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Atmospheric PCDD/PCDF emission inventory for Turkey

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ABSTRACT

While studies related to national emission inventories for polychlorinated dibenzo–p–dioxins (PCDD) and furans (PCDF) form the first steps of worldwide elimination of these pollutants, consistency between the methodologies applied for emission estimation is of great importance in the aspect of monitoring the changes in emissions. This study presents PCDD/PCDF emission inventory for Turkey estimated using a standardized toolkit developed by UNEP Chemicals. The total emission rate in Turkey was estimated as 723 g I–TEQ yr^{-1}. For those source categories without enough information on air pollution control equipment, emissions were calculated as 1 873 g I–TEQ yr^{-1} using the highest emission factors to represent the worst–case conditions. Ferrous–and–nonferrous metal production was ranked first with emissions ranging from 583 g I–TEQ yr^{-1} (min) to 1 419 g I–TEQ yr^{-1} (max). Other important source categories were determined to be coal burning for residential heating and mineral product manufacturing using fossil fuels with emissions of 38 g I–TEQ yr^{-1} and 3.65 g I–TEQ yr^{-1}, respectively. The contribution of ferrous–and–nonferrous metal production to the total emission ranged from 76% (min) to 81% (max). In contrast to other industrialized countries, PCDD/PCDF emissions from waste combustion plants were found to be negligible in Turkey.

Keywords: *Turkey, emission inventory, PCDD/PCDF, POPs*

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1. Introduction

Persistent organic pollutants (POPs) are the leading group of those hazardous compounds, of which polychlorinated dibenzo–p–dioxins (PCDD) and dibenzo furans (PCDF) comprise the major sub–group. They are two of the twelve POPs included in the Stockholm Convention on POPs (Stockholm Convention, 2001). PCDD/PCDFs, together with polychlorinated biphenyls (PCBs) and hexachloro-benzene (HCB) are listed in Annex C of the Stockholm Convention on POPs; they are unintentionally generated and are commonly named "by–products". All POPs listed in Annex C require "*continuing minimization and, where feasible, ultimate elimination*" to protect human health and the environment as the objective of the Convention (Stockholm Convention, 2001). Parties have to establish and maintain emission inventories of unintentionally generated POPs to reduce and prevent the continuous emissions. Emission reduction or minimization of PCDD/PCDFs will be achieved by application of the best available techniques (BAT) and the best environmental practices (BEP). Draft guidelines on BAT/BEP have been developed by an expert group under the Stockholm Convention (Stockholm Convention, 2006). For intentionally produced POPs, e.g. pesticides and industrial chemicals such as HCB and PCBs, this will be attained by discontinuing their production and using alternative non–hazardous chemicals.

In general, although present in minute quantities in the environment, POPs are defined as organic substances that: (i) possess toxic characteristics; (ii) are persistent; (iii) bioaccumulate; (iv) capable of long–range transboundary atmospheric transport and deposition; and (v) are likely to cause significant adverse effect on human health or environmental effects near to and distant from their sources (Van der Gon et al., 2007). To prevent these adverse effects, the UNECE Convention on Long–Range Trans–boundary Air Pollution (CLRTAP) has been extended in 1998 by a specific POP protocol. The objective of the protocol is to control, reduce or eliminate discharges, emissions and losses of persistent organic pollutants. It has been reported that the combustion of chlorine containing materials in addition to the production of chlorinated chemical products and their byproducts (Brzuzy and Hites,1996; Wang et al., 2003), steelworks, metal refinery factories, power stations, coal and oil industries, domestic cooking and heating, municipal and medical waste incineration, vehicle exhaust emissions, cement, lime, glass and brick production were the main important sources of PCDD/PCDFs in the environment (Karasek and Hutzinger, 1986; Cohen et al., 2002; Chen et al., 2004).

In order to assess the possible effects of PCDD/PCDFs on the environment, the first step is to develop proper emission inventories for these pollutants. Worldwide, number of national inventories related to emissions of these pollutants is very limited. Since the 1980s, countries have attempted to estimate the emissions of PCDD/PCDFs from all sources in their territories. Early inventories were prepared for Canada (Sheffield, 1985), Germany (Fiedler et al., 1990; Wintermeyer and Rotard, 1994), and the USA (Thomas and Spiro, 1996). After year 2000, more studies have been conducted worldwide such as for Ireland (Hayes and Marnane, 2002), Hong Kong (Kai–Hon Lau et al., 2003), Japan (Japan Ministry of Environment, 2004), New Zeland (Buckland et al., 2000) Taiwan (Chen, 2004) and Portugal (Quina et al., 2011).

Since mid–1990s, national authorities started to prepare emission inventories also due to reporting requirements under international conventions such as the POPs Protocol under the UNECE Convention (UNEC, 1998) on Long–range Transport of Air

Pollution (LRTAP) (UNECE, 1979) or under the Stockholm Convention on POPs (Stockholm Convention, 2001). A review by UNEP Chemicals in 1999 (UNEP, 1999) identified only 15, nearly all from developed northern countries (UNEP, 2005). Most recent review on PCDD/PCDF emission inventories summarizes air emissions and total emissions for 23 countries from five continents (Fiedler, 2007). The countries listed cover a wide range of land surface, population, industrial development or prosperity.

National inventories report the emissions of PCDD/PCDFs in toxicity equivalents (TEQ), most of them using the international toxicity equivalency factors (I–TEF) as established by the NATO/CCMS Working Group on Dioxins and Related Compounds in 1988 (NATO/CCMS, 1988). Japan applies the scheme of the World Health Organization (WHO) (Van den Berg, 1998) and also includes the dioxin–like PCBs in their emission reports (Konda, 2001).

