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Abstract. This paper reports our efforts to construct a baseline input-output model with environmental accounts for use in modeling geographically specific e-waste recycling systems. We address conceptual and practical issues that arise when recyclable end-of-life commodities and related activities are incorporated in the traditional input-output model including: 1) shortcomings of existing industry and commodity accounts that do not represent recycling activities and recyclable end-of-life products explicitly; 2) accounting challenges related to flows of end-of-life products observed mainly in physical volumes; and 3) valuing end-of-life products whose transactions prices vary widely. These three issues complicate the incorporation of end-of-life commodities within the conventional input-output framework. We present a way to record transactions of end-of-life products in both physical and monetary terms in the input-output model with environmental accounts (IO_{EA}). Specifically, we present a case of e-waste recycling for the Atlanta Metropolitan Area with an empirically based hypothetical scenario.

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Rationale and Considerations For An Extended IO Model Of E-waste Recycling

As the electronic waste stream continues to grow, more and more hazardous materials will be introduced into the environment unless substantially more effective and extensive recycling occurs. Only 15 – 20% of the approximately 2.2 million tons of electronics that became obsolete in 2005 were recycled, (EPA, 2007). Concern over environmental degradation has led eighteen states and at least one city to establish mandatory e-waste recycling acts, and several more states are in the process of introducing e-waste legislation.[2] The recycling of e-waste not only reduces its environmental impacts, it creates green business and job creation opportunities.

To better inform environmental and economic development policy formation, researchers have begun constructing models that tie process level engineering data to macroeconomic modeling frameworks, most notably input-output (Suh and Kagawa, 2005; Nakamura and Konda, 2009). In this paper, we report on our efforts to develop a baseline input-output model with environmental accounts for use in modeling a geographically specific e-waste recycling system. These efforts are part of a larger research effort focused on material flows for sustainable industrial systems in urban regions. Proper electronic waste handling is a critical component of such a system, but our modeling efforts are intended to be applicable to other materials for which disposal avoidance is sought.

While the IO framework provides a foundation for assessing the economic impact of recycling activities, doing so requires substantial modification of the conventional IO framework for two primary reasons (Jackson et al., 2008). First, conventional IO frameworks do not identify the recycling industry or related commodities explicitly. Instead, various recycling activities such as collection and processing are embedded within the conventional aggregate waste management sector. Consequently, the traditional industry and commodity accounts must be reconstituted to separately identify recycling industries and commodities.

The second reason pertains to the nature of e-waste, as well as waste in general. From an environmental perspective, an end-of-life electronic product is simply waste with no perceived economic

[2] E-waste legislation information was retrieved from Electronic Take Back Coalition (http://www.computertakeback.com). Accessed September 9, 2008.

value. The waste flow is only observed in physical units. However, recyclers -- particularly e-waste collectors-- view e-waste as a type of resource that has positive real economic value. This value can enter at any link in the transaction chain; for example, between households and e-waste collectors or e-waste collectors and processors. However, the physical quantity of e-waste streams and the economic value of e-waste in transactions between economic agents are not easily converted in a conventional IO table. The IO accounts must be modified to fully capture these relationships. It is also important to understand that ecological outputs of e-wastes, particularly post-use e-waste, do not directly result from industrial production activities.[3]

In the remainder of this paper we describe our progress in constructing an extended baseline IO model that explicitly incorporates the recycling industry and its related commodity accounts for analysis of the economic impact of e-waste recycling activity. We refer to this model as a baseline IO_{EA}. It is developed by modifying the existing account where the IO_{EA} model accounts for the physical flow of e-waste as well as the economic value induced by subsequent transaction chains as e-waste works its way through a region-wide economic system. We also address conceptual and practical modeling issues that are embedded in an extended IO approach. We present a prototype IO_{EA} model with a hypothetical case of the e-waste stream. The list below details the conceptual and practical issues encountered in integrating e-waste flows and related recycling industrial activities into the IO_{EA} framework.

Conceptual Issues:

- The reconstitution of relevant industry and commodity accounts
- Characteristics of e-waste as a resource: IO_{EA}
- Monetizing e-waste transactions
- Sources of financing for recycling e-waste: Advance Recovery Fee and Extended Producer Responsibility
- Technology assumptions in the commodity-by-industry IO framework

[3] As we observed at the outset of this paper, the ecological accounts we model are constructed for the purpose of describing e-waste circulation.

- The model driver

Practical Issues:

- Separating commodity recycling from the existing waste management sector
- Balancing physical and monetary flows

The remainder of this paper is divided into two sections. First, we discuss the conceptual issues of IO models relevant to the EOL products. Second, we present a prototype IO_{EA} model with hypothetical e-waste stream and transactions.

Conceptualizing EOL Product Characteristics

Each product has its own life-span. When the originally intended function of a product is exhausted, it becomes an end-of-life (EOL) product. If the end-of-life product is disposed of in a landfill, it loses all economic value. Indeed, it has a negative value in terms of disposal costs for end users, and a negative environmental consequence in terms of landfill volume and potential environmental degradation.

Recycling businesses use EOL products as inputs to their business operations. However, there is no corresponding commodity account for an EOL product in the benchmark IO table. Although the scrap sector captures by-product waste commodities generated in the production process in a Use Table commodity row and a Make Table commodity column, the quality of these data has declined (Swisko, 2000)[4]. In addition, there is no corresponding scrap industry that produces scrap as a primary product. Because the range of scrap materials across industries is very wide, it is impossible to identify specific materials in the scrap sector from the IO accounts data alone.

