Dioxins and WtE plants: State of the Art

European-wide overview of long-term analysis of dioxins in WtE plant surroundings

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Executive Summary

Over the last few decades the European Waste-to-Energy (WtE, waste incineration with energy recovery of municipal and similar commercial and industrial waste) sector has put in considerable effort in reducing its environmental impacts. The aim of this overview is to show some meaningful examples of the results of these efforts regarding dioxin and furan emissions.

This overview has been carried out based on extensive data received from CEWEP members on monitoring of dioxins and furans from the stack and in the surroundings of WtE plants all over Europe. It only covers a fraction of all research and data available, but it allows for an in-depth assessment of the current situation regarding these pollutants in and around WtE plants.

1. Assessments and comparisons between **emissions at the stack of WtE plants** and **concentrations measured in the surroundings** have shown that when dioxins are found in the surroundings of a WtE plant there is **no correlation** with the plant's emissions.

2. EU Waste-to-Energy plants are subjected to and comply with one of the **most stringent regulations** in terms of pollution prevention and control. Since 2019 an even more ambitious set of limits for dioxins and furans has been put in place with the publication of Waste Incineration BAT (Best Available Techniques) Conclusions[1]. Today, dioxin emissions from WtE account for **less than 0.2% of the total industrial dioxin emissions**[2]**.**

3. Monitoring of dioxins is associated with both **stringent limits** and **extended periods**, meaning that measurements must be carried out during operating stages, including start-up and shutdown.

4. Data assessments, comparisons and long-term experience of operators have shown similar emission patterns between periodic measurements[3] and continuous sampling[4]. A well-managed EU WtE plant emits extremely low concentrations of dioxins and furans (sometimes below the limit of detection of the instruments) thanks to its sophisticated combustion control and pollution abatement system. This happens regardless of the specific measuring equipment.

[1]Given the complexity of the legal framework defining emission ranges, the numbers are not included in the text. However, they can be found in detail in *Table 7 'BAT-associated emission levels (BAT-AELS) for channelled emissions to air of TVOC, PCDD/F and dioxin-like PCBs from the incineration of waste'* in the BAT Conclusions for waste incineration: Commission implementing decision (EU) 2019/2010 of 12 November 2019 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration.

[2] The European Pollutant Release and Transfer Register, https://industry.eea.europa.eu/#/home

[3] Periodic measurements of dioxins: sampling of dioxin emissions for **short** periods of time (6-8 hours).

[4] Continuous sampling of dioxins: sampling of dioxin emissions for **long** periods of time (2-4 weeks).

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European legislation and dioxin emissions

Dioxins and WtE efforts to prevent and control pollution

Dioxins and dioxin-like compounds form an extensive group of more than 200 chemical compounds, which differ greatly in levels of toxicity. Because of their resistance to environmental degradation these chemicals are highly bio accumulative and are therefore labelled as persistent organic pollutants (POPs). Long-term exposure to high concentrations can have a negative impact on human health. Thus, the WtE sector is committed to continue its effort to minimise emissions of dioxins and furans.

Historically the WtE sector has been associated with dioxin[5] emissions. However, since 1989 European WtE plants are subject to specific stringent legislation to prevent and control pollution. Since then these legal requirements have been continuously tightened making **WtE one of the most strictly regulated industrial sectors in Europe**.

WtE plants serve society, protect the environment and the climate by reducing the volume of waste, treating polluted substances in an environmentally sound way and recovering climate-friendly energy and materials in the process. WtE plays a crucial role in achieving zero pollution and circular economy objectives by diverting waste from landfills and treating residues from sorting and recycling processes in line with the EU Waste Hierarchy. Nevertheless, the public perception of WtE plants as major sources of dioxins persists, although it does not reflect the current situation.

A drastic decrease in dioxin emissions due to stringent European legislation and efforts by the WtE sector

The EU collects a large volume of data regarding industrial emissions. Data collected for the E-PRTR[6] shows that dioxin emissions from WtE account for **less than 0.2% of the total industrial dioxin emissions** (it should be noted that the register does not include transport emissions; if that was to be the case, the contribution of WtE sector would be even lower).

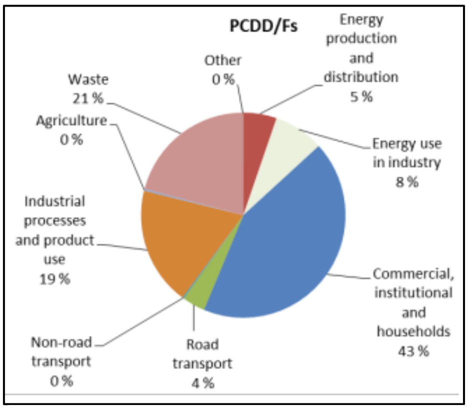
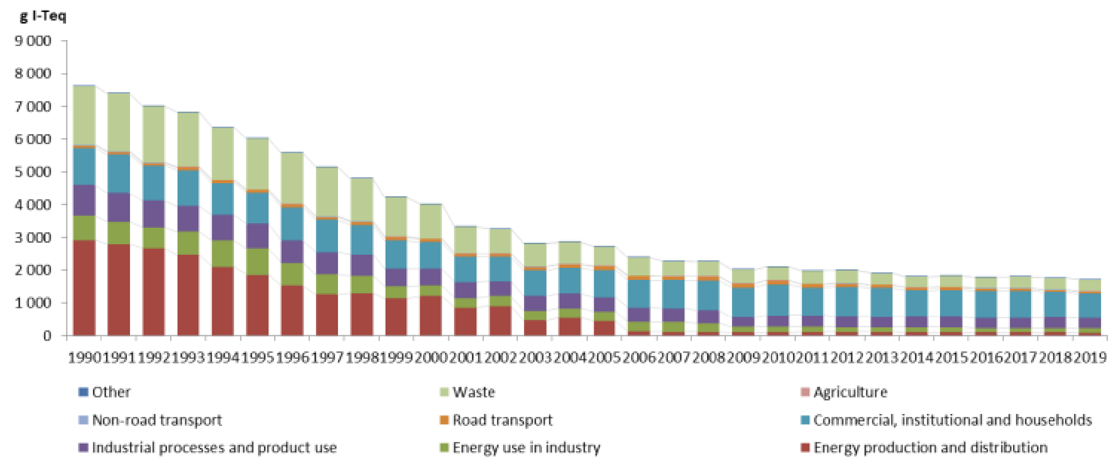


Figure 1: Dioxin (labelled as PCDD/F) emissions in the EU: share by sector group in 2019. The Waste-to-Energy sector is included in the 'Energy production and distribution' category. Source: EEA, 2021

Secondly, the EU emission inventory report by the European Environment Agency (EEA)[7] shows a **great decline in dioxin emissions between 1990 and 2019 in the EU**. This is due to efforts put in place by operators of different industrial sectors including the Waste-to-Energy sector to reduce their emissions. The report indicates that the key sources of dioxins and furans currently are households (in the category 'Commercial, institutional and households'), iron and steel production (in the category 'Industrial processes and product use') and other waste (in the category 'Waste'), which

[5] From this point, "dioxins" should be read as dioxins and furans.
[6] The European Pollutant Release and Transfer Register, https://industry.eea.europa.eu/#/home
[7] European Environment Agency (EEA). (2021). *European Union emission inventory report 1990-2019 under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention).* EEA. Available at https://op.europa.eu/en/publication-detail/-/publication/95c98553-0b94-11ec-adb1-01aa75ed71a1/language-en

together make up 67% of total dioxin emissions. It should be noted that WtE is included in the 'Energy production and distribution' category and that the open burning of waste and other non-BAT compliant handling of waste makes up the majority of dioxins emissions in the 'Waste' category. The main results of the EEA report are shown in Figures 1 and 2.



