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Price response of waste resources under demand shocks: four case studies

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ABSTRACT

To quantify potential price changes of waste feedstocks that may be caused by increased demand, this study explored four case studies: 1) recyclable materials at local waste collection and recycling facilities in seven US states, 2) recyclable materials on internationally traded markets, 3) a wood-powered plant in Reading, PA, and 4) an MSW-powered plant in Tulsa, OK. The four case studies provided a total of ninety-one waste material price observations yielding twenty-seven price-supply relationships expressed as price elasticity of supply (PES) and unit price change with change in demand. For the two case studies related to recyclable materials with a global market shock, price changes vary widely from $0.08-$7.84 per ton with each percent change in demand. For the two case studies related to local market shocks in biomass used for energy, observed price changes range from $0.08-$0.23 per ton per percent change in demand. Based on these results, a base range of $0.10-$0.20 per ton per percent change in demand is recommended for local market shocks. I.e., for a facility that collects organic wastes on the order of 200,000-400,000 tons per year at price near zero, a doubling of demand could increase procurement prices by about $10.00-$20.00 per ton. Actual price changes with respect to change in demand may be non-linear. Shocks with broader geographic extent may increase price response due to a reduced opportunity for surrounding markets to mitigate localized market changes.

1. Introduction

Renewable transportation fuels, or biofuels, have received increased attention in recent years in efforts to reduce petroleum consumption and imports, as well as cut down GHG emissions. In addition to technological challenges, costs of production limit the economic competitiveness of biofuels, with about 1/3 to 1/2 of biofuels production costs attributable to the biomass feedstocks. One approach to reduce these costs is to use low-cost waste resources, e.g., organic fraction of municipal solid waste (MSW), secondary wastes (e.g. mill residues and processing wastes), and biosolids (treated sewage sludge). The 2016 Billion-ton report (USDOE 2016) estimates biomass waste resources (i.e. citrus residues, non-citrus residues, manures, food waste, forest residues, forest thinnings from non-timberland, paper and paperboard, plastics, primary and secondary mill residue, sugarcane bagasse, sugarcane trash, textiles, tree nut residues, and yard trimmings) to be accessible at a cost of ~$30-$40 per dry ton[1]. Of the approximately 1 billion tons of biomass reported to be potentially available above current uses, about 140 million tons are comprised of the wastes identified above. Milbrandt et al. (2018) identify over 70 million dry tons of sewage sludge, animal manure, and food waste are generated in the United States annually. In a follow-on study, Badgett et al. (2019) indicate that a portion of these organic wastes maybe available at negative prices, meaning that the feedstock could be available for free or a potential biorefinery could be paid to use these resource as they present a liability to producers. All these studies identify a large untapped supply of wastes at low prices relative to other feedstocks. This analysis explores the potential change in waste feedstock prices in response to change in demand through observations from four case studies.

2. Background

Though the low cost of waste resources is economically attractive, the change in price of waste resources that may occur with changing demand is largely unknown. For example, waste resources like MSW are currently collected with a tipping fee, i.e., a charge for waste disposal. Today these resources may have low or negative prices. However, if the waste becomes a scarce resource, fundamental economics

[1] Dry ton equivalent, with moisture contents that vary by feedstock. Reported in 2014 dollars.

suggests that the procurement price may change from negative to zero or positive. Thus, assuming low or negative prices for waste-based feedstocks in the future could lead to erroneous technoeconomic results. Previous examples of waste resource prices used as a feedstock (e.g., used cooking oil, landfill gas, dried distillers' grains) suggest that negative costs can turn to positive costs as demand from industries grows. Work to date identifies waste feedstock prices as a function of disposal cost, but we are not aware of efforts to evaluate waste biomass price changes as a function of changes in demand. For example, in an economic analysis of wet organic waste resources in the US, Badgett et al. (2019) acknowledge: "In the future, prices could be determined by market demand for the materials rather than the cost of disposing them. …once the market value of these materials is realized at large scale, the amount of feedstock available at negative prices will decrease as demand for them increases."

The objective of this study is to evaluate how prices of organic wastes may change if demand increases over time. As the waste-to-energy industry explores economically advantaged feedstocks, it is currently unclear if low or negative prices for waste resources will persist in a free market if demand for these feedstocks increases. This analysis explores the relationship of waste feedstock price and demand under four scenarios of observed price shocks in the US.

3. Methodology

Price elasticity of supply (PES) quantifies the change in the market value of a resource associated with a corresponding change in demand. This analysis quantifies changes in waste resource values by estimating PES using traditional resource economics methods, which differ from technoeconomic analysis. PES is expressed as the percentage change in cost divided by the percentage in supply. A "perfectly elastic" supply curve, which corresponds to infinite PES, means that increasing supplies are available at a constant price level. This can represent the early stages of development where potential supply of a given resource is orders of magnitude greater than demand for the resource (e.g., the supply of books). The opposite of infinite PES is the "perfectly inelastic" curve, corresponding to zero PES, where there is no change in supply even as costs increase. This situation can arise when supplies are limiting, finite, and there is no substitute for the resource (e.g., the supply of land). PES can be characterized as elastic (PES > 1) or inelastic (PES < 1). A PES that is elastic bodes well for the biofuels industry, indicating that some change in cost is expected, even as commercialization of the feedstock and associated quantity of demand increases. Conversely, an inelastic PES indicates that cost increases at a rate greater than the increase in quantity of demand. It is worth noting that PES can change from elastic to inelastic with increasing scale of demand. Thus, PES values must be specified for relevant quantities of demand (e.g., PES at 1 million tons per year of demand maybe be less than PES at 10 million or 100 million tons per year of demand). Almost by definition, PES of wastes is not perfectly elastic, because there is some limit to how much waste production will increase in response to market opportunities. Failing to account for PES inherently assumes perfectly elastic PES, i.e., no change in cost with change in quantity of demand. This underscores the need to quantify PES to improve the understanding of future prices of waste-based feedstocks.

