Ministère de la Santé
et des Services sociaux

Health Hazards Associated with Residual Materials Treatment Sites

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AUTHORS

Christine Blanchette (landfill - leachate section)
Direction de santé publique de la Montérégie

Emmanuelle Bouchard-Bastien (social and psychological dimensions section)
Institut national de santé publique du Québec

Isabelle Demers (composting section)
Ministère de la Santé et des Services sociaux

Mathieu Gauthier (environmental noise section)
Institut national de santé publique du Québec

Virginie Noel Aloise (vermin and Nordic issues sections)
Direction de santé publique du Nord-du-Québec

David Simard (landfill sections - biogas and odours)
Direction de santé publique du Saguenay-Lac-St-Jean

Mathieu Simard (incineration section)
Direction de santé publique du Saguenay-Lac-St-Jean

WITH THE COLLABORATION OF

Karine Chaussé
Institut national de santé publique du Québec

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Summary

The operation of residual materials treatment sites (RMTSs), including landfills, incinerators, and composting sites, is well regulated in Québec, which effectively restricts and controls the release of potentially hazardous substances for the environment and human health. Nevertheless, the possible effects on human health associated with the various residual materials management methods continue to raise concerns among the public and the scientific community.

The main health impacts documented in connection with RMTSs are respiratory and gastrointestinal problems, cancers, reproductive problems, and congenital anomalies, in addition to a variety of non-specific effects such as nausea, headaches and various irritations. These potential health effects are often reported but rarely confirmed. Psychological and social impacts, particularly regarding the social acceptance of projects and nuisances, are also reported.

Landfill

Although some epidemiological studies indicate a slight increase in the health risk associated with landfills, the overall evidence is contradictory or inconclusive and does not clearly establish a causal link between health effects and landfills.

Nevertheless, the main health concerns associated with landfills are tied to the biogas and leachate generated by these sites. Landfill sites also generate nuisances such as high noise levels (machinery used for routine site operations), foul odours (decomposition of organic matter) and the presence of vermin (gulls, rodents, etc.) drawn by the large amount of food.

Methane (CH_4) and carbon dioxide (CO_2) are the main constituents of biogas, and their concentrations near a landfill site generally do not represent a significant health risk.

As for leachate, many of its contaminants are known to be toxic and carcinogenic. Percolation of leachate to groundwater or runoff into surface water can also lead to the contamination of drinking water sources.

Incineration

Pollutants from incineration identified as posing the greatest potential risk to human health, based on their persistence in the environment, bioaccumulation and inherent toxicity or the quantity emitted, are organic compounds (dioxins, furans, PCBs, PAHs, etc.), metals, dust (with a molecular weight of less than 10 microns), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The literature review indicates that no significant association of higher cancer incidence or adverse reproductive and developmental effects has been established for incineration plants. Some studies have nevertheless revealed associations with certain pathologies. Consequently, given the conflicting evidence from epidemiological studies on the impacts of incineration plant emissions on human health, it is difficult to establish a causal link between the proximity of incinerators and health effects.

Composting

Putrescible organic matter is not toxic in itself. Theoretically, well-controlled composting should not pose a danger to human health or the environment. In practice, however, some contaminants are present in the compost and may pose a health risk. The most significant releases associated with composting are dust and bioaerosols, which can result in increased respiratory problems. Odours also constitute an important impact of composting activities. Health impacts caused by organic contaminants and metals may also be associated with composting sites.

The literature review could not establish a link between bioaerosol emissions from a composting facility and health problems in surrounding populations. Furthermore, the levels of organic contaminants and metals in the compost are low and do not pose a significant health risk. Many studies have shown that the main concern with respect to bioaerosols and dust is for workers, as they are more exposed to these contaminants and are therefore more likely to develop respiratory diseases.

Nuisances

Activities involving the management of residual materials can result in nuisances that affect the quality of life of people living near RMTSs. The most common nuisances reported are foul odours, noise, and the presence of vermin.

Various compounds resulting from the handling or treatment of residual materials can generate odours. The most common odorous compounds associated with waste treatment are sulphur compounds (hydrogen sulphide, dimethyl sulphide, ethyl mercaptan, methyl mercaptan, etc.), ammonia and other volatile organic compounds such as vinyl chloride and hydrocarbons. Odour perception is complex and varies from one individual to another. Several factors can influence the response to a given odour: hedonic tone, sensitivity, olfactory memory, etc. If the smell is perceived as being associated with a potential threat, then the likelihood of concern and increased discomfort is greater. Exposure to unpleasant odours is difficult to assess. It is influenced by many factors such as the concentration of odorous compounds at the source, the rates of emission, dispersion and degradation of these compounds, meteorological factors, the frequency, intensity and duration of the odour episode, and the distance between the odour source and the exposed population. Assessing the health risks associated with foul odours is challenging, given the diversity of exposures and possible responses for each individual. Although it has not been clearly demonstrated that odours have toxic effects on health, they are nonetheless a major nuisance, even a source of irritation that can significantly affect the quality of life of people living near waste treatment sites.

As for noise, it can represent a significant percentage of the complaints associated with an RMTS. Depending on the nature of the noise, its intensity, the time at which it occurs, its duration and frequency, it can have harmful effects on physical health (sleep disturbances, cardiovascular disease, etc.) as well as psychosocial effects (nuisance or interference with activities and rest, learning in a school environment, etc.). The construction phase of an RMTS project may expose local residents to noise generated by the transportation of equipment or materials, as well as noise generated by construction activities. The exact nature of noise during operation varies from one RMTS to another, but generally includes transportation noise and industrial noise.

On the nuisance front, vermin can cause trauma (e.g., glass shards, sharp objects, etc.) when moving detritus and contribute to the dispersion of pathogens or become a vector themselves. Health risks associated with vermin have been reported, although they have not been evaluated nor clearly established in the literature.

Social and Psychological Dimensions

According to the World Health Organization (WHO), health is not only the absence of disease, but also the state of physical and psychological well-being that enables the full development of individuals and communities. As such, the well-being of communities near RMTSs is an important public health concern, as are the social and psychological effects of these projects.

Taking social acceptance factors into account when analyzing RMTS projects is relevant insofar as these factors modulate the social and psychological impacts, and thus provide a better understanding of, for instance, sources of conflict, stress, or feelings of hope. Social acceptance (public consent) may vary within a community once a final waste disposal project is announced. Several factors influence social acceptance, such as the historical and socio-economic context, the financial impacts (positive or negative), the company's attitude regarding communication and risk management (transparency, management of nuisances (odours) and consultation with the population and elected officials), potential health risks, etc.

The social and psychological impacts associated with the planning and operation of an RMTS can be numerous. Effects on the social fabric, particularly regarding socio-political dynamics, have been documented in the literature. Some projects may create spontaneous citizen groups and social cleavages. Studies also report psychological impacts as soon as the project is announced and planned. Residents reported feelings of stress, anxiety, fear, and anger, as well as feelings of helplessness, unfairness, and loss of trust in authority.

Nordic Issues

Communities north of the 55th parallel face significant logistical problems regarding the management of residual materials. Landfilling is impossible in most of these regions. As a result, waste accumulates on the surface, is mostly burned, or is sent to the southern regions of Québec.