Note: I-Teq, international toxic equivalent.

Figure 2: PCDD/F emissions in the EU: sectoral trends in emissions between 1990 and 2019. Waste-to-Energy is included in the 'Energy production and distribution' category. Source: EEA, 2021

All this data shows that only a very small fraction of dioxin emissions in Europe is produced by the WtE sector. This result is complemented and supported by extensive research[8] performed to assess the impacts on the surrounding of WtE plants that has found no evidence of a negative impact on human health or the environment. This achievement is reached thanks to their advanced flue gas cleaning systems and combustion control.

In 2019 Waste Incineration (WI) BAT Conclusions[9] set the new environmental standard for the sector. They put in place a set of even more ambitious requirements regarding emission limits and added a number of controlled substances and monitoring rules. Thus, a new and more ambitious framework for dioxins and furans in WtE plants is currently enforced.

[8] A thorough overview of studies on the impact of WtE on human health and the environment can be found at https://www.cewep.eu/category/facts/health-and-environment/

[9] See footnote 1 for reference

Monitoring of dioxins

WtE plants: a sink for pollution, with stringent monitoring at the stack

The studies and data collected on the subject (summaries of the studies can be found as from p.6) show that **WtE plants have very low emissions and impact on their surroundings**. In fact, the WtE sector has decades of experience in abating and monitoring dioxins and furans. State-of-the-art WtE aims to destroy the toxic organic substances in the residual waste streams whilst recovering energy and materials from residues. Studies[10] [11] investigating the mass balance of POPs in WtE plants conclude that WtE acts as a sink for pollution and effectively minimises dioxins entering into the environment. For example, a 2005 German study "Waste incineration, a farewell to dioxins"[12] found no significant emissions of dioxins, heavy metals and fine particles from waste incineration even though the sector's capacity had been increasing (see page 6 for more information).

WI BAT Conclusions[13] establish that operators must **monitor dioxin and furan emissions from the stack of the plants during normal operating conditions as well as during other periods, such as start-up and shutdown**. Monitoring can be performed through continuous sampling or periodic measurements (only if it is proven that their emissions are low and stable). In 2014 a French study examined the comparison of periodic measurements, i.e. short-term, versus continuous sampling, i.e. long-term, for dioxin measurements across 100 Waste-to-Energy lines. It found only a modest difference between the results of different kinds of sampling (see page 7 for more details). This result rejects the claims that during abnormal conditions emissions of dioxins from WtE plants will raise significantly. **Even if continuous sampling did not provide a different conclusion compared to periodic sampling**, it is sometimes implemented by WtE plant operators in Europe as a useful tool to demonstrate the environmental safety of their facilities.

Biomonitoring of dioxins in the environment of WtE plants

To complement the information gathered with emission measurements, European WtE plants are also often engaging in measurement campaigns in their surroundings (see examples in the studies below).

POPs such as dioxins accumulate over time in **biomarkers**, with chicken eggs being especially sensitive to this accumulation. Identifying the exact source of dioxin contamination is a very complex exercise: on the one hand contamination can be linked to a wide range of sources (e.g. household heating, agricultural practices and industrial activities), on the other hand one might have to look way back in the past to find the source due to the persistency of these pollutants.

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[10] Van Caneghem, J., Block, C., Van Brecht, A., Wauters, G., & Vandecasteele, C. (2010). Mass balance for POPs in hazardous and municipal solid waste incinerators. Chemosphere, 78(6), 701-708.

[11] Van Caneghem, J., Block, C., & Vandecasteele, C. (2014). Destruction and formation of dioxin-like PCBs in dedicated full scale waste incinerators. Chemosphere, 94, 42-47.

[12] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. (2005). *Müllverbrennung – ein Gefahrenherd? Abschied von der Dioxinschleuder.*

[13] Commission implementing decision (EU) 2019/2010 of 12 November 2019 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration

Identifying the emission source: a challenging task

The measurement of dioxins in environmental samples or animal products solely demonstrates whether or not dioxins are present in the examined biomarker. **It is not possible to guarantee the dioxin emission source based solely on the levels in biomarkers**. These pollutants can originate from both recent sources and historical pollution. Unfortunately, the dioxin group consists of a long list of compounds, and it is not easy to find a correlation with a possible origin. The measurements and associated congener distributions should therefore be compared with a framework of measurements, including the ones performed at the stack. Only a complete assessment of all potential sources in the surroundings - such as households, other industries, traffic, etc. – can unambiguously specify where the problem lies.

Specifically for the municipal waste incineration process, attempts to define and identify a typical congener pattern were often not conclusive. Furthermore, all combustion processes, whether they involve waste or not, show similar patterns[14]. The same goes for some industrial metallurgical processes[15] and even traffic, as illustrated in Figure 3 based on air quality samples taken in the environment of a WtE plant in Barcelona. There are of course other activities, such as pulp bleaching, which render unique congener patterns so that source identification is an easier task.

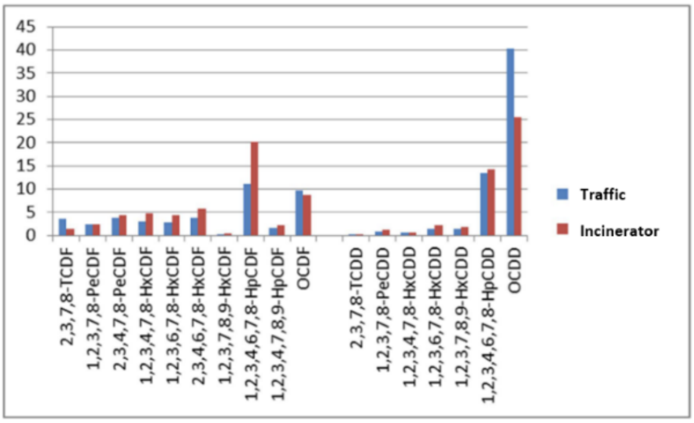

Figure 3: The result of the fingerprinting technique indicating the percentage distribution of the congeners detected in an air sample. Source: Tersa, Barcelona

[14] Huang, H., & Buekens, A. (1995). On the mechanisms of dioxin formation in combustion processes. *Chemosphere*, *31*(9), 4099-4117.

[15] Buekens, A., Cornelis, E., Huang, H., & Dewettinck, T. (2000). Fingerprints of dioxin from thermal industrial processes. *Chemosphere*, *40*(9-11), 1021-1024.

