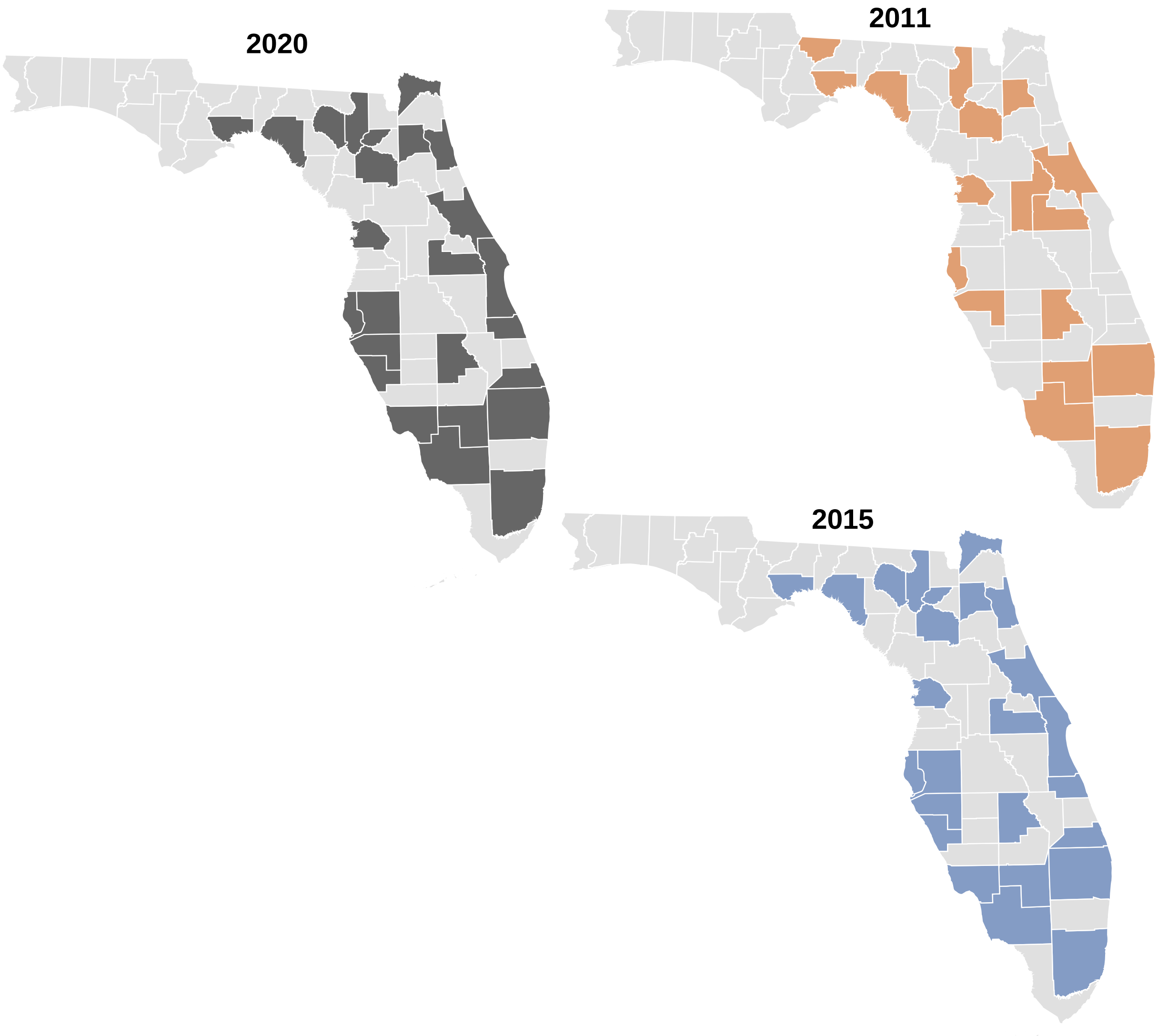

Figure 7. Data collected on the single-family residential costs for Florida counties for 2020, 2015, and 2011.