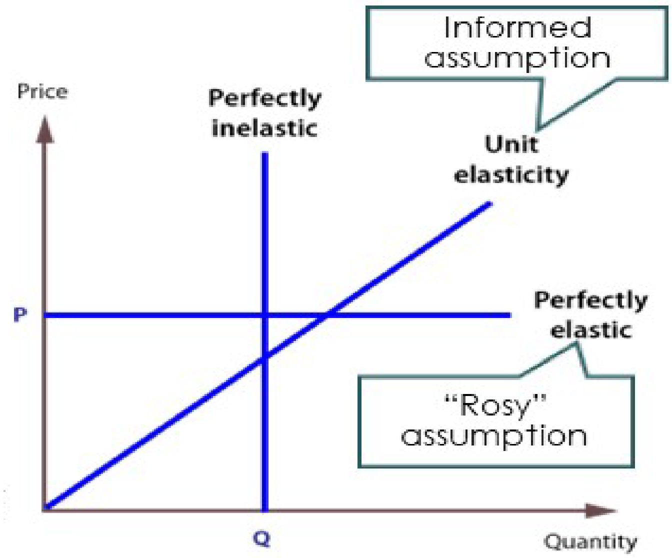

Figure 1. Illustration of perfect elasticity (no change in price with change in demand) perfect inelasticity (no change in quantity with change in demand) and unit elasticity (relationship between change in price and change in demand).

This analysis looks at four case studies where waste prices were impacted with changing demand:

- Impacts of the Operation Green Fence policy on seven waste collection and recycling facilities across the US.
- Impacts of the Operation Green Fence policy on traded plastics recycling prices.
- Demand/price interactions of MSW feedstocks at the Evergreen Community Power Plant (ECPP) in Reading, Pennsylvania.
- Demand/price interactions of MSW feedstocks the Ogden-Martin Tulsa Municipal Waste Incineration Facility (now Covanta Tulsa Renewable Energy) in Tulsa, Oklahoma.

These case studies were identified in consultation with BioResource Management, Inc., a private biomass supply management company based in Gainesville, FL. The case studies were gathered as best-available known examples where observed price changed in apparent response to observed changes in demand as an approach to calculate PES. It is not possible to say with certainty how much of the observed price changes are attributable to the observed changes in demand. Thus, these results should be considered as example scenarios that may collectively indicate a potential range of PES values that may be assumed for waste biomass resources.

4. Case Study #1: The China Green Fence Policy impact on seven waste collection and recycling facilities in the US

4.1 Introduction

The production, life cycle, and environmental effects of plastics continues to receive scrutiny. The world produces over 300 million tons of plastics per year, about half of which is in the form of single-use products (IUCN 2020). More than 14 million tons of these products end up in oceans annually (IUCN 2020). Prior to 2015, the US exported about 18 million tons per year of scrap commodities to China and Hong Kong (U.S. Internation Trade Commission 2020), primarily through container ship backhauls for cheap transportation. Low logistics costs combined with low labor costs and adequate market prices made recycling marginally profitable for China (Balkevicius et al. 2020). Beginning in 2013, China enacted the Green Fence policy, which curtailed imports of waste for recycling due to increasing environmental costs and lower profit margins (Resource Recycling 2020). On July 18th 2017, China submitted "Notification to the World Trade Organization Committee on Technical Barriers to Trade 17-3880". This notification abruptly stopped China's import of many recyclable wastes, due to changes in economic viability attributable to sorting costs relative to oil price. Citing "Protection of human health or safety; Protection of animal or plant life or health, Protection of the environment" the notification may have also been attributable to externality costs (health and environmental) in China where commercial profit margins were already small. This notification was applicable to twenty-four products, including major categories in the plastics industry such as PET, PS, and PVC.

4.2 Methodology

The China Green Fence Policy in effect caused a demand shock, reducing US exports to China to 6.8 million tons in 2019, a reduction to about 1/3 of 2015 levels (U.S. Internation Trade Commission 2020; US Census Bureau 2021). This analysis surveyed changes in tipping fees from seven waste collection and recycling facilities corresponding to the demand shock from 2015 to 2020:

- Housatonic Resources Recovery Authority (Brookfield, CT). Housatonic Resources Recovery Authority (HRRA) is a regional, governmental, waste management and recycling authority that contracts with twelve municipalities in western Connecticut and a population of over 237,000 people. As a result of China's policy changes, they saw their tipping fees for recyclables increase from $10/ton in 2015 to $65/ton in 2019. https://hrra.org/wp-content/uploads/2019/10/Tip-Fee-History-Summary.pdf
- Birmingham Recycling & Recovery (Birmingham, AL). Birmingham Recycling & Recovery is a commercial recycling plant in Birmingham, AL. The company's processing facility accepts all residential curbside recycling from the greater Birmingham area (Jefferson, Shelby, and Blount counties). In 2019, they increased rates from $30/ton to $65/ton and added a $50/ton fee for contamination. https://abc3340.com/news/local/recycling-costs-soar-as-metro-birminghams-top-processing-facility-raises-rates
- Waste Management SMaRT Center (Spokane, WA). Waste Management Spokane Materials and Recycling Technology (SMaRT) Center is a single stream recycling facility located in Spokane, WA. The center can process 100,000 tons of recyclables per year from businesses and residents in Washington, Idaho, and British Columbia. Richland, WA is one of the cities that contracts with the SMaRT Center. In 2017, the SMaRT Center paid Richland $16/ton. However, in 2018 Richland began paying $123/ton to dispose of their recyclables. http://wmnorthwest.com/smartrecycling/

- G.W. Shaw & Son (Greenville, NH). G.W. Shaw & Son is a family owned and operated solid waste disposal and recycling company based in southern New Hampshire that services many Massachusetts and New Hampshire communities, including Leominster, MA. They raised their disposal fees for recycling from $0/ton in 2018 to $88/ton in 2019. http://gwshawandson.com/index.html
- Beacon Plant Recycling Center (Beacon, NY). The Beacon Plant Recycling Center is a transfer station in Beacon, NY. They contract with a local waste hauler, City Carting, to collect residential MSW and recyclables in the surrounding communities. In 2017, the Beacon Plant Recycling Center paid City Carting $15/ton for single stream recyclable waste in 2017 and began charging $61/ton in 2018. This fee increased to $85/ton in 2019. https://www.cityofbeacon.org/index.php/departments/garbage-and-recycling/
- Modern Waste Systems (Napoleon, MI). Modern Waste Systems provides curbside recycling pickup and disposal on a contractual basis for Raisin Township in MI. Due to the recycling commodity markets, the township saw their recycling disposal rates increase from $19/ton in 2017 and 2018 to $133/ton in 2019. https://www.modernwastesystems.com/
- Waste Connections (Wichita, KS). Waste Connections is a trash and recycling company in Wichita, Kansas. They contract with Waste Management (WM) to process recyclable waste for the Wichita area. In 2018, WM did not pay a tipping fee for recyclable waste, however, in 2019, Waste Connections increased their tipping fees to $90/ton. https://www.wasteconnectionswichita.com/

These waste collection and recycling facilities adjusted prices with changing demand during this period. In essence, the facilities charged low tipping fees in the range of $10-$20 per ton (i.e., low disposal costs) before the China Green Fence Policy but had to increase tipping fees in the range of $60-$100 per ton after the policy to cover processing costs. Tipping fees shown as procurement prices are shown in Table 1.