Data collection on monitoring of dioxin and furan emission in the Waste-to-Energy sector

This section provides summaries of some dioxin and furan measurement studies undertaken at the stack and in the surroundings of numerous WtE plants across Europe. A few of the studies look into air quality (see Belgium, Italy (Desio), Spain (Barcelona), Portugal) and soil (see Spain – Mallorca). Direct emissions from the plants are analysed in studies from Germany, Denmark and Sweden. Biomonitoring exercises have been performed in Italy (SpoTT), Austria and the Netherlands while studies from France and Belgium are comparing measurements from continuous and periodic dioxin sampling. The examples shown further on are only a small fraction of all the studies, research and dioxin monitoring that are continuously carried out by academia and the WtE industry.

Taken together these examples provide an extensive body of evidence showing that whenever the state-of-the-art techniques mentioned in the section above were used, it proved that current **WtE plants are safe, and that the legislation guarantees the necessary protection of human health and the environment**.

Figure 4: Map with the data contributions on dioxin monitoring per country selected for this report, which will be discussed further on.

Overview of the measurement methods

The following studies contain the results of analyses for the amount of dioxins, displayed according to their toxic equivalent quantity (TEQ)[16].

For an overview of the measurement methods and the associated units of the results, please refer to tables 1 and 2.

Symbol	Name	Value
g	gram	1 g
ng	nanogram	10^{-9} g
pg	picogram	10^{-12} g
fg	femtogram	10^{-15} g

Table 1: Units of mass and orders of magnitude

Measurements	Units	Explanation	Examples
Emission levels	ng TEQ/Nm^3	Sampling at the stack provides a clear record of the emissions' composition. The units represent the amount of dioxins (ng I-TEQ) measured in the gas flow rate (Nm^3)	*Germany France Belgium Denmark Sweden*
Deposition levels	pg TEQ/(m^2day)	The transfer of atmospheric pollutants to the earth's surface is measured by sampling the precipitated pollutants on various locations. This results in the amount of dioxins (pg TEQ) on a surface area (m^2) per day.	*Belgium*
Immission levels	fg or pg/m^3	Analysing air samples on various locations provides information on the ambient air quality. The amount of dioxins (pg or fg TEQ) in an air volume (m^3) is measured.	*Italy Spain Portugal*
Soil samples	ng TEQ/ kg dm	Represents the amount of dioxins (ng TEQ) measured in a certain amount of soil (kg dm; with dm = dry matter)	*Spain*
Vegetation samples	ng TEQ/kg dm	Represents the amount of dioxins (ng TEQ) measured in a certain amount of vegetation (kg dm; with dm = dry matter).	*Austria*
Sampling of animal products	pg TEQ/ g fat	As dioxins are highly soluble in fat, animal products such as cow milk or chicken eggs are sampled to determine the amount of dioxins (pg TEQ) found per amount of fat (g fat).	*Netherlands*
Sampling of human blood	-	To monitor the accumulation of dioxins in human blood and thus also the impact on human health.	*Italy*

Table 2: Overview of measurements used to monitor dioxin levels with associated units

[16] To display a clear overview of the toxicity range of dioxins and to facilitate risk assessment, the concept of the toxic equivalency factor (TEF) has been developed. The TEFs have been assigned based upon their relative potency compared to the most toxic dioxin TCDD. A summation of the TEF-converted quantities of dioxins renders the toxicity equivalent quantity (TEQ). I-TEQ and TEQ are used interchangeably, but have the same meaning.

Emission measurements

Germany

A 2005 German nationwide study “Müllverbrennung, Abschied von der Dioxinschleuder”[17] examined the dioxin emissions from 66 German waste incineration plants from 1990 to 2005. It found no significant contribution by the Waste-to-Energy industry, even though the sector’s capacity almost doubled from 9.2 million tonnes in 1990 to 16.9 in 2005.

Strict regulations stipulating the emission limit values for waste incineration plants in Germany were introduced in December 1990. Since 1996, all plants are compliant with these requirements and installed advanced flue gas cleaning systems.

Emissions of dioxins and furans from all 66 German Waste-to-Energy plants have been reduced by a factor of 1000 between 1990 and 2000 (Table 3). Other industries have also known a great reduction in emissions, yet **the greatest decline is observed in the Waste-to-Energy sector**.

Dioxin emission sources (Germany)	**Emissions per year in g TE**		
	1990	**1994**	**2000**
metal extraction and processing	740	220	40
waste incineration	400	32	0.5
power plants	5	3	3
Industrial incinerators	20	15	< 10
domestic fireplaces	20	15	< 10
traffic	10	4	< 1
crematoria	4	2	< 2
total emission air	1,200	330	<< 70

Table 3: Dioxin emission sources in Germany, annual loads of dioxin in grams per unit of toxicity (g TE). Source: BMUV, 2005

[17] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. (2005). *Müllverbrennung – ein Gefahrenherd? Abschied von der Dioxinschleuder.* https://www.itad.de/wissen/studien/2005_abschied_von_der_dioxinschleuder.pdf

France

A French study [18], carried out as a contribution to the elaboration of the Waste Incineration BREF[19], compared the periodic and continuous sampling for measurement of PCDD/F emissions of 100 Waste-to-Energy lines for the year 2014. The emission levels measured during continuous samplings were very similar to periodic samplings (Table 4).

These results show that, while continuous sampling is a useful tool as it allows to demonstrate in a clear way the safety of the plant, a well-managed combustion leads to very low dioxin emission levels no matter the sampling system. Moreover, as continuous sampling can also happen to include abnormal operations, this shows that even outside normal conditions emissions of dioxins are not significantly higher.

	average of periodic samplings	average of continuous samplings
ng ITEQ /Nm^3	0,011	0,019

Table 4: Dioxin emission levels in 100 French Waste-to-Energy lines for periodic and continuous monitoring in 2014. Source: SVDU-FNADE, 2014

Belgium

A practical example of continuous sampling of dioxin emissions is illustrated by Figure 5, showing a monthly overview of dioxin emissions from the grate furnaces at a Belgian Waste-to-Energy plant, including values obtained during start-up and shutdown. Apart from indicating the low emission levels, a comparison with periodic sampling for the same grate furnaces is included over the course of 4 years (2002 to 2005) and shows that continuous sampling and periodic measurements provide very similar values, both well below the emission limit value.

To complement measurements at the stack, dioxin depositions in the vicinity of the plant are examined. Figure 6 indicates the decrease of dioxin emissions throughout the years (2004 until 2019) in 2 monitoring stations that were installed in the deposition areas of 2 WtE plants. The graph on the right shows that there were no dioxin concentrations measured in either station after 2015. The most prominent measurements in the last years are PCB[20] depositions, which are typical of a scrap processing plant located near the deposition area and therefore unrelated to the activities of a WtE plant.

[18] SVDU & FNADE. (2014). SVDU-FNADE study: comparison between periodic and continuous sampling measurements for PCDD/F.
[19] WI BREFs = Best Available Techniques (BAT) reference documents, published by the Commission
[20] Polychlorinated biphenyls (PCBs): Man-made organic compounds that belong to the group of chlorinated hydrocarbons. Same as dioxins the various compounds differ greatly in toxicity and can be formed during industrial processes.