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4 Swisko (2000) observed that "industry reporting of scrap sales in the census of manufactures appears to have deteriorated, with the result that industry scrap sales that appear in earlier input-output tables do not necessarily appear in later tables. For example, the 1992 U.S. input-output Make Table does not show any sales of scrap from industry 39, metal containers, but the 1987 Make Table shows a scrap sales value of $256 million from this industry." (p.4)

When the EOL product is used as an input for recycling business, the transaction value of EOL products can vary much more wildly than the prices of conventional commodities in the conventional IO model. For some cases, if final users pay for the recycler to take the EOL product, the EOL product has a positive value to the recycler. In contrast, if the recycler pays the final user for the EOL product, there is a cost to the producer. If final users simply donate the EOL product, it has no apparent price or quantifiable value. If we ignore negative values in recording the transactions in IO accounts, some information on the physical quantities of the EOL product may be lost. Incorporating negative values, however, could lead to the computation of a misleading weighted average price-quantity relationship. Thus, we need to develop a systematic way to record the three kinds of transactions --- the recycler either makes a payment, receives a payment, or no payment occurs -- for the EOL product in physical and monetary terms.

Reconstituting Industry and Commodity Accounts

Though the conventional IO table does not specify the transactions of EOL products explicitly, it is clear that some industries do deal with EOL products and that the IO table contains these transactions in some form. For example, the “Waste management and remediation services” (Benchmark IO industry code-562000) sector in the Benchmark IO table corresponds to NAICS 562 which includes waste collection, disposal, and material recovery facilities. Thus, we make the key assumption that the existing IO table contains a certain level of recycling activity of EOL products within aggregated industry sectors.

The assumption that the existing IO table captures recycling activity and EOL products influences the development of the IO_{EA} model. Assuming that the existing IO table implicitly captures recycling activity, the modeling task is one of separating the aggregate industrial sector in which recycling activities are embedded into appropriate sub-sectors for the EOL product of interest for research purposes. Conversely, if implicit capture of recycling activities and EOL products is not assumed, then the modeling task is to create an entirely new industry and commodity for e-waste that augments the existing IO accounts. In general, we acknowledge that some levels of e-waste collection and processing activity occur in all metropolitan areas, although the level of such business activities is relatively small in most areas. In the larger research program in which the IO_{EA} model is being developed, our spatial focus is on metropolitan regions, in which the vast majority of all products is created, consumed, and reaches end-of-life status. Thus, the assumption is that any existing regional IO tables already embody recycling industrial activities and related commodities, albeit embedded within aggregated industries. The first modeling task, then, is to adjust existing industrial activities and commodity production by establishing a baseline IO table that includes accounts for recycling industry and commodity.

IO model with Environmental Accounts (IO_{EA})

We begin by considering the two interrelated subsystems of interest: the economic system and the eco-system. Conceptually, the flow of e-waste relevant to electronics production is a transaction between the economic system and the eco-system as illustrated in Figure 1. Every tangible product in the economic system eventually reaches the eco-system when its functional life ends. Some EOL products include valuable materials that can be kept out of the landfill and reprocessed. For example, glass, plastic, iron, lead, aluminum, and cooper are found in CPUs and monitors (Kang and Schoenung, 2005). Hence, some eco-system wastes will be reintroduced into economic system. From a recycling business perspective, EOL products can be considered as a natural resource that is extracted from an urban area. Some recycling businesses earn income from the discarded EOL products. We regard their economic activity as similar to that of the mining industry: in our focus an urban waste mining activity extracts recyclable or reusable materials. Therefore, e-waste from urban mining can be treated in much the same manner as that of a natural resource in the IO account. Although natural resources are usually not explicit in the conventional IO table, there are some models for environmental analysis that do include accounts for natural resource or ecological commodities (Lange, 1988; Huang et al., 1994; Allan et al., 2007; Dabi and Anderson, 2007).

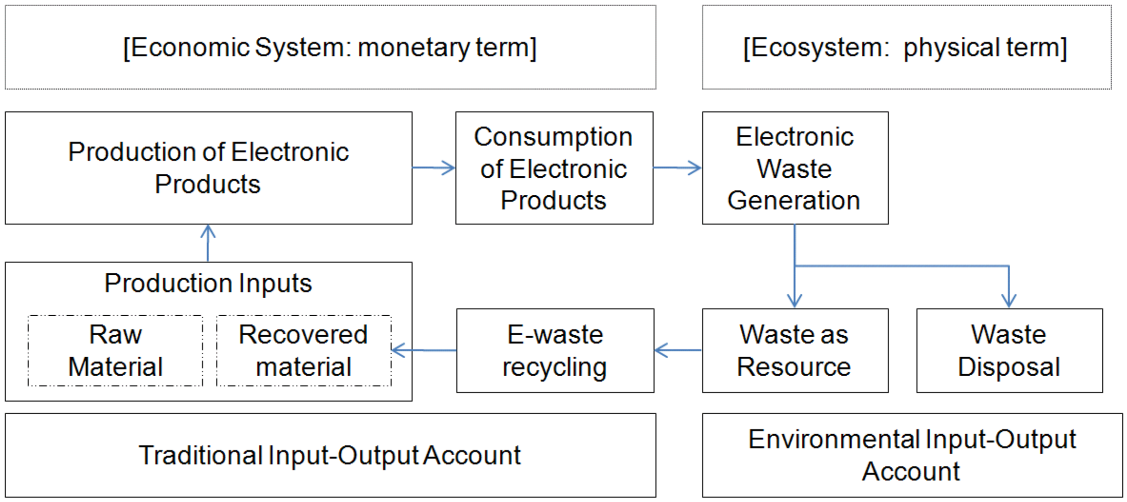

Figure 1. Flows and transactions between the economic system and eco-system of e-waste

Previous researchers have developed accounting methods for recording eco-system related transactions. In a seminal paper, Leontief (1970) discussed how to treat pollution generation and abatement activity in a conventional IO model. His paper presented a model where a row of pollution generation and a column of a pollution abatement industry are directly added into the inter-industry table. This model has been criticized in part for its concentrate focus solely on pollution. Isard (Lonergan and Cocklin, 1985) also attempted to integrate a full-scale economic system and ecological system into an IO model. However, the development of a practical model was limited by the excessive data requirements to reflect the ecological system.