5 MODELED ALTERNATIVE RECYCLING PROGRAMS IN FLORIDA

Numerous changes can be made to a local government's recycling program, including changes to the collection frequency, introduction of larger capacity recycling bins, education to promote recycling participation, limiting the types of materials accepted, and even eliminating the program. As part of the second aim of this study, the annual household cost and GHG emissions footprint for nine changes (or alternatives) to the current recycling program were modeled. The summarized results for these changes (assumed to be applied to each of the three years) are shown in Figure 8. The first set of three bars correspond to the scenario "defaults" and these match with the data shown in Figure 6.

The impact of changing collection from once a weekly to biweekly, as well as increasing recycling participation to 80%, had no impacts on GHG emissions because the total mass and recyclables composition were assumed to remain the same as the defaults. However, there were impacts to costs, primarily the cost of recyclables collection, which decreased in both scenarios. The total annual costs decreased by $17-19/HH-yr (for 2020, 2011, 2015) when recycling collection changed from once a week to once every two weeks (Figure 8) The impact of increasing participation to 80% meant more households were placing their recycling bins out on the curb, and this led to a decrease in recycling collection costs. On average, an increase of recycling participation decreased annual costs by $4/ HH-yr (Figure 8). Another change to the recycling system modeled was increasing the recycling rate to 40%. This scenario assumed all recyclable materials would be collected at a higher rate. As expectant, the costs decreased, and depending on the market conditions the cost decrease was substantial (e.g., $10/HH-yr decrease in 2020 versus $42/HH-yr decrease in 2011) (Figure 8). As we recycle more material, we also displace the use of virgin materials and reduce the overall GHG emissions footprint. The increased recycling provided a larger GHG emissions offset ranging from 2 to 8 times greater than the "defaults" scenarios for 2020 and 2015, respectively. The three scenarios (biweekly, 80% participation rate, and 40% recycling rate) will require extensive effort and resources from local governments in educating their residents that may not be easily feasible.

Given that recycling costs are on the rise, there are some communities that have begun eliminating their recycling programs. We modeled the impacts on costs and GHG emissions in the scenario "eliminate recycling". When the recycling program is halted this means the mass of material initially diverted to a recycling bin is now placed within the garbage bin. Our modeling accounted for this and assumed the recycled mass would be disposed of through landfilling and combustion based on the ratios used in the "defaults" scenario. Comparing the costs of this scenario to "defaults" there is a cost savings for 2020 and 2015 at $12/ HH-yr and $5/ HH-yr. While for 2011, when markets are at their peak there is an opposite effect, where eliminating recycling causes a financial savings loss of $1/HH-yr (Figure 8). In other words, there are certain market conditions, recycling stream compositions, and recycling rates which result in a recycling cost breakeven. The impact to GHG emissions when eliminating recycling is significant, from Figure 8 the GHG emissions footprint increases by 20, 2.5, and 3 times for 2020, 2015, and 2011. The difference in magnitude of the increase is due to the difference in recycling composition, original recycling rate, and the inherent mass balance (the generation rate per household is largest for 2020 (see Table A1)).

With the aim of reducing processing costs, local governments can potentially use commodity price value as a metric to determine materials to target removal from their recycling program. In some parts of the US, this is already occurring where communities are reducing the number of items permitted in the recycling bin, particularly, these are mixed plastics, mixed paper, and glass (Brian Tucker, 2019) citing low historical commodity prices and potential increased contamination rates as key factors. When modeling the impact of eliminating these materials (on an individual basis) from the recycling program and collecting them as garbage, the cost impact was like that of eliminating recycling in 2011. The impact of removing these materials overall does not create a cost savings suggesting that the cost to collect as garbage and dispose directly in a landfill or combustion facility may be more expensive than processing them at a MRF and then marketing them for sale. The GHG emissions impact for no longer recycling these materials results in an increase in the total annual GHG emissions footprint (Figure 8).