Table 1. Quantity of comingled recyclables exported to China (US Census Bureau 2021) and associated procurement price by year, expressed as inverse of tipping fee, of select waste collection and recycling facilities in seven states. As exports decreased, procurement prices also decreased.

Year	Quantity from US to China (million tons)	CT	AL	WA	NH	NY	MI	KS
		Procurement price ($ per ton)						
2015	18.3	-$10						
2016	17.9	-$25						
2017	15.4	-$25		$16		$15	-$19	
2018	10.3	-$65	-$30	-$123	$0	-$61	-$19	$0
2019	6.8	-$65	-$65		-$88	-$85	-$133	-$90

4.3 Results

Price elasticity of supply was quantified as change in price of comingled recycling waste per precent change in demand. Simple linear regression was fitted to each of the seven quantity/price relationships. Slopes, showing change in price associated with change in quantity used, were derived from the linear equations for each of the seven facilities (Figure 2). To quantify elasticities as change in procurement price per change in percent of material accepted, slopes for each location are divided by 100 to account for change in quantity as a percent. Resulting elasticities for the seven locations are shown in Table 2. The positive correlation of price and quantity used is notably consistent across all locations over five years in seven states, including observations in the US South, Northeast, Northwest, and Central regions.

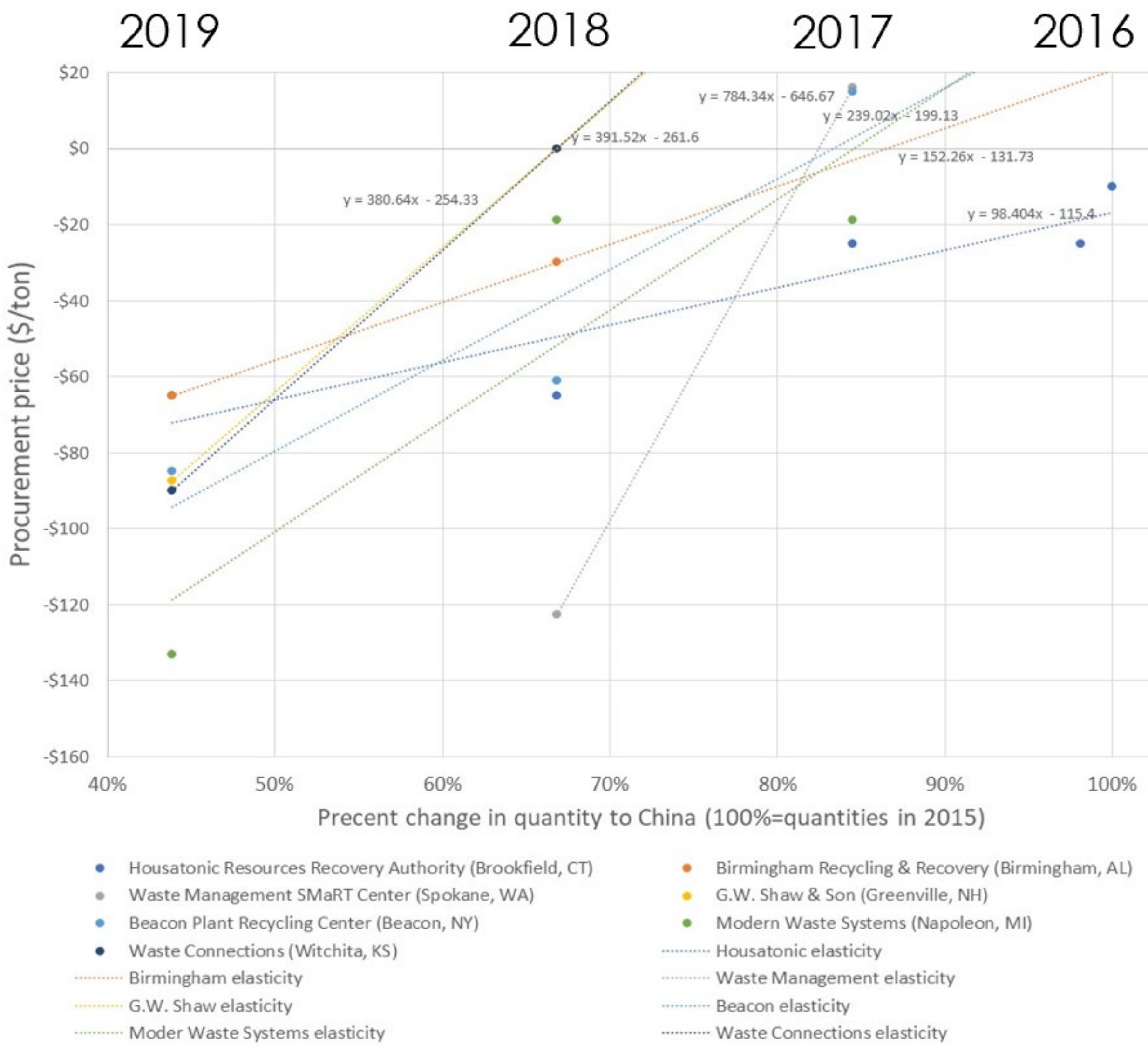

Figure 2. Data (quantity of US mixed recyclables exported from the US to China and procurement prices from select locations in seven states) and fitted elasticity lines. Values derived from the data shown in Table 1.