Since, in most cases, the different types of residual materials are not sorted, they are exposed to the elements. The waste accumulates and thus causes the gradual release of toxic compounds through leaching. There are also issues related to spontaneous fires and open burning.

The lack of leachate treatment can result in large amounts of contaminants entering streams and groundwater. Pollutants such as lead, mercury and cadmium can be absorbed by marine mammals and fish, which remain an important source of food in the region, in addition to contributing to the precariousness of existing drinking water sources in the area.

Spontaneous combustions were observed at some sites, these events being of great concern for the health and safety of the population.

These spontaneous combustions can cause a critical increase in volatile organic compounds (VOCs) such as benzene and dioxin-furans, which can have significant impacts on health. Open burning of waste, which is permitted under the Regulation respecting the landfilling and incineration of residual materials (RLIMR), also produces a significant amount of air emissions and residual solids such as carbon dioxide, methane, VOCs and dioxins and furans. The lack of a capture mechanism and adequate infrastructure for the management of discharges makes open burning particularly harmful to the health of people living nearby.

Finally, the lack of fencing around many northern landfills leads to significant health and safety issues. On the one hand, the population can have free access to them and thus be exposed to toxic or traumatic agents and suffer serious accidents. On the other hand, animals such as bears may be drawn to these sites to feed themselves. Once accustomed to human food, bears will venture closer and closer to communities and the proximity to humans increases the risk of attack and/or accident.

Conclusion

Overall, the literature available to date provides little support for concerns about the potential health effects associated with RMTSs, although significant results are reported. Two interpretations are therefore possible: exposure to the contaminants emitted by RMTSs is too low for health effects to be observed, or the studies are not sensitive enough to link the contaminants present to the health problems observed. However, the difficulty in demonstrating a causal link between exposure to RMTS contaminants and health effects does not imply an absence of risk, as these effects remain biologically plausible. Reducing the health risks associated with RMTSs therefore involves reducing waste generation at the source.

LIST OF ACRONYMS

BAPE	Bureau d’audiences publiques sur l’environnement
VOC	Volatile organic compounds
NMVOC	Non-methane volatile organic compounds
CRD	Construction, renovation, and demolition
eqCO2	CO2 equivalent
PAH	Polycyclic aromatic hydrocarbons
ICI	Industries, commerces and institutions
INSPQ	Institut national de santé publique du Québec
CDWL	Construction or Demolition Waste Landfill
NL	Northern Landfill
SL	Sanitary landfill
EL	Engineered Landfill
RMTS	Residual Materials Treatment Site
MELCC	Ministère de l’Environnement et de la Lutte contre les Changements climatiques
MSSS	Ministère de la Santé et des Services sociaux
MTQ	Ministère des Transports du Québec
WHO	World Health Organization
RLIRM	Regulation respecting the landfilling and incineration of residual materials

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1. Introduction

1.1. Setting the Context

As part of the mandate entrusted to the Bureau d'audiences publiques sur l'environnement (BAPE) on the site inventory and management of final waste, the Commission of Inquiry requested the Ministère de la Santé et des Services sociaux (MSSS) to prepare a report on the health impacts of a residual materials treatment site (RMTS).

There are several definitions of the term “residual material,” but all have in common the notion that they are undesirable materials that the holder wants to get rid of. In this report, the term “residual material” will be used to refer to all materials and residues destined for disposal, whether they are reclaimable.

In Québec, residual materials can be classified according to:

- their regulatory name: contaminated soil; biomedical, mining, and radioactive waste; pulp and paper; organic sludge, etc.
- the generator (sector): municipal; industrial, commercial, and institutional (ICI); construction, renovation, and demolition (CRD).

In this context and considering the constraints attached to the BAPE's activity schedule, this report presents the main toxicological aspects, nuisances, as well as the psychological and social impacts associated with residual materials that can be managed by landfilling, incineration, or composting. The social acceptability associated with RMTSs is also discussed. The health impacts of other residual materials management methods, which should not be neglected, may be the subject of further clarification if necessary. Moreover, the aspect of workers' health is not covered in this report, although it may be briefly mentioned a few times. Also note that increased telework (due to COVID-19 or for other reasons) was not considered for this report. However, this could have an impact on the perception of nuisances (noise, odours, etc.) and on psychological and social effects. While operators focus on the daytime operation of RMTSs on weekdays, it is now more likely that local residents will be present at their homes and be adversely affected.

1.2. Roles and Responsibilities of Public Health Stakeholders in Residual Materials Management

Under the Public Health Act (R.S.Q., c S-2.2), the Minister for Health and Social Services and the regional directors of public health must intervene, each at their own level, to prevent diseases, traumas and social problems that have an impact on health and influence the determinants of the health of the population.

According to the WHO, the determinants of health: “refer to a set of individual or collective factors that influence health status, including personal, social, economic and environmental factors. The various determinants of health interact with each other, so that a person's health is the complex sum of these components" (Bouchard-Bastien et al., 2020). Appendix 1 presents a Québec conceptual framework of the determinants of health (MSSS, 2014).

When analyzing projects, public health stakeholders must, among other things, consider the project's potential impact on the determinants of health. Their role is to ensure that physical, psychological, and social health issues are properly considered, analyzed, and mitigated to improve the integration of a project into society, with a view to protecting the health of the population.

The integration of public health issues often results in the analysis of risks related to biological, chemical, or physical agents of environmental origin, including the resulting nuisances. Moreover, in line with the WHO and MSSS orientations, public health concerns also include the impacts that projects may have on the social determinants of health.

From a public health point of view, the unavoidable issues that are generally considered are: water quality, air quality, soil quality, technological risks, psychological and social impacts, environmental noise, nuisances, traumas and impacts on the healthcare and services system.

With regard more specifically to RMTS's development or expansion projects, public health actors intervene at three levels:

- for RMTS projects subject to the Environmental Impact Assessment and Review Procedure (EIARP)
- for smaller-scale projects subject to ministerial authorization under section 22 of the Environment Quality Act (R.S.Q., c. Q-2)
- for the management of problematic situations: several complaints from citizens, nuisance issues, etc.

As such, public health plays an important role and is an essential partner in the management of residual materials.

1.3. Health Risk Assessment

Risks of health effects depend on the probability of exposure to a hazardous agent[1], combined with its negative effects on the health of the population (Cortin et al., 2016). These adverse effects may affect health directly (morbidity, disability, and mortality) or indirectly, for instance through social or economic impacts (Cortin et al., 2016). Exposure to hazardous substances released from residual materials disposal or treatment sites varies according to the method of residual materials management and must be quantitatively sufficient for the risk to occur. To reduce this risk, the release of substances that are potentially hazardous to the environment and human health must be limited and controlled as much as possible.

The risk of health effects depends on the types and quantities of residues managed. Where residual materials are treated, they are often mixed together. This makes it difficult to characterize the hazard associated with this mixture or with products resulting from its decomposition (if applicable). Alternatively, the health impact assessment can be done by considering the effects that could occur for each substance released individually for each type of facility.

[1] Hazardous agent: an element that may be a biological, chemical, or physical entity, a process, a human activity, or a belief in a practice that may adversely affect health (Cortin et al., 2016).

