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The Statistical Distributions of Industrial Wastes: an Analysis of the Japanese Establishment Linked Input-output Data

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1. Introduction

Both waste management policies and the economic theories underlying them model the behaviour of a representative company or establishment using. For example, toxic wastes such as dioxin are regulated by the mean emission volume standard measured per Nm^3, where the mean is estimated using data. As we will show, most establishments (particularly combustion plants) satisfy the required emission standard, while only a few exceed the regulation limit and must be checked by the authorities until regulation standards are met. But regulators must monitor all establishments incurring unnecessary costs.

Fullerton and Kinnaman 1995, among other theoretical contributions, show that taxing downstream establishments can achieve the second best policy. (See also Walls & Palmer 1998, who discuss more general market conditions.) Recent research shows that regulating downstream establishments promotes research and development by firms in upstream stages of a supply chain under certain market conditions (Calcott & Walls, 2000; Greaker & Rosendahl, 2006). These theoretical implications are important for policy making about how to design a tax system, but these theories also assume a typical producer and the regulation standard with respect to their mean emissions of waste materials. In practice, however, even though the coefficients of variation for the distributions of heavy metals in fly ash found in municipal solid waste are known to reach 50% (Nakamura et al., 1997), little statistical evidence in the published literature exists on the variation in industrial establishments' waste generation and reuse-recycling per unit production, which is basic information required for economic and ecological design and general policy decisions.

In this paper we fill this gap in the literature and show the distributions of generation rates for various types of wastes and by-products in the production processes of establishments in Japanese manufacturing industries. We use the METI survey data (Survey on the Industrial Waste and By-Products, Japanese Ministry of Economy, Trade and Industry, 2005 and 2006). This survey gives the amounts of 37 types of industrial wastes generated for four different levels of the production processes (generation, intermediate reduction, reuse-recycle, and disposal to landfill) at 5048 establishments.[1]

[1] See the Clean Japan Center (2005 and 2006) for details of this survey data.

We have linked the METI survey data with the Japanese Input-Output (I-O) table. Using this linked data and the data on energy/CO_2 requirements in industrial waste treatment, we are able to calculate the induced amounts of industrial wastes.[2] For example, waste oil and waste plastic are generated in large quantities at 3080 and 3694 establishments, respectively. Estimated amounts of waste oil and waste plastic generated range, respectively, between 0 and 2.50 and between 0 and 2.11 (metric) tonnes per million yen of output. On the other hand, waste ferroalloy slag is produced at only 11 establishments, and its quantity ranges from 5.8 to 64.6 tonnes per million yen of output. We estimate that production of every car with a 2000cc engine or its equivalent induces, for example, 0.051 tonnes of all types of wastes combined in hot rolling processes and 0.677 tonnes of all types of wastes combined in iron steel making in upstream production activities. We estimate that a 2000cc equivalent automobile production generates 1.49 tonnes of all types of wastes combined. We believe that these averages and the distributions for waste generation rates along a production supply chain provide (currently unused) useful information for policy makers for further reductions in the generation of waste materials.

2. Using the input-output analysis for evaluating waste management policies

2.1 Economic input-output-LCA: the theoretical background

The input-output analysis is a powerful tool to evaluate environmental impacts within an interdependent economic system (Leontief 1970, Baumol and Wolff 1994). When production of a final product requires intermediate goods (e.g. parts), inter-industry effects along a supply chain generate various wastes in stages of the life cycle of the final product.

The input-output (I-O) table is like a recipe of all economic activities for a national economy. Each column describes all the inputs used for an immediate economic activity, such as producing an automobile, supplying services such as education. It covers all economic activities and I-O relations are described in monetary terms. Recently publicly available I-O tables have been applied to the Economic Input-Output Life Cycle Assessment (EIO-LCA) (Hendrickson et al., 2006; Suh, 2010). Eiolca.net summarizes limitations of EIO-LCA compared to Process-Based LCA.

One such limitation that EIO-LCA is difficult to apply to an open economy is overcome by using the methods given by us (Hayami & Nakamura, 2007). The most apparent disadvantage of EIO-LCA is that product assessments contain aggregate data containing uncertainty as Eiolca.net describes. Assume there are n commodities (including services) in an economy, each of which is an input for production of other commodities. A typical producer k produces output $x_j^{(k)}$ of j-th commodity, which requires as inputs $X_{ij}^{(k)}$, where $i=1,2,...,n$. Governments provide the official I-O table with aggregate figures for all producers of j-th commodity $x_j=\sum_{k=1}^{mj} x_i^{(k)}$, where m_j is the number of producers of the j-th commodity. The same aggregation procedure is applied to inputs as follows: $X_{ij}=\sum_{k=1}^{mj} X_{ij}^{(k)}$. EIO-LCA assumes that matrix of input coefficients A_{ij} defined below is stable and represents a typical producer's activity.

$$A_{ij} = X_{ij}/x_j = \sum_{k=1}^{mj} X_{ij}^{(k)} \Big/ \sum_{k=1}^{mj} x_j^{(k)} \qquad i,j = 1,2,\ldots,n \tag{1}$$

[2] Induced amounts of output mean the amounts of output generated by upper (supplier) stages of a production supply chain in response to the production activities undertaken at downstream establishments.

But these input coefficients A_{ij} are different from producer k's input coefficients A_{ij}

$$A_{ij}^{(k)} = X_{ij}^{(k)} / x_j^{(k)} \qquad i,j = 1,2,\ldots,n \text{ and } \quad k = 1,2,\ldots,m_j \tag{2}$$

Similarly, by applying EIO-LCA to waste management with the same assumptions made above, we get the amount of waste i generated in producing output x_j (we consider 37 waste materials as defined below):

$$W_{ij} = Waste_{ij} / x_j = \sum_{k=1}^{mj} W_{ij}^{(k)} \Big/ \sum_{k=1}^{mj} x_j^{(k)} \qquad i = 1,2,\ldots,37 \;\; j = 1,2,\ldots,n \tag{3}$$

Similarly, producer (k) generates i-th waste producing the j-th product:

$$W_{ij}^{(k)} = Waste_{ij}^{(k)} / x_j^{(k)} \qquad i = 1,2,\ldots,37 \;,\; j = 1,2,\ldots,n \;\text{ and }\; k = 1,2,\ldots,m_j \tag{4}$$

Japan Ministry of Economy, Trade and Industry (METI) conducts an annual survey that reports the amounts of 37 types of wastes observed in 4 stages: amounts generated by final production, $W_{ij}^{(k)}$; amounts of reduction in intermediate steps of production, $V_{ij}^{(k)}$; amounts recycled, $U_{ij}^{(k)}$; and amounts sent for landfill, $T_{ij}^{(k)}$.[3] The most important assumption in our I-O analysis is that input coefficients and waste coefficient per output remain constant over time. If we can show empirically that these coefficients have narrow bell shape distributions, then the relative stability of these coefficients follows. In this paper, we will show using our data how the coefficients of waste generation $W_{ij}^{(k)}$ distribute.