Table 2. Elasticities expressed as change in procurement price associated with change in quantity accepted.

Location	PES	Δ price ($/ton) per Δ percent quantity
Housatonic Resources Recovery Authority (Brookfield, CT)	1.2	$0.98
Birmingham Recycling & Recovery (Birmingham, AL)	0.9	$1.52
Waste Management SMaRT Center (Spokane, WA)	0.8	$7.84
G.W. Shaw & Son (Greenville, NH)	0.7	$3.81
Beacon Plant Recycling Center (Beacon, NY)	0.8	$2.39
Modern Waste Systems (Napoleon, MI)	0.9	$2.92
Waste Connections (Wichita, KS)	0.7	$3.92
Total average:	0.9	$3.34
Average excluding Waste Management SMaRT Center	0.9	$2.59

Results suggest that procurement price of comingled recyclables is positively correlated with its use. Price elasticities range from $0.96 to $7.19 dollars per ton for each percent change in quantity accepted. The average price elasticity is $3.21 per ton for each percent change in quantity, i.e., a 10% increase in quantity used would correspond with approximately a $32 per ton increase in procurement price. It is unclear if these elasticities represent short-run or long-run elasticities. However, little change in waste production is expected under any circumstances. Thus, we do not expect price elasticities to change with time, though they can change with changing market demand, i.e., with alternative uses.

In addition to change in quantity, change in quality specification may be a factor in the observed changes in price. That is, while decreasing exports caused increasing tipping fees and decreasing procurement prices, decreasing tolerance for contaminated material also caused an increase in tipping fees due to increased costs of material sorting. This is an additional factor, but the directionality in terms of demand and price is the same. Attribution to this and other potentially unknown factors have not been quantified in this analysis.

5. Case Study #2: The China Green Fence Policy impact on export prices for bulk scrap materials

5.1 Introduction

As described in section 4.1 above, the China Green Fence Policy reduced US exports of recyclable plastics to China from 18.3 million in 2015 to 6.8 million in 2019. Section 4 explored the impact of this demand shock on tipping fees at waste collection and recycling facilities in the US. This section explores the impact of this policy and demand shock on international market prices for recyclable materials.

5.2 Methods

To further assess the impact of the supply shock from the China Green Fence Policy, industry commodity price data were explored. These commodity price changes over time were compared with quantities received in China to provide another approach to quantify PES of waste materials attributable to supply shock from the China Green Fence Policy. Price history by waste type were purchased from www.recyclingmarkets.net. The data subscription is for post-consumer secondary materials pricing (e.g., glass, paper, plastics). Price data were downloaded for 2015-2020 to capture prices before and after the 2017 China Green Fence Policy. Data from seventeen waste types were used to as candidates to quantify PES. The US Census Bureau's USA Trade Online dynamic data tool for current and cumulative U.S. export and import data for 2015-2020 were used in conjunction with the price data purchased from recyclingmarkets.net.

5.3 Results

Though slopes for bulk export prices were lower than slopes of prices at facilities reported in section 4 above, all commodity price examples show positive correlation between waste demand and waste price. The derived PES values calculated from the data slopes and corresponding r-square values are reported in Table 3, below. R square values range from 0.65 to 0.96.

Table 3. R-square, PES ($/ton price increase per 1% demand increase), identification of plastics, and identification of an r-square value > 0.5.

Waste type	R^2	PES	Δ price ($/ton) per 1% Δ quantity	Plastics?	R2>.5?
Polystyrene EPS (Baled, $/t, picked up)	0.23	2.4	$ 0.14	Yes	
Colored HDPE (Baled, $/t, picked up)	0.84	0.5	$ 2.27	Yes	Yes
FILM - Grade A (Sorted, 800+lb Bales, $/t, picked up)	0.96	0.6	$ 2.08	Yes	Yes
HDPE Rigid (Baled, $/t, picked up)	0.65	0.2	$ 2.07	Yes	Yes
FILM - Grade B (Sorted, 800+lb Bales, $/t, picked up)	0.74	0.3	$ 1.14	Yes	Yes
Aseptic Cartons ($/ton, delivered)	0.96	0.1	$ 1.07	Yes	Yes
FILM - Grade C (Sorted, 800+lb Bales, $/t, picked up)	0.80	0.3	$ 0.43	Yes	Yes
Commingled (#3-7, Baled, $/t, picked up)	0.97	0.3	$ 0.37	Yes	Yes
Commingled (#1-7, Baled, $/t, picked up)	0.79	0.9	$ 0.32	Yes	Yes
Aluminum Cans (Loose, $/t, dropped off at RC)	0.25	0.3	$ 5.32		
Corrugated Containers ($/ton, delivered)	0.44	0.6	$ 0.70		
Steel Cans (Sorted, Densified, $/ton, dropped off at RC)	0.41	0.3	$ 0.38		
White Goods (Loose, $/ton, picked up)	0.25	0.8	$ 0.37		
Steel Cans (Sorted, Loose, $/ton, dropped off at RC)	0.34	0.1	$ 0.27		
Mixed Paper ($/ton, delivered)	0.82	0.3	$ 1.01		Yes
Sorted Residential Papers ($/ton, delivered)	0.87	0.1	$ 0.99		Yes
3 Mix Glass ($/ton delivered)	0.70	3.3	$ 0.08		Yes
Average		0.7	$ 1.12		

The PES values derived from the export data range from $0.08 to $5.32 per ton for each percent change in quantity accepted. It is unclear how many of the seventeen waste types derived from recyclingmarkets.net were impacted by the China Green Fence Policy. To explore this, two columns were added to Table 3, identifying those wastes that are plastics, and identifying those wastes that show an R^2>0.5. Of the nine waste categories identified as being comprised of plastics, eight show an R^2>0.5. Of the eleven waste categories identified as having an R^2>0.5, eight of them are identified as being comprised as plastics. This suggests that at least some of the PES relationship reported here is attributable to the China Green Fence Policy. Some notable exceptions include aluminum, which has the highest PES value ($5.32 per ton) but was not excluded by the China Green Fence Policy, and two paper categories, which were also not excluded but show R^2 values > 0.8. A possible explanation may be that comingled wastes that were not specified in the China Green Fence Policy may have been nonetheless impacted by the policy in terms of market prices due to shared operations in waste handling. Of the eight plastics from the traded analysis that showed an R^2>0.5, price increases ranged from $0.32 to $2.27 per ton with each percent change in demand, with an average value of $1.22 with each percent change in demand.