2. Landfill

There are different types of landfill sites authorized in Québec under the Regulation respecting the landfilling and incineration of residual materials (RLIMR) (R.S.Q., c. Q-2, r.19):

- engineered landfills (EL)
- Construction or Demolition Waste Landfill (CDWL)
- trench landfills
- northern landfills
- remote landfills

For the sake of brevity, the term “landfill” will be used in this chapter to refer to both ELs and CDWLs. Trench, northern and remote landfills are subject to special planning and management requirements, and the health effects that may be associated with them are discussed in Chapter 7.

2.1. Types of Releases and Population Exposure

Landfills receive a large variety of residual materials from the municipal, commercial, and industrial sectors. The proportions of each type of residual material vary considerably depending on the nature of the site (EL vs. CDWL) and the nature of the materials authorized on the site over the years (regulatory changes, changes in the vocation of the site, recovery efforts and detour of materials prior to final landfilling, etc.).

Landfills are often very large and therefore generate significant amounts of biogas and leachate. The composition and quantity of biogas and leachate can vary greatly from site to site depending on several factors:

- characteristics of the residual materials themselves: nature (municipal, industrial, construction waste, etc.), quantity and physico-chemical properties, etc.
- characteristics of the landfill: mode of operation (landfilling time and conditions), control of discharges into the environment, size of the site (surface area) and age of the landfill, etc.
- climatic conditions: temperature, precipitation, etc.

Biogas is generated by the large amount of putrescible material on the site and is therefore primarily associated with sanitary landfills (SLs) and engineered landfills (ELs). As such, CDWLs have long been perceived as having low health risks, since the waste landfilled there is not easily putrefiable and not easily soluble, thus producing a minimal amount of leachate and biogas. However, CDWLs are not without danger. For instance, plasterboard (gypsum) is leachable and putrefiable as soon as it is wet, while wood secretes phenols as it decomposes and releases biogases into the atmosphere. Furthermore, demolition residues may get mixed with other materials such as paint, varnish, and creosote. These products, often based on oil and organic compounds, can migrate into the soil, and contaminate water sources (Recyc-Québec, 2006).

In addition to biogas and leachate, landfills generate nuisances such as foul odours (decomposition of organic matter), high noise levels (machinery used for routine site operations) and the presence of vermin (gulls, rodents, etc.) attracted by the abundance of food.

These nuisances, which are discussed in more detail in Chapter 5, can hinder activities and affect the quality of life of citizens living near landfill sites.

2.1.1 Biogas

Various processes are involved in the generation of biogas within landfills, including aerobic or anaerobic bacterial decomposition of organic matter, volatilization, and chemical reactions between the various components (ATSDR, 2008).

Composition

Landfill biogas contains many substances (see Table 1), and its composition will vary over time, depending on the dominant stage of decomposition (aerobic, anaerobic, methanogenic) (Figures 1 and 2) of the organic matter. The release of biogas (active period) from landfills lasts about 30 years (Desrosiers, 2004; Olivier, 1999). Biogas compounds can be classified in several ways, depending on the reference consulted. They include aliphatic hydrocarbons, aromatic hydrocarbons, oxygenated compounds such as alcohols, aldehydes, esters, etc., halogenated compounds, reduced sulphur compounds, terpenes, nitrogenous compounds such as ammonia and various inorganic compounds (Duan et al., 2021).

Table 1 Typical landfill biogas composition (adapted from ATSDR, 2008)

Compound	Percentage of volume	Characteristic
Methane	45 to 60	Methane is produced naturally. It is colourless and odourless. In Canada, methane emissions from landfills account for 20% of the total emissions
Carbon dioxide	40 to 60	It is found in the atmosphere at a concentration of about 0.04%. It is colourless and odourless. Slightly acidic.
Nitrogen	2 to 5	Nitrogen represents about 79% of the atmosphere. It is colourless, odourless and insipid.
Oxygen	0.1 to 1	Oxygen represents about 79% of the atmosphere. It is colourless, odourless and insipid.
Ammonia	0.1 to 1	Colourless gas with a very characteristic strong pungent odour.
NMVOC Composés organiques volatils non-méthaniques	0.01 to 0.6	NMVOCs are mainly composed of carbon and hydrogen atoms. They may also contain oxygen, nitrogen, sulfur, or metal atoms. The most common NMVOCs in biogas are benzene, chloroform, vinyl chloride, dichloroethane, dichloroethylene, dichloromethane, carbonyl sulfide, ethyl benzene, hexane, tetrachloroethylene, toluene, xylene, etc.
Sulfures	0 to 1	Sulfides such as hydrogen sulfide, dimethyl sulfide and mercaptans are produced naturally and give the biogas the special rotten egg smell. Sulfides can cause an unpleasant odour at very low concentrations.
Hydrogen	0 to 0,2	Colourless and odourless gas.

Carbon monoxide	0 to 0,2	Colourless and odourless gas.

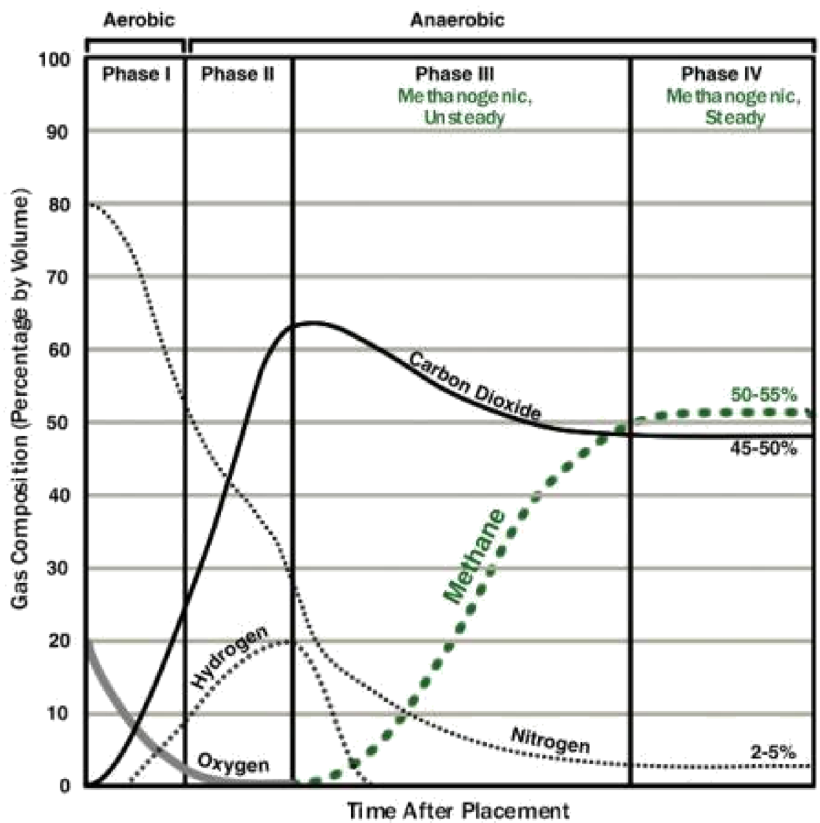

Figure 1 Variation in production of major biogas components by time (from US EPA, 2021)