Removing the low commodity materials individually does not provide local governments an optimized recycling system. However, applying this strategy and modeling the impacts of a more focused suite of accepted recyclables that have a historically higher commodity price, and when recycled generate a much higher environmental offset, does provide an optimized system. The materials included in the modeling were newspaper, cardboard, aluminum and steel cans, HDPE and PET bottles. We modeled a restructured recycling program that targeted recycling these materials only and assuming they were recycled to each have a 1) 100% recycling rate and 2) 75% recycling rate. We show that such a program (assuming 100% recycling rate) results in decreasing GHG emissions by 5, 2, 3.5 times as much for 2020, 2015, and 2011 (Figure 8), and provides a significant cost decrease of $12/HH-yr for 2020, $15/HH-yr for 2015, and $37/HH-yr for 2011. The resulting cost savings is greater than eliminating the recycling program for all years (Figure 8). Since a recycling rate of 100% is not realistic we also show the results for a 75% recycling rate. These results show there is a reduction in costs, though not as dramatic, for 2015 and 2011. For 2020, there is an increase in cost, suggesting that because of the recycling stream composition, generation rate, and overall recycling rate for 2020 removing the large mass of low commodity materials and recycling only the high commodity values at 75% is not sufficient to provide a cost savings. However, since there was a cost savings for a 100% recycling rate (for 2020) of the targeted stream there is an optimal recycling rate within the range of 75% to 100%. Overall, a targeted recyclables program that focuses on a similar suite of materials provides local governments and residents a more optimized system to participate in recycling with the goals of lower costs and mitigating GHG emissions impacts.

With increasing demand for recycled materials, the importance of the impact of these scenarios on potential recovered material quantities become elevated. Take for example, recent policies in California and Washington which require manufacturers to produce products with a set minimum of post-consumer recycled content (e.g., 15%), and other states (e.g., Oregon, Maine, New Jersey) are following in a similar fashion. In fact, based on conversations with recycling operators these minimum content regulations are positively impacting the plastics commodity markets in 2021 and 2022 and are expected to continue as the demand for recycled plastic currently outpaces supply. One notable concern of manufacturers is that they do not want to produce one type of container in California and another in say, Florida. Therefore, minimum content legislation in several large states is influencing the demand for recycled plastic on a national level.

In Florida, for example, the 2021 consumption of plastic PET liquid refreshment bottles (LRB) products was 0.01 tons/person (data collected from communications with Florida Beverage Association) thus 220,000 tons of LRB PET were consumed in Florida. If 15% of all produced PET needs to come from post-consumer PET, it can be expected that the current LRB PET collected from households (157,989 tons) and recycled mass (for 2020 assumed to have a high recycling rate of 50%) can supply 100% of the total post-consumer demand. However, if the Target High Commodity Only Option 2 (where the recycling rate is assumed to be 75%) was successful then the post-consumer PET collected cans be used to supply 54% of the total Florida consumed mass (the 220,000 tons). Note all these results are specifically for the single-family residential waste stream and rely on generalized assumptions.