Subsequent efforts have focused on developing a method of making an ancillary satellite account for the eco-system (Victors 1972; Huang et al., 1994; Lange, 1998; United Nations, 2003). These efforts establish a satellite account primarily to record ecological input and output, sometimes including stocks in physical terms (See right side of Figure 1 depicting eco-system account). An advantage of creating a satellite account is that the primary economic account remains intact, which indicates that it can serve as an analytical tool to elucidate the relationship between the physical quantity of ecological input and output and economic activity. The IO_{EA} can be developed for a specific industry, natural resource, or ecological output.[5] Occasionally, this class of model has been called a hybrid flow account since the entire model consists of physical flows as well as monetary flows (United Nations, 2003). Working environmental IO models, however, are still rare because there is limited access to information about ecological resources and outputs (Allan et al., 2007; Dabi and Anderson, 2007). We describe the framework of a satellite environmental account system for waste modeling below.

Environmental Account

The purpose of the IO_{EA} model is to bring together physical and monetary flows. Table 1 shows how the environmental account augments the conventional IO. The inner matrices from industry to total output are identical to the conventional commodity-by-industry IO table, while row and column accounts are added for physical flow. The ecological output column accounts for waste or pollution generated by industry or households. The ecological input row records the re-use or accumulation of waste. The trade of waste across regions is also recorded in the export and import accounts. All wastes generated or imported are re-introduced to the economic system, discarded in the eco-system, or exported outside of the region. Thus, the sum of rows in the ecological input row is equal to the sum of columns in ecological output in physical terms. The physical input and output of waste should be balanced in a region-wide system.

Table 1. Commodity-by-industry IO with environmental accounts

	Industry	**Commodity**	**Institution (capital)**	**Export**	**Total output**	**Ecological Output**
Industry		Make		Commodity Export	Industry Output	E-waste generated by industry
Commodity	Use		Final Demand		Commodity Output	
Factor	Wage/Proprieta ry income					

[5] United Nations (2003) notes that “it is quite legitimate to include only a limited set of natural resources, ecosystem inputs, and residual outputs, depending on the most urgent environmental concerns to be taken into consideration. It is certainly not necessary to complete an exhaustive natural resource input table, or a residual output table.” (pp. 130)

Institution		Institutional Make				E-waste generated by household
Import	Commodity Import					E-waste imported
Total Outlay	Industry Outlay	Commodity Outlay				
Ecological Input/residual	E-waste as production input		E-waste accumulation in landfill	E-waste exported		

Source: United Nations (2003) Handbook of National Accounting: Integrated Environmental and Economic Accounting

Driving IO_{EA}

Establishing a closed-loop system can bring a number of economic benefits to the regional economy. A closed-loop system provides local manufacturers with a wide range of recovered materials and reduces the intensity of raw material use and landfill accumulation. The effective use of natural resources generally enhances regional scale resource productivity. The products with recycled-material content also offer new products and product differentiations that can lead to enhanced market competitiveness.

Building a closed-loop system requires a certain level of environmental industrial activities that are preventive and remedial. These industry activities produce environmental goods and services and offer local employment opportunities. Local jobs can contribute to the income growth of low income communities and groups (Robert, 2004; Leigh and Patterson, 2006; Stéhane et al., 2007). While conventional IO data are limited in their ability to reveal these types of changes, our baseline IO model is an attempt to elucidate the flow of EOL product and subsequent economic activities in the IO table, so that some of these economic effects are captured.

We identify at least two baseline IO_{EA} model drivers. First, shifts in societal demand from discard to recycling are a fundamental driving force. Due to growing awareness of environmental degradation as well as rising costs of raw and other materials, there is growing demand for recycling EOL products. However, actual final demand shifts will appear very small in the IO model because final users do not typically purchase recycling services directly. Generally, final users demand only removal and collection services for EOL products. Most demand for recycling activity is intermediate demand. For instance, the e-waste processors made profits mostly from selling recovered materials, not from transactions with final users of electronic products according to the survey of California Integrated Waste Management Board in 2007. Consequently, although final demand shifts do drive the model, the magnitude of these shifts is very small.

The second driver of the IO_{EA} model is the structural economic difference between conventional disposal and recycling activity. Disposal of EOL products requires little economic activity, while recycling EOL products generates a number of economic activities, including collecting, sorting, dismantling, mechanical and chemical processing, and even research and development (R&D). Different industrial requirements can result in significant differences in the economic impacts between landfill and recycle options. These gaps are captured by differences in intermediate demand structure.

A Prototype IO_{EA} Model

Our prototype model uses IO data[6] for the 13 counties which make up the core of the Atlanta metropolitan area. The original dataset was aggregated into a 4×4 commodity by industry account in Table 2.

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[6] 2006 IO data come from IMPLAN, an established provider of region-specific economic accounts. The thirteen counties in the metropolitan model are Fulton, Gwinnet, Cobb, Douglas, Cherokee, DeKalb, Clayton, Fayette, Forsyth, Rockdale, Henry, Coweta, and Paulding.