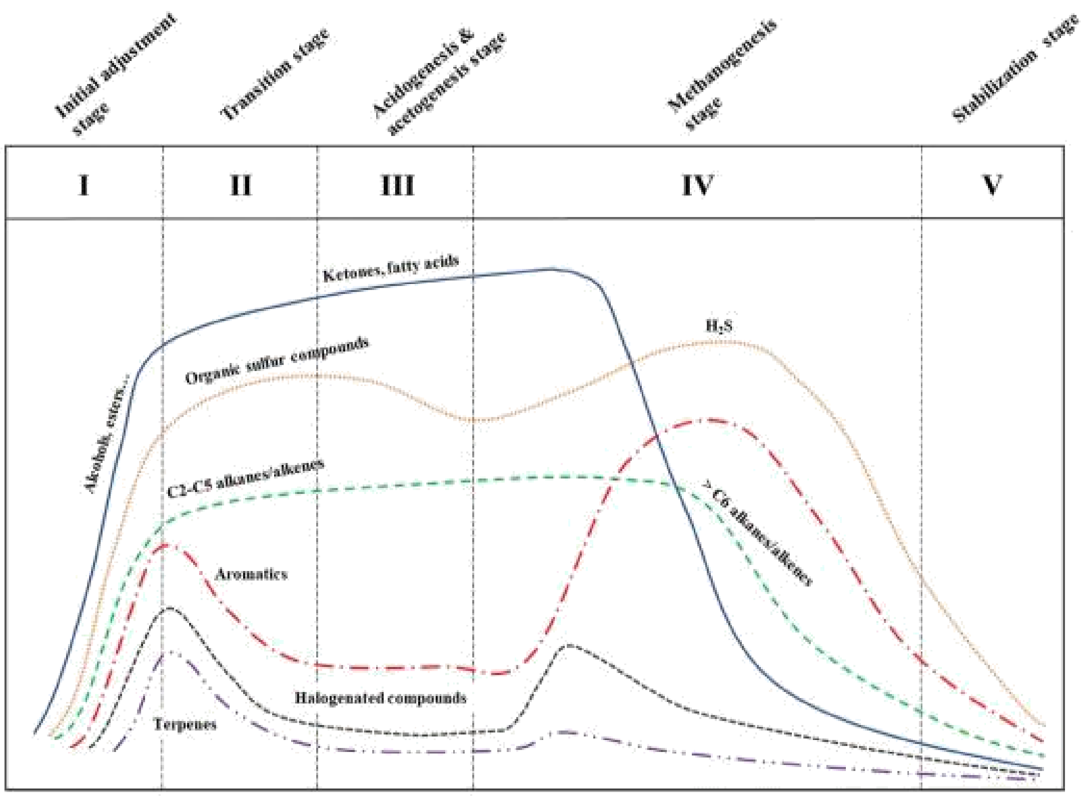

Figure 2 Qualitative representation of the change in concentration of trace compounds in the biogas as a function of time (from Duan et al., 2021)

The main constituents of biogas are methane (CH_4, 45% to 60%) and carbon dioxide (CO_2, 40% to 60%) (ATSDR, 2008). The concentrations of carbon dioxide and methane found in the vicinity of a landfill site do not represent a health risk. However, by contributing to global warming through the greenhouse effect, they have an indirect impact on the health of the general population in many ways (Watts et al., 2017; WHO, 2016). For the year 2018, emissions from municipal waste in landfills produced 12 MtCO2e in Canada, or 1.6% of emissions (Environment Canada, 2020). This excludes emissions from wood waste landfills, composting, water treatment sludge, incinerators, and open burning. If emissions from these disposal methods are included, there are instead 20 Mt of CO2e produced by waste management in Canada. (Environment Canada, 2020). Methane accumulation can also pose a safety risk due to the potential for explosions (ATSDR, 2008).

In addition to oxygen and nitrogen, a multitude of other trace compounds are found in biogas. In a study by Allen et al. (1997), more than 140 different non-methane volatile organic compounds (NMVOCs) were identified. Although they account for less than 1% of the biogas composition, the chemical and physical properties of these compounds make them a public health concern. At high concentrations, NMVOCs can be respiratory or eye irritants and can cause headaches. They can cause allergic reactions and asthma (Camak, 2014; Kim, 2013) and can have negative impacts on the liver, kidneys, and central nervous system. Several NMVOCs present in biogas such as benzene, chloroform, vinyl chloride etc. are known or suspected carcinogens.

In the context of population exposure to landfill biogas, acute effects are less likely to occur and carcinogenicity, after long exposure, is the main public health concern of NMVOCs. However, the context may be different for workers who perform the activities on the site, but this is not the subject of this report.

The presence of foul odours is the main cause of complaints about existing landfills and is one of the main reasons for opposition to the construction of new landfills (Cai et al., 2015). Trace biogas compounds are responsible for the odour problems associated with landfills. This is discussed in Chapter 5.

Population Exposure

Population exposure depends on the overall emissions from the landfill, including the method used to dispose of the gas and whether a biogas collection system is present. The efficiency of biogas collection systems ranges from 50% to 95% and is primarily influenced by the management of the landfill (US EPA, 1995).

Biogases are primarily emitted into the atmosphere and is carried by winds to the surrounding communities. They may also migrate laterally through the soil into building basements via permeable soils, or through preferential pathways such as nearby sewer systems, and concentrate in indoor air. Exposure of the population living near landfills occurs through inhalation of contaminated indoor or outdoor air (ATSDR, 2008; Gandolla, 1997).

2.1.2 Leachate

A wide variety of contaminants can be found in landfill leachate, the main ones being (Bélanger et al., 1993; Health Canada, 2004):

- Organic contaminants: benzene, vinyl chloride, dichloromethane, tetrachloroethylene, tetrachloromethane, chlorophenols
- Inorganic contaminants: nitrate/nitrite, arsenic, cyanides, cadmium, chromium, mercury, lead
- Biological contaminants: bacteria (coliforms of the Enterobacteriaceae family), viruses (hepatitis A and Norwalk group), protozoan parasites (*Giardia lamblia and Cryptosporidium parvum*).

The chemical composition of the leachate is highly dependent on the nature of the landfilled residual materials and the water input management. Some contaminants are carried away more rapidly than others by the leachate water. For instance, chlorides dissolve quickly, while heavy metals take longer to percolate (Olivier, 1999). Leachates are generally characterized by parameters such as pH, conductivity, global nitrogen, biological oxygen demand (BOD), chemical oxygen demand (COD), and their contents of toxic or undesirable metals and metalloids. BOD and COD are the parameters that indicate the concentration of organic matter. Depending on the chemical and biological evolution of the residual materials, there are three types of leachate: young (< 5 years), intermediate and stabilized (> 10 years) leachates. Table 2 presents the evolution over time of the physico-chemical properties of a leachate compared to black wastewater. Table 3 illustrates the physico-chemical quality of the leachate. The limit values set by the RLIMR are added for comparison.