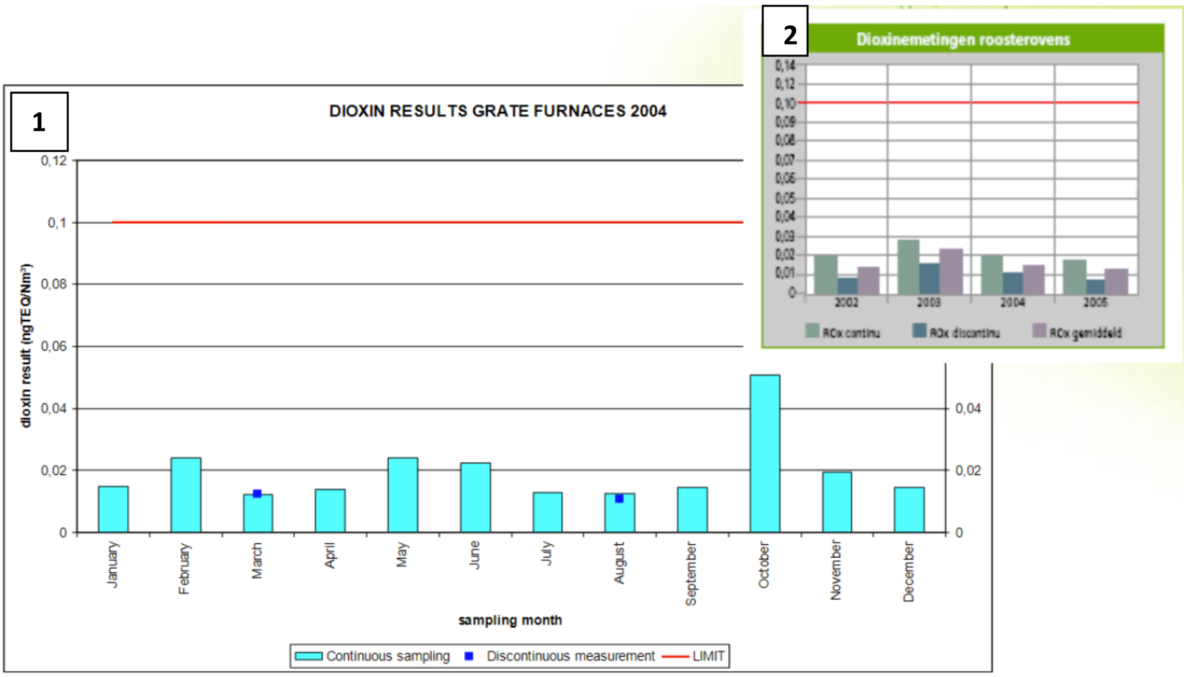

Figure 5: 1) Monthly overview of continuous monitoring of dioxin emissions in 2004 from grate furnaces at a Belgian Waste-to-Energy plant. 2) Comparison of dioxin emissions obtained through continuous and periodic sampling from 2002 to 2005 for the same grate furnaces. Source: Indaver, Belgium

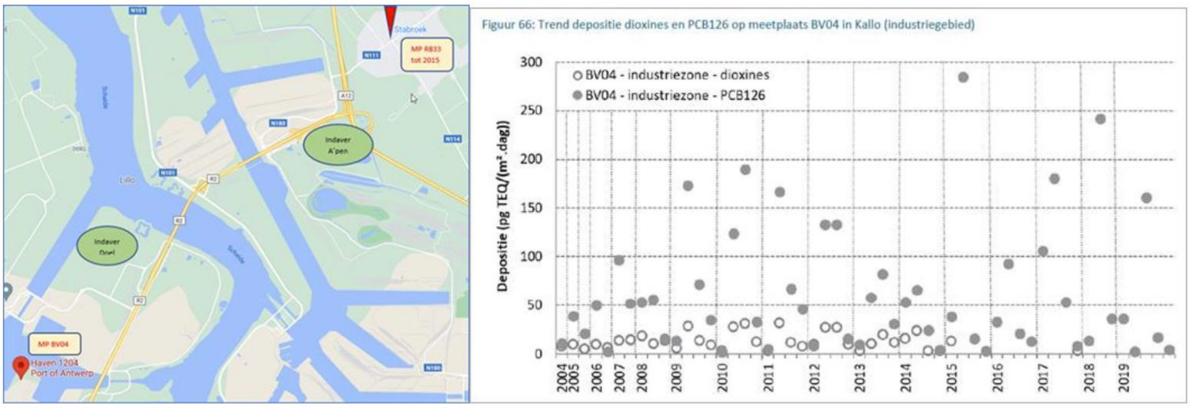

Figure 6: Monitoring of dioxin depositions around a Belgian WtE plant. On the left figure the two plants are indicated in green and the predicted deposition areas in red (MP BV04 and MP R833). The right figure shows the deposition of dioxins (pg TEQ/(m2.dag)) from 2004 to 2019. Since 2015 the stations have no longer measured dioxin depositions (clear bullet points) due to the low values. MP R833 has completely disappeared, MP BV04 only measures PCB depositions (dark bullet points) due to scrap processing nearby. Source: Indaver, Belgium

Denmark

Periodic sampling of flue gas at both lines of a Danish Waste-to-Energy plant shows that all dioxin and furan measurements are below 0,002 ng I-TEQ/Nm^3 (Table 5). The dioxin and furan concentrations in the samples were below the detection limit of the measuring methods, that is why the table shows a "<" sign.

	Line 1		Line 2	
Year	**Sampling period**	**Dioxins/furans (ng I-TEQ/Nm3)**	**Sampling period**	**Dioxins/furans (ng I-TEQ/Nm3)**
2019	21-May	< 0.001	27-May	< 0.001
	23-May	< 0.0005	28-May	< 0.0005
	3-Jun	< 0.001	12-Sep	< 0.002
	13-Sep	< 0.002	2-Oct	< 0.002
	8-Oct	< 0.002	21-Oct	< 0.002
	3-Dec	< 0.002	4-Dec	< 0.002
2020	21-Jan	< 0.002	22-Jan	< 0.002
	10-Mar	< 0.001	11-Mar	< 0.001
	26-May	< 0.001	27-May	< 0.001
	9-Sep	< 0.001	10-Sep	< 0.001
	29-Sep	< 0.002	24-Nov	< 0.002
	23-Nov	< 0.002	25-Nov	< 0.002
2021	23-Feb	< 0.002	24-Feb	< 0.001

Table 5: Dioxins and furans monitoring in flue gas at a Danish Waste-to-Energy plant from 2019 to 2021. Source: ARC, Denmark

Waste-to-Energy plants have a highly controlled combustion and sophisticated flue gas cleaning system in place which consists of interlinked elements that all help to prevent pollutants (including dioxins) from entering the environment with a very high efficiency, as can be seen in the example shown in Figure 7.