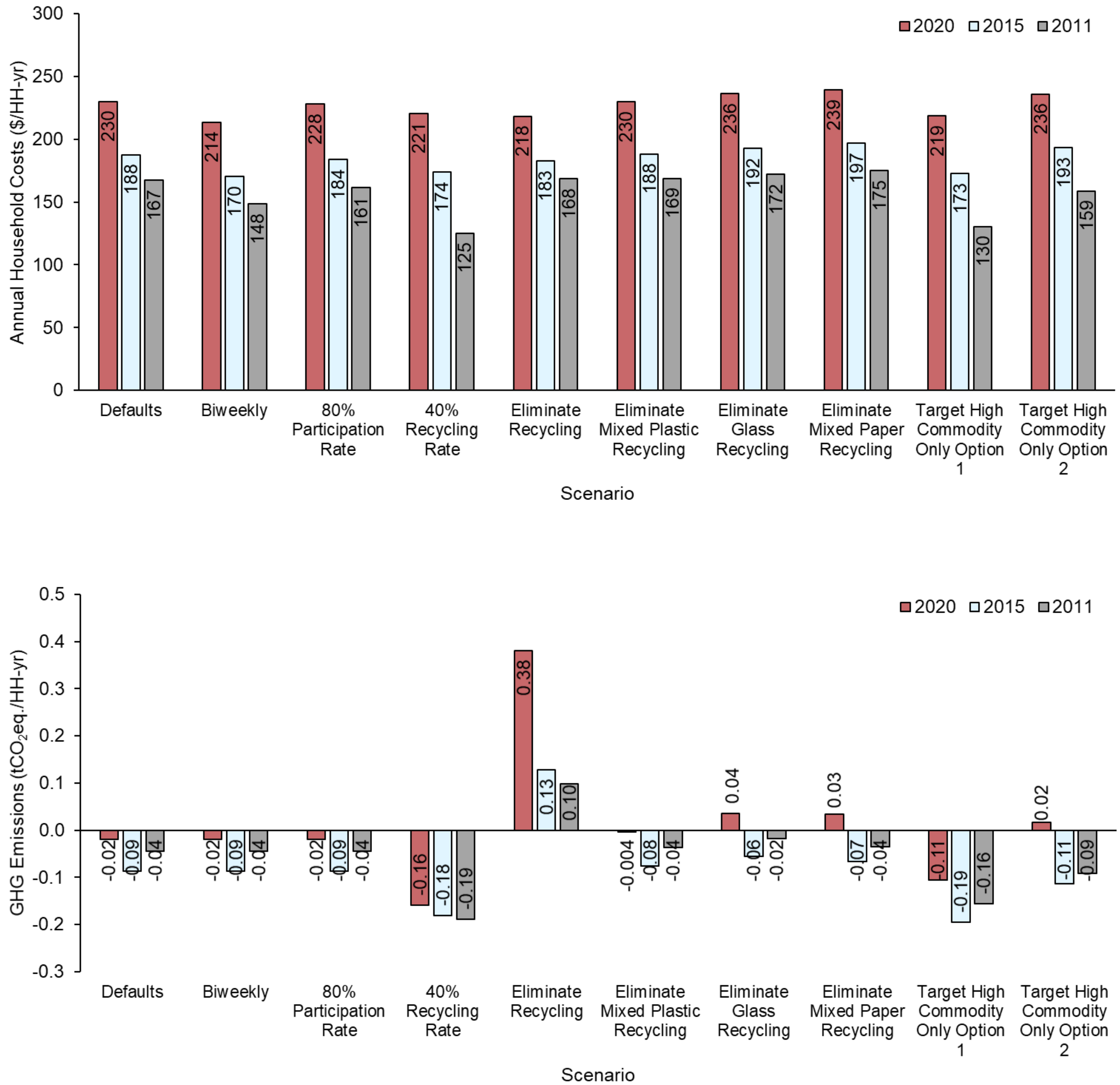

Figure 8. Waste management based annual household cost and GHG emissions for the Default scenario and 9 alternative recycling program scenarios.

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7 APPENDIX

Table A1. The total population and single-family population reported and the estimated single-family generation rate(s). Data retrieved from DEP solid waste annual reports and uses data from Table 1.

Population parameter (persons)	2020	2015	2011
Population	21,596,068	19,815,183	18,907,759
Single family population	16,835,330	15,781,261	16,457,310
Ratio of Single family population	78%	80%	87%
Generation Rate (lb/person-yr)	4.74	3.50	2.97
Generation Rate (lb/HH-wk)	87.3	66.7	56.0

Table A2. The total combusted and landfilled masses for all waste generated in Florida for 2020, 2015, and 2011. Data retrieved from DEP solid waste annual reports.