Table 2. Initial aggregated IO data for the Atlanta 13 counties

Atlanta Input-Output 2006		Industry				Commodity				Institution	Export	Total Output
		Primary	Manufacturing	Service	Waste Management	Primary	Manufacturing	Service	Waste Management			
Industry	Primary					345.48	6.13	0.13	0.00		431.36	783.10
	Manufacturing					10.32	55,130.65	248.10	0.00		41,823.90	97,212.96
	Service					0.00	552.15	196,119.42	0.00		130,429.99	327,101.56
	Waste Management					8.08	0.00	0.00	600.54		221.76	830.38
Commodity	Primary	14.80	261.21	33.05	0.00					67.82		376.88
	Manufacturing	21.25	7,725.95	7,681.47	28.49					40,253.93		55,711.10
	Service	79.30	17,011.92	66,623.61	103.62					116,940.53		200,758.98
	Waste Management	0.43	99.23	303.77	60.06					137.05		600.54
Factor	Employee Compensation	172.47	19,118.50	112,800.48	263.39							132,354.84
	Proprietary Income	210.78	17,714.09	95,294.02	183.49							113,402.40
Institutions	Household					0.00	0.00	0.00	0.00			0.00
	Others					13.01	22.17	4,391.33	0.00			4,426.51
Import		284.06	35,282.05	44,365.15	191.32							80,122.58
Total outlay		783.10	97,212.96	327,101.55	830.38	376.88	55,711.10	200,758.98	600.54	157,399.34	172,907.01	

Units: Million dollars

New sector and commodity

While we cannot fully quantify the volume of e-waste that is being recycled in Atlanta, we have been able to identify a number of local e-waste recyclers. Thus, we assume that a certain level of e-waste recycling activities is already embedded in existing waste management sector accounts. Two types of e-waste recycling businesses are identified: “e-waste collector” and “e-waste processor”. These sectors are defined below.

- <u>E-Waste Collection Industry:</u> makes up of collection firms that pick up “post-use e-waste” from households and businesses directly, or, from drop-off locations, and deliver “post-use e-waste” to processors. The e-waste collection industry produces “collected e-waste”.

- E-Waste Processing Industry: makes up of processing firms that receive "collected e-waste" from e-waste collectors, dismantle e-waste, and recover a range of valuable materials such as plastic, lead, cooper, and gold and so on. The "recovered materials" that the e-waste processing industry produces are entries in the traditional commodity sectors of the Make matrix.

For the commodity-by-industry account, we also create a new commodity. The e-waste collector provides a service of collecting e-waste from final users who want to recycle their EOL electronic products. This service represents a transaction between households and businesses and the e-waste collector. In this service, the e-waste commodity is physically transferred from the final user to the collector. We identify the commodity generated during this transaction as "Post-use e-waste".[7] The e-waste collector delivers "post-use e-wastes" collected from households and businesses to the e-waste processor, whose capital requirements and production processes can differ dramatically. In general, the e-waste processor pays for collected e-waste.[8] Therefore, "collected e-waste" is added as a new commodity to the IO_{EA} table.

A hypothetical case of e-waste generation and treatment

In our hypothetical case, we assume that the Atlanta region generates 24,000 metric tons of e-waste annually. As shown in Table 3, these e-wastes come from each industrial sector and the household sector. E-wastes generated will be either recycled, disposed of within the region, or exported outside the region. Of the 24,000 metric tons, we assume only 10% is being re-introduced for recycling. We next assume that 70% of e-waste is discarded into landfills and the remaining 20% is exported.

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[7] Lee and Coppers (2008) note that environmental engineering research strives to identify valuable components in LCD monitors that make up growing volumes in the e-waste stream in order to inform recyclers about what they will receive and what materials they will need to manage. The plastic housings and frame, the power supply, and the controller in LCD can be expected be similar to those of existing e-waste such as CPUs, but uncertainty lies in the LC assembly and the film set.

[8] 2006 Net Cost Report published by California Integrated Waste Management Board (2007) notes that "intense competition among recyclers is driving up prices paid to the collector." (pp. 3-3) In 2005, the transaction price between collector and recycler ranged from 2 to 3 cents per pound, while some recyclers reported transaction price as high as 10 cents per pound paid to collector in 2007.

Table 3: A hypothetical case of e-waste generation and treatment

E-waste generation		E-waste treatment	
Primary	2,000	Recycle	2,400 (10%)
Manufacturing	4,000	Disposal	16,800 (70%)
Service	6,000	Export	4,800 (20%)
Household	12,000		
Total	24,000	Total	24,000

Unit: Metric tons

Establishing Environmental Accounts

The hypothetical case of waste generation and treatment can be incorporated now into the environmental IO accounts (Table 4). The generation of e-waste by the household and industrial sector is recorded respectively in industry and household accounts of the ecological output column, while e-waste that is recycled or disposed of in landfills is recorded in the ecological input row. For example, the primary sector generates 2,000 metric tons of e-waste as an ecological post-use e-waste output recorded in the ecological output column, primary industry row. The 2,400 metric tons of e-waste are reintroduced into the economic system by e-waste collectors. Because the e-waste collector physically extracts e-waste from the urban mine, an ecological input of 2,400 metric ton e-waste is recorded in the ecological input row e-waste collector industry column. The total ecological input is equal to the total ecological output.