Since many countries do not have the technical and financial capacity to measure all releases from all potential PCDD/PCDF sources, with Turkey being among them, UNEP Chemicals has developed the "Standardized Toolkit for the Identification of Quantification of Dioxin and Furan Releases" (UNEP, 2003), a methodology to estimate annual releases without PCDD/PCDF analyses. The Toolkit has been used in a number of studies since 2001 (UNEP, 2001). The Toolkit methodology and format is being used by parties to report national releases of PCDD/PCDFs under the obligations of the Stockholm Convention on POPs. In February 2005, the second edition of the Toolkit was published (UNEP, 2005).

This study was also based on UNEP toolkit as briefly described in the following section in order to categorize and quantify the national PCDD/PCDF sources and emissions in Turkey.

2. Methodology

The Methodology of the current study was constructed on the Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases (UNEP, 2005). Annual releases of PCDD/PCDFs were given in toxic equivalent quantities using the International Toxic Equivalent System (NATO I–TEQ) instead of World Health Organization (WHO–TEQ). The toolkit has a large volume of knowledge which should be evaluated thoroughly before starting to prepare a nation–wide PCDD/PCDFs release inventory. Fiedler (2007) well summarized the toolkit for a quick reference. Since the main way of calculating the emissions is the same, Chen (2004) put out the essentials of the same methodology referencing USEPA's report (USEPA, 1998) for the necessary emission factors. There are a number of steps included in the application of the UNEP toolkit, namely:

(1) Apply a screening matrix to identify the main source categories. Then, check sub–categories to identify existing activities and sources in the country. The toolkit provides the main categories and available sub–categories in a tabulated form to easily go over,

(2) Obtain detailed information on the processes and classify processes into similar groups by applying the standard questionnaire,

(3) Quantify the identified sources with default/measured emission factors,

(4) Finally, apply nationwide to establish a full inventory, and report results using guidance given in the standard format.

The emissions of a specific activity can be estimated in g I–TEQ yr^{-1} by multiplying an annual activity rate (kg yr^{-1} as the mass of product manufactured or its raw material consumed) by a specific emission factor (g I–TEQ kg^{-1}) for that activity. All emission factors used in estimating the possible releases of PCDD/PCDFs from various sources are also available in the toolkit and were used in the current study.

Current literature lists emission data for industrial facilities from which dioxin/furan emissions originate. However, the operational conditions in the plant (especially in the incineration step), the technology that is used, and suitability of air pollution control equipment are known as the most influencing parameters in dioxin/furan emissions and these parameters are not the same for all plants. Besides, excessive costs and labor requirement for dioxin/furan analysis make it impossible for the current study to collect samples from a great number of sources and quantify all. Considering all these limitations, this study focused on the use of UNEP Toolkit Standardized Emission Factors to estimate the emissions. The emission data was estimated for those plants for which proper information on air pollution control equipment is available. On the other hand, for those sources with limited or no available data on air pollution control equipment, the emissions were estimated as maximum and minimum values using the highest and the lowest emission factors to represent the best and worst case conditions. The activity data for source categories were obtained from activity reports of the industries and Turkish Statistical Institute (TSI, 2010).

3. Results and Discussions

Major categories described in the toolkit were evaluated together with the corresponding activity rates and annual PCDD/PCDF releases were estimated. Following the order of categories given in the toolkit, details of PCDD/PCDF emissions from major sources were discussed. Besides, emissions for those source categories without enough information on air pollution control equipment were estimated using the highest emission factors available to represent the worst–case conditions. Comparison of the relative contribution of major source categories, as percentages of total emissions is shown in Table 1.

Table 1. *Dioxin/furan emission inventory in Turkey for the year 2010*

Source Categories	Emission Factor (μg I–TEQ t^{-1})	Activity Rate (ton yr^{-1})	Emission (gr I–TEQ yr^{-1})
Waste Incineration			
Hazardous Waste Incineration	0.75	21117	0.016
Medical Waste Incineration	1.0	8000	0.008
Iron ore sintering			
High waste recycling, including oil contaminated materials	20	4 500 000	90 (max)
High technology, emission reduction	0.3		1.35 (min)
Iron production			
Dirty scrap, scrap preheating, limited controls	10	31 000 000	310 (max)
Clean scrap/virgin iron, afterburner, fabric filter	3		93 (min)
Foundries			
Cold air cupola or rotary drum, no APCS	10	1 291 700	13 (max)
Hot air cupola or induction furnace, fabric filter	0.03		0.04 (min)