Disposition	2020	2015	2011
Combusted mass	4,030,019	3,920,726	4,557,205
Landfilled mass	23,462,005	14,803,308	14,011,463
Combusted ratio	15%	21%	25%
Landfilled ratio	85%	79%	75%

Table A3. The average reported landfill Class 1 and WTE Facility tipping fees for 2020, 2015, and 2011 for Florida. Data retrieved from DEP solid waste annual reports.

Fee ($/Ton)	2020	2015	2011
Landfill Class I	47.73	45.26	47.12
WTE Facility	49.49	57.12	52.86

Note: Averages were estimated using only data reported by counties (e.g., counties not reporting the data were not included in the average).

Table A4. The 2020 recyclables curbside participation rate, diversion rate, and recycling rate for each scenario (including the default, which uses direct reported data from FDEP).

Scenario	PR %	DR %	RR %
Defaults	72%	42%	32%
Biweekly	72%	42%	32%
80% Participation Rate	72%	42%	32%
40% Recycling Rate	72%	50%	40%
Eliminate Recycling	0%	0%	0%
Eliminate Mixed Plastic Recycling	72%	42%	32%
Eliminate Glass Recycling	72%	34%	24%
Eliminate Mixed Paper Recycling	72%	34%	24%
Target High Commodity Only Option 1	72%	31%	21%
Target High Commodity Only Option 2	72%	26%	16%

Table A5. The 2015 recyclables curbside participation rate, diversion rate, and recycling rate for each scenario (including the default, which uses direct reported data from FDEP).

Scenario	PR %	DR %	RR %
Defaults	66%	37%	33%
Biweekly	66%	37%	33%
80% Participation Rate	80%	37%	33%
40% Recycling Rate	66%	44%	40%
Eliminate Recycling	0%	0%	0%
Eliminate Mixed Plastic Recycling	66%	37%	33%
Eliminate Glass Recycling	66%	31%	27%
Eliminate Mixed Paper Recycling	66%	32%	28%
Target High Commodity Only Option 1	66%	32%	28%
Target High Commodity Only Option 2	66%	25%	21%

Table A6. The 2011 recyclables curbside participation rate, diversion rate, and recycling rate for each scenario (including the default, which uses direct reported data from FDEP).

Scenario	PR %	DR %	RR %
Defaults	61%	32%	28%
Biweekly	61%	32%	28%
80% Participation Rate	80%	32%	28%
40% Recycling Rate	61%	44%	40%
Eliminate Recycling	0%	0%	0%
Eliminate Mixed Plastic Recycling	61%	32%	27%
Eliminate Glass Recycling	61%	26%	21%
Eliminate Mixed Paper Recycling	61%	28%	24%
Target High Commodity Only Option 1	61%	30%	25%
Target High Commodity Only Option 2	61%	23%	19%

Table A7. Solid waste management cost data for 2020 from various Florida counties.

Location	Year	Annual Garbage Collection Costs	Annual Recyclables Collection Costs	Annual Disposal Costs	Annual Recyclables Processing Costs	Annual Admin Charges	Total Annual Cost	Annual Revenue from Marketed Recyclables
Alachua	2020	$111	$34	$47	$10	$19	$221	
Brevard	2020	$194					$194	
Citrus	2020				$87		$358	$21
Clay	2020	$154		$72			$226	
Collier	2020			$98				
Columbia	2021							
Hendry	2020	$85	$24	$82	$3	$1	$195	
Highlands	2020	$112						
Hillsborough	2019	$122	$28	$83	$0	$11	$244	
Indian River	FY 2019-2020	$61	$60				$121	
Lee	FY2022						$207	
Manatee	2020						$172	
Martin	2020	$169	$27	$66			$263	$51
Miami-Dade	2019	$260	$33	$158		$47	$498	
Nassau	2020							$8
Okeechobee	2020						$220	
Orange	2020	$146		$42		$20	$208	
Palm Beach	2019	$157	$47	$175	$13	$8	$401	$80
Pinellas	2020	$134		$58			$192	
Sarasota	2020	$71	$35	$54	$19	$7	$187	
St. Johns	2019		$20		$80	$6		$34
Suwannee	FY2019-2020	$142						
Taylor	2020	$166						
Union	2019	$191						
Volusia	FY19-20	$222			$65	$13	$299	
Wakulla	2020						$210	
Average		***$147***	***$35***	***$89***	***$45***	***$14***	***$244***	***$39***
Min		**$61**	**$20**	**$42**	**$3**	**$1**	**$121**	**$8**
Max		**$260**	**$60**	**$175**	**$87**	**$47**	**$498**	**$80**