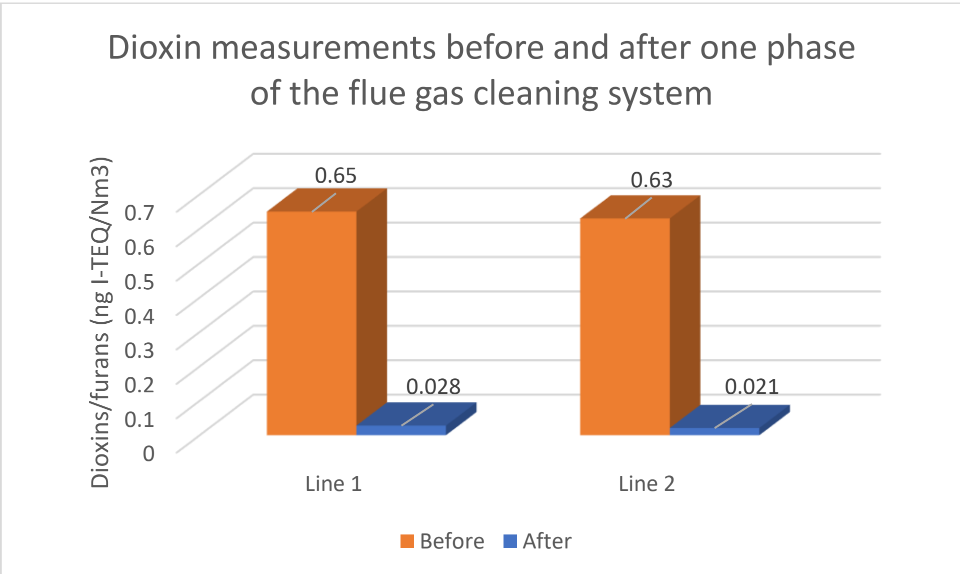

Figure 7: Dioxin reduction measured in the flue gas cleaning line before and after DeNOx steps in 2019. On average a 96% decrease of dioxins and furans is attributed to this flue gas cleaning phase. Source: ARC, Denmark

Several nationwide studies[21] [22] [23] confirm the small contribution of the Waste-to-Energy sector to dioxin emissions. A 94% reduction from 32.5 g I-TEQ in 1990 to 2.1 g I-TEQ in 2004 is observed in emissions from waste incineration and despite an increase in capacity, the low emission levels continue until today (Figure 8). This is mainly due to the installation and improved performance of flue gas cleaning systems in WtE plants. Furthermore, all studies refer to residential areas as the most dominant dioxin emission source. In 2018, it even accounted for 90% of the emissions, of which 94% was attributed to the combustion of wood for heating. Connected to the higher local emissions from wood stoves is the clear seasonal variation of ambient air quality with maximum dioxin concentration in winter.

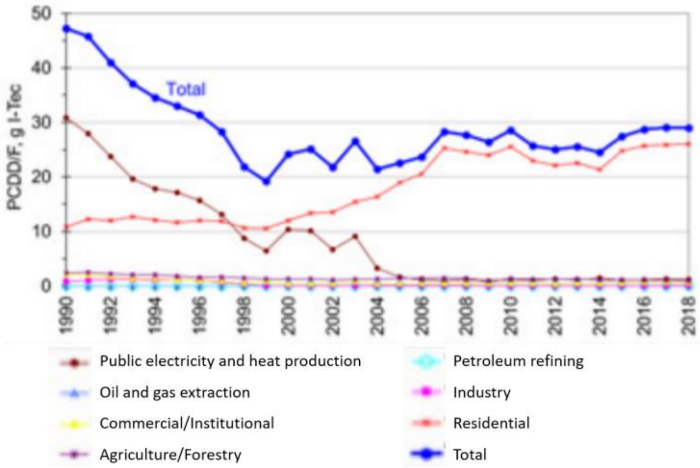

Figure 8: PCDD/F emission evolution over time for stationary combustion plants from different sectors in Denmark. Waste-to-Energy is included in 'Public electricity and heat production' together with large power plants.

Sweden

A collaboration[24] between academics and the Swedish WtE industry resulted in a nationwide study on 'Dioxins and waste incineration'. The conclusion is clear: in comparison to other primary sources today, WtE is a small contributor of emissions to air, with no effect on the levels of dioxins in the ambient air. It thus prevents dioxins from entering the environment, provided that the residues are handled in a safe way.

From 1986 onwards stringent regulations ensured that the WtE industry in Sweden met strict environmental requirements. This turning point resulted in a drastic reduction in dioxin emissions from more than 100 g per year in the mid-1980s to less than 1g in 2015, in spite of a quadrupling of the capacity and a six-fold increase in energy production. The effect can be clearly observed in Figure 9.

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[21] Henriksen et al., Dioxin Air Emission Inventory 1990 – 2004 (2006). Danish Centre For Environment and Energy

[22] Vikelsøe et al., Dioxin in the Atmosphere of Denmark (2006). Danish Centre For Environment and Energy

[23] Nielsen M., Danish emission inventories for stationary combustion plants. Inventories until 2018. (2021). Danish Centre for Environment and Energy

[24] Marklund et al., Dioxins and waste incineration (2017). Avfall Sverige & SteMar Konsult

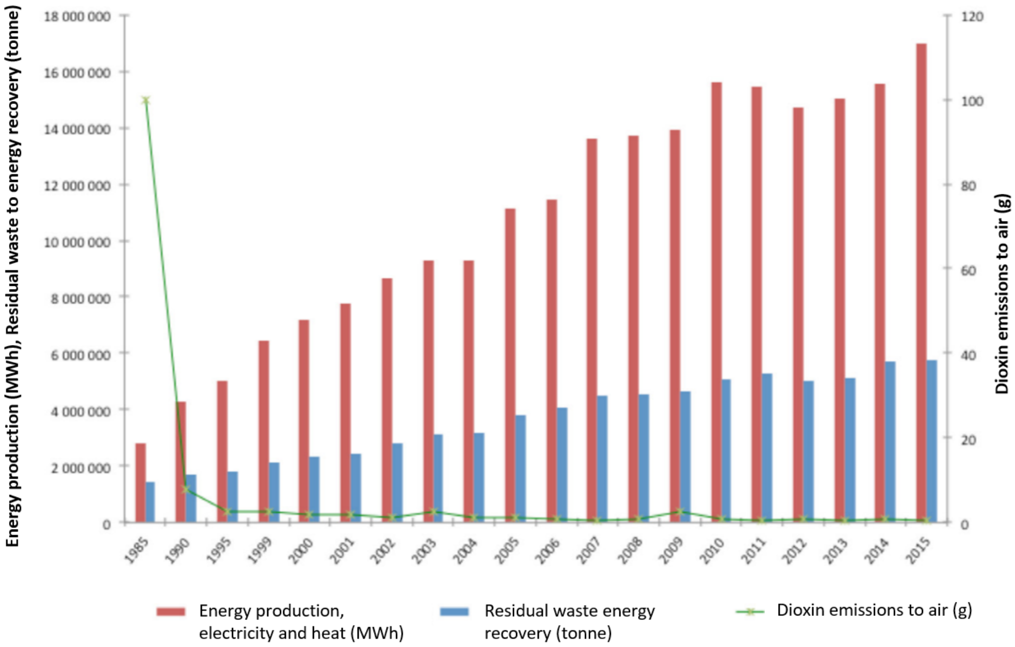


Figure 9: Emission to air of dioxins from waste incineration in Sweden compared to energy production. Source: Avfall Sverige & Marklund et al.