Table 1. *Continued*

Source Categories	Emission Factor (μg I–TEQ t^{-1})	Activity Rate (ton yr^{-1})	Emission (gr I–TEQ yr^{-1})
Copper production			
Secondary Cu – Basic technology	800	605 000	484
Smelting and casting of Cu/Cu alloys	0.03	256 000	0.00768
Coke production			
No gas cleaning	3	5 892 960	17.6 (max)
After burner/dust removal	0.3		1.76 (min)
Aluminum Production			
Processing scrap Al, minimal treatment of inputs, simple dust removal	150	63 000	9.45 (max)
Scrap treatment, well controlled, good APCS	35		2.2 (min)
Lead production			
Secondary lead from scrap, PVC battery separators	80	10 000	0.8 (max)
Pure primary lead production	0.5	675 000	0.34 (min)
Zinc production			
Kiln with no dust control	1 000	464 000	464 (max)
Melting (only)	0.3		0.14 (min)
Magnesium production	250	120 000	30 (max)
Using MgO/C thermal treatment in Cl_2, no effluent treatment, poor APCS			
Thermal reduction process	3		0.36 (min)
Heat and Power Generation			
Coal fired power boilers	10 [a]	182 052 [b]	1.82
Heavy fuel fired power boilers	2.5	7 848	0.02
Light fuel oil/natural gas fired power boilers	0.5	353 520	0.18
Biogas–/landfill gas fired boilers, motors/turbines and flaring	8	1 645	0.013
Mixed biomass fired power boilers	500	22788	11.4
Household heating and cooking – Biomass			
Virgin wood/biomass fired stoves	100	61 011	6.1
Domestic heating – Fossil fuels			
Coal-fired stoves	100	380 000	38
Natural gas-fired stoves	1.5	1 147 568	1.72
Cement kilns			
Shaft kilns	5.0	55 741 176	278.7 (max)
Wet kilns, ESP/FF temperature <200 °C and all types of dry kilns	0.05		2.78 (min)
Lime			
Cyclone/no dust control, contaminated or poor fuels	10	3 225 000	32.25 (max)
Good dust abatement	0.07		0.225 (min)
Brick			
Cyclone/no dust control, contaminated or poor fuels	0.2	15 981 100	3.2 (max)
Good dust abatement	0.02		0.32 (min)
Glass			
Cyclone/no dust control, contaminated or poor fuels	0.2	3 000 000	0.6 (max)
Good dust abatement	0.015		0.045 (min)
Ceramics			
Cyclone/no dust control, contaminated or poor fuels	0.2	5 175 000	1.035 (max
Good dust abatement	0.02		0.1035
Asphalt mixing			
Mixing plant with no gas cleaning	0.07	26 000 000	1.82 (max)
Mixing plant with fabric filter, wet scrubber	0.007		0.182 (min)
Transport			
4–Stroke engines			
Unleaded fuel without catalyst	0.1	1 052 543	0.21
Diesel engines	0.1	1 052 543	1.38
Heavy oil fired engines	4.0	1 074	0.0043
Uncontrolled combustion			
Forest fires	5.0	1 701 447	3.18
Uncontrolled domestic waste burning	300	239 000	71.7
Production and Use of Chemicals and Consumer Goods			
Black liquor boilers, burning of sludge, wood	0.07	4 190 856	0.3
PVC only	0.0003	840 000	0.0002
Total			1 873 Max 723 Min

[a] *μg I–TEQ.TJ^{-1}*
[b] *TJ yr^{-1}*

Total PCDD/PCDF emission was estimated as 723 g I–TEQ yr^{-1} with the worst–case condition emissions of 1 873 g I–TEQ yr^{-1}. Ferrous (iron sintering) and nonferrous metal production (especially copper and zinc), combustion processes in mineral product manufacturing (especially cement manufacturing), biomass burning for power generation and heating are the source categories with the highest emissions. Similar to the results of current study, another emission inventory (Pulles et al., 2005) and UNIDO POP's

Project (UNIDO, 2006) reported that the highest contributions to total emissions in Turkey were from metal production processes, industrial combustion processes in which fossil fuels are used, and combustion processes for residential heating purposes. Although studies before the year 2000 stated that waste combustion plants were ranked first in primary PCDD/PCDF emissions, results of the current study revealed that contribution from these sources is negligible in Turkey. In general, improvement and installation of high–technology air pollution control equipment in modern waste combustion plants and strict emission European limit (0.1 ng I–TEQ Nm^{-3}) are considered to be the most probable reasons for the reduction of PCDD/PCDF emissions in this source category. For instance, the emission inventory by UNIDO (2006) pointed out that ferrous and nonferrous metal production and mineral products manufacturing are the major sources similar to the present study.

Emission from medical waste incineration plants in Belgium in 1985 was 67.5 g I–TEQ yr^{-1} while it decreased to 0.48 g I–TEQ yr^{-1} in 1998. A similar decrease was observed for waste incineration plants in this study. Similar results were reported by Alcock et al. (2001), Chen (2004), and Quina et al. (2011). National emission rates similar to that in this study (712 g I–TEQ yr^{-1}) were reported for Poland and Argentina (Table 2). Estonia, Sri Lanka and Malta seem to have similar release rate per capita to the value found in this study (9.42 µg I–TEQ ca^{-1} yr^{-1}). The emission rate for Turkey was reported as 1 012 g I–TEQ yr^{-1} in 2000 UNECE–Europe Inventory (Van der Gon et al., 2007) in which emission factors from EMEP–CORINAIR (EMEP/CORINAIR, 2004) and European Emission Inventory for hazardous materials and POPs (Berdowski et al., 1997) were used. In contrast to 2000 UNECE–Europe inventory (Van der Gon et al., 2007), emission rate was estimated as 182.6 g I–TEQ yr^{-1} in the UNIDO POP's project in 2002 (UNIDO, 2006) (Table 2).

In this study, however, UNEP Toolkit emission factors were used along with 2010 source activity data, the maximum and the minimum emission rates were estimated as 1 873 g I–TEQ yr^{-1} and 723 g I–TEQ yr^{-1}. The difference in total emissions between UNIDO POP's project in 2006 and in the current study in which UNEP Toolkit emission factors were used can be explained by selection of different emission factors and by the increase in capacities of a number of industrial sectors (iron–steel production, nonferrous metal production, mineral products manufacturing, and energy production). Same reasons apply to the differences between the current study and previous emission inventories for Turkey (Pulles et al., 2005; Van der Gon et al., 2007).

The spatial distribution of emissions in Turkey was given in Figure 1. The emission map clearly visualizes the PCDD/PCDF emission rates by region with the highest emissions in Marmara, Mediterranean, and Aegean regions being the western part of the country. The map was formed using spatial emission data in Turkey. Thirty three points of emission were included in the map. The emissions were assumed to take place in city centers. Krigging method was used for this purpose.

3.1. Waste incinerators

Solid waste disposal policy in Turkey is almost completely based upon landfilling instead of incineration because of economic aspects. Therefore, there is no municipal waste incineration plant yet in Turkey. On the other hand, there is one hazardous waste incineration plant (HWIP) located in Kocaeli and one medical waste incineration plant (MWIP) located in Istanbul. HWIP is currently serving for all industries all around Turkey with a capacity of 35 000 tons yr^{-1} on 330 running days a year and MWIP is serving for Istanbul with a capacity of 7 920 tons yr^{-1} on 330 running days a year. Actually, the capacities of both plants are not sufficient for the respective waste generation capacities. New HWIPs are planned according to the industrial settlements and requirements throughout the country.