Generally, ecological input accounts are used to estimate the total ecological input requirement, and ecological output accounts are also used to assess the total environmental impact of production (Dabi and Anderson, 2007). The interpretation of our IO_{EA} is different. E-waste as an input only makes sense for the e-waste collector. In addition, the amounts of ecological outputs of e-waste generated from industries and households are not correlated with production but, rather, with consumption and other factors. These accounts depict the source of EOL products generation and destination of EOL products within both the economic and ecological system. They also account for the volume of EOL products flows in physical terms.

Table 4: A hypothetical case of environmental accounts

Atlanta Input-Output 2006		Industry						Commodity									Ecological Output		
		Primary	Manufacturing	Service	Waste Management	E-waste collector	E-waste processor	Primary	Manufacturing	Service	Waste Management	Post-use e-waste	Collected e-waste	Institutions	Export	Total Output	Post-use	Pre-consumer	total
Industry	Primary																2,000		2,000
	Manufacturing																4,000		4,000
	Service																6,000		6,000
	Waste Management																		
	E-waste collector																		
	E-waste processor																		
Commodity	Primary																		
	Manufacturing																		
	Service																		
	Waste Management																		
	Post-use e-waste																		
	Collected e-waste																		
Factor	Employee Compensation																		
	Proprietary Income																		
Institution	Household																12,000		12,000
	Others																		
Import																			
Total outlay																			
Ecological Input						2,400								16,800	4,800		24,000		24,000

Units: Ecosystem - metric tons

Transactions of EOL products in the Economic System

Valuing e-waste transactions is problematic, but it can be categorized into three cases as introduced above: (1) final users pay the collector to take their e-waste; (2) collectors buy e-waste from the final user; or (3) final users donate e-waste to collectors. For this example, we assume that only 10% of e-wastes generated by each industry/household are traded by e-waste collectors (Primary: 200 tons; Manufacturing 400 tons; service: 600 tons; Household: 1200 tons), while others are either disposed of in a landfill or exported. Further, we assume each industry makes payments to e-waste collectors for removing e-wastes at cost of $100/metric ton. For the 1,200 metric tons of e-waste generated by households, e-waste collectors purchase 600 metric tons at $100/metric ton, while for the other 600 metric tons, households pay collectors an average of $50/metric ton. In sum, 2,400 metric tons are traded with payments made between industry/household and e-waste collectors for recycling purpose.

Table 5: Accounts for hypothetical trades of e-waste

		Industry						Commodity								
		Primary	Manufacturing	Service	Waste Management	E-waste collector	E-waste processor	Primary	Manufacturing	Service	Waste Management	Post-use e-waste	Collected e-waste	Institution	Export	Total Output
Industry	Primary															
	Manufacturing															
	Service															
	Waste Management							-0.31			-0.30					
	E-waste collector											0.18	0.12			
	E-waste processor							0.31								
Commodity	Primary															
	Manufacturing															
	Service															
	Waste Management	-0.02	-0.04	-0.06	-0.15									-0.06		
	Post-use e-waste	0.02	0.04	0.06		0.03								0.06		
	Collected e-waste						0.12									
Factor	Employee Compensation															
	Proprietary Income															
Institution	Household										-0.03	0.03				
	Others															
Import																
Total outlay																

Units: Million Dollars

As shown in Table 5, the e-waste transactions between e-waste collectors and final users are mainly recorded in the “post-use e-waste” commodity row and column. Then, since these transactions also are assumed to be already embedded in the IO table in the waste management sector, e-waste related transactions are extracted (subtracted) from the waste management industry and commodity. Hence, in this example, the manufacturing sector pays $0.04 million for “post-use e-waste” commodity. That transaction is recorded in the manufacturing industry column, post-use e-waste row. This amount is subtracted from “waste management” commodity output. The household pays $0.06 million for post-use e-waste, which is the offset of final demand between the waste management commodity and post-use e-waste commodity.

The e-waste collector industry receives fees from industry and households. We can consider these as a kind of production of post-use e-waste commodity by e-waste collectors. In the make matrix, $0.18 million is recorded in the post-use e-waste column by the e-waste collector industry. In addition, the e-waste collector provides a delivery service of “collected e-waste” to the processor. This transaction, $0.12 million, is recorded in the collected e-waste commodity column by e-waste collector industry row. This change in the make matrix is then subtracted from production of waste management. Finally, the e-waste processor produces a certain amount of recovered materials. An amount of $0.31 million of recovered materials is recorded in the e-waste processor industry row by primary commodity column. That amount is subtracted from the primary commodity of waste management industry. In fact, the waste management sector of the Atlanta 13 county area produces $8 million of the “oil and gas extraction” commodity.

Through Tables 4 and 5, the physical units of e-waste can be converted into monetary units. This conversion is dependent on the unit price of transaction and the quantity of post-use e-waste. The trade of 2,400 metric tons of e-waste among the household/business, collector, and processor sectors directly creates an economic value as large as $0.64 million.

Structure of USE & MAKE matrix

Data on the expenditure and revenue of new added industries is needed to build a baseline IO_{EA} model. However, these data are not readily available and are usually derived from direct surveys of e-waste collectors and processors. Because the state of California was an early adopter of e-waste recycling legislation and programs, we use data collected by the California Integrated Waste

Management Board (CIWMB), a state agency, for the model presented here.[9] The California E-waste Recycling Act passed in 2003 requires the collection of an electronic waste recycling fee at the point of sale, and uses those fees to pay qualified entities for the costs of e-waste collection and recycling. Participating e-waste collectors and processors must report their operating costs and revenues annually to CIWMB[10]. The "2006 Net Cost Report" published by CIWMB provides a weighted average cost and revenue for collectors and processors as shown in Table 6. For establishing the baseline IO_{EA} model, these cost and revenue data are adapted to our previously described industry sector classification for the IO_{EA} model (See Table 7). Then, we create the Make and Use tables depicted in Table 8.