6. Case Study #3: Waste wood and recyclables used at Evergreen Community Power Plant (ECPP) in Reading, Pennsylvania

6.1 Introduction and summary

In 2008 a recycled cardboard paper mill in Reading, Pennsylvania permitted and constructed a cogeneration plant to produce steam and electricity for the mill. The facility, called the Evergreen Community Power Plant (ECPP) is a circulating fluidized bed boiler with onsite biomass storage and unloading facilities. The plant ceased activities in 2018. This case study reviews the changing cost of procuring the biomass material required for the project during its operation from 2008 through 2013. In this example, biomass procurement costs for ECPP increased from $0 for 135,200 tons in 2008 to $5 per ton for 208,000 tons in 2010, and then increased to $6.93 per ton for 346,000 tons in 2012. The ECCP project history and PES analysis and results are described below.

6.2 ECCP project history

Figure 3. Evergreen Community Power Plant (ECPP) circa 2020. (Photo credit Entech Engineering).

ECPP's site plan was approved by the Pennsylvania Department of Environmental Protection (PADEP) in 2007, for the removal of two existing 12 million BTUs per hour input (MMBTU/hr) boilers and the construction of one 482 MMBTU/hr boiler. The plan noted that an existing 99 MMBTU/hr natural gas boiler would remain on site as backup for process steam. The plan called for the large boiler to use a small amount of natural gas for start-up and an estimated 56 tons per hour of biomass (or biofuel as referred to in the original plan). The actual consumption would depend upon the BTU content of the fuel and actual demand may have varied.

The paper mill had a steam requirement of about 70,000 pounds per hour, estimated to be about 75 MMBTU/hr, and an internal electrical demand of about 8.5 MW or about 90 MMBTU/hr (exact needs would be based on the temperature and pressure of the steam), for a total internal need of about 170 MMBTU/hr. A 33MW steam extraction turbine was included in the project; the assumption was that excess electricity, perhaps 25 MW, would be sold to the local utility.

This plant was described by USDOE in a 2011 project profile as a plant that uses "forestr [sic] industry waste, shredded construction wood waste, and demolition debris". ECPP was permitted to utilize a wide range of fuels. The following specification was taken from one of the permits issued to ECPP:

"CFB boiler fuels include engineered, stained and laminated scrap wood, composite scrap wood, sawdust, wood, shavings, slab wood, wood scraps with applied finishes from industrial operations, textile wastes (such as scrap carpet, scrap diaper fiber, scrap burlap bags, soiled rags), creosote-treated wood waste, pentachlorophenol-treated wood waste, pre-consumer plastic waste, rubber waste, latex materials, paint including latex paint and coating sludge, food processing sludge, paper mill sludge, packing materials, standard and laminated paper, newspaper, coated cardboard, construction wastes, demolition wastes, waste tires, discarded conveyor belts, post-consumer plastic wastes with plastic recycling codes of 4 through 7, and other fuels allowed under DEP General Permit WMGM027."

In the DEP General Permit WMGM027, practically every form of organic waste was allowed except post-consumer municipal solid waste (MSW). However, many of the ingredients of MSW are included in the list of materials allowed. USDOE estimated the total project cost of $140 million.

Discussions were underway with potential biomass suppliers in 2006 and 2007. One supplier, a wood waste recycling yard about 15 miles away from the ECPP site (Main Supplier), was to be the primary source of biomass. In 2007 the Main Supplier agreed to ship approximately 2,600-2,700 tons per week to ECPP beginning in 2008. This amount of biomass supply exceeded the requirement for the mill's internal energy requirement, estimated to be about 2,190 tons per week (depending upon moisture and ash content) . It was less than the potential maximum boiler demand of about 7,360 tons per week. The price agreed to in this transaction was that the Main Supplier would pay $5 per ton toward the freight expense. This probably covered freight costs, and biomass from the Main Supplier was to cost $0/ton delivered to ECPP (point "2009" in Figure 4). The Main Supplier was providing all woody materials—practically no construction waste, plastic, or waste fiber, mostly 40% or less moisture content, some pentachlorophenol treated wood, which was probably in excess of 7,000 BTU/lb instead of the pro forma 5,500 BTU/lb. This is most likely the agreement that provided financing assurances for construction.

In 2008 deliveries began to ECPP from the Main Supplier. All the other suppliers contacted did not initiate deliveries until much later, and as the plant was also generating pulp mill sludge and other wastes, this was probably the only external source of fuel. Total external fuel procurement appeared to be about 124,800 tons per year. Procurement price was $0 per ton. It appears this continued until sometime in 2010.

In 2010 ECPP decided it needed more fuel. This was probably due to either a), other producers failing to deliver committed quantities, or b) ECPP receiving a power purchase agreement for the excess electrical capacity of about 25 MW. Sometime in 2010, ECPP approached the Main Supplier about increasing delivery capacity from 2,400 tons per week to 4,000 tons per week. To do this, the Main Supplier and ECPP agreed that ECPP would pick up the biomass at the Main Supplier's site for free and pay all trucking cost. This changed the procurement price to ECPP for biomass from $0 to $5 or slightly more per ton (freight may been more than $5 at this point) (point "2010" in Figure 4). Two things, therefore occurred; the demand increased for biomass, and with it the procurement price increased.

This was apparently still happening in 2011, when the DOE visited ECPP and developed the project profile in November of 2011. At that time ECPP told DOE that their fuel cost was $0 but their "fuel transportation cost" was $2,400,000 annually. It appears that, at least in 2012, according to reported carbon dioxide emissions (required to be reported after 2011), about 346,000 tons were being consumed.

If this is correct, the average procurement cost at this point was $6.94 per ton in transportation cost (points “2011” and “2012” in Figure 4). This implies that, considering the arrangement with the Main Supplier, the last 138,000 tons may have had a marginal cost of $9.86 per ton. The DOE suggested that the project was unprofitable, that insufficient wood markets were developed in PA, and that perhaps ECPP would need to begin procurement in New Jersey and New York. This would lead to higher transportation costs and therefore higher procurement costs.