The obligatory monitoring of dioxin emissions showed levels well below 0.1 ng TEQ/m^3. Moreover, monitoring throughout different operation stages evened out all recorded values over the long term. Thus, emission levels at the stack should be considered as the mean for period of operation. The decline in emission levels and total amount of dioxins produced from combustion is due to more modern installations with an optimised combustion process and flue gas cleaning systems. The latter makes sure that more than 99% of the dioxins are captured in the flue gas residues. Only a minor fraction, which is estimated to be less than 10g per year in the whole of Sweden, ends up in the bottom ash and slag (0.0008% of the circa. 1.2 million tonnes of bottom ash produced yearly in Sweden). All combustion residues are handled accordingly to prevent dioxins from entering the environment.

The report also mentions the substantial contribution of dioxin emissions from landfill fires. Compared to the emission factor of incineration of municipal solid waste, the emission factor for surface landfill fires can be up to 5000 times higher[25].

[25] These estimates are very uncertain since it heavily depends on landfill content composition and further research is necessary.

Air quality measurements

Italy

The Desio Waste-to-Energy plant in northern Italy was the subject of an academic paper[26] [27] reviewing the impact of the plant's emissions on air quality. The study spans over a period of two years (2015 and 2017) and concludes that the contributions of the WtE plant are very low. Table 6 shows the results in pg TEQ m^{-3} for dioxin emissions using a continuous sampling system. Furthermore, comparison of the plant's dioxin emission data with that of traffic in the area made clear that emissions from heavy traffic can be up to a thousand times higher.

Month	Year 2015	Year 2017
Jan	1.10	0. 41
Feb	0. 61	0. 26
Mar	0. 71	0. 48
Apr	1.00	0.74
May	1.06	0.76
Jun	0. 43	0.04
Jul	1.25	0.71
Aug	0. 72	0.67
Sep	1.71	0.41
Oct	1.47	1.35
Nov	1.15	0.71
Dec	2.54	0.61(*)

(*) Missing December 2017 data the average concentration of the previ-ous months was used

Table 6: Monthly average dioxin concentration (pg TEQ m^{-3}, normal conditions, dry gas 11% 0_2) from dioxin continuous sampling system. Source: Lonati et al., 2019

Spain

Air quality monitoring around the Barcelona Waste-to-Energy plant

The example of air quality monitoring at 7 different locations around Barcelona demonstrates the low dioxin quantities in air. The study was carried out over the course of 2 sampling periods: May-July 2018 and December 2018-March 2019. As this period included different stages of the plant's operation, it allows for a review of air quality in the plant's vicinity during shutdown for maintenance, and in full and partial operation mode. Table 7 indicates that the highest concentrations in the environment were measured during full operation in December and February, yet still shows no significant impact by the Waste-to-Energy plant.

Air quality measurements for dioxin levels (fg TEQ/m³)

		1	2	3	4	5	6	7	8	9
		08-maig	23-maig	29-maig	14-juny	05-jul	17-des	29/01/2019	19/02/2019	27/02/2019
		16-maig	25-maig	01-juny	18-juny	09-jul	19-des	31-gen-19	21/02/2019	01/03/2019
Museu Blau		X								
Garcia Faria		9.7	4.7	4.5	3.8	4.6	9.4	5.2	7.3	20.9
CAP Besos										
Urgell			10	8.0	6.7	5.2	6.9	3.7	6.4	18.8
Poliesportiu la Mina		8.5	6.9	4.4	5.3	4.4	29.0	5.8	24.1	11.7
Escola Catalunya			X	X	6.4	X	36.5	7.5	14.2	25.4
Biblioteca Can Fabra		7.9	8.9	4.9	4.7	5.8	17.5	6.8	17.2	29.3
Eugeni d'ors							11.4	8.8		

Plant operation
Two ovens in operation and shutdown **Complete shutdown** Startup and two ovens in operation **Full operation**

Table 7: Monitoring of air quality on 7 locations in the environment of the WtE plant. The dioxin immissions are given in fgTEQ/m³ for the indicated sampling periods in 2019. The different stages of operation do not show significant variations in air quality for dioxins. Source: Tersa, Barcelona

[26] The actual impact of waste-to-energy plant emissions on air quality: A case study from northern Italy, Detritus – Volume 06 – June 2019, pages 77-84

[27] Utilitalia. (2020). *White paper on municipal waste incineration.*

Biomarker measurements

Austria

Biomonitoring can also be carried out through sampling of vegetation in the environment. Whilst the measurements provide a value for the amount of dioxins in the vegetation sample, they do not determine per se the source from which the pollutants came. If higher dioxin levels are detected in this way, a further extensive investigation is required.

An example of an Austrian plant is given in Figure 10 with a grass culture grown specifically to monitor the plant's emissions during construction and the first 2 years of operation. The graphs show no great difference between the predicted deposition areas at a distance of 650 m and 1 km and the reference location. The median values per year for all three locations are all measured well below 0.4 ng/kg dm. All measurements throughout the year are included in the boxplot[28] display.