Using input coefficients, A_{ij}, we can calculate the demand for goods made in stages of upstream sectors of a supply chain. Unit production of j-th sector output induces production of i-th sector whose output is given by A_{ij}. Similarly production of A_{ij} induces production of $A_{ki}\, A_{ij}$ in k-th sector. Repeating this, we can obtain output induced for any stage in upstream portions of a supply chain. Formally, multiplication of the I-O coefficients matrix A from left gives us induced output for all relevant goods and services in the immediate upstream stage of a supply chain.

$$f,\ Af,\ A^2 f,\ \cdots \tag{5}$$

where f is a vector of demands for final goods and services

By multiplying production output for final production (downstream) stage and subsequent upstream stages (f, Af, ...) by waste generation matrix W, we obtain the amounts of waste generated in the corresponding stages of a supply chain: Wf, WAf, WA^2f, ...

2.2 Construction of a linked data set

We briefly describe the procedure we used to link the Wastes and By-products Survey (WBS) data to the I-O table. We first note that the definition of a sector is different between the two data sets. WBS is based on the Japan Standard Industry Classification (JSIC) system,

[3] $V_{ij}^{(k)}$ is defined as: $V_{ij}^{(k)}$=*Intermediate Reduction/Waste Generated* ($Waste_{ij}^{(k)}$); and $U_{ij}^{(k)}$ and $T_{ij}^{(k)}$ are similarly defined. The denominator is the amount of waste generated, rather than production output. The waste generated is measured at the gate of an industrial process. Generated wastes are reduced (sludge dewatering), recycled/reused, and finally disposed of (mainly by landfill). Waste reduction is often undertaken in production processes, for example, for reducing the failure rate (or increasing yields) for the processes.

but the I-O table uses its own more detailed classification system so that the stability of I-O coefficients over time is preserved. JSIC codes are divided into one or more of 401 I-O sectors, using the allocation matrix given in the appendix tables of the I-O table. This allocation method depends on the sales figures reported for different products of each establishment in WBS. One difficulty we encountered was for the steel industry sector. The steel industry in the I-O table is divided into 13 sectors and two related sectors (coal products and self power generation). Many of these I-O sectors belong to a single establishment in WBS because of their continuous casting production, and there are no sales figures reported on WBS for transactions for these I-O sector goods since these transactions occur within the same establishment. To properly allocate output of steel industry establishments in WBS among relevant I-O sectors, we have collected needed information by interviewing the Japan Iron and Steel Federation and the Nippon Slag Association. We then modified the allocation table to reflect our information.

Secondly, in order to obtain the total amounts of industrial wastes in Japan, we multiplied the amounts derived from WBS by the proportionality constant since WBS is a survey and does not cover all Japanese establishments. The proportionality constant for each sector was obtained by comparing sales figures for the sector from the Census of Manufacturers data and WBS. Sectors of these two data sets are comparable since both use the JSIC system to define their sectors.

Table 1 lists 37 types of industrial wastes discussed in this paper. Industrial wastes in Japan are classified into (1)37 types given in Table 1 and (2)especially regulated industrial wastes. Special industrial wastes in the latter category (2) are highly hazardous and include material contaminated with PCB, asbestos, strong acid with pH less than 2, strong alkali with pH higher than 12.5, highly inflammable waste oil and infectious wastes. WBS excludes wastes in category (2) that need to be treated separately. Industrial wastes other than those in category (2) include certain toxic substances (e.g. heavy metals, Pb, Cd) that must be treated properly.

For each establishment and each type of waste, the following material balance equation must hold:

$$Waste_{ij}^{(k)} = W_{ij}^{(k)} x_j^{(k)} \text{ and } 1 = V_{ij}^{(k)} + U_{ij}^{(k)} + T_{ij}^{(k)} \quad i=1,...,37\,;\, j=1,...,401, \text{ and } k=1,...,5048 \qquad (6)$$

All wastes are measured by weight in metric tonnes, and output $x_j^{(k)}$ is measured in monetary unit (in 1 million yen).

3. The estimated results

3.1 Distributions of unit waste generation rates

The first objective of this paper is to estimate the statistical distributions of waste generation rates among establishments.

Table 2 presents descriptive statistics for these waste generation rates, $W_{ij}^{(k)}/x_j^{(k)}$, for waste of type i for establishment k in sector j. The number of observations (Nobs) denotes the number of establishment with non-zero production, $x_j^{(k)}>0$. Waste plastics other than synthetic rubber have the largest number of observations, which means waste plastics are the most common industrial waste. For all industrial wastes except waste animal-solidified, the sample mean is larger than the median, and the maximum value is far larger than the sample mean. This means that the distributions of unit waste generation rates *W/x* are asymmetric to left, with a few smaller values occur with very high frequencies and a long tail for large values.

JSIC: 0110	Cinders other than coal	0111	Coal cinders
0210	Inorganic sludge other than polishing sand	0211	Inorganic sludge of polishing sand
022	Organic sludge	0230	Organic-inorganic mixed sludge other than polishing sand
0231	Organic-inorganic mixed sludge of polishing sand	031	Waste oil other than chlorinated solvent waste
032	Waste oil chlorinated solvent waste	040	Used acidic liquid
050	Waste alkali	061	Waste plastics other than synthetic rubber
062	Waste plastics synthetic rubber	070	Wastepaper
080	Chips and sawdust	090	Waste textile
100	Animal and vegetable remnants	101	Waste animal-solidified
110	Rubber waste	121	Scrap iron
122	Non-ferrous metal scrap	131	Scrap glass
132	Clay, porcelain, ceramic scrap	133	Scrap slab concrete
141	Waste moulding sands	1420	Slag other than steel, ferroalloy, and copper
1421	Iron-steel slag	1422	Ferroalloy slag
1423	Copper slag	1430	Slag other than aluminum dross
1431	Aluminum dross	150	Demolition debris
160	Animal manure	170	Animal carcasses
1800	Soot and dust other than coal ash	1810	Soot and dust flay ash
190	Processed material for disposal		

Table 1. 37 waste materials reported in the Wastes and By-Products Survey (WBS)

Waste	**Nobs**	**Mean**	**Median**	**Max**	**SD**
cinders other than coal	306	0.137	0.002	20.524	1.204
coal cinders	50	0.038	0.003	0.957	0.141
inorganic sludge excl. polishing sand	1815	0.091	0.006	25.744	0.905
inorganic sludge polishing sand	52	0.157	0.003	6.453	0.893
organic sludge	986	0.268	0.007	47.229	2.082
organic and inorganic mixed sludge	776	0.049	0.005	1.583	0.165
mixed sludge polishing sand	18	0.171	0.003	2.829	0.664
waste oil excl. chlorinated solvent waste	3080	0.019	0.002	2.495	0.090
waste oil chlorinated solvent waste	303	0.018	0.001	1.425	0.099
used acidic liquid	1242	0.153	0.002	50.131	1.738
waste alkali	1184	0.045	0.002	2.937	0.192
waste plastics excl. synthetic rubber	3694	0.027	0.005	2.114	0.080
waste plastics synthetic rubber	282	0.038	0.005	0.610	0.071
wastepaper	2612	0.069	0.005	2.631	0.244
chips and sawdust	2089	0.035	0.002	5.796	0.295

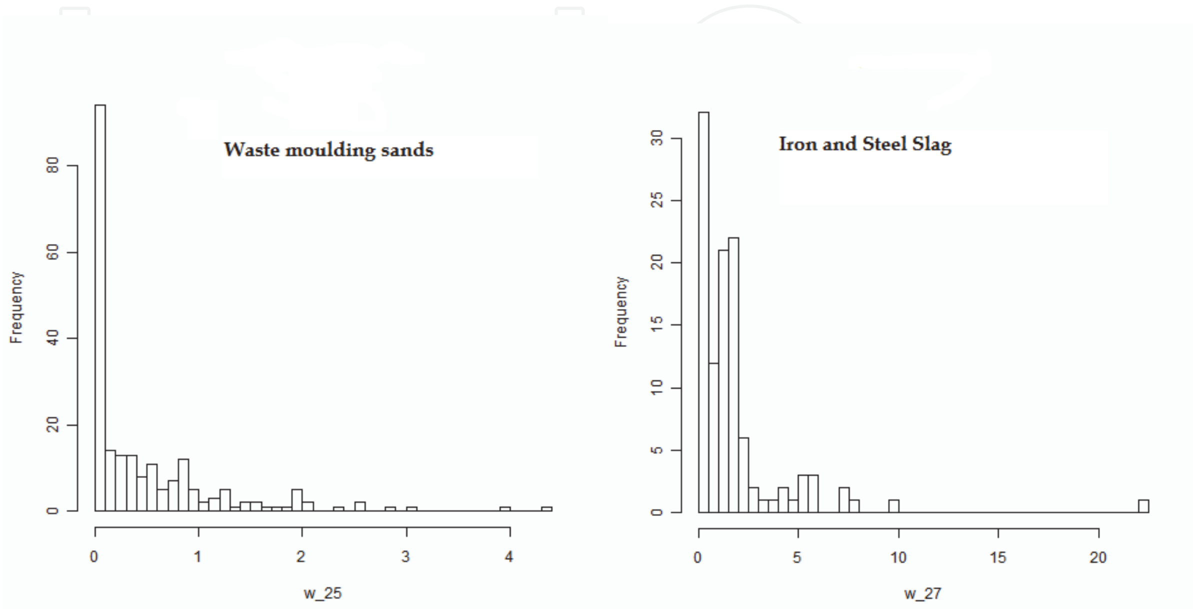
waste textile	261	0.033	0.001	5.898	0.366
animal and vegetable remnants	443	0.103	0.002	3.109	0.309
waste animal-solidified	2	1.174	1.174	2.230	1.494
lubber waste	61	0.017	0.000	0.280	0.051
scrap iron	3037	0.066	0.008	5.991	0.233
non-ferrous metal scrap	1464	0.017	0.002	0.561	0.050
scrap glass	1492	0.012	0.000	3.612	0.140
clay, porcelain, ceramic scrap	620	0.030	0.001	3.319	0.195
scrap slab concrete	8	0.687	0.008	4.733	1.653
waste moulding sands	214	0.493	0.195	4.326	0.708
slag excl. steel, ferroalloy, and copper	74	0.316	0.052	7.561	0.966
iron-steel slag	111	1.859	1.291	22.222	2.678
ferroalloy slag	11	11.191	3.956	64.592	19.683
copper slag	17	3.479	0.050	23.219	7.228
slag other than aluminum dross	192	0.193	0.038	4.485	0.527
aluminum dross	50	0.144	0.058	1.825	0.277
demolition debris	303	0.077	0.001	19.809	1.139
animal manure	6	0.001	0.000	0.003	0.001
animal carcasses	12	0.003	0.000	0.017	0.006
soot and dust excl. coal ash	434	0.160	0.008	3.462	0.354
soot and dust fly ash	46	0.067	0.032	0.534	0.109
processed material for disposal of industrial waste	119	0.007	0.001	0.170	0.020

Table 2. Descriptive Statistics for the unit waste generation rate *W/x* in 2006

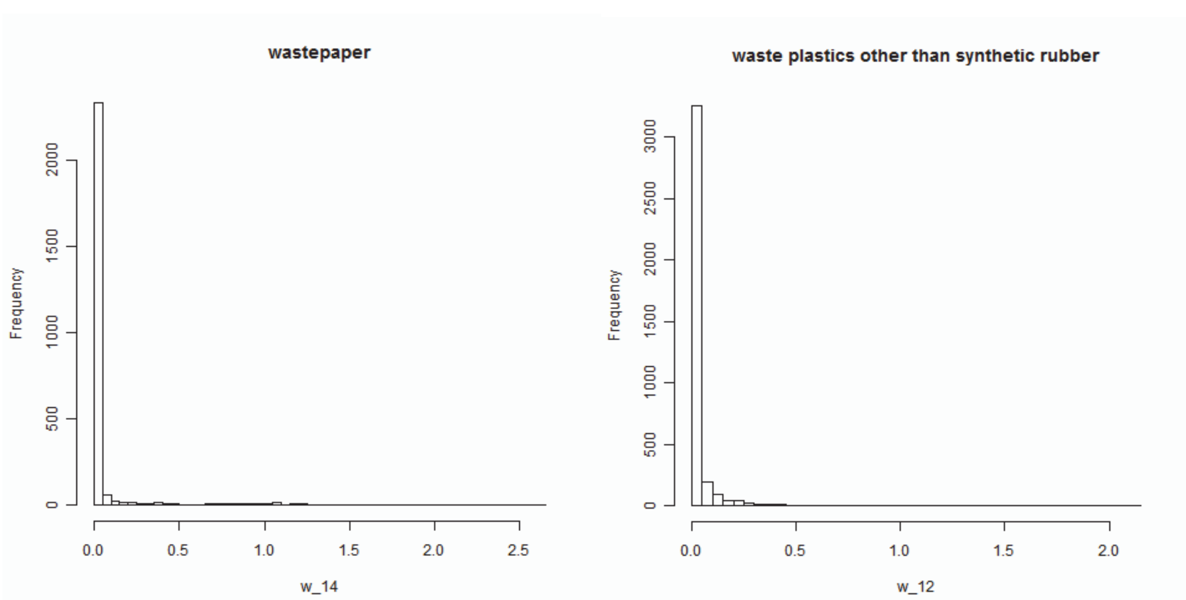
Several typical shapes of statistical distributions are shown in Figures 1a and 1b. Figure 1a shows the distributions for waste moulding sands and iron and steel slag. Iron and steel slag does not have a large distance between the mean and the median, but it has a large maximum, 22.22 tonnes per 1 million yen, which is 12 times as large as the mean, 1.859 tonnes per 1 million yen. Standard deviation (SD) is larger than the mean, and the coefficient of variation is 1.44. Figure 1b shows two of common types of distributions for *W/x* for wastepaper and waste plastics, which concentrate around 0. Both have the median of 0.005 tonnes per 1 million yen of production. But the mean is 0.069 tonnes for wastepaper and 0.027 for waste plastics, with a maximum, 2.631 for wastepaper, and 2.114 for waste plastics. Extremely large maximum values may reflect irregular production and inventory practices at some establishments.

Figure 2 shows that the distributions for recycling rates for inorganic sludge and polishing sand. Both figures have concentrations around 0 and 1. This means that establishments face an all or nothing choice. Once a waste material is recycled, the establishment should choose recycling all wastes. This result follows because of the high initial cost of recycling equipment and the availability of outsourcing. But outsourcing is not available if the establishment location is far from the center of the recycling industry. As a result, the final disposal method (landfill here) is also highly concentrated around 0 and 1, as in Figure 3.

We have tried statistical fitting of these empirical distributions derived here with only a partial success. First, we tried to use the Gamma distribution to fit observed distributions for unit generation rate, *W/x*. But only 7 out of 37 distributions for industrial waste have been found not to be significantly different from the Gamma distribution. An appropriate theoretical distribution to fit the empirical distributions for recycling ratio, U/W, is the Beta distribution since recycling rations range between 0 and1. But our test of the goodness of fit rejected the Beta distribution for all cases.



a)



b)

Fig. 1. a)Typical distributions of waste generation coefficients: Waste Moulding Sands (214 establishments and Iron and Steel Slag (111 establishments), b) Typical distributions of waste generation coefficients: Wastepaper (2612 establishments), and Waste plastics other than synthetic rubber (3614 establishments)

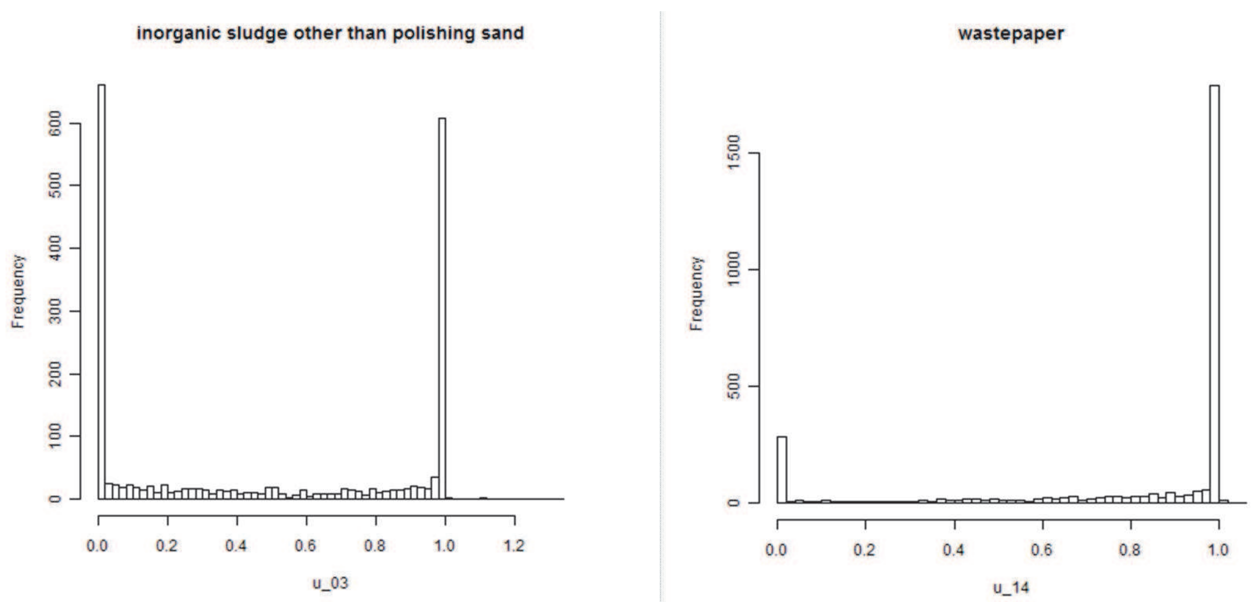


Fig. 2. Typical distributions of recycling rates: Inorganic sludge other than polishing sand (1815 establishments), and Wastepaper (2612 establishments)

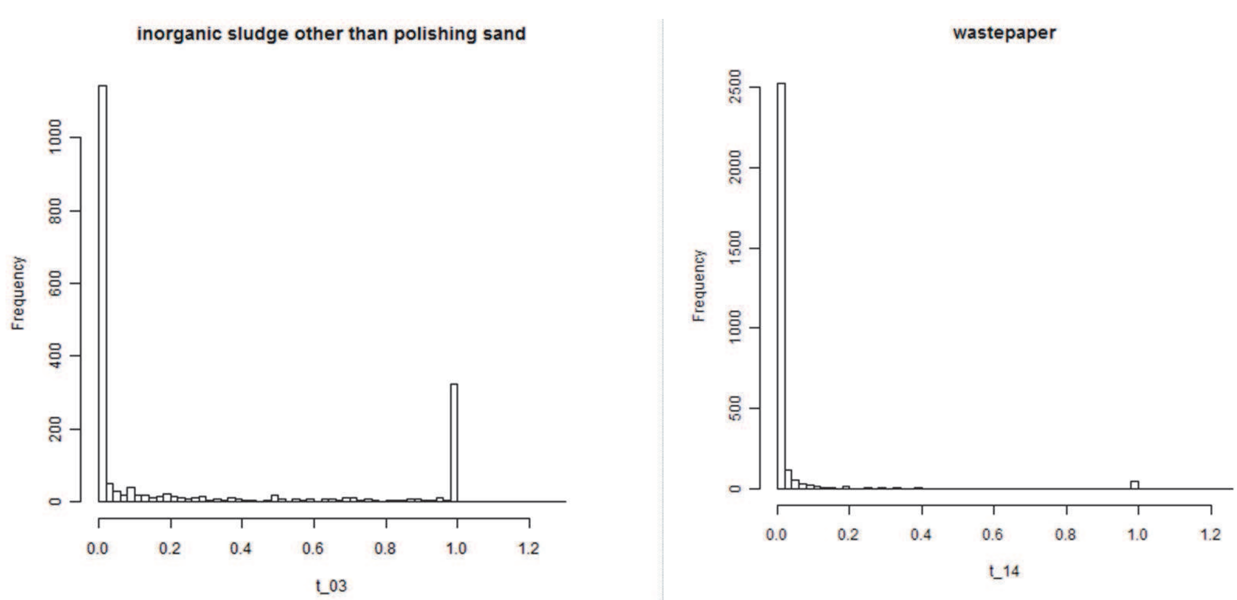


Fig. 3. Typical distributions of landfill rates: Inorganic sludge other than polishing sand of 1815 establishments (left), and wastepaper of 2612 establishments (right)

Bootstrap resampling can calculate confidence intervals for the unit waste generation rate, *W/x,* from estimated empirical distributions. Table 3 shows simulated confidence intervals and the mean. The empirical distribution of $W_{ij}^{(k)}/x_j^{(k)}$ used is based on observations from WBS 2005 and 2006. We used as re-sampling size 5000 for non-parametric estimation. The simulated mean uses weighs of output and our results correspond to unit waste generating rate *W/x*.[4] We find that six out of seven wastes show the same statistical characteristics: (1)the median is smaller than the mean; and (2)the distributions have a long tail. But iron-steel slag (193 observations) has a nearly symmetric distribution as shown in Figure 4a. According to the central limit theorem, the distribution of a sample mean with a finite variance converges to the normal distribution. But our statistical test of the goodness of fit does not support gamma or normal distributions. The convergence in distribution to the normal distribution is not seen for distributions of other wastes either as shown in Figure 4b. The distribution for a positive random variable becomes exponential at the maximum entropy; in the present case a statistical test rejects the exponential distribution also.

	2.50%	5%	Median	95%	97.50%	Mean
Inorganic sludge	0.0073	0.0089	0.0343	0.2271	0.5347	0.0887
Sludge of polishing sand	0.0055	0.0071	0.0396	1.0490	1.1367	0.1888
Waste plastics	0.0062	0.0074	0.0227	0.0822	0.1100	0.0322
Waste paper	0.0024	0.0029	0.0156	0.4156	0.5044	0.0714
Scrap iron	0.0097	0.0119	0.0431	0.1666	0.2272	0.0623
Scrap glass	0.0001	0.0001	0.0007	0.0292	0.0822	0.0110
Iron-steel slag	1.4132	1.4787	1.9442	2.6046	2.7613	1.9810

Table 3. Simulated confidence intervals and the mean for unit waste generation rate *W/x*

Results for the distributions of the recycling rate using the same procedure as before are given in Table 4 and Figures 5a and 5b. Compared to distributions for the waste generation rates, distributions for the recycling rates are nearly symmetric. And the figures are clearly different from those given in Figure 2 for population the distributions (histograms) of the waste generation rate. This difference arises because, in case of distributions for recycling rates, there is the effect of aggregation of recycling rates. The sample mean is almost the same value as the sample median in Table 4. We can conclude that, for the distributions for recycling rates, *U/W*, for all sectors, observed values are close to both the mean and median of the simulated value and their confidence intervals are symmetric.

These results on the distributions of unit waste generation rate *W/x* and recycling rate *U/W* imply that the potential problems in policy making from assuming the representative (average) waste management activity come mostly from the distributions for unit waste generation rates *W/x*. The mean assumed in theory does not always reflect the typical intensity of waste generation. It also means that regulations based on the mean of a representative establishment does not always give effective regulations to the majority of establishments. Most of the establishments can clear the regulation standard, because the standard is based on the mean of the distribution. But as we have shown, the mean does not capture the essential property of the distributions underlying the waste generation rate.

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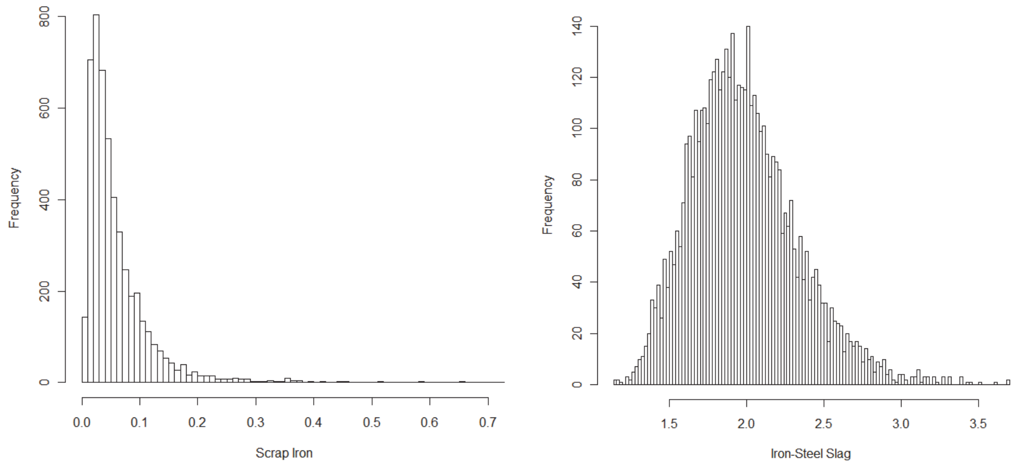
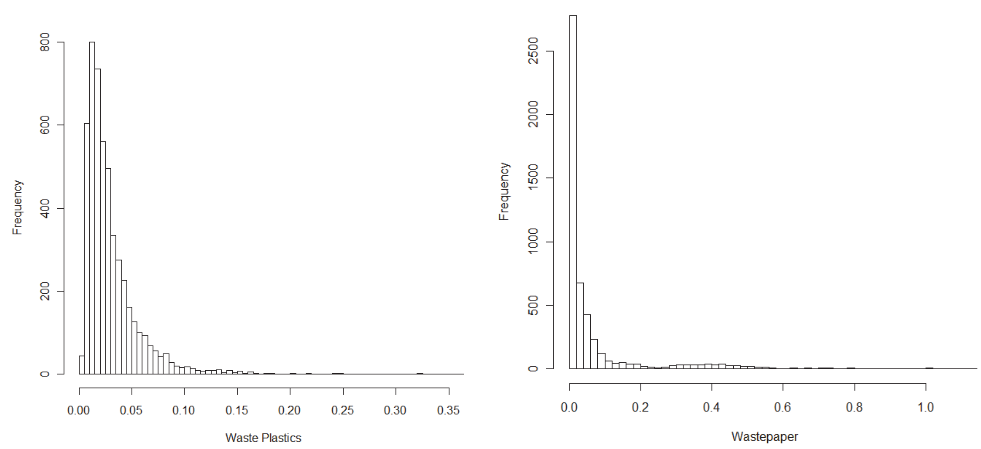
[4] This is because $W_{ij} = \frac{\sum_k Waste_{ij}^{(k)}}{\sum_k x_j^{(k)}} = \sum_k \left(\frac{x_j^{(k)}}{x_j}\right)\left(\frac{Waste_{ij}^{(k)}}{x_j^{(k)}}\right) = \sum_k \left(\frac{x_j^{(k)}}{x_j}\right) W_{ij}^{(k)}$, generating Wij(k) from the empirical distribution of Wij(k) and taking the weighted average gives Wij, which the Input-Output calculation uses.



a)

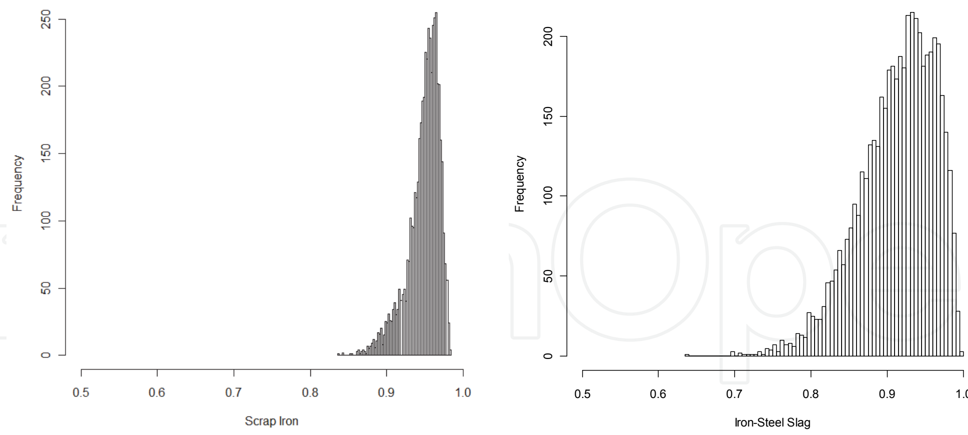


b)

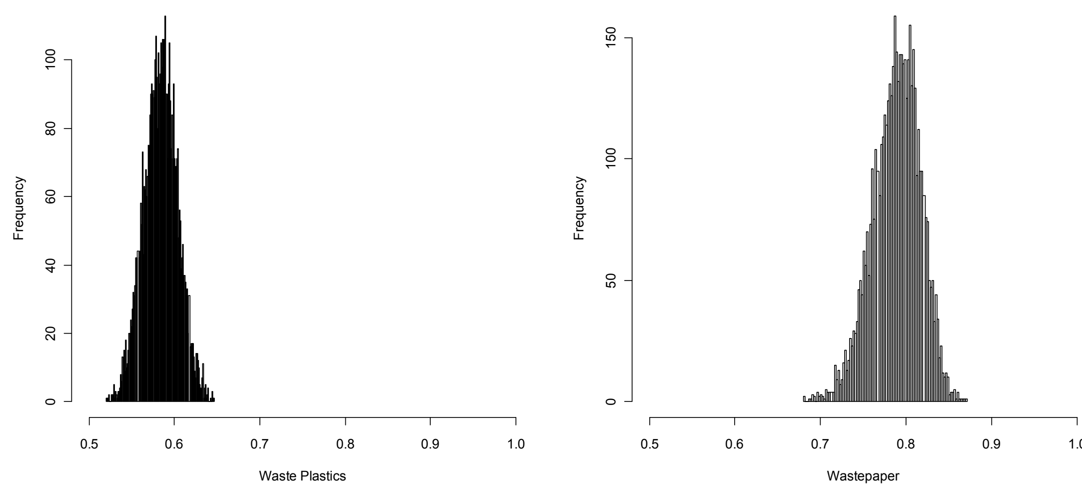
Fig. 4. a) Distributions for unit waste generation rates, *W/x,* (bootstrapped weighted mean): Scrap Iron (left) and Iron-Steel Slag (right) b) Distributions for unit waste generation rates, *W/x,* (bootstrapped weighted mean): Waste plastics (left) and Wastepaper (right)

	2.50%	**5%**	**Median**	**95%**	**97.50%**	**Mean**
Inorganic sludge	0.398	0.414	0.513	0.609	0.626	0.513
Sludge of polishing sand	0.158	0.212	0.513	0.825	0.861	0.513
Waste plastics	0.546	0.552	0.584	0.616	0.622	0.584
Waste paper	0.730	0.741	0.791	0.831	0.837	0.789
Scrap iron	0.894	0.905	0.953	0.974	0.977	0.949
Scrap glass	0.436	0.480	0.677	0.858	0.886	0.679
Iron-steel slag	0.798	0.822	0.920	0.979	0.984	0.913

Table 4. Simulated confidence interval and mean of the recycling rate *U/W*



a)



B)

Fig. 5 a. Distribution of recycling rate *U/W (*bootstrapped weighted mean): Scrap Iron (left), and Iron-Steel Slag (right)b. Distribution of recycling rate *U/W (*bootstrapped weighted mean): Waste plastics (left), and Wastepaper (right)

3.2 Upstream waste generation: Calculation from the input-output analysis

The second objective of this paper is to estimate the amounts of waste generated in various stages of production along a supply chain, starting from downstream production the final product to upstream production of supplies. We us the I-O table linked to the WBS data set explained in Section 2.1 above. Tables 5a and 5b, respectively, describe the total amounts of wastes generated average production supply chains for cellular phones and passenger car production in Japan in 2000. In both cases, pig iron is the most significant contributor of industrial waste. This is because production of pig iron generates heavy wastes such as iron-steel slag. The second most significant contributor is electricity for cell phones and passenger car final assembly for passenger cars. The total amounts of wastes generated are about 410 thousand tonnes for cellular phones and over 9 million tonnes for passenger car production. The cellular phone assembly sector generates relatively small amounts of wastes but the passenger car assembly sector generates large amounts of wastes.

One of the most important wastes generated in producing pig iron is iron-steel slag, whose unit generation rate distributes in a rather narrow range, has a symmetric distribution as shown in Figure 4a and its variance is smaller compared to other wastes generated in any other sectors. Unit waste generation rate for iron and steel slag lies between 1.4132 and 2.7613 at a 95% level (Table 3).

Cellular phone production supply chain in Japan, 2000: final assembly and associated indirect (induced) stages of production by upstream suppliers	**Total amounts of wastes and by-products generated in stages of a supply chain (in tonnes)**
Pig iron	44,620
Electricity	42,440
Other electronic components	35,617
Copper	26,882
Plastic products	22,913
Crude steel (converters)	18,306
Paper	17,331
Cellular phone final assembly (direct stage)	*13,434*
Printing, plate making and book binding	13,367
Cyclic intermediates	12,002
Thermoplastics resins	9,258
Reuse and recycling	8,043
Aliphatic intermediates	7,925
Crude steel (electric furnaces)	7,782
Paperboard	6,832
Hot rolled steel	6,731
Cold-finished steel	6,151
Corrugated card board boxes	5,437
Petrochemical basic products	5,092
Lead and zinc (inc. regenerated lead)	4,490
Pulp	3,768
Other non-ferrous metals	3,696
Ferro alloys	3,621
Liquid crystal element	3,344
Integrated circuits	3,297
Other industrial inorganic chemicals	2,922
Iron and steel shearing and slitting	2,891
Electric wires and cables	2,802
Corrugated cardboard	2,791
Other metal products	2,601
Direct (final assembly of cell phones)	*13,433*
Total (all stages of production supply chain combined)	*410,713*

Table 5a. Generated wastes and by-products induced by cellular phone production

Passenger car production supply chain in Japan, 2000: final assembly and associated indirect (induced) stages of production by upstream suppliers	**Total amounts of wastes and by-products generated in stages of a supply chain (in tonnes)**
Pig iron	1,822,777
Passenger car final assembly (direct stage)	*1,486,409*
Crude steel (converters)	835,245
Motor vehicle parts and accessories	766,708
Electricity	422,843
Crude steel (electric furnaces)	365,982
Hot rolled steel	307,681
Internal combustion engines for motor vehicles and parts	276,001
Motor vehicle bodies	235,853
Cold-finished steel	200,976
Cast and forged materials (iron)	198,766
Ferro alloys	173,293
Coated steel	147,778
Reuse and recycling	132,619
Plastic products	120,871
Sheet glass and safety glass	108,440
Paper	89,860
Copper	84,560
Cyclic intermediates	81,456
Printing, plate making and book binding	70,531
Aliphatic intermediates	57,100
Thermoplastics resins	55,511
Synthetic rubber	46,305
Non-ferrous metal castings and forgings	44,044
Paperboard	39,111
Petrochemical basic products	37,843
Iron and steel shearing and slitting	37,178
Other metal products	37,135
Electrical equipment for internal combustion engines	36,679
Steel pipes and tubes	33,723
Direct (final assembly of passenger cars)	*1,486,409*
Total (all stages of production supply chain combined)	*9,090,400*

Table 5b. Generated wastes and by-products by Passenger Car production

Electricity sector also generates a significant amount of waste material, fly ash. The distribution for its unit waste generation rate is shown in Figure 6, with its 95% confidence interval (0.040, 0.110). Another waste, ferroalloy slag is generated by production supply chain stages for both cell phones and passenger cars. Its unit waste generation rate has a rather irregular distribution as shown in Figure 6, with its 95% confidence interval being very wide and given by (2.47, 34.96). This suggests that waste management policies based on point estimates for the unit waste generation rate for ferroalloy waste may lead to quite erroneous implications in practice.

We have shown that unit waste generation rates for various wastes generated by production supply chains distribute in different manners, sometimes with large variances and asymmetric ways. This means serious limitations about the accuracy of policy decision making relying on point estimates for the waste generation by production supply chains as we do in EIO-LCA and other types of life cycle analyses.

Given this limitation in mind, we may still be able to use information on waste generation in upstream production stages. Table 6 shows the total amounts of all wastes combined and amounts of CO_2 emissions in the final (direct) assembly stage, a few upstream stages and all stages combined of the average production supply chain for passenger cars with 2000cc engines. Table 6 gives information about the stages which generate more waste than others. Generally waste materials tend to be generated evenly along stages of a supply chain while CO_2 emissions tend to be generated more unevenly and fluctuate widely along stages of a supply chain. From policy perspectives, we conclude that application of production process LCA is more difficult for CO_2 emissions than for generation of the 37 waste materials.

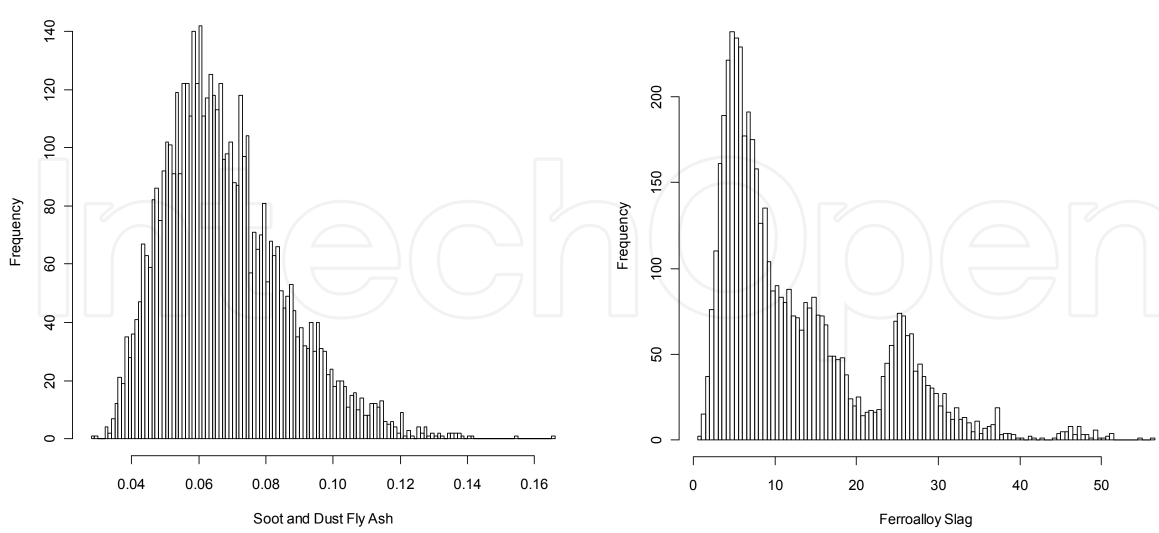


Fig. 6. Distribution of the unit waste generation rate *W/x* (bootstrapped weighted mean): Fly ash (left) and ferroalloy slag (right)

All wastes combined (summed in weight)	Each Stage	Cumulative	
	(in tonnes)	(in tonnes)	Ratio
direct stage (final assembly)	0.244	0.244	0.164
1st indirect stage	0.263	0.507	0.340
2nd indirect	0.226	0.733	0.491
3rd indirect	0.255	0.988	0.662
4th indirect	0.232	1.219	0.817
……	……	……	…..
Total (all stages combined)		1.493	1
CO_2 emissions	**Each Stage**	**Cumulative**	
	(in tonnes)	**(in tonnes)**	**Ratio**
Direct	0.108	0.108	0.020
1st Indirect	0.707	0.814	0.155
2nd Indirect	1.206	2.020	0.384
3rd Indirect	1.152	3.172	0.602
4th Indirect	0.897	4.069	0.773
……	…..	…..	…..
Total		5.266	1

Table 6. Total wastes combines and CO_2 generated by stages of the average production supply chain in Japan: passenger cars with 2000cc engines

4. Conclusion

Using the datasets that recently became available, we have obtained empirical distributions for generation, recycling and landfill rates for the 37 types of waste materials that are generated in the production processes of Japanese manufacturing establishments. Some of the statistics reported are for the total amounts of all the wastes combined to save space. Many empirical distributions obtained are not symmetric and have a long tail with the mean much larger than the median, making it inappropriate for policy decision making based on the mean generation rates. For example, if the regulation level is set at the industry mean, it is likely that most establishments satisfy the regulation level without efforts while a few large violators exceed the level by a big margin. In such a case it is more cost effective to set the regulation standard at a level much higher than the mean, thus saving the monitoring costs at most establishments while spending efforts to identify the few violators.

In the second part of the paper we have shown how to estimate the amounts of wastes generated along stages of the average production supply chain and then given estimates for production processes of cellular phones and passenger cars. We have repeated this for emissions of carbon dioxide. In this supply chain analysis, we have shown that, given the large amounts of wastes generated in stages of upstream production supply chains, it is misleading to formulate waste management policies based only on the wastes generated in the final demand stages of supply chains. Our estimation results suggest that, in setting waste management policies, policy makers need to consider (1)not only the wastes generated from the final assembly stage but also the wastes generated from upstream stages of production supply chains and (2)such policies need to have different regulation standards for upstream stages depending on the final sector product and also the waste being considered to be regulated. For example, we have found that the amounts of CO_2 emissions vary significantly from one stage to another of the Japanese production supply chain for passenger cars.

5. Acknowledgments

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6. Endnotes

An earlier version of this paper was presented at the 18th International Input-Output Association Conference held at the University of Sydney in Australia, June 20-25, 2010. Preparation of the datasets used was done using Programming Language Pyhon 2.7 and statistical analyses were done using R 2.12.1. Further details are available by e-mailing: hayami@sanken.keio.ac.jp.

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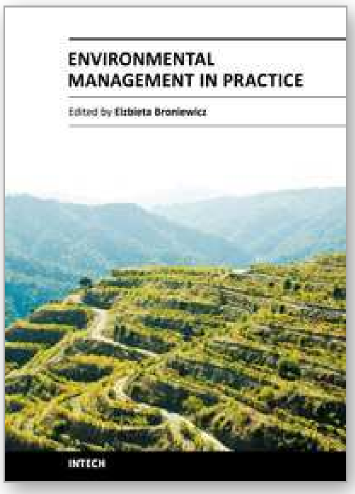

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In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.