Table 6. Expenditure and revenue of e-waste collector and processor

	Collector	Processor	Related Industry
Revenue	2	5.8	
Total Cost	18.7	27.4	
Items			
Transportation	2.4	2.7	transportation
Advertising	1.1	0.8	Professional
Processing and Disposal	0.4	3.7	
Supplies	0.5	1.2	
Depreciation	0.2	0.6	Other Payment
Insurance	0.4	1	Finance
Debt Service	0.1	0.2	Finance
Fuel	0.1	0	Retail
Maintenance	0.8	0.3	Other Service
Utilities	0.4	0.3	Utilities
Facilities and Equipment Rent/Lease	1.9	2.2	Real estate
Security	<<0.1	<<0.1	Administrative
Other Additional Costs	0.9	0.6	Other Service
General Overhead	0.4	1.6	Other Payment
Labor	9.1	11.9	wage
Property Taxes	<<0.1	<<0.1	Indirect Tax

Unit: cent per pound

Source: 2006 Net Cost Report by CIWMB

9 The example here is called an empirically based hypothetical model because of the use of California-based data for the Atlanta region.

10 In California 2006, there were $59 million in reimbursement claims for processed e-wastes by processors.

Table 7: A hypothetical case of structure in expenditure and revenue

	E-Waste Collector	E-Waste Processor
Revenue	0.30	0.31
Total Expenditure	20.25	27.20
Expenditure structure		
Primary	0	0
Manufacturing	0.90	1.50
Service	5.30	5.10
Waste Management	0.40	3.70
post-use e-waste	4.55	0
Collected e-waste	0	5.00
Employee Compensation	9.10	11.90

Unit: cent per pound

According to the 2006 Net Cost Report, costs for both e-waste collectors and processors exceeded revenues on average. Labor costs are nearly 50% of total expenditures in both business types. Revenue for e-waste processors results from recovered materials, while the revenue for the e-waste collectors comes from payment for collection of post-use e-waste and delivery of collected e-waste. Most businesses in the State of California report that their collecting and processing activity resulted in a financial loss. Using these self-reports, CIWMB determines the reimbursement rate it will give to approved collectors and processors. In 2006, this rate was $0.20 per pound for collectors and $0.28 per pound for processors.

Financing the recycling cost

In our IO_{EA} modeling effort, we need to incorporate a financing structure for e-waste recycling. As shown in Table 6, most recycling related business operates on the margin. Two financing models of e-waste are being used by states in the U.S. The first is the Advance Recovery Fee (ARF) that, to date, is only used by the State of California. The second is Extended Producer Responsibility (EPR) that was adopted by seventeen states as of 2008[11].

[11] Extended Producer Responsibility (EPR) was adopted by Maine (2004), Maryland (2005), Washington (2006),

With EPR, electronic manufacturers are required to pay directly for recycling their products. Electronic manufacturers can establish their own recycling facility for processing their e-waste. Otherwise, electronic manufacturers must pay for outsourcing the recycling of e-waste by their recycling businesses. For example, the state of Maine adopted a shared producer responsibility system in 2005. Electronic manufacturers paid an average of $0.33 per pound for consolidators' transportation and recycling services in 2006.

In our baseline IO model, it is assumed that the electronic manufacturer pays e-waste processors for recycling services, at $0.27 per pound. Thus, annual payments for recycling services would be $1.44 million to recycle 2,400 metric tons of e-waste; that is, e-waste processors receive $1.44 million. Additionally, it is assumed that the electronics manufacturer pays e-waste collectors $0.22 per pound; that is, $1.2 million is paid annually to make up for financial losses of e-waste collectors. To incorporate this transaction within the IO framework, disaggregated "electronic manufacturing" industry and commodity sectors are added. The payment by the electronic manufacturing industry is recorded in the e-waste collector and e-waste processor industry rows of the Make matrix. These values are also recorded in the electronic manufacturer industry column in Use matrix.

Table 8: Make and Use matrix of a prototype model

Atlanta Input-Output 2006		Industry							Commodity						
		Primary	Manufacturing	Electronic Manufacturing	Service	Waste Management	E-waste collector	E-waste processor	Primary	Manufacturing	Electronic Manufacturing	Service	Waste Management	Post-use e-waste	Collected e-waste
Industry	Primary								345.48	6.13	0.00	0.13	0.00	0.00	0.00
	Manufacturing								10.32	51,671.26	45.98	248.10	0.00	0.00	0.00
	Electronic Manufacturing								0.00	9.14	3,404.28	0.00	0.00	0.00	0.00
	Service								0.00	552.15	0.00	196,119.42	0.00	0.00	0.00

Connecticut (2007), Minnesota (2007), North Carolina (2007), Oregon (2007), Taxes (2007), Hawaii (2008), Illinois (2008), Michigan (2008), Missouri (2008), New Jersey (2008), Oklahoma (2008), Rhode Island (2008), Virginia (2008), West Virginia (2008). This list was retrieved from Electronic Takeback Coalition (http://www.electronicstakeback.com/legislation/state_legislation.htm). Accessed January 27, 2009.