Table 2 Changes over time in typical SL leachate content and comparison with the composition of the black wastewater (from Olivier, 1999)

Parameter	Leachate, 1 to 2 years (mg/L)	Leachate, 5 years (mg/L)	Leachate, 15 years (mg/L)	Wastewater (mg/L)	Limit values RLIRM (mg/L)
pH	6 - 7	7 - 8	7 - 8	7 - 8	6.0 – 9.5[a]
Chemical demand in oxygen (COD)[b]	20 000 – 40 000	500 – 3 000	-	350	-
Biological demand in oxygen over 5 days (BOD_5)[c]	10 000 – 20 000	50 – 100	50	250	150[a]
Organic carbon total (TOC)	9,000 – 15,000	100 – 1,000	-	100	-
Volatile acids	9,000 – 25,000	50 – 100	-	50	-
Ammoniacal nitrogen (expressed in N)	1000-2000	-	60	15	25[a] 1.5[d]
Organic nitrogen (expressed in N)	500 – 1,000	-	10	10	10[d]
Total dissolved solids	20,000	5,000	2,000	-	-
Chlorides (expressed as Cl^-)	1000-3000	500 – 2,000	500	-	250[d]
Hydrogen carbonate	1000-3000	1000-2000	-	-	-
Sulphates (expressed in SO_4^{-2})	500 – 1,000	50 – 500	-	-	500[d]
Phosphate	50 – 150	10-50	-	-	-

[a] According to section 53 of the RLIMR, which deals with leachate and water collected by any collection system.

[b] COD: Quantity of dissolved oxygen required for the decomposition of both mineral substances and biodegradable and non-biodegradable organic substances.

[c] BOD_5: Quantity of dissolved oxygen required for the bacterial decomposition of organic matter in water. The 5-day period is only part of the requirement.

[d] According to section 57 of the RLIMR dealing with groundwater.

Table 3 Physico-chemical quality of leachate from several household and industrial waste landfills (adapted from Clément et al., 1993)

Parameter	Minimum value (mg/L)	Value maximum (mg/L)	Average geometric (mg/L)	Limit values RLIRM (mg/L)
pH	4.9	8.9	6.9	6,0-9,5[a]
COD (mg O_2/ L)	10.0	86,000	1231.0	-
DBO_5 (mg O_2/L)	0	73,000	388,0[b]	150[a]
TOC	3.0	22,500	218.0	-
Ammonia	0.9	2,154	47.0	25[a] 1,5[c] (N ammoniacal)
Chlorides (expressed in Cl^-)	7.0	8,800	523.0	250[c]
Sulphates (expressed in SO_4^{-2})	3.0	3,239	121.0	500[c]
Chromium	0	23	0,07[b]	0,05[c]
Copper	0	16	0,04[b]	-
Iron	0.05	1,995	11.5	0,3[c]
Nickel	0	79	0,12[b]	0,02[c]
Lead	0	46	0,05[b]	0,01[c]
Zinc	0	326	0,36[b]	0.17[a] 5[c]

[a] According to section 53 of the RLIMR, which deals with leachate and water collected by any collection system.
[b] Except for zero concentrations.
[c] According to section 57 of the RLIMR dealing with groundwater.

As with the properties outlined in section 2.1.1, many of the contaminants found in leachate are known to be toxic and carcinogenic.

Percolation of leachate to groundwater or runoff to surface water may result in contamination of drinking water sources. If the water supply source for a water system is located near a landfill site, the water consumed by the population could be contaminated to a greater or lesser degree, depending on the degree of contamination of the raw water, the treatments given to this water and the controls carried out before its distribution in the drinking water system. The population supplied by small waterworks systems (whose treatment is not always optimal) or private wells may be at greater risk of exposure to contaminants present in the leachate. Exposure to leachate is therefore mainly by ingestion, but also by inhalation when contaminated water is sprayed (e.g., during showers) and by direct contact with the skin and mucous membranes (e.g., during aquatic activities).

2.2. Health Risks

Many health effects are suspected to be related to living near a landfill. Previous mismanagement of discharges from many landfills, as well as the nature of the waste that can or may have been landfilled, contribute to the idea of potential causal links.

To assess the health risks associated with landfills, the WHO (WHO, 2000) recommends considering human activities within a one-kilometre radius and surface and ground water within a two-kilometre radius. WHO also recommends prioritizing the effects listed by the Agency for Toxic Substances and Disease Registry (ATSDR), based on the toxicological and epidemiological literature:

- birth defects and reproductive disorders
- cancers
- respiratory diseases
- immune system disorders
- neurotoxic disorders
- kidney dysfunction
- liver dysfunction.

This list is consistent with the major categories of health effects identified in numerous epidemiological studies and literature reviews of landfills: cancers, birth defects, reproductive problems, and low birth weight babies. Other health effects, such as respiratory problems, irritations of various kinds, increased drug consumption, neurological problems, etc., are also identified in the literature, at varying frequencies.
Several literature reviews have been published on the health-associated effects in populations living near landfills (Kihal Talantikite et al., 2017;

Ncube et al, 2016; Mattiello et al, 2013; Forastiere et al, 2011; Porta et al, 2009; Giusti, 2009; Saunders, 2007; Enviros Consulting and University of Birgmingham, 2004; Franchini et al. 2004; Rushton, 2003; Vrijheid, 2000). Although excess risks are sometimes observed, the main literature reviews consulted describe the scientific evidence linking health effects to landfills as “insufficient”, “weak” or “inadequate” (Porta et al., 2009).

The cancer risks associated with proximity to landfills have been the subject of several studies. Although some studies have reported excess risk (e.g., Comba et al., 2006; Minichilli et al., 2005; Altavista et al., 2004; Goldberg et al., 1999; Michelozzi et al., 1998; Lewis-Michl et al., 1998), evidence of increased cancer risk is considered inconsistent and inadequate (Ncube et al., 2016; Mattiello et al., 2013; Porta et al., 2009).

In terms of reproductive effects, low birth weight babies and birth defects,
the results tend to show an increased risk associated with proximity to landfills (Kihal Talantikite et al., 2017; Linzalone and Bianchi, 2005; Enviros Consulting and University of Birmingham, 2004; Vrijheid, 2000). According to Giusti (2009), the strongest association between a health effect and landfills is for birth defects. Conversely, the studies by Elliott et al. (2001) and Jarup et al. (2007) were unable to demonstrate excess congenital malformations and low birth weight once confounding factors were taken into consideration. According to Ncube et al. (2016), it is impossible to conclude that

to teratogenic effect leading to a low-birth-weight baby. Of the 29 studies reviewed by Saunders (2007), where the results were evenly split between a possible association of effect or not, the author concludes that the link between adverse birth outcomes and proximity to a landfill is not convincing.

Several authors expressed reservations about the apparent link to landfills, as the available information did not indicate whether landfills were the direct cause or one of the contributing factors. Furthermore, several studies have been conducted including landfills that accept (or have already accepted) hazardous materials. However, when the results are compared to those obtained in studies in which no hazardous materials are buried, the health effects noted are much less significant (Kihal Talantikite et al., 2017; Porta et al., 2009). These authors conclude that a landfill accepting only municipal waste does not pose a health risk with respect to birth defects and various reproductive problems.