Table 2. *PCDD/PCDF emissions by countries*

Country	Population (millions)	Annual air emission (g I– TEQ yr^{-1})	Annual air emission per capita (µg I–TEQ ca^{-1} yr^{-1})	References
Turkey (This study)	75.6	723 (lower estimate) 1 873 (upper estimate)	9.42 24.6	This study
Turkey	72.7	960	13.2	Pulles et al. (2005)
Turkey	74.5	182.6	2.45	UNIDO (2006)
Turkey	67.8	1 012	15	Van der Gon et al. (2007)
Argentina	37.4	874	23	Garcia et al. (2004), Cuba Ministry of Science, Technology and Environment (2003), Paraguay Ministry of Environment (2003)
Australia	19.7	495	25	DEH (2004), UNEP (2004)
Ecuador Republic	13.7	65.5	4.8	DINAMA (2005), UNEP/GTZ/CONAMA (2004)
Estonia	1.4	14	10	Lassen et al. (2003)
Philippines	84.5	328	3.9	UNEP (2003).
Croatia	4.5	116	26	Lassen et al. (2003).
Cambodia	13.4	273	20	DEH (2004), UNEP (2004)
Cuba	11.2	195	17	Garcia et al.(2004), Cuba Ministry of Science, Technology and Environment (2003), Paraguay Ministry of Environment (2003)
Latvia	3.4	22	6.5	Lassen et al. (2003)
Lithuania	3.6 3.4	17 48	4.7 14	Lassen et al. (2003) Pulles et al. (2005)
Paraguay	5.2	70.7	14	Garcia et al. (2004), Cuba Ministry of Science, Technology and Environment (2003), Paraguay Ministry of Environment (2003)

Table 2. *Continued*

Country	Population (millions)	Annual air emission (g I–TEQ yr^{-1})	Annual air emission per capita (µg I–TEQ ca^{-1} yr^{-1})	References
Poland	38.6	490	13	Lassen et al. (2003).
Sri Lanka	19.9	172	8.6	DEH (2004), UNEP (2004).
Chile	15.7	51.9	3.3	DINAMA (2005), UNEP/GTZ/CONAMA (2004)
Thailand	62.4	286	4.6	UNEP (2003), Thailand (2006), Republic of Lebanon Ministry of Environment (2006).
Uruguay	3.3	18.7	5.7	DINAMA (2005), UNEP/GTZ/CONAMA (2004)
Jordan	5.3	64.3	12	UNEP (2003)
Vietnam	78.4	16	0.2	UNEP (2003), Thailand (2006), Republic of Lebanon Ministry of Environment (2006)
Zambia	10.3	290	28	UNEP (2004)
Cyprus	867[a]	6.6	7.6	Pulles et al. (2005)
Czech Republic	10.3	320	31	Pulles et al. (2005)
Estonia	1.4	8.7	6.2	Pulles et al. (2005)
Hungary	10.1	120	11.8	Pulles et al. (2005)
Latvia	2.3	18	7.82	Pulles et al. (2005)
Malta	0.4	3.9	9.75	Pulles et al. (2005)
Poland	38.1	790	20.7	Pulles et al. (2005)
Romania	21.6	490	22.7	Pulles et al. (2005)
Slovak Republic	5.4	180	33	Pulles et al. (2005)
Slovenia	2.0	36	18	Pulles et al. (2005)
Bulgaria	7.5	290	38.6	Pulles et al. (2005)
Portugal	11	74 (upper estimate) 21 (lower estimate)	6.72 2	Quina et al. (2011)
Total	621.6	6 866 (lower estimate) 8 100 (upper estimate)	11 13	

[a] Thousands

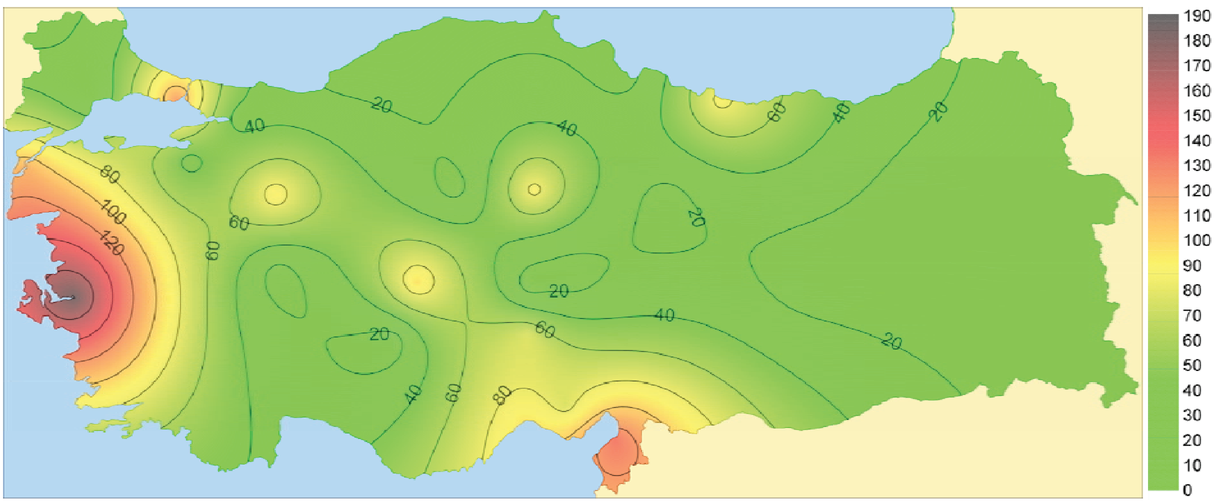

Figure 1. *PCDD/PCDF emission map of Turkey. Emission rates are in g I–TEQ yr^{-1}.*