To summarize, biomass procurement costs for ECPP increased from $0 for 135,200 tons in 2008 to $5 per ton for 208,000 tons in 2010, and then increased to $6.93 per ton for 346,000 tons in 2012.

Sometime in 2013, apparently ECPP decided it could not afford to pay this average cost for biomass. ECPP began to aggressively pursue materials that had a higher disposal (tipping) fee involved, and therefore had a lower cost of procurement. This expanded the fuel mix into unsorted construction and demolition debris, plastics, and non-wood organic industrial wastes. This is evidenced by at least three other former suppliers identified for this study that stated they began to ship material about this time, and the material types that they handle.

ECPP continued to consume about the same amount of biomass, as evidenced by the CO2 emissions, but the type had changed. The Main Supplier was still delivering biomass at 4,000 tons per week. ECPP told the Main Supplier to reduce the amount delivered back to the original contract of 2,500 tons per week, and ECPP stopped paying the transport cost. At this point, it appears there was perhaps no other supplier bringing the same type of clean woody biomass material. The demand for the Main Supplier’s biomass was reduced to about 130,000 tons and the price returned to $0 for ECPP add (point “2013” in Figure 4).

This continued until 2018, with other suppliers shipping material as well as the Main Supplier. According to suppliers, ECPP began to experience mechanical difficulties and handling problems associated with handling and storing the new type of biomass. These problems, the reduction of natural gas prices, and perhaps low or declining power purchase prices, probably led ECPP to decide to cease operations.

6.3 Methods

For this case study, the following sources were used to quantify the relationship between supply and price:

- USDOE Mid-Atlantic Clean Energy Application Project Center (DOE)Project Profile, Evergreen Community Power Plant, published November 12, 2011.
- Permitting and reported emissions data for ECPP and the paper mill from 2008 through 2018, obtained from the PA Department of Environmental Protection (PADEP);
- Observations from meetings and conversations with the largest single supplier of biomass to the facility (Main Supplier). Prior meetings were held in 2019, and a phone interview was conducted in September 2020 directly related to this study.
- Observations from conversations with two other known biomass suppliers of the facility with phone interviews in September 2020.

From these sources, the following supply and price reference points are provided:

- 2008: Initial planned biomass procurement cost for up to 350,000 tons was projected to be $0.
- 2009: Only about 135,000 tons were supplied at the expected price of $0.
- 2010: Demand increased to 208,000 tons, and the price increased to $5.00 per ton.
- 2011-2012: Demand increased to about 346,000 tons, and the price increased to $6.93 per ton average, at an estimated marginal cost of $9.86 per ton.

- 2013-2015: Demand for the Main Supplier decreased again to 135,000 tons, and the price again decreased to $0.
- Notably, cheaper and more heterogeneous waste feedstocks introduced in 2015-2018 may have caused engineering and economic challenges contributing to plant closing in 2018.

6.4 Results

Quantities used and feedstock prices observed at the ECPP from 2011-2013 were integrated and price/demand relationships were plotted with linear regression (Figure 4). The strong linear correlation suggests that feedstock price rose from $0 to about $7 per ton for was biomass as demand almost tripled from about 135,000 tons per year to 350,000 tons per year. Over the 2009-2013 period, the supply/price relationships suggest an increase demand for biomass of 100k tons increased the biomass procurement cost by about $3/ton. Alternatively, a 10% increase in demand for biomass increased the biomass procurement cost by about $1.08/ton, up to the maximum demand of 350,000 tons per year. Under this price relationship, initial demand of less than 100,000 tons per year could have a negative price (i.e., tipping fee). The maximum price observed, $9.86/ton, coincided during the highest level of demand.

Figure 4. Relationship between procurement price as a function of demand (left) and percent of maximum demand (right) based on biomass procurement costs for ECPP in 2009, 2010, 2011, 2012, and 2013.

7. Case Study #4: Covanta Tulsa Waste-to-Energy Facility in Tulsa, Oklahoma

7.1 Introduction and project background

The Covanta Tulsa Waste-to-Energy Facility (CTWEF), formerly known as the Ogden-Martin Tulsa Municipal Waste Incineration Facility, is a waste-to-energy facility located in Tulsa, Oklahoma. The facility opened in 1986 as the Walter B. Hall Resource Recovery Facility and was conceived as a response to growing residential municipal solid waste disposal concerns and volatile energy generation prices stemming from the deregulation of the price of natural gas.

The CTWEF consists of three, single pass, mass-burn refractory-lined waterwall boilers. Each of the three have a nameplate capacity of 375 tons per day. The boiler designs also include a heat exchanger consisting of a system of boiler tubes in the furnace walls that are used to circulate water that recovers heat from the combustion chamber to produce steam and/or electricity.

The facility was built to burn 1,125 tons per day of solid waste at an estimated BTU of 4,750 BTU/lb, equating to an annual consumption of about 409,000 tons per year. About one-third of the facility's generated steam is used to power a turbine generator to produce 16.5 MW of renewable energy that is sold to American Electric Power's (AEP's) Public Service Company of Oklahoma (PSO).

About two-thirds of the rest of the generated steam is sold to Holly Frontier, Inc., an independent refinery adjacent to the facility. The steam allows the refinery to offset the need to use fossil fuels to generate their own steam. The CTWEF also utilizes a portion of the generated steam to produce electricity for facility operations and an on-site office building, which employs about forty personnel.

Figure 5. Covanta Tulsa Waste-to-Energy Facility, formerly Ogden-Martin Tulsa Municipal Waste Incineration Facility (OMTMWIF) (Photo credit Covanta).