The health effects investigated (cancers, birth defects) are rare. They therefore need to be studied in a large population base to detect statistically significant excesses. To compensate for the lack of statistical power, the authors include several landfills in their studies, thereby broadening the population pool in which health effects can be observed. However, most of the literature reviews consulted point to the many limitations of epidemiological studies and, consequently, the difficulty of interpreting the results. The main challenge is the lack of population exposure data (Kihal Talantikite et al. 2017; Mattiello et al. 2013; Porta et al. 2009). Indeed, different radii (1, 2 or 3 km) are used to investigate health effects. It is also assumed that the population's exposure to contaminants is uniform within the radius, which is unlikely in practice. Also, in multi-site studies, authors often combine landfills receiving municipal and/or hazardous waste, with the definition of the type of waste accepted in a landfill varying from country to country (Kihal Talantikite et al., 2017; Mattiello et al., 2013; Porta et al., 2009). Lack of control for confounding factors (e.g., smoking, socio-economic status, etc.) is also widely cited as contributing to the difficulty in interpreting results.

In conclusion, although some epidemiological studies report a slight increase in the risk associated with landfills, the evidence is generally contradictory or inconclusive and does not clearly establish the existence of a cause-and-effect relationship.

3. Incineration

Incineration is a less common waste disposal practice than landfilling in Québec, considering that there are four facilities in the province (Recyc-Québec, 2020). Incineration of household waste represents a solution to reduce the volume of waste to be landfilled, while providing a potential energy solution with the heat released by the combustion of this waste (Asthana et al., 2007). However, incineration also produces releases (solid and gaseous) of a variety of chemical compounds, some of which can have adverse effects on human health, even at relatively low doses.

3.1. Types of Releases and Population Exposure

Upon combustion, the raw materials can transform and release compounds that are more toxic than the original compound. These compounds then become bioavailable and are concentrated in the incineration products: gases, fly ash, grate ash and bottom ash.

Figure 3 shows the origin of the main pollutants in household waste.

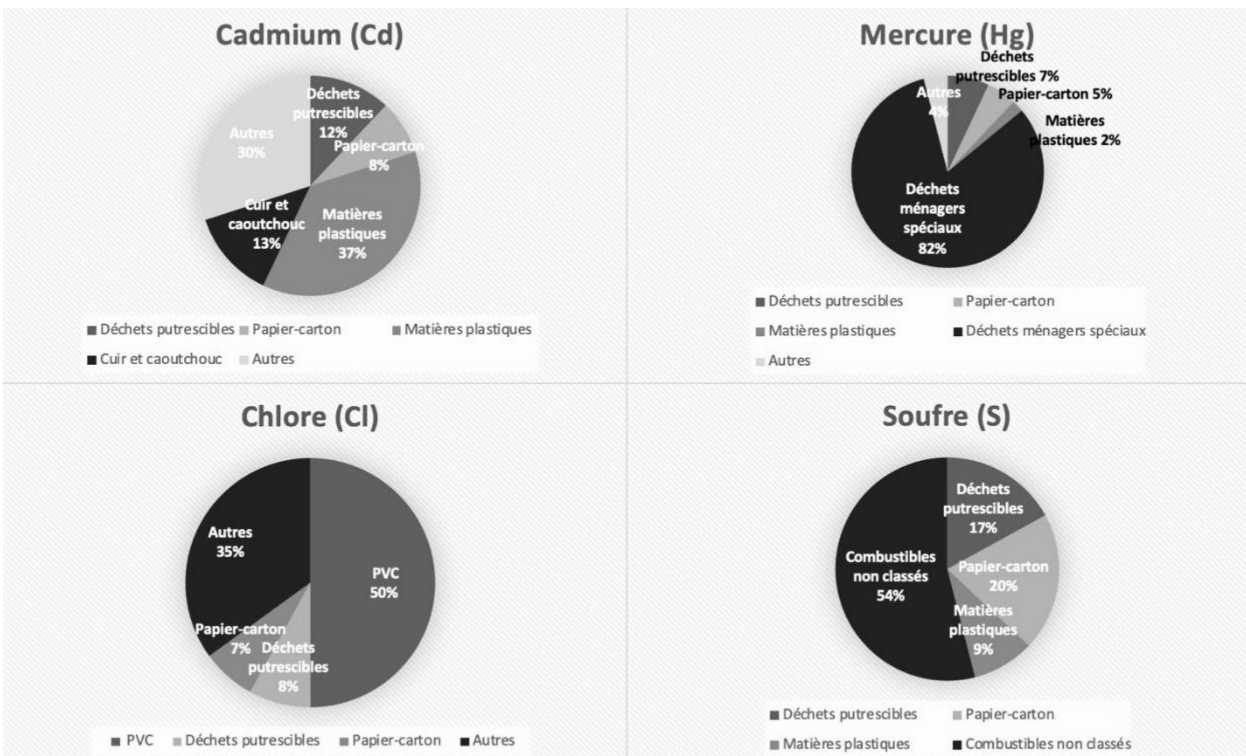

Figure 3 Source of some pollutants found in the discharges from incinerators (based on data from MEDD, 2004)

In the case of fluorine, paper and cardboard make up 50% of the sources and plastics 10%. As for lead, it comes mainly from sources of metallic lead and additives in glass. For zinc and copper, their respective sources are solder from special waste or cans and copper pipes, while arsenic comes mainly from glass (MEDD, 2004).

3.1.1 Air Emissions

Following the high-temperature combustion of household waste, the gaseous pollutants are treated and then directed to a chimney for release into the outside air. The treatment systems are designed to capture dust and metals, neutralize acid gases, and destroy dioxins and nitrogen oxides contained in the waste or generated during incineration. However, the efficiency of the filtration system varies considerably depending on the age of the incinerator and the desired air emission characteristics. The operating conditions of the incinerator are a determining factor in the efficiency of waste combustion, as well as the nature and quantity of contaminants emitted (Franchini, et al., 2004; Gérin, et al., 2003).

The main gaseous contaminants released into the atmosphere from incinerators are nitrogen oxides, sulphur dioxide, carbon monoxide, hydrogen chloride, and hydrogen fluoride (Health Canada, 2004; Olivier, 1999).

Atmospheric emissions from incinerators are also made up of dust (materials reduced to very fine powder) and fly ash (residues of burnt materials, small and easily airborne) that have not been captured by the flue gas cleaning systems. These emissions are composed of inert materials (e.g., silica) and volatile metals (arsenic, cadmium, chromium, magnesium, mercury, lead, zinc).

Substances that are not completely burned, such as insoluble organic compounds (PAHs, PCBs, dioxins, furans), soluble organic compounds (phenolic and benzene compounds, VOCs), and lime used to neutralize acid gases, may also condense on dust and fly ash (Health Canada, 2004; Olivier, 1999).

The greater the elevation of the stack, the more it will limit the deposition of pollutants into the immediate environment. Once in the atmosphere, the plume (atmospheric release) will be influenced by meteorological conditions, as well as its physical state (temperature and rate of release). Furthermore, due to their relatively small size ($< 10\ \mu m$), some particles may escape the capture (filtration) process before they leave the stack and end up in the air, where they behave like gases. Microparticles of cadmium, lead or zinc may also be present (Yoo et al., 2002).

Once the plume is transported by wind or rain, through prior condensation, it is deposited in the environment, either near the incinerator or not. Some of these may pose a higher risk if they accumulate in soils, including persistent organic pollutants (POPs) and heavy metals. Dioxin and furan contamination of plants appears to be low since these toxins are liposoluble.