	Waste Management								7.77	0.00	0.00	0.00	597.60	0.00	0.00
	E-waste collector								0.00	0.00	0.00	0.00	0.00	**1.38**	0.12
	E-waste processor								0.31	0.00	0.00	0.00	0.00	0.00	**1.44**
Commodity	Primary	14.80	261.07	0.14	33.05	0.00	0.00	0.00							
	Manufacturing	21.24	6,681.00	186.82	7,246.02	27.37	0.05	0.08							
	Electronic Manufacturing	0.02	289.33	568.80	435.45	0.99	0.00	0.00							
	Service	79.30	15,477.93	1,533.99	66,623.61	103.07	0.28	0.27							
	Waste Management	0.41	87.54	9.01	303.71	59.69	0.02	0.20							
	Post-use e-waste	0.02	0.04	**1.20**	0.06	0.00	0.03	0.00							
	Collected e-waste	0.00	0.00	**1.44**	0.00	0.00	0.00	0.12							

Units: Million Dollars

The Baseline IO_{EA}

The IO_{EA} model ensures the balance of physical and monetary flows. Table 8 shows the final balanced commodity and industry IO_{EA} account for e-waste recycling. E-waste collectors re-introduce 2,400 metric tons of e-waste into the economic system. During these activities, e-waste collectors purchase various commodities for $0.38 million, pay wages of $0.48 million, and produce $1.5 million of “post-use e-waste” and “collected e-waste”. The output and outlay of the e-waste collector sector are balanced at $1.5 million. As a result, total outlay and output are the same in both Table 2 and Table 8. Only the industry and commodity compositions have changed.

Table 9: Baseline commodity and industry IO model with environmental account for Atlanta 13 county area

Atlanta Input-Output 2006		Industry							Commodity							Institution	Export	Total Output	Ecological Commodity		
		Primary	Manufacturing	Electronic Manufacturing	Service	Waste Management	E-waste collector	E-waste processor	Primary	Manufacturing	Electronic Manufacturing	Service	Waste Management	Post-use e-waste	Collected e-waste				Post-use	Pre-consumer	total
Industry	Primary								345.48	6.13	0.00	0.13	0.00	0.00	0.00		431.36	783.10	2,000		2,000
	Manufacturing								10.32	51,671.26	45.98	248.10	0.00	0.00	0.00		38,859.35	90,835.00	4,000		4,000
	Electronic Manufacturing								0.00	9.14	3,404.28	0.00	0.00	0.00	0.00		2,964.54	6,377.96			
	Service								0.00	552.15	0.00	196,119.42	0.00	0.00	0.00		130,429.99	327,101.56	6,000		6,000
	Waste Management								7.77	0.00	0.00	0.00	597.60	0.00	0.00		221.76	827.13			
	E-waste collector								0.00	0.00	0.00	0.00	0.00	1.38	0.12		0.00	1.50			
	E-waste processor								0.31	0.00	0.00	0.00	0.00	0.00	1.44		0.00	1.75			
Commodity	Primary	14.80	261.07	0.14	33.05	0.00	0.00	0.00								67.82		376.88			
	Manufacturing	21.24	6,681.00	186.82	7,246.02	27.37	0.05	0.08								38,095.24		52,257.82			
	Electronic Manufacturing	0.02	289.33	568.80	435.45	0.99	0.00	0.00								2,158.70		3,453.28			
	Service	79.30	15,477.93	1,533.99	66,623.61	103.07	0.28	0.27								116,940.53		200,758.98			
	Waste Management	0.41	87.54	9.01	303.71	59.69	0.02	0.20								136.99		597.57			
	Post-use e-waste	0.02	0.04	1.20	0.06	0.00	0.03	0.00								0.06		1.41			
	Collected e-waste	0.00	0.00	1.44	0.00	0.00	0.00	0.12								0.00		1.56			
Factor	Employee Compensation	172.47	17,836.89	1,281.61	112,800.48	262.28	0.48	0.63										132,354.84			
	Proprietary Income	210.78	17,632.20	81.89	95,294.02	182.40	0.64	0.45										113,402.40			
Institutions	Household								0.00	0.00	0.00	0.00	-0.03	0.03	0.00				12,000		12,000
	Others								13.01	19.14	3.03	4,391.33	0.00	0.00	0.00						
Import		284.06	32,569.00	2,713.05	44,365.15	191.32	0.00	0.00													
Total outlay		783.10	90,835.00	6,377.96	327,101.55	827.13	1.50	1.75	376.88	52,257.82	3,453.28	200,758.98	597.57	1.41	1.56	157,399.34	172,907.01				
Ecological Input							2,400									16,800	4,800		24,000		24,000

Units: Economic system- million Dollars, Ecosystem - metric tons

Comparison of Multipliers

To generate a solvable structure, we need to make an assumption about the nature of technology. Industry-based technology implies that an industry uses a fixed input structure to produce primary and secondary commodities, while commodity-based technology implies that a commodity has the same input structure regardless of the industry that produces it (Jackson et al, 2008). Miller and Blair (1985) discussed conditions under which one or the other technology assumption is preferred. If the secondary commodity is considered to be a by-product, the industry-based technology assumption is most appropriate because input structures for primary and secondary products cannot be identified separately. On the other hand, if the secondary product is considered as to be a subsidiary commodity instead of a by-product, then the commodity-based technology assumption is most appropriate.

Even if the waste is not generated directly from the industrial processes, it can be considered as a byproduct of regular production in that "the amount of this byproduct will be a function of the overall level of each activity, rather than the outcome of a specific decision to produce more scrap according to any particular production function." (Jackson et al, 2008). For the e-waste case, the technology-based assumption is more appropriate than the commodity-based assumption.