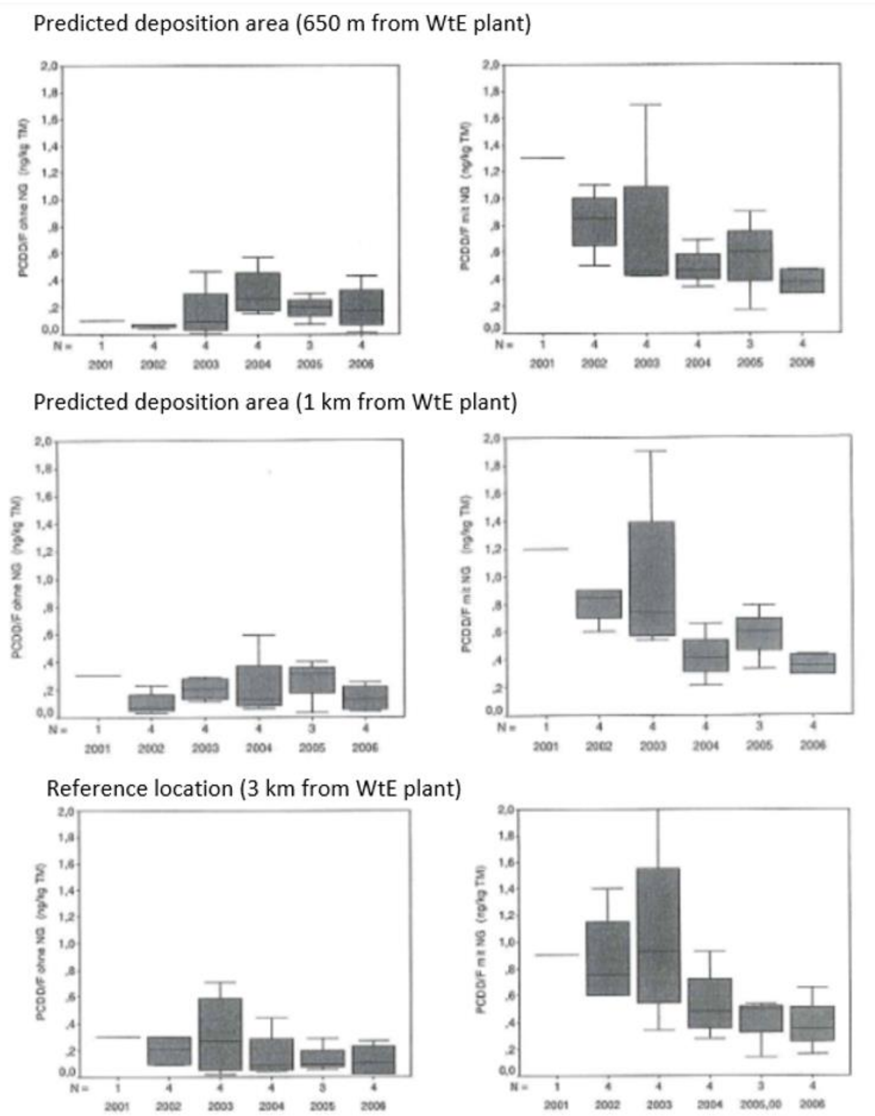


Figure 10: Active biomonitoring of dioxins around an Austrian WtE plant with 'Weidelgras'. In 2001 marks a growing season of the grass without measurements. Monitoring started during construction (2002 – 2004) and the first 2 years of operation (2005-2006). Samples were taken 4 times per year. Graphs on the left show the dioxins toxicity equivalents without taking the non-detectable congeners into account. Graphs on the right show the dioxins equivalents including the non-detectable congeners into account as a worst case scenario. The Y-axis label: PCDD/F (ng/kg dm) Source: KRV, Austria

[28] Boxplot: graphic display of a dataset with the top point of the line of every box representing the maximum value measured. The lowest point of the line under the box is the minimum value measured. The box itself contains all the data between the first quartile (25%) and the third quartile (75%) of the data ordered by increasing value. In the box the median or middle value is indicated with a line. The data are thus displayed in a way to give an indication of how the measurements are spread out.

Italy

SPoTT program at Turin WtE plant

An example of impact assessment on a large scale is the SPoTT program, a population health surveillance allowing the assessment of health effects in the areas surrounding the Turin Waste-to-Energy plant. Dioxin levels in blood of 100 people (50 living in the environment of the WtE plant and 50 living outside of the emission zone) and 13 farmers within the radius of 5 km of the plant were examined in this project. Over the course of 3 years (2013-2016) healthcare professionals carried out examinations to monitor the accumulation in 3 time periods: before the commissioning of the plant, after one year of operation and after three years of operation. Over time, the levels of dioxins in blood did not increase and no significant differences between the groups were noted.

Netherlands

Due to dioxin's high fat solubility, another biomonitoring method is to examine the accumulation of dioxins in animal products. The analysis results signal the presence of a pollutant but do not determine the source of the contamination. Thus, the detection of high dioxin levels in the sample is a warning sign that contamination occurred, and the source of this needs to be identified. However, when levels are low, it confirms that there are no significant emissions in the area.

A Dutch Waste-to-Energy plant used this approach to observe the dioxin levels in cow milk in predicted deposition areas. The results are given in Figure 11 and show a steady trend of low measurements throughout the years. The comparison to the Dutch background level of dioxins in cow milk indicates that there are no deviations for the samples in the vicinity of the Waste-to-Energy plant.

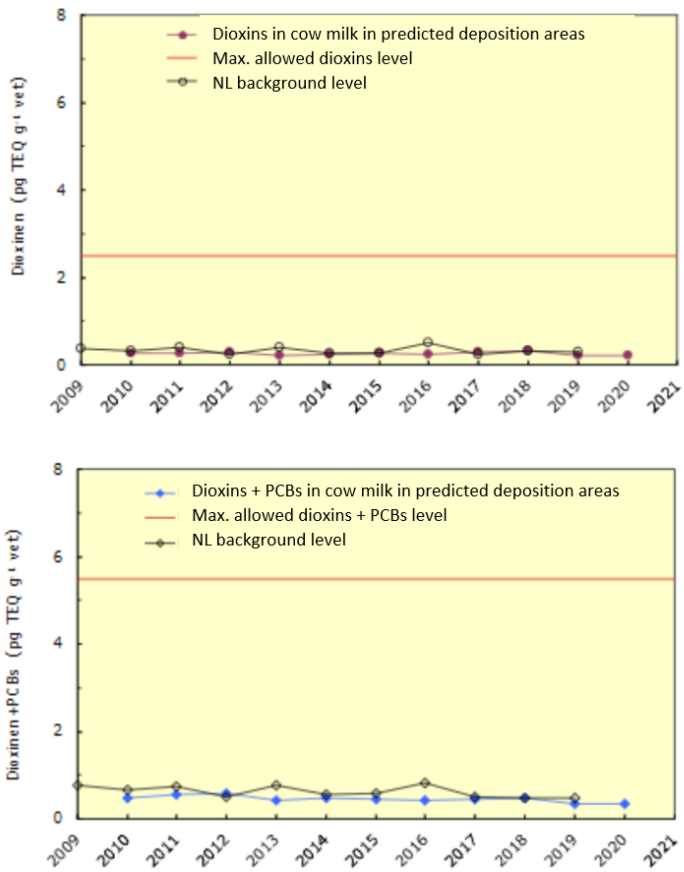


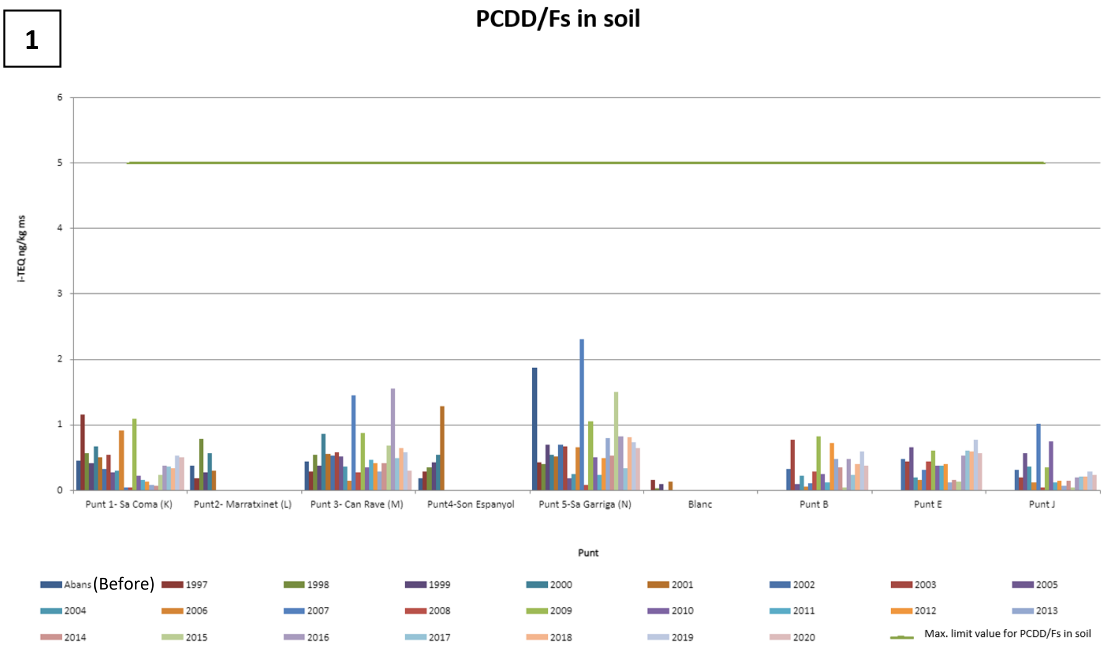
Figure 11: Biomonitoring of dioxin emissions around a Dutch WtE plant. The graphs show the distribution of dioxins and dioxins + PCBs (pg TEQ/g fat) in cow milk, sampled in predicted deposition areas. Source: Omrin, Netherlands