3.1.2 Solid Combustion By-products

In addition to the gaseous part, the incineration of household waste, in a simplified model, also generates a solid slag heap, called bottom ash, composed of a mixture of metals, glass, silica, alumina, limestone, lime and other unburned materials as well as large and heavy unburned particles, called grate ash. They contain little or no dioxins and furans. Grate ash and bottom ash are physically stable, have low solubility, high buffering capacity and alkaline pH (Bélanger et al., 1993; Gérin, et al., 2003).

Because of their metal content (zinc, lead, copper, chromium, nickel, cadmium, arsenic, and mercury), grate ash and fly ash are similar to hazardous waste and must be chemically or mechanically stabilized before landfilling (Olivier, 1999). With the adoption of the RLIMR, engineered landfills can now accept residues from any waste incineration facility, including biomedical waste incinerators, including grate ash and fly ash, which can cause environmental and soil contamination problems.

3.2. Toxicity and Exposure

Pollutants from incineration identified as having the greatest potential for impact on human health, based on their persistence in the environment, bioaccumulation and inherent toxicity or amount emitted, are organic compounds, metals, dust (less than 10 microns molecular weight), sulphur dioxide (SO2) and nitrogen oxides (NOx) (Enviros Consulting and University of Birmingham 2004; Rushton 2003; Pheby, et al. 2002; Humfrey, et al. 1997). The carcinogenic potential and toxicity of these contaminants (oxides and dust) are presented in Table 4.

Table 4 Carcinogenicity and toxicity of main contaminants issued by incinerators

Organic compound	IARC classification [a] and associated cancers	Human toxicity [b, c]
Dioxins and Furans	Class 1 (2,3,7,8-Tetrachlorodibenzo - *para* - dioxin). All cancers together. Class 3 (benzofurans polychlorinated and dibenzo-polychlorinated para- dioxins).	Dermatological effects, hepatic effects, effects neuropsychic (headache, insomnia, nervousness, irritability, depression, anxiety, loss of libido, encephalopathy), weakening of the system immune system, cardiovascular disease, effects on reproduction.
Polychlorinated biphenyls (PCB)	Class 2A. Liver, hematopoietic lymphoid system pathways. ,	Rashes on the skin, gastrointestinal effects, Hepatic effects, thyroid hormone abnormalities, eye problems, weakened immune system in children, various neurological effects , reproductive effects.
Hydrocarbons aromatic polycyclic (PAHs)	Varies according to the compound in question. Benzo(a)pyrene (B(a)P) is one of the most toxic PAHs (Class 1).	Effects on the respiratory system, genotoxic effects , skin effects, haematological effects.
volatile organic compounds (VOCs)	Varies according to the compound which it is subject.	Variable effects according to VOCs: ranging from simple odour discomfort to skin and eye irritation (aldehydes), decreased respiratory capacity , until mutagenic effects, teratogenic and carcinogenic (benzene). The symptoms of exposure to weak VOC concentrations are namely: fatigue, headache, dizziness, weakness, pain in the joints, numbness, or tingling peripheral, euphoria, chest tightness and loss of balance.

Dust	Varies according to the nature of the dust.	The most dangerous dusts are those whose The most dangerous dusts are the ones whose diameter is less than 2.5 µm, as they may bind to and transport toxic compounds to the pulmonary alveoli, thus accentuating the effects of these compounds. Trigger or accentuation (which can lead to death) of the disorders respiratory and cardiac, particularly in susceptible populations; carcinogenic effects or possible mutagens.
Nitrogen oxides (NO_x)	Non classified.	Irritation of the upper respiratory tract, respiratory problems (distress, infection, edema, emphysema), eye irritation and tearing.
Sulfur Dioxide (SO_2)	Class 3.	Breathing problems (irritation of the nose and throat, airway obstruction, alteration ventilatory function, of the seizures asthma). The people with asthma are particularly sensitive.

[a] International Agency for Research on Cancer (IARC) classification: (1) Carcinogenic to humans; (2A) Probably carcinogenic to humans; (2B) Possibly carcinogenic to humans.
[b] All exposure routes combined; acute and chronic exposures.
[c] Sources: ATSDR, 2007; INERIS, 2007; INRS, 2007; IPCS, 2007.

In a joint study report by the Ministère de la Santé et des Sports, the Institut de veille sanitaire and the Agence française de sécurité sanitaire des aliments on the impregnation by dioxins and heavy metals of populations living near incinerators in eight French municipalities, the authorities were unable to establish a dose-effect relationship on the population studied.

Hence, for dioxins and *polychlorinated biphenyl-dioxin like* (PCB-DL), the exposure of the population studied was within the European average and the only statistically significant difference established with the impregnation of dioxins from plumes from old incinerators was for farmers consuming their own animal products (milk, meat, and eggs) (IVS, 2009). Dioxin levels in people exposed to the smoke plume were also approximately the same as those in other unexposed European populations and lower than those found in heavy fish consumers (IVS, 2009). In the case of heavy metals, blood lead and cadmium levels in exposed individuals remained within normal values, even though consumption of local foods exposed to the plume contributes to a moderate increase in blood lead levels (IVS, 2009). Table 5 summarizes the chemical profile of metals and organic compounds present in the exhaust fumes.

Table 5 Chemical profile of metals and organic compounds present in the outgoing elements following incineration (2001 data) (IVS, 2009)

Parameter	Percentage of total emissions due to incinerators	Total emissions from the incinerators (Tons)
Metals		
Cadmium	16%	1.8
Mercury	12%	13.8
Lead	9%	-
Zinc	13%	170
Copper	6%	5.2
Organic compounds		
Dioxins / furans	65%	304 g*
PCB	20%	-

*Quantity issued prior to the 2002 Ministerial Order that lowered the standard to 0.1 ng / m^3.

3.3. Health Risks

There are several studies on exposures to incineration discharges and their potential effects on human health (Trait et al., 2020). Most of these studies deal with the link between dioxin exposure and cancer, or the incidence of a type of cancer following chronic exposure to pollutants from incineration.

A retrospective study of cancer case rates between 2005 and 2014 in the urban area around the household waste incinerator in Nice that was exposed to air emissions found a statistically significant correlation between lung cancer and myeloma incidence in men for the period 2005-2009 (Barjoan et al., 2020). With the entry into force of European Union 2000/76/EC directive in 2000, which aimed to lower the standard for atmospheric dioxins to 0.1 ng TEQ/m3 in 2005, this statistically significant correlation was not observed for the period 2010-2014, suggesting that the decrease in the incidence of these cancers could be connected to the decrease in atmospheric dioxin concentrations (Barjoan et al., 2020). A 1974-1987 study found an association between the increased rate of pediatric cancers in children born near incinerators, despite possible biases.

De Titto (2019) reported that no significant association with a higher incidence of cancer and adverse reproductive and developmental effects was found in the scientific literature. Other literature reviews and meta-analyses have established associations with certain pathologies. In the face of conflicting evidence from epidemiological studies on the contribution of incinerator emissions to human health, Table 6 presents data from an epidemiological meta-analysis that addresses multiple pathologies influenced by incineration emissions (Tait et al., 2020).