Table 10 reports output multipliers from the industry-by-industry and the industry-by-commodity formats. Output multipliers of pre-existing industries are virtually identical in the initial and modified tables, although the output multiplier of the waste management sector decreases slightly. This is consistent with expectations, given that the e-waste collector and e-waste processor industries have been removed from the pre-existing waste management sector. However, while output multiplier values for the e-waste collector and waste management sectors are very similar in the industry by industry and industry by commodity total requirement, the output multipliers for e-waste processors are 0.15 to 0.20 larger than those for waste management. This supports the expectation that although e-waste collection impacts are similar to those of conventional waste-management, e-waste processing activities generate greater economic value than do conventional waste management activities such as waste collection, landfill, and hazardous waste treatment. Thus, recovering valuable materials diverted from landfills has greater potential to expand economic opportunities than conventional waste management options.

Table 10: Comparison of multipliers

Industry	Output Multiplier			
	Industry by industry total requirement		Industry by commodity total requirement	
	Original	Modified	Original	Modified
Primary	1.186	1.186	1.151	1.151
Manufacturing	1.321	1.321	1.320	1.320
Electronic Manufacturing	1.476	1.476	1.472	1.472
Service	1.289	1.289	1.261	1.261
Waste Management	1.297	1.296	1.297	1.296
E-waste collector	-	1.321	-	1.293
E-waste processor	-	1.502	-	1.488

Simulation of economic impacts: intermediate input structural change

The purpose of the prototype model is to construct an extended baseline IO model with environmental accounts. This model structure can then be used for assessing the economic impact of increasing recycling activities based on scenario analyses. Here identify two operational driving forces for simulation. First, going beyond our hypothetical case's assumption that 10% of e-wastes are recycled, we can estimate how much new industrial activity will be required in each industry if the recycling rate rises to 30% or 50%. We can imagine a change in societal norms and preferences could drive increased recycling activities and induce subsequent economic impact. Second, the resulting economic impacts can be modeled by capturing the structural change in economic system transactions in which the intermediate inputs by e-waste collection and processing industries differ from those of traditional waste management industry.

We focus here on examining the second driving force, the economic impact of intermediate input structural change. When considering the trade-off between the recycling option and landfill option, the positive impact of structural change can become a fundamental economic rationale for a policy promoting e-waste recycling industries. To determine this impact, we run a simulation based on the original and modified models holding final demand constant as it is in the original model. While the total final demands of the two models are exactly the same, the distribution of final demand among industries differs. A small portion of final demand of the waste management sector in the original model is transferred to the e-waste collection industry in the modified IO model. Then, we compare the difference in output and employee compensation derived from the change in intermediate input structure. Because there are no corresponding industries for the e-waste collection and processing industry in the original model, the output and employee compensation of the waste management sector in the original model is compared with the sum of waste management, e-waste collection and processing industries in the modified model. The overall positive economic impact of the structural change is shown in table 11. Total output ($0.067 million) and total employment compensation ($0.024 million) increase in a small portion. The differences indicate that once 10% of e-wastes are recycled through the e-waste collection and processing industries, rather than landfilled through the traditional waste management industry, some additional industrial outputs and employee compensations are induced. Though the magnitude of impact is relatively small in the simulation, the total economic impact will expand further as the structural change is associated with the increase of recycling industrial activities.

Table 11: Economic Impact of Structural Change

Industry	Output			Employee Compensation		
	Original	Modified	Difference	Original	Modified	Difference
Primary	202.819	202.819	0.000	44.669	44.669	0.000
Manufacturing	44,601.977	44,601.979	0.002	8,758.307	8,758.307	0.000
Electronic products	2,716.458	2,716.458	0.000	545.854	545.854	0.000
Service	153,350.879	153,350.935	0.057	52,882.818	52,882.838	0.019
Waste Management	358.055	356.596	0.008	113.574	113.077	0.004
E-waste Collector	-	0.675	-	-	0.216	-
E-waste Processor	-	0.791	-	-	0.285	-
Sum	201,230.187	201,230.254	0.067	62,345.223	62,345.247	0.024

Unit: Million Dollars

Discussion

Our goal in this paper has been to synthesize and reconcile economic and environmental modeling issues needed for establishing a baseline IO_{EA} model. Research to develop an economic model to incorporate the flow of recyclable commodities and related industries into the IO framework explicitly is still relatively scarce. Most literature on environmental accounts or related activities focuses on pollution by industries or natural resources. The distinguishing characteristic of our modeling approach lies in integrating the circulation of recyclable materials into the IO model.

In this paper, two major conceptual issues have been addressed. The first is how the IO table should be reconstituted to integrate e-waste flow. Not only are industry and commodity classifications adjusted but, so too is the environmental account that describes the flow of e-waste within the eco-system. The second issue addresses how the transaction of physical e-waste can be monetized consistently within existing IO accounts. Since there is no unique unit price for the transaction of e-wastes, the physical terms of e-waste cannot simply be converted into monetary terms of e-waste. In the developed prototype model, a case that covers possible transactions of selling, buying, and donating is represented. We have also addressed several conceptual and practical issues such as financing, technology assumptions, balance of flow, and drivers of the model

There are growing demands for green jobs and green economic development. Management of materials that are recyclable and reusable is a critical task for greening the economy. By integrating both physical flows and monetary flows within the input-output framework, our approach allows local and regional policy makers to assess the economic impact of managing identifiable flows of materials that have been diverted from landfills for a specified geography. As such it permits feasibility analysis of creating recycling and reuse systems to further regional specific sustainability. Finally, as analysis of our prototype model shows, there is potential greater overall economic impact or growth (in terms of jobs and income generated) from recycling electronics versus landfilling them. While it is clear from an environmental perspective, that it is much more preferable to recycle than landfill electronics, our research shows there is an economic rationale to create electronics recycling systems. Further, in particularly trying economic times such as those currently being experienced, these systems can be part of the solution to creating new economic activity.

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