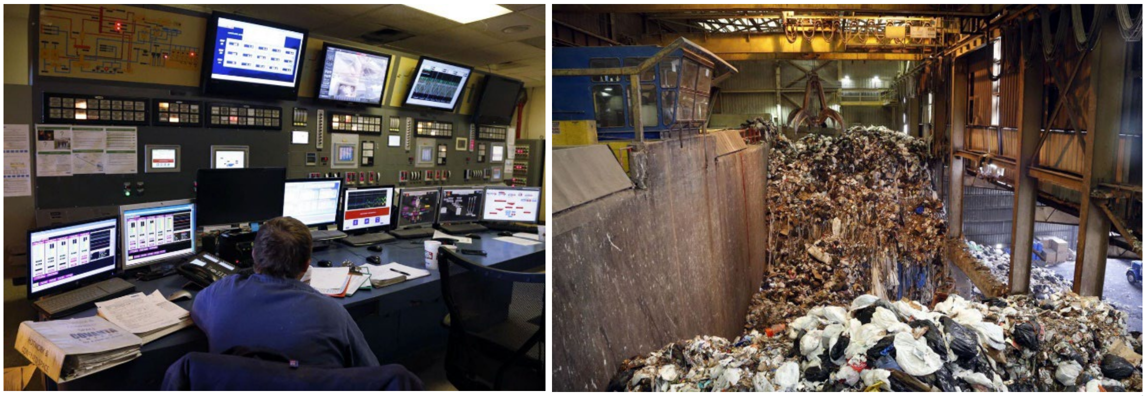

Figure 6. Covanta Tulsa Waste-to-Energy control room and waste handling. (Photo credit Tulsa World December 14th, 2016).

The CTWEF entered the market in 1986 with two of the three mass burn waterwall boilers in operation. Based on the facility's air permit renewal application no. 2014-1722-TVR, these two combustion units were consuming approximately 273,000 tons of MSW per year. Their procurement cost (negative, actually a tipping fee revenue) for this volume was approximately -$22.00 per ton which was the average market disposal cost for MSW in the Tulsa market at the time.

To secure financing for the facility, the CTWEF was required to obtain waste disposal contracts at -$22.00 per ton for the combined two-unit capacity volume of 273,000 tons per year. At some point after financing was secured and construction began, Holly Frontier, Inc. emerged as a contract buyer for a portion of the facility's generated steam.

To accommodate the additional steam demand, CTWEF constructed a third combustion unit that was brought online in 1987. Based upon the facility's air permit renewal application no. 2014-1722-TVR, this additional combustion unit consumed approximately 136,000 tons of MSW per year. To attract the additional waste volumes, the facility leveraged their steam contract with Holly Frontier, Inc. to offer disposal rates at approximately -$10.50 per ton for up to 136,000 tons per year. I.e., to increase their waste supply by 50%, the facility reduced disposal costs (tipping fees) from $22.00 per ton to $10.50 per ton.

CTWEF also took advantage of interlocal agreements with municipalities to secure long-term municipal solid waste handling and disposal contracts at -$10.50 per ton. Also known as piggybacking, interlocal agreements allow public agencies to enter a collaborative contract with the same service provider to take advantage of more efficient, less costly public services. The combination of decreased tipping fees and interlocal agreements allowed OMTMWIF to secure the additional waste volumes. This event of increased demand resulted in an increase in average procurement cost from -$22.00 to -$18.00 per ton. This implies that the last 136,000 tons of MSW had a marginal cost of $11.50 per ton.

This period of CTWEF aggressive waste volume acquisition efforts lasted until they had acquired the additional 136,000 tons needed for the third combustion unit, bringing their total annual consumption to 409,000 tons of MSW per year. For waste beyond this desired target of 409,000 tons per year, OMTMWIF increased tipping fees back to -$22.00 per ton to cover disposal costs. CTWEF's procurement cost change had a detrimental effect on Tulsa MSW processors by reducing incomes from tipping fees. According to one landfill owner located approximately 13 miles from OMTMWIF, landfills decreased their disposal rates from -$14.00 to -$12.00 per ton, offered sliding-scale fees, and lowered hauler contract rates to maintain their waste volumes.

Negative-cost waste will find its cheapest outlet. The fact that CTWEF was the cheapest disposal option enabled them to attract additional waste volumes from a market with finite waste. Essentially, CTWEF undercut the market to draw in waste and increase their feedstock supply by 50%. This reduction in tipping fees benefited waste producers, who paid less for disposal, but was detrimental to CTWEF and surrounding waste receivers, who were paid less to receive MSW. After CTWEF achieved their desired demand volume and increased their disposal fees, others in the market began to increase their disposal fees as well. For many, it took them 5 to 7 years before they were able to recover to the -$22.00 per ton average.

7.2 Methods

Historic waste disposal prices were obtained from conversations with a local landfill operator that has been in the Tulsa, OK market for over 30 years. Historic waste processing volumes were derived from a review of permitting and reported emissions data for the CTWEF from 2019, obtained by the Oklahoma Department of Environmental Quality Air Quality Division. Online articles and publications regarding the CTWEF were reviewed for historical context. These sources provided the following price and demand reference points:

- In 1986, CTWEF entered the Tulsa municipal solid waste market with an annual demand of 273,000 tons from a fixed-supply waste shed.
- Average market waste procurement costs were -$22.00 per ton.
- To secure financing, all CTWEF initial volume was under contract at-$22.00 per ton.
- A new steam customer led to the addition of another boiler in 1987, increasing waste demand by 136,000 tons per year.
- The increased demand resulted in an increase in average procurement cost from $22.00 to -$18.00 per ton, i.e., CTWEF's last 136,000 tons of MSW had a marginal cost of $11.50 per ton higher than the original cost.
- To this day, the CTWEF, to maintain a reliable supply, charges $10.00 per ton lower tipping fee than local landfills.

7.3 Results

This case study provides a fourth example of empirical evidence illustrating how facilities that want to attract waste may have to forgo some portion of tipping fees (i.e., feedstock costs may increase) for bioenergy processes that require waste biomass. The elasticities in the range of $0.08-$0.23 per ton for each 1% increase in quantity of biomass needed. This elasticity is lower than the $1.12-$3.34 per ton for each 1% increase in quantity observed in the cases of sorted recyclables and like the $0.11 per ton for each 1% increase in quantity observed in the case of the waste wood and recyclables used at Evergreen Community Power Plant. A potential explanation is that pre-sorted recyclable that previously had a positive price may have a higher price elasticity (i.e., greater change in price with change in demand) than negative-cost comingled waste materials.