Table 6 Identified Health Effects in Populations Residing Near Incinerators (Tait et al., 2020)

Health effect	Comment
Impacts of incineration on health risks (78 studies analyzed)	
Reducing exposure to pollutants in incineration plants using new technologies	20% of the studies concluded that population exposure to contaminants was reduced with the new incinerators and incinerators that have been refurbished.
Cellular and functional damage (cell survival, activation of immune cells and oxidative damage)	Exposure of human A459 cells to atmospheric particles from incinerators with increased production of reactive oxygen species. Increased lymphocyte activation in incineration plant workers.
Increase of PCDD and PCDF in the blood	Survey of 16 workers in a closed incinerator in 1997 showing blood levels of PCDD 4.7 times higher and PCDF 2.1 times higher at the population level.
Increased blood levels in mercury and lead	Chinese study (serum Hg concentrations higher than the control group), Spanish study in children (higher lead concentrations in hair).
	Urine concentrations 3.5-15 times higher PAH metabolites in older incinerator workers.
Increased concentrations of polycyclic aromatic hydrocarbons (PAHs)	
Health impacts of incineration (33 studies analyzed)	
Cancers	
Cancers	
Bowel cancer	Cohort study of people living near an incinerator. The relative risk was 2.1 for men and 2.0 for women.
Stomach, gallbladder, lung, and pleura cancers	Ecological study on several incinerators and exposed populations considering the distance to the incinerator. The overall risk ratio was 1.06.
Cancer rates	Japanese study found no correlation between dioxin exposure from incineration plants.
Cancer incidence.	Ecological study on 2 incinerators that found no significant association between exposure to pollutants and
Premature delivery	Three studies concluded that exposure to incinerator pollutants was positively correlated with premature delivery.
Sperm quality	Study on sperm samples from incinerator workers that established that the number of sperm was lower in these workers with and that they had more damage in their DNA.

Miscarriage	A cross-sectional study based on medical records that identified that women exposed to incinerator discharges were at greater risk of miscarriage.
Skin lesions	Presence of more skin lesions depending on the degree of exposure to dioxins.
Cardiovascular mortality	0.19% increase in cardiovascular mortality in people exposed to 40 µg/m3 PM10 concentrations from incinerators.

Incineration represents a final method of waste disposal that reduces the number of materials going to landfill and, similarly, helps to reduce the leaching of pollutants into the soil and groundwater. Incinerating residual materials generates combustion sub-waste (smoke, slag, REFIOM) that can affect populations and environments near these plants, raising public and environmental health issues. Given the risks associated with exposure to dioxins and furans, incineration must be performed with methods that minimize their synthesis and the combustion by-products must be disposed of without accumulating in the environment. A need to better characterize the emissions to determine the composition for better regulation at the legal level remains to be addressed.

4. Composting

In 2018, the overall recycling rate for organic materials in the municipal sector in Québec was 35% (Recyc-Québec, 2020). Considering that one of the targets of the Quebec Residual Materials Management Policy is to recycle 60% of putrescible organic matter by 2023 (MELCC, 2019), composting is bound to develop more and more in the near future.

Putrescible organic matter is not toxic. Theoretically, well-controlled composting should not pose a danger to human health or the environment (Domingo and Nadal, 2009; Olivier, 1999). In practice, however, some contaminants are present in the compost and may pose a health risk.

4.1. Types of Releases and Population Exposure

Compost can be contaminated by the various elements in its composition. While some are biodegradable, others are persistent. Some are volatile and can contaminate the air in composting facilities and surrounding areas. Composting facilities can also be a nuisance to nearby populations (odours, noise, vermin, and other animals).

This report will focus on the most significant discharges from composting, namely dust and bioaerosols. Health impacts related to organic contaminants and metals may also be associated with composting sites and these are briefly discussed in this chapter. Odours are also an issue related to composting activities and are discussed in Chapter 5, as are nuisances associated with vermin and other animals.

4.1.1 Dust and Bioaerosols

Composting sites are likely to emit significant amounts of dust of all kinds, depending on the inputs in the compost. Among the most important, particles of biological origin (animal, plant and microbiological) are grouped under the term bioaerosols (Pearson et al., 2015; Deloraine et al., 2002). These can combine with dust and be dispersed in the air.

Bioaerosols present in compost and potentially hazardous to health can be grouped into three categories (Pearson et al., 2015; Beffa et al., 1998; Deportes et al. 1995; Millner et al. 1994):

- Pathogenic or fecal organisms present in the starting materials: bacteria, viruses, parasites
- Pathogenic or allergenic organisms developing during composting or storage: this is especially the case for thermophilic actinomycetes, fungi and their spores
- Toxins, enzymes, and allergens released by bacteria and fungi: mycotoxins, endotoxins, and glucans.

Authors of several literature reviews (Prasad et al., 2004; Smith, 2002; Deloraine et al, 2002; Hester and Harrison, 2002) agree that the amount of bioaerosols emitted from composting is highly variable and depends on many factors such as the nature of the inputs, the type of composting, the level of compost maturation, the size of the facility, the configuration of the composting site and surrounding land (fences, trees, etc.), and the amount of bioaerosols emitted.), the method and frequency of turning the compost piles, atmospheric conditions (wind direction and intensity, temperature, relative humidity), the moisture level of the piles, and the concentrations of bioaerosols already present in the background.

Therefore, bioaerosol emissions are considered unique to each site. However, studies do suggest that (Smith, 2002; NPHS, 2002; Jager and Eckrich, 1997):

- Bioaerosol concentrations are generally higher at composting sites than at any other waste treatment site
- All dusts measured are respirable, with the respirable fraction (< 5 µm) representing 90% of these particles.

The main routes of exposure to bioaerosols and dust are ingestion and inhalation, with inhalation exposure being the most significant (Pearson et al., 2015). Studies of bioaerosol dispersion outside composting sites show that bioaerosol concentrations return to background levels within 100-500 m of the site. Most concentrations reach background levels within 250 m of the site (Hester and Harrison, 2002b). For this reason, the authors agree that beyond 250 m from a composting site, the population is not likely to be exposed to significant concentrations of bioaerosols (Hester and Harrison, 2002b; Deloraine et al., 2002; Environment Agency, 2001).

Oral exposure can occur in various ways. First, exposure can occur through direct ingestion of compost during activities such as gardening and horticulture. This exposure is more of a risk for children, who tend to put things in their mouths more often, or for people with pica behaviour. It would be more important since their intestinal absorption coefficient is much higher than that of adults, particularly for heavy metals (ENSP, 2002).

Plants can also be directly contaminated by atmospheric fallout from dust and bioaerosols or by a process of spraying from the soil during thunderstorms (CSHPF, 1998). Therefore, the absorption of plants grown near composting sites could represent an exposure pathway for local populations.

4.1.2 Organic Contaminants and Metals

Various organic contaminants can be present in the compost, such as halogenated hydrocarbons, PAHs, VOCs, and pesticides (Domingo and Nadal, 2009). Compost can also be contaminated with ferrous and non-ferrous metals. These metals come mainly from various undetected waste (e.g., beer corks, batteries). Metals such as arsenic, cadmium, chromium, lead, mercury, and nickel may be present in the compost (Domingo and Nadal, 2009).

The persistence of organic contaminants during composting depends on their physico-chemical characteristics (solubility, volatility, etc.), the nature of