Table A8. Solid waste management cost data for 2015 from various Florida counties.

Location	Year	Annual Garbage Collection Costs	Annual Recyclables Collection Costs	Annual Disposal Costs	Annual Recyclables Processing Costs	Annual Admin Charges	Total Annual Cost	Annual Revenue from Marketed Recyclables
Alachua	2015	$105	$32	$39	$9	$30	$214	$24
Brevard	2015	$140						
Citrus County	2015	$228		$257	$56			$15
Clay	2015	$146		$84			$230	
Columbia	2016						$106	
Gadsden	2015						$189	
Glades	FY 2106-17		$18					
Hendry	2015	$97	$27	$62	$3	$11	$199	$26
Highlands	2015						$112	
Indian River County	2015	$116	$31				$147	
Lake	2015						$178	
Manatee	2015	$91	$36	$36			$161	
Martin County	2015	$151	$27	$52			$231	$46
Miami-Dade	2015	$228	$30	$157		$39	$454	
Okaloosa	2017	$111	$40					
Okeechobee	2015						$220	
Orange	2015	$186	$4	$40		$8	$238	
Palm Beach	2015	$118				$44		
Pinellas	2015	$118		$50			$168	
Sarasota	2015						$217	
Suwannee	FY2014-2015	$71						
Taylor	2016						$136	
Volusia	FY14-15	$166				$14	$179	
Wakulla	2015						$161	
Average		***$141***	***$53***	***$92***	***$30***	***$23***	***$196***	***$29***
Min		**$71**	**$4**	**$36**	**$3**	**$8**	**$106**	**$15**
Max		**$228**	**$40**	**$257**	**$56**	**$44**	**$454**	**$46**

Table A9. Solid waste management cost data for 2011 from various Florida counties.

Location	Year	Annual Garbage Collection Costs	Annual Recyclables Collection Costs	Annual Disposal Costs	Annual Recyclables Processing Costs	Annual Admin Charges	Total Annual Cost	Annual Revenue from Marketed Recyclables
Alachua	2011	$99	$31	$41	$8	$26	$204	$83
Citrus	2011			$244	$72			$33
Clay	2011	$154		$84	$0		$238	
Collier	2005						$91	
Columbia	2011						$113	
Gadsden	2011						$189	
Hendry	2011	$59	$3	$35		$9	$106	$100
Highlands	2011						$112	
Lake	2011						$184	
Manatee	2011	$87	$35	$34			$156	
Miami Dade	2011	$228	$28	$130		$37	$386	
Okeechobee	2011						$220	
Orange	2011	$170		$58		$8	$236	
Palm Beach	2011	$102		$19		$41		$137
Pinellas	2011	$118		$50			$168	
Taylor	FY2011-2012	$121						
Volusia	FY11-12	$158				$13	$171	$39
Wakulla	2011						$297	
Average		***$130***	***$24***	***$77***	***$40***	***$22***	***$191***	***$78***
Min		**$59**	**$3**	**$19**	**$8**	**$8**	**$91**	**$33**
Max		**$228**	**$35**	**$244**	**$72**	**$41**	**$386**	**$137**