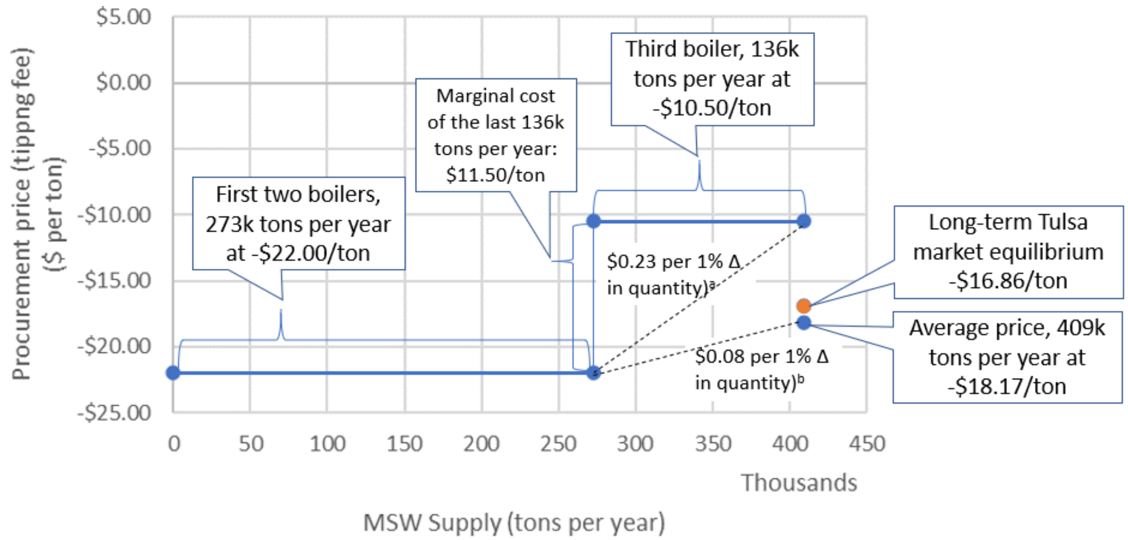

Figure 7. Relationship between procurement price as a function of demand at the Covanta Tulsa Waste-to-Energy Facility. [a] $0.23 per ton increase with each 1% increase in demand where price discrimination is possible. [b] $0.08 per ton increase with each 1% increase in demand where price discrimination is not possible. Prices are discounted to 1986 dollars.

8. Summary

This study provides four case studies exploring examples of changes in waste material prices under observed demand shocks. These case studies provided a total of ninety-one waste material price observations yielding twenty-seven price-supply relationships expressed as price elasticity of supply (PES) and unit price change with change in demand. Two of the case studies are related to markets for recycling, and two of the case studies are related to biomass used for energy. For the two case studies related to recyclable materials, price changes vary widely from $0.08-$7.84 per ton with each percent change in demand, with down selected observations ranging from $0.32-$3.92 per ton with each percent change in demand. For the two case studies related to biomass used for energy, there are three observations of price change per percent change in demand: $0.08, $0.11, and $0.23 per ton. Overall results are summarized in Table 4. In sum, these results suggest that for low-value unprocessed wastes, a minimum of $0.08 per ton per percent increase in demand should be assumed, with a likely range of $0.10-$0.20 per ton per percent increase in demand. I.e., for a facility that collects organic wastes on the order of 200,000-400,000 tons per year at price near zero, a doubling of demand could increase procurement prices by about $10.00-$20.00 per ton. The higher range of price changes on the order of $0.32-$3.92 per ton per percent demand increase may be unlikely for raw organic wastes but may be applicable for recyclable plastics or organic wastes that may have a high-value secondary market such as landscaping mulch.

Table 4. Summary table of case studies.

Case study	Supply shock	Price shock	Number of price observations	Number of elasticities calculated	Range of Δ price per 1% Δ quantity	Down selected range Δ price per 1% Δ quantity	Average down selected Δ price per 1% Δ quantity
					$ per ton		
#1. Green Fence Policy impact on prices at waste collection and recycling facilities	Global	Local	19	7	\$0.98-\$7.84	\$0.98-\$3.92	\$2.59
#2. Green Fence Policy impact on scrap export prices.	Global	Global	62	17	\$0.08-\$5.32	\$0.32-\$2.27	\$1.22
#3. Demand shocks at the Evergreen Community Power Plant in Reading, PA.	Local	Local	4	1	n/a	n/a	\$0.11
#4: Covanta Tulsa Waste-to-Energy Facility, Tulsa, Oklahoma	Local	Local	6	2	\$0.08-\$0.23	\$0.08-\$0.23	\$0.16

The spatial extent of the supply shed and competing markets are other factors to be considered in estimating price elasticity of supply. In the two case studies that observe price changes with recyclable plastics, some price observations were local (i.e., the seven waste collection and recycling facilities) some price observations were global (i.e., the international prices for materials) but all the price observations were impacted by a global shock on the order of 10 million tons annually. In these instances, the impact of the global policy was that both local and international prices were universally depressed as demand for the material decreased. Conversely, the two case studies that observe price changes of organic wastes illustrated local shocks, in which case surrounding locations can mitigate localized price effects. Overall, the four case studies may be characterized as follows:

- <u>#1. Green Fence Policy impact on prices at waste collection and recycling facilities in seven US states</u>: A global supply shock impacted material prices at all facilities on the order of \$1.00-\$4.00 per ton with each 1% change in global demand.
- <u>#2. Green Fence Policy impact on scrap export prices</u>. A global supply shock impacted internationally traded material prices and limited alternative disposal options exacerbated price impacts to about \$0.30-\$2.30 per ton with each 1% change in global demand.
- <u>#3. Demand shocks at the Evergreen Community Power Plant in Reading, PA</u>. A local supply shock caused an average \$0.11 per ton change with each 1% change in local demand, with the price change likely suppressed by adjustments in surrounding waste handling alternatives.

- #4: Covanta Tulsa Waste-to-Energy Facility, Tulsa, OK. A local supply shock caused an average $0.08-$0.23 per ton increase with local demand, with long-term adjustments in surrounding markets observed.

Though the limited sample size precludes definitive conclusions regarding price elasticities of waste resources, all twenty-seven elasticities calculated were greater than zero, suggesting that some price increase of wastes should be expected if demand for waste increases. A base range of $0.10-$0.20 per ton per percent change in demand is recommended for local supply shocks and may increase with demand shocks at the extensive margin.

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