Both HWIP and MWIP have rotary kiln technology, most commonly used at commercial waste incineration plants designed to accept a wide range of wastes and both are operated to comply with the international emission standard of 0.1 ng I–TEQ Nm^{-3}. The HWIP is equipped with a high–technology air pollution control system including an electrostatic precipitator for particulate removal, a wet scrubber for acidic gases, and a granular activated carbon bed filter for PCDD/PCDF control. Acidic gases are controlled by a dry scrubber in MWIP while powdered activated carbon is injected into the gas stream and collected in a fabric filter unit for the removal of PCDD/PCDFs. Therefore emission factors of 0.75 µg I–TEQ ton^{-1} and 1 µg I–TEQ ton^{-1} were used for HWIP and MWIP plants, respectively. Besides these plants, there is an incinerator having a capacity of 17 500 tons yr^{-1} for the petro-chemical complex wastes in Izmir, Turkey. This incinerator has also sophisticated air pollution control (APC) devices for the treatment of combustion gases, involving wet scrubber, activated carbon and fabric filter systems. TSI (2010) reported that a total of 29 117 tons of waste were incinerated in the year 2008, 21 117 tons of which being hazardous waste and the rest being medical wastes. It was reported that the amount of incinerated wood wastes and biomass sum up to 10 000 tons (Acara, 2006). According to the report, annual dioxin/furan emissions were estimated to be 0.016 g I–TEQ yr^{-1} for hazardous waste incineration by using UNEP's emission factors of 0.75 µg TEQ ton^{-1}. Annual dioxin/furan emissions from medical waste incineration activities were estimated as 0.008 g I–TEQ yr^{-1} using UNEP's emission factors of 1 µg I–TEQ ton^{-1}. An emission limit of 0.1 ng Nm^{-3} set by WHO require inclusion of PCDD/PCDF control units in air pollution control systems and this lead to a drastic reduction in PCDD/PCDF emissions from waste incineration plants (Figure 2) (De Fre et al., 1998; Chen, 2004, Quass et al., 2004). The most probable reason for the difference in emissions from waste incineration plants between UNIDO POP's project and current study is the selection of different emission factors. Since adsorbent injection system and fabric filters are used for dioxin/furan emission control in medical waste incineration plant, an emission factor of 1 µg TEQ ton^{-1} was assumed in this study. In contrast, in UNIDO POP's project, an emission factor of 3 000 µg TEQ ton^{-1} that is set for those plants in which the wastes are incinerated in batch mode and the air pollution control equipment is absent or is at minimum capacity/capabilities. Further, the increase in capacities of ferrous/non–ferrous metal production, mineral products manufacturing and energy production sectors lead to an increase in total emissions, thus, a relative decrease in percent contribution of waste incineration plants to total emissions.

3.2. Ferrous and non–ferrous metal production

This study points out that ferrous–and–nonferrous metal production is one of the most important sources of PCDD/PCDFs. The emission rates are given as maximums and minimums due to the fact that there is lack of information about air pollution control systems in these facilities. There are a total of 26 iron and steel production plants, 23 of which having electric arc furnaces and the rest being integrated facilities. Turkey's Association of Iron and Steel Manufacturers (TAISM, 2011) stated that total capacity of iron and steel production plants was 31 million tons in 2011. Twenty five million tons of this was from electric arc furnaces.

The amount of iron ore sintering was 4.5 million tons per year. Emission factors of 20 µg I–TEQ ton^{-1} and 0.3 µg I–TEQ ton^{-1} for sintering were used to calculate the annual emissions of PCDD/PCDFs. The emissions were estimated as 1.35 g I–TEQ yr^{-1} (min) and 90 g I–TEQ yr^{-1} (max). The emissions from iron production were estimated as 310 g I–TEQ yr^{-1} and 93 g I–TEQ yr^{-1} assuming emission factors of 10 µg I–TEQ ton^{-1} and 3 µg I–TEQ ton^{-1}, respectively.

There are 1 071 foundries in Turkey, fifteen of which are large scale foundry complexes. The number of medium scale casting facilities is 267, while 415 are small scale. Turkey's Association of Casting Industries (TTFA, 2011) stated that the production capacities of all foundries in Turkey sum up to 1 291 700 tons. Sixty percent of this is pig casting, 20% is sphero–casting, 11% is steel casting, 9% is aluminum casting, and the rest is non–ferrous casting. The most important customers of casting industries are machine production, electric appliances production, automotive and construction industries. Annual dioxin/furan emissions were estimated to be 13 g I–TEQ yr^{-1} and 0.04 g I–TEQ yr^{-1} for this category using UNEP's emission factors of 10 µg I–TEQ ton^{-1} and 0.03 µg I–TEQ ton^{-1}, respectively.

Copper production is widespread in Turkey. Most of production is carried out by private facilities. Thirty six thousand tons of primary copper and 605 000 tons of secondary copper were produced in 2005 (SPO, 2007). The productions of copper alloys such as copper and brass extrusion as well as copper and flat brass products were reported to be 15 000, 180 000, 16 000 and 45 000 tons, respectively. An important part of the production of blister copper is realized with flash smelting method in Turkey (SPO, 2007). Copper production using scrap copper is carried out in various plants located in Istanbul, Izmir, Ankara, Balikesir, Eskisehir and Mersin. The production of copper using scrap copper was estimated as 50 000 tons by National Implementation Plan (Acara, 2006).

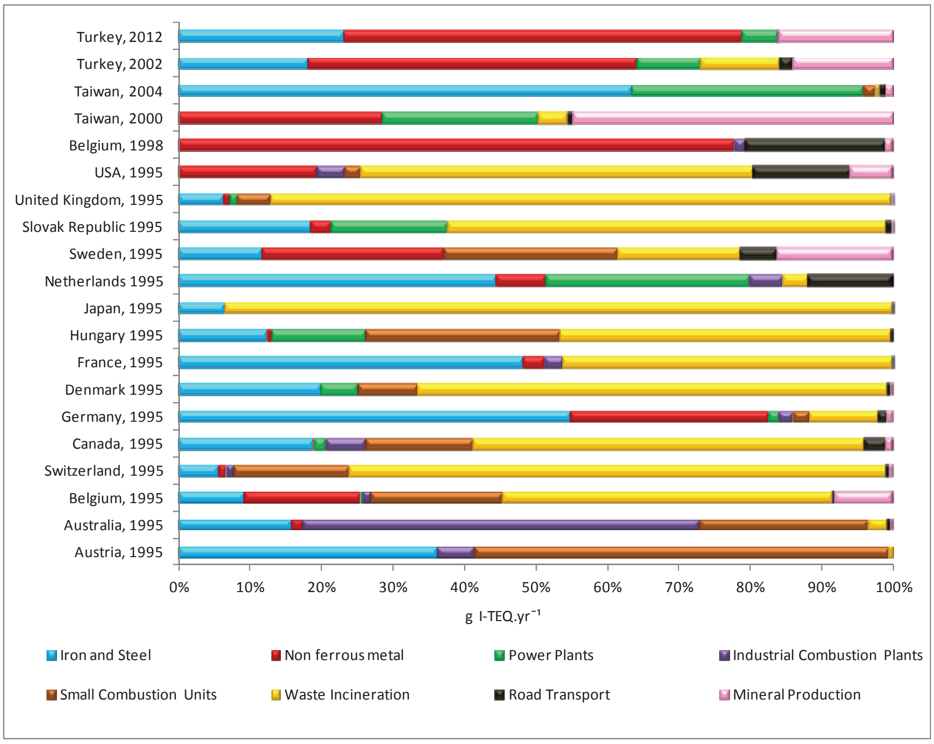

Figure 2. *PCDD/PCDF emissions by sectors in various countries.*

Annual dioxin/furan emissions were estimated to be 484 g I–TEQ yr^{-1} and 0.00768 g I–TEQ yr^{-1} for this category using UNEP's emission factors of 800 µg I–TEQ ton^{-1} and 0.03 µg I–TEQ ton^{-1}, respectively.

Aluminum production is mainly carried out as primary aluminum production in a facility located in Konya, the capacity of which was 60 000 tons yr^{-1} in 2005 (Acara, 2006). Total production capacity of plants operating in the aluminum industry is about 400 000 to 450 000 tons yr^{-1} (SPO, 2007). Annual production capacity is estimated as 200 000 to 220 000 tons for extruded products, 150 000 tons for flat products, 60 000 tons for conductors (SPO, 2007). Production of aluminum using scrap aluminum has been conducted in various large scale facilities located in Istanbul, Izmir, Ankara and Mersin. Secondary aluminum production capacity was 63 000 tons yr^{-1} in 2005 (TAIA, 2005). Annual dioxin/furan emissions were estimated to be 9.45 and 2.2 g I–TEQ yr^{-1} for this category using UNEP's emission factors of 150 µg I–TEQ ton^{-1} and 35 µg I–TEQ ton^{-1}, respectively.

Lead and zinc are produced by small and medium scale plants in Turkey. 685 000 tons of lead ore and 464 000 tons of zinc ore were produced in 2007 (MEEI, 2010). There is one lead recycling plant (in Ankara) and 15 zinc recycling plants in Turkey. 10 000 tons of lead has been produced using scrap lead. Annual dioxin/furan emissions were estimated as 0.8 and 0.183 g I–TEQ yr^{-1} for lead production by using UNEP's emission factors of 80 µg I–TEQ.ton^{-1} and 0.5 µg TEQ.ton^{-1}, respectively. Annual dioxin/furan emissions were estimated to be 464 and 0.14 g I–TEQ yr^{-1} for zinc production using emissions factors of 1 000 µg I–TEQ.ton^{-1} and 0.3 µg I–TEQ ton^{-1}, respectively.

Coke is obtained by removal of volatile substances from coal through heating under anaerobic conditions at temperatures higher than 700 °C. There are 5 coal–gas plants in Istanbul, Ankara, Izmir and 3 iron–steel coke plants in Karabuk, Eregli and Iskenderun. Coke is produced in these plants for industrial and heating purposes. Average coke production has been reported to be 5 892 960 tons in 2010 (TSI, 2010). Coke plants in Turkey use old technologies in general and they do not have air pollution control devices. Annual dioxin/furan emissions were estimated as 17.6 and 1.76 g I–TEQ yr^{-1} by using UNEP's emission factors of 3 µg TEQ.ton^{-1} and 0.3 µg I–TEQ ton^{-1}, respectively.

Magnesium alloys are produced using various methods involving extrusion, forging and rolling techniques. Especially, the pressure casting production for automotive sector comprises 70% of all magnesium casting products and corresponds to 120 000 tons of capacity. Annual dioxin/furan emissions were estimated to be 30 and 0.36 g I–TEQ yr^{-1} using UNEP's respective emission factors of 250 and 3 µg I–TEQ ton^{-1} for this sector.

3.3. Heat and power generation (industrial combustion)

Four distinct technologies were used for power generation in Turkey: thermal, hydroelectric, geothermal, wind power and biomass. Total energy production in Turkey in 2011 was 211.2 billion kWh (TETC, 2011) and the sector statistics are shown in Figure 3. Dioxin/furan emissions occur only in thermal plants and the amount of emissions for this category varies depending upon fuels used. Coal, natural gas, and fuel–oil are used as fuels to produce energy. About 47% (98.2 billion kWh) of total energy production was from natural gas, 17% (36 billion kWh) was from lignite, 7% (14.57 billion kWh) was from imported coal, and 3% was from biomass. Total energy from liquid fuels and biogas were 2 180 GWh 457 GWh, respectively, thus emissions from these sectors were much lower compared to others (Table 1). Total emission rate from energy production was estimated as 2 g I–TEQ yr^{-1}, 91% of which is from coal combustion. Turkish Coal Enterprises Corporation (TCEC, 2009) reported that 13 million tons of coal was used for domestic heating in 2007. Assuming that calorific value of the coal was 7 000 kcal kg^{-1} and that 3.8x10^{5} TJ of energy was generated. Total natural gas consumption for domestic heating in Turkey in 2010 was about 8.778 trillion cubic meters (RTEMRA, 2011). Assuming a calorific value of 8 703 kcal m^{-3} for natural gas, total energy production was 319 869 TJ yr^{-1}. Similarly, the amount of wood consumed for domestic heating was 11 million cubic meter (GDF, 2011). Based on the assumption that the density of wood is 500 kg m^{-3} and that the calorific value is 2 650 kcal kg^{-1}, total energy production from wood combustion was estimated as 61 011 TJ yr^{-1}. Total emission rate from heat production was estimated as 45.82 g I–TEQ yr^{-1}, within which the coal stoves comprise the highest emission share.

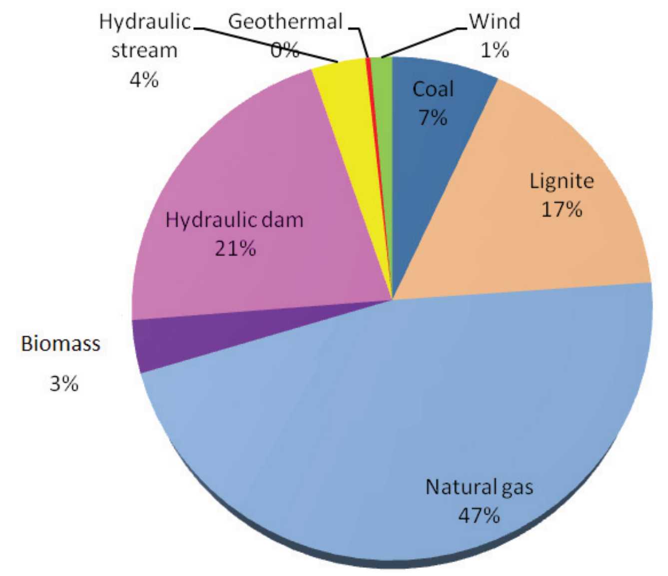

Figure 3. *Rate of energy production sources by sectors (Turkish Electricity Transmission Company, 2011).*

3.4. Production of mineral products

There are 41 cement factories in Turkey. Eight of these are in Marmara Region, four in Aegean Region, four in Mediterranean Region, nine in inner Anatolia, six in Black Sea Region, and six in Southeastern Anatolia. Total production capacity was 55 741 176 tons in 2009 (TSI, 2010). Annual dioxin/furan emissions were estimated to be 278.7 and 2.78 g I–TEQ yr^{-1} for cement production using emission factors of 5 and 0.05 µg I–TEQ ton^{-1}, respectively.

There are 140 lime production facilities in Turkey, 40 of which are industrial complexes and the rest is bush–and–brae type cooker (LIA, 2010). Total production capacity is 5 million tons per year. However, 3 225 000 tons of quick lime was produced in 2008. Annual dioxin/furan emissions were estimated to be 32 and 0.226 g I–TEQ yr^{-1} for lime production using emissions factors of 10 µg I–TEQ ton^{-1} and 0.07 µg I–TEQ ton^{-1}, respectively.

According to a research conducted by Turkish Association of Brick and Tile Manufacturers, there are 417 brick and tile manufacturing plants in Turkey. Forty nine of these produce tiles and the rest is for brick production. It was reported that total capacities of these sectors are 15 981 100 tons yr^{-1} and 1 522 500 tons yr^{-1}, respectively (BTIA, 2008). Annual dioxin/furan emissions were estimated to be 3.2 and 0.32 g I–TEQ yr^{-1} for brick production using UNEP's emission factors of 0.2 µg I–TEQ ton^{-1} and 0.02 µg I–TEQ ton^{-1}, respectively.

Glass Sector Report of Ministry of Industry states that Turkey's total glass production was 2.9 million tons in 2010 (TMI, 2010). Ninety percent of this capacity belongs to Sisecam in Turkey. The production capacity of Sisecam for the main production areas of flat glass, glassware, glass packaging and glass fiber was reported as 2.6 million tons in 2009. Annual dioxin/furan emissions were estimated to be 0.6 and 0.045 g I–TEQ yr^{-1} for glass production using UNEP's emission factors of 0.2 µg I–TEQ ton^{-1} and 0.015 µg I–TEQ ton^{-1}, respectively.

Coating materials and medical supplies are the most advanced sub–sectors within ceramic industry. Turkish Ceramic Federation reports that 225 million m^2 (5 175 000 tons) of ceramic were produced in 2008. As a result, annual dioxin/furan emissions were estimated to be 1.035 and 0.1035 g I–TEQ yr^{-1} for this category using UNEP's emission factors of 0.2 µg I–TEQ ton^{-1} and 0.02 µg I–TEQ ton^{-1}, respectively.

Asphalt is usually produced by local authorities (municipalities) in Turkey. Raw materials of asphalt are produced only by Petroleum Refineries Joint Stock Company and 26 million tons of bituminous hot mix was produced in 2008 (ACAT, 2011). Dioxin/furan emissions were estimated to be 1.82 and 0.182 g I–TEQ yr^{-1} for this category using UNEP's emission factors of 0.07 µg I–TEQ ton^{-1} and 0.007 µg I–TEQ ton^{-1}, respectively.

3.5. Transportation

The number of motor vehicles was 14 316 700 in 2009 (TSI, 2010). Toolkit emission factors for motor vehicles were employed to estimate the air emissions. For the calculations, total fuel consumption was used. Fuel consumption data was obtained from activity reports of petroleum industries union. Production of leaded gasoline was stopped in 2002. Currently, super and unleaded gasoline is produced. Report of Petroleum Industry Association states that 2 105 087 tons of gasoline, 13 775 694 tons of diesel and 1 074 tons of fuel oil (no. 4 and 6) were consumed in 2010 (PETDER, 2010). Therefore, annual dioxin/furan emissions were estimated to be 0.21 g I–TEQ yr^{-1} for four–stroke engines, 1.38 g I–TEQ yr^{-1} for diesel engines, 0.0043 g I–TEQ yr^{-1} for heavy oil–fired engines using UNEP's emission factors of 0.1 µg I–TEQ ton^{-1}, 0.1 µg I–TEQ ton^{-1}, and 4 µg I–TEQ ton^{-1}, respectively. Considering the fact that the ships use diesel or other heavy fuels, the calculations included ship emissions as well. The emissions from transit passing ships were not calculated due to the fact that no data is available (fuel consumption per mile, fuel type, and fuel composition). Assuming that the urban traffic emissions comprise 0.2% of total emissions, the contribution from transit passing ships would be even much lower.

3.6. Uncontrolled combustion processes

A total of 2 904 hectares of Turkey's forest area was damaged in 2010 (TMFWW, 2011). Turkey prepared National Draft Implementation Plan for Stockholm Convention relating to persistent organic pollutants in 2002. According to this plan, a total of 4 562 hectares of forest area was damaged by fires which corresponds to a million tons of wood. Therefore, a total of 2 904 hectares of forest fire was interpreted as 636 563 tons of wood for the year 2010. Fires in landfills, residents, and factories were not included in the inventory due to the lack of information about these sources. Another source of PCDD/PCDFs is uncontrolled combustion of wastes. TSI (TSI, 2010) stated that 239 000 tons of waste was disposed of by open burning in 2008. Annual dioxin/furan emissions for forest fires and uncontrolled domestic waste burning were estimated to be 3.18 g I–TEQ yr^{-1} and 71.7 g I–TEQ yr^{-1} using UNEP's emission factors of 5 µg I–TEQ ton^{-1} and 300 µg I–TEQ ton^{-1}, respectively.

3.7. Production of chemicals and consumer goods

Pulp and paper are mostly produced by private sector in Turkey. 4 190 856 tons of paper and 4 316 761 tons of pulp paper were produced in 2010 (TSI, 2010). Production of a ton of paper from wood and waste paper requires 440 and 1.2 tons of water, respectively. A petrochemical corporation produced a total of 153 369 tons of PVC in 2010 (PETKIM, 2010). Plastic sector has a total maximum operating capacity of 6 million tons, however, 840 000 tons of plastic products manufacture were estimated (PAGEV, 2010). Annual dioxin/furan emissions were estimated to be 0.3 g I–TEQ yr^{-1} using UNEP's emission factor of 0.07 µg I–TEQ ton^{-1} for pulp paper and $2.52x10^{-4}$ g TEQ yr^{-1} using an emission factor of 0.0003 µg I–TEQ ton^{-1} for only PVC production.

3.8. Miscellaneous

Tobacco and Alcohol Market Regulatory Board states that 107 billion 555 million pieces of cigarettes were consumed in Turkey in 2009 while the consumption was reduced to 93 billion 354 million pieces as a result of abatement regulations on public smoking. This data reveals that 93 354 tons of tobacco was produced in 2010 based on the fact that 1 piece of cigarette contains one gram of tobacco. Annual dioxin/furan emission was estimated to be 0.01 g I–TEQ yr^{-1} using an emission factor of 0.1 µg I–TEQ ton^{-1}.

3.9. Waste disposal/landfilling

There are 43 waste disposal plants involving 37 landfills, 2 waste incineration facilities and 4 composting plants in Turkey according to the waste disposal and recycling plants statistics (TSI, 2010). These facilities have 391 073 000 tons of waste storage capacity. In addition, 10 037 000 tons of waste were disposed of in 2008. Total capacity of composting plants was 551 000 tons yr^{-1} in 2008 (TSI, 2010). In 2008, 143 038 tons of waste was composted and 46 827 tons of compost was produced (TSI, 2010). In 2005, the amount of leachate discharged without treatment was reported as 237 000 tons (Acara, 2006). However, no air emission factors were reported for this category in Toolkit Standardized Emission Factor Tables. Therefore, the emissions for this category were not included in the inventory.

4. Conclusions

Studies concerning PCDD/PCDF emission inventories on regional, national, and global scales give information about the global PCDD/PCDF pollution and elimination of these pollutants. This study involves the detailed investigation of the sources of PCDD/PCDFs and estimation of emission inventory for Turkey.

Since there is not enough information on air pollution control equipment for various sectors, the highest and the lowest possible emission rates were reported using the highest and the lowest emission factors. The highest contributions were from ferrous/non–ferrous metal production as well as residential heating with fossil fuels, while the emissions from waste incineration plants were negligible in contrast to previous reports (UNIDO, 2006). The following conclusions were derived from this study:

- Maximum and average rates of PCDD/PCDF emissions in Turkey were estimated as 1 873 g I–TEQ yr^{-1} and 723 g I–TEQ yr^{-1}, respectively.
- Ferrous and non–ferrous metal production is the most important source of PCDD/PCDFs with the contribution to total emissions as 76% on average up to 82% as maximum. Other important source categories are listed as the coal burning for heating purposes and cement production.
- Emissions from waste combustion plants are negligible since these plants are equipped with air pollution control equipments.
- There is still limited information about air pollution control equipment for some source categories. Thus, emissions from these source categories with high uncertainties (ferrous and

nonferrous metal production as well as mineral product manufacturing, etc.) were estimated using the highest emission factors to represent worst–case conditions. Research concerning emissions from those source categories with limited information about air pollution control equipment must be performed in order to reduce uncertainties of emission inventories.

- PCDD/PCDF emission inventories must be updated periodically to take into account new production technologies and capacity changes.

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