Spain

Monitoring of dioxins in soil samples around the Mallorca Waste-to-Energy plant

The sampling and analysis of soil samples in the environment of a Waste-to-Energy plant in Mallorca is illustrated in Figure 12 and renders the trend in dioxin levels from 1997 to 2020. From the data shown it can be concluded that all measured dioxin depositions are well below the maximum limit value in soil (5 I-TEQ ng/kg.ms) and are in general considered lower than 1 I-TEQ ng/kg.ms. From 1997 (start of operation) onwards one peak measurement was registered at 'Punt 5-Sa Garriga (N)' (closest to the plant) in 2007. At the same sampling point the second highest amount of dioxins in a soil sample was measured before the WtE plant went into operation.

1



2

Figure 12: 1): Dioxin levels (i-TEQ ng/kg ms) for soil samples in the environment of a WtE plant from 1997 until 2020. The x-axis shows the sampling locations. 2) Map indicating the sampling locations and the WtE plant (circled in green circle)

Portugal

Air quality measurement in predicted deposition locations is a great tool to assess the plant's impact on the most exposed areas. Figure 13 shows this approach for a Portuguese WtE plant and displays the decrease in dioxin emissions throughout the years in a clear way. The seasonal variation of dioxin levels is also included, showcasing the higher levels in winter months.

In 2005 the graph displays a higher maximum value compared to the other years. However, the median is quite low, indicating that the upper half of the values are very spread out. The same is observed in the seasonal variety where high values in the 2005 winter months are measured.

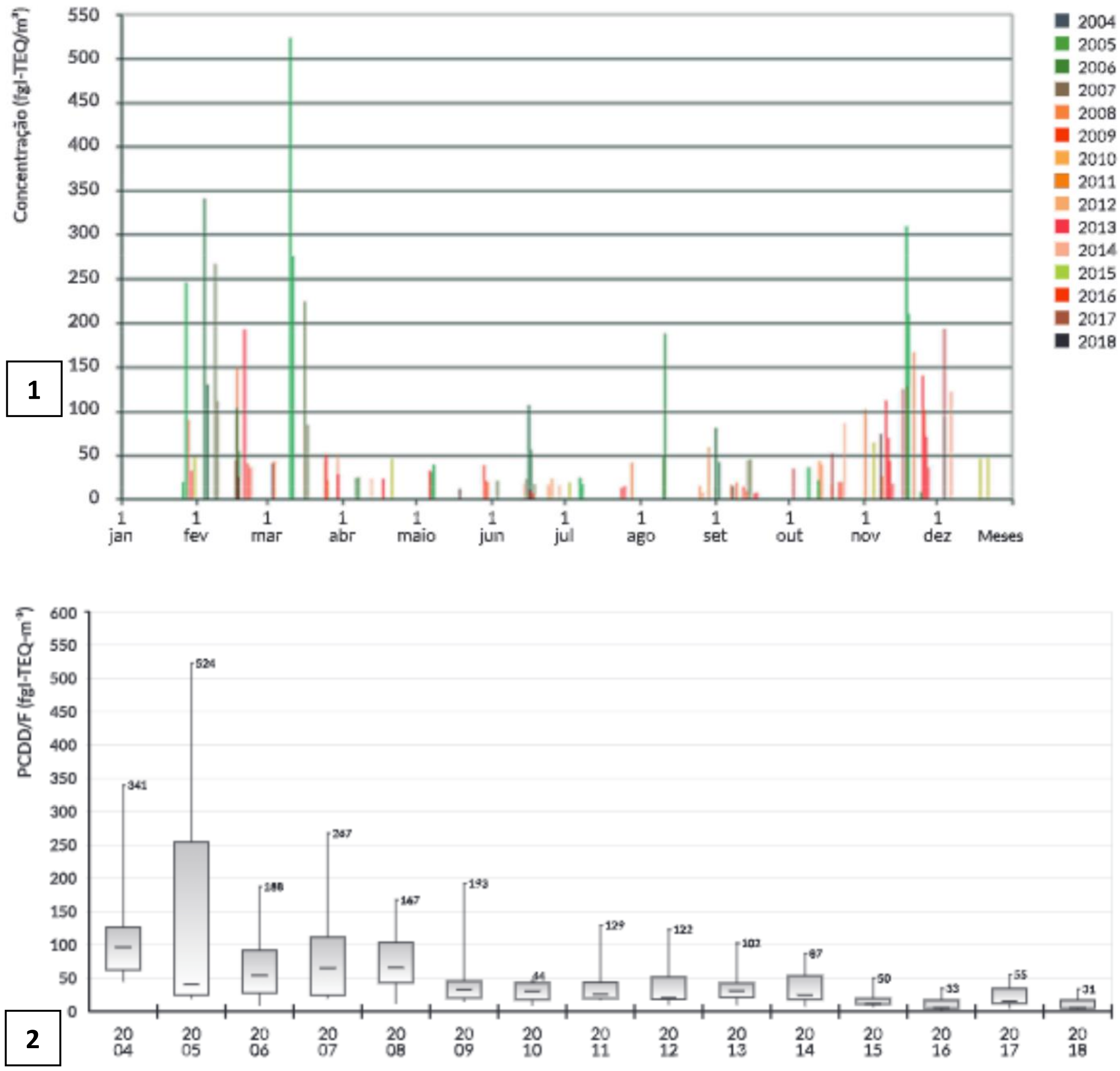


Figure 13: Monitoring of dioxins around a Portuguese WtE plant through measurement of air quality in predicted deposition areas. Sampling was carried out 4 times a year over a period of 3 days. 1) The first graph shows the seasonal variation of dioxin levels from 2004 to 2018. 2) The second graph indicates the analysis results for PCDD/F (fg I-TEQ/m^3) from 2004 – 2018. Source: Lipor, Portugal