



Estimation of hazardous waste factors

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ABSTRACT

The first step of establishing a reliable waste inventory is the determination of waste factors. This study presents a detailed survey for the estimation of waste factors from different manufacturing sectors. Waste factors were obtained in units of “tons of hazardous waste generated per 1 ton of production of related industry” using waste generation figures given by Turkish Statistics Institute (TURKSTAT) and production figures given by The Union of Chambers and Commodity Exchanges of Turkey (TOBB). Estimated waste factors were cross-checked with the information obtained from field surveys conducted for basic metal and metal finishing industries. The hazardous waste factors obtained from TURSTAT and TOBB data for Basic Metal Industries (37) and Manufacture of Fabricated Metal Products, Machinery and Equipment (38) are 0.0035 and 0.0068, respectively. From the field surveys, the average hazardous waste factor of eight facilities in category (37) is estimated as 0.054 and that for six facilities in category (38) is determined as 0.007. In a parallel evaluation, hazardous waste factors obtained from production and waste generation figures declared by nine facilities in Basic Metal category (37) and 16 facilities in Metal Finishing category (38) are calculated as 0.017 and 0.012, respectively. These varying results indicate that for reliable waste factors estimation, hazardous waste generation and production figures of the industries should be attained correctly and checked with various data obtained from different sources before they are used for establishing the waste inventories.

Keywords: Hazardous waste; Inventory; Waste lists; Waste factors

1. Introduction

Hazardous wastes constitute one of the major environmental problems. Management of hazardous wastes should be based on accurate information about the amounts of different types of hazardous wastes. Accordingly, an accredited and up-to-date hazardous waste inventory is a crucial source of information. In order to establish a reliable waste inventory, hazardous waste generation should be determined on the basis of

manufacturing activities. The monitoring and auditing activities for the waste amounts and flows can only be managed appropriately if the waste generation for manufacturing activities is known [1].

The first step of establishing a reliable waste inventory is determination of the waste factors. Waste factors basically construct the relationship between waste generating manufacturing activities and the generated wastes. It is possible to estimate the waste factors by obtaining correct production and waste data based on manufacturing industry classifications. If the production figures and the corresponding waste generations can be correctly attained

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for representing industry categories, the waste factors calculated based on these information for each manufacturing sector based on manufacturing activities can be used to estimate accurate waste amounts for the planning and operation of hazardous waste treatment and disposal facilities as well as the design of new .

The waste factors should of course be updated on a yearly basis with the updated production and waste generation [2].

This study presents the results of a detailed survey for the estimation of waste factors from different manufacturing sectors. The study was conducted based on the statistical data presented by Turkish Statistics Institute (TURKSTAT) [3] and The Union of Chambers and Commodity Exchanges of Turkey (TOBB) [4]. The waste factors, described in this study as “tons of hazardous waste generated per 1 ton of production of related industry”, were obtained using the waste generation figures given by TURKSTAT and the production figures given by TOBB for different manufacturing sectors. The estimated waste factors were cross-checked with the information obtained from the field survey conducted for the basic metal and metal finishing industries established and currently active in Turkey.

2. Materials and methods

2.1. Establishment of waste factors

The waste factors, which are of prime importance in compilation of waste inventories, might be determined either from the measured, or calculated, or estimated data. They could be described in terms of and calculated as (i) waste generated per employee per year, or (ii) waste generated per product (production unit) per year. Despite of the current developments in the field of statistics [5], as well as more data being recently available, it is still a challenge to gather reliable information on waste quantities and waste streams.

Hence, waste factors are of great significance for establishing and clarifying the following issues:

- waste quantities and waste streams.
- short falls in harmonization with the relevant EU acquis.
- impact of efforts on control of waste streams and waste minimization.
- essentials of projections and scenarios.

Current improvements in data declaration, accessibility, and gathering are useful in establishing the waste factors, as well as in determining the advantages and disadvantages of applying those factors at technological, industrial, and economical levels. Then again,

establishment of waste factors is not quite straight forward and requires intense effort. Due to the complicated nature of the process and despite of the many studies carried on to date, there has been no consensus on a particular waste factor, neither on national nor on international basis. In addition, there is no single description of “waste factor” accepted and adopted by all parties, which then makes it impossible to comparatively evaluate the information collected and declared as “waste factors”. Accordingly, the “waste factors” established so far have provided only a limited ease for the governance of waste management and planning efforts [6].

Establishment of the waste factors i.e., in terms of waste generated per employee or per production unit, etc., has remained so far at an unsatisfactory level because of practice of conventional waste management policies and lack of appropriate and sufficient data. In contrast, the new trends in “sustainability” highlight the importance of “source-oriented” approaches, such as waste minimization and prevention. Consequently, it is clearly required (i) to collect data and information with a focus of industrial production processes being the source of the waste generated, and (ii) to use a systematic approach for structuring the implementation methodologies. Those two issues remain to be essential for establishment of reliable and comparable waste factors [6].

To construct reliable waste inventories at the national basis, the current situation should be determined as accurate as possible. For that, it is required to determine the production–waste relations and to establish the waste factors relating the generated waste to the industrial processes based-production data.

The “production, waste, and hazardous waste quantities” data could be generated by compiling the production data present at TOBB database [4] for all industrial sectors in Turkey and evaluating those together with the environmental statistics presented by TURKSTAT [3]. Yet, there are still concerns regarding the reliability of the presented production and waste generation data and the way of collecting them. Within this context, it is crucial to evaluate the information harvested from the databases together with the data presented at the “Waste Management Plans” prepared for each city, and the information declared by hazardous waste generating facilities in the “Waste Declaration Forms” presented to the Ministry of Environment and Forestry (MoEF) on a yearly basis.

In short, to be able to execute reliable hazardous waste inventory works, it is strongly required to establish the “production-based sectoral waste factors”, which should be determined by using the production, waste, and hazardous waste data correctly determined in relation with the manufacturing activities.

2.2. Cross-checking and matching the categories and codes for industrial sectors

The first step of establishing the “production-based sectoral waste factors” through relating the manufacturing activities with the waste and hazardous waste generation is to select the main industrial sectors generating the wastes. Yet, it should be noted at this point that, the coding systems, hence the codes, used by the national agencies in Turkey to describe the industrial categories and sub-categories are different that those assigned by the EU counterparts and used at the international platform. This difference in coding results in substantial difficulties while comparing the different databases and points to the need for a mutual way of expressing the industrial sectors and the relevant categories. Hence, to be able to compare the national data with those of the EU countries, it is required to cross-check and adopt the categories of the main industrial sectors and their sub-sectors in Turkey with those in EU, and to match the codes in both sources.

TURKSTAT statistical environmental data is collected using the national codes of activities (US-97) which is established as a result of merging the economic activities given in *ISIC Rev. 3* and *NACE Rev. 1*. *ISIC* classification is the “International Standard Industrial Classification of All Economic Activities”, published and kept updated by the United Nations Statistics Division (UNSD) and *NACE* is a 4-digit activity classification which is the “General Industrial Classification of Economic Activities within the European Communities” and was originally published by EUROSTAT in 1970, being continuously updated. The statistical environmental data collected and published by TURKSTAT presents the waste and hazardous waste productions according to the classification of industrial sectors given in US-97. TOBB also presents a database keeping track of employee and annual production amounts of all industrial sub-sectors. TOBB industry database is established according to the production codes that are determined by the international codification system, *ISIC Rev. 2*. TOBB industry database is an updated information source containing data on industrial establishments in Turkey and it is being continuously improved.

In order to establish the relationship between different activity classifications of TURKSTAT and TOBB, it is necessary to match codes of different sector categories for the manufacturing industry. Although there are some exceptional sub-categories, TURKSTAT and TOBB codes matching of manufacturing industry classifications for the main categories is presented in Table 1. The table also presents the 3-digit TOBB codes used for the classification of waste accepted to İZAYDAŞ waste incineration and disposal facilities. The waste shares of different industrial categories are given in Table 1 based

on the data from year 2006 [7]. As shown in Table 1, sub-sectors of 381, 382, 383, and 384 clustered under the main manufacturing sectors of 38 and 39 (TOBB codes) make up 33% of the total amount of waste accepted to İZAYDAŞ in 2006.

2.3. Establishing hazardous waste generation–production relations

It is necessary to investigate the correlation between hazardous waste generation and production figures for different industrial sectors. The only official source of information for the hazardous waste generation in Turkey is the TURKSTAT inventory of 2004 [3]. The production figures for different sectors have been calculated using TOBB database and thus waste factors based on unit production are estimated. TURKSTAT inventory data of 2004 is based on the Environmental Statistics for Manufacturing Industry surveys conducted among all public manufacturing industries and among large private manufacturers employing more than 10 employees and comprising more than 80% of the added value generated by all private manufacturing sectors.

TURKSTAT inventory also includes waste sludge figures which are nearly twice the amount of total hazardous waste generated, although not all treatment plant sludges are hazardous. Therefore amounts given for waste sludge are excluded and the waste factors were estimated without taking into account the generation of hazardous treatment plant sludges.

The TURKSTAT–TOBB code coupling given in Table 1 was used to match the hazardous waste amounts given in TURKSTAT 2004 database and the production amounts that were calculated using TOBB data for all sectors from 31 to 39, by adding all production data given for each sub-category in each manufacturing sector. The calculated hazardous waste and production figures and their ratio as waste factor for each manufacturing sector are given in Table 2 [9]. Table 2 shows that, the highest waste factor of 8.3% is reported for Manufacture of Fabricated Metal Products, Machinery and Equipment (38) and Basic Metal Industries (37), while the highest ratio of hazardous waste to total waste of 24% is observed for Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products (35) sector. Although the hazardous waste to total waste ratio of manufacture of chemicals industry (35) is the highest ratio, the amount of hazardous waste generated is lower than Metal Finishing Industry (38) and Basic Metal Industries (37), since the waste factor of Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products (35) is 10 folds less than Manufacture of Fabricated Metal Products, Machinery and Equipment (38)

Table 1
Main manufacturing categories (comparison of manufacturing activity codes according to different classifications)

TOBB TOBB code (ISIC Rev. 2)	TURKSTAT category and code (US-97/ISIC Rev. 3)	Waste share (TURKSTAT data)	İZAYDAŞ share (İZAYDAŞ 2006 data)	Important subcategories (TOBB based-İZAYDAŞ 3-digit code)	HWCR [8]** waste category (Waste types generated)
38	Manufacture of fabricated metal products, machinery and equipment Manufacture of machinery and equipment n.e.c.* (29) Manufacture of office, accounting and computing machinery (30) Manufacture of electrical machinery and apparatus n.e.c. (31) Manufacture of radio, television and communication equipment and apparatus (32)	6%	33%	381, 382, 383, 384	08, 11, 12, 15
39	Other manufacturing industries Manufacture of medical, precision and optical instruments, watches and clocks (33) Manufacture of motor vehicles, trailers and semi-trailers (34) Manufacture of other transport equipment (35)				
35	Manufacture of chemicals and chemical, petroleum, coal, rubber and plastic products Manufacture of coke, refined petroleum products and nuclear fuel (23) Manufacture of chemicals and chemical products (24) Manufacture of rubber and plastics products (25)	12%	30%	351, 352, 353, 354, 355	06, 07, 08
32	Textile, wearing apparel and leather industries Manufacture of textiles (17) Manufacture of wearing apparel; dressing and dyeing of fur (18) Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)	2%	2%	321, 323	04
37	Basic metal industries Manufacture of basic metals (27)	44%	4%	371, 372	11, 12, 13, 15
31	Manufacture of food, beverages and tobacco Manufacture of food products and beverages (15) Manufacture of tobacco products (16)	25%	1%	311, 312, 313	02
33	Manufacture of wood and wood products, including furniture Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20) Manufacture of paper and paper products (21)	2%	2%	341, 342	03, 08, 09
34	Manufacture of paper and paper products, printing and publishing Publishing, printing and reproduction of recorded media (22) Manufacture of furniture; manufacturing n.e.c. (36)				
36	Manufacture of non-metallic mineral products, except products of petroleum and coal Manufacture of other non-metallic mineral products (26)	9%	1%	361, 362, 369	—

*n.e.c.: not elsewhere classified;

**HWCR: Turkish Hazardous Waste Control Regulation.

Table 2
Total and hazardous waste amounts of different manufacturing sectors in relation to production (waste factors)

TOBB code	Main manufacturing category		Waste amounts (TURKSTAT 2004)			Turkish production amounts (TOBB data) (tons/y)	Waste factors (waste/production) (TURKSTAT/TOBB data)	
	TOBB category (ISIC Rev. 2)	TURKSTAT code (US-97/ISIC Rev. 3)	Waste share (TURKSTAT data)	Total waste amounts (tons/y)	Hazardous waste amounts (tons/y)		Hazardous waste/total waste ratio	Total waste/production
38	Manufacture of fabricated metal products, machinery and equipment	(28) (29) (30) (31) (32) (33) (34) (35)	6%	1,812,337	147,990	21,770,602	0.083	0.0068
39	Other manufacturing industries							
35	Manufacture of chemicals and chemical, petroleum, coal, rubber and plastic products	(23) (24) (25)	12%	1,711,741	406,001	212,255,744	0.008	0.0019
32	Textile, wearing apparel and leather industries	(17) (18) (19)	2%	505,146	6571	17,047,513	0.03	0.0004
37	Basic metal industries	(27)	44%	7,764,699	327,986	93,571,825	0.083	0.0035
31	Manufacture of food, beverages and tobacco	(15) (16)	25%	3,531,444	270,202	319,787,883	0.011	0.00085
34	Manufacture of wood and wood products, including furniture	(20) (21) (22) (36)	2%	479,455	4024	13,739,213	0.035	0.0003
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33	Manufacture of paper and paper products, printing and publishing							
36	Manufacture of non-metallic mineral products, except products of petroleum and coal	(26)	9%	1,692,660	33,630	97,432,664	0.0174	0.00035
	Total manufacturing industry		100%	17,497,482	1,196,404	775,605,444	0.0226	0.00154

and Basic Metal Industries (37), despite its high production amount of 212,255,744 tons/y.

Therefore it is better and more reliable to describe the “hazardous waste factor” as hazardous waste production per unit production. It is seen from Table 2 that Manufacture of Fabricated Metal Products, Machinery and Equipment (38) and Basic Metal Industries (37) sectors have the highest hazardous waste factors per unit production as 6.8% and 3.5%, respectively. Despite the highest amount of hazardous waste of 406.001 tons/yr being generated by manufacturing of chemicals industry (35), the hazardous waste factor per unit production of Manufacture of Chemicals and Chemical, Petroleum, Coal, Rubber and Plastic Products (35) sector is only 1.9%, which is the third highest factor due to the high production amounts reported for the sector. In this context, the criterion used for selection of priority sectors should also be based on the magnitude of waste generation factor, in addition to the main criterion, namely, the amount of hazardous waste produced from a given sector.

3. Results and discussion

The study is focused on the estimation of hazardous waste factors for Basic Metal Industries (37) and Manufacture of Fabricated Metal Products, Machinery and

Equipment (38) manufacturing categories. The hazardous waste factors were estimated using the data obtained from the declared waste and production amounts of a total of 24 industrial facilities and using data collected and/or cross-checked by site visits performed to 14 different industrial facilities. The estimated hazardous waste factors from the information gathered from visited industrial facilities are given in Table 3 [10]. The data used for estimation of the hazardous waste factors belongs to year 2007.

The hazardous waste factors obtained from TURKSTAT and TOBB data for Basic Metal Industries (37) and Manufacture of Fabricated Metal Products, Machinery and Equipment (38) are 0.0035 and 0.0068, respectively. From the field surveys, the average hazardous waste factor of 8 facilities in basic metal category (37) is estimated as 0.054 and that for 6 facilities in metal finishing category (38) is determined as 0.007.

The hazardous waste generation and annual production figures for 2007 were declared by 24 facilities belonging to Basic Metal Industries (37) and Manufacture of Fabricated Metal Products, Machinery and Equipment (38) manufacturing sectors, in the official waste declaration forms submitted to MoEF. Although these facilities were not visited, the data presented in their declarations were found reliable for estimation of the hazardous waste factors as given in Table 4.

Table 3
Hazardous waste factors estimated from the information gathered from visited industrial facilities

Visited industrial facilities	Manufacturing industry	
	Manufacture of fabricated metal products, machinery and equipment (38)	Basic metal industries (37)
	Waste factors (hazardous waste/production)	
Facility 1	0.0095	–
Facility 2	–	0.020
Facility 3	–	0.054
Facility 4	0.0004	–
Facility 5	–	0.0009
Facility 6	–	0.042
Facility 7	–	0.016
Facility 8	0.0086	–
Facility 9	–	0.032
Facility 10	–	0.14
Facility 11	–	0.13
Facility 12	0.0040	–
Facility 13	0.0152	–
Facility 14	0.0052	–
Average	0.007	0.054
Waste factors estimated from TURKSTAT&TOBB data	0.0068	0.0035

Table 4
Hazardous waste factors estimated from the information gathered from industrial facilities which declared annual production amounts

Industrial facilities which declared annual production amounts	Manufacturing industry	
	Manufacture of fabricated metal products, machinery and equipment (38)	Basic metal industries (37)
	Waste factors (hazardous waste/production)	
Facility 1	0.0031	–
Facility 2	0.0440	–
Facility 3	0.0013	–
Facility 4	–	0.0003
Facility 5	0.0001	–
Facility 6	0.0150	–
Facility 7	–	0.0330
Facility 8	–	0.0389
Facility 9	–	0.0032
Facility 10	–	0.0710
Facility 11	–	0.0005
Facility 12	–	0.0073
Facility 13	0.0093	–
Facility 14	0.0022	–
Facility 15	0.0537	–
Facility 16	0.0101	–
Facility 17	0.0078	–
Facility 18	–	0.0014
Facility 19	0.0281	–
Facility 20	0.0006	–
Facility 21	0.0010	–
Facility 22	0.0001	–
Facility 23	0.0032	–
Facility 24	–	0.0001
Average	0.0120	0.0173
Waste factors estimated from TURKSTAT&TOBB data	0.0068	0.0035

In a similar evaluation to the visited facilities, the hazardous waste factors obtained from the production and waste generation figures declared by nine facilities in Basic Metal Industries (37) and 16 facilities in Manufacture of Fabricated Metal Products, Machinery and Equipment Industry (38), are calculated as 0.0173 and 0.0120, respectively.

The comparison of the results given in Table 3 and Table 4 show that the hazardous waste factors estimated by the data collected and cross-checked by site visits are more reliable and are in the same order of magnitude with the hazardous waste factors estimated using TURKSTAT and TOBB data for all facilities in Turkey. This difference lies behind the fact that the definitions of hazardous waste are still interpreted differently by different facilities and thus the declarations may still be misleading if not cross-checked by experts. This issue, although one of the major bottlenecks of reliable data

collection for establishing appropriate waste management strategies, is beyond the scope of this study.

4. Conclusions

Although the calculated waste factors vary widely due to production figures, the waste factors obtained from TURSTAT and TOBB databases for metal finishing industry category are quite reliable since they are consistent with the values observed in the field survey. Hence, they can be used as a first step of waste inventory establishment study for this sector. However, the waste factors observed for the main metal industry in the field survey are one order of magnitude higher than the waste factors obtained from TURSTAT and TOBB databases.

These varying results indicate that for reliable waste factors estimation, hazardous waste generation and production figures of the industries should be attained

correctly and should be cross-checked with various data obtained from different sources before they are used for establishing the waste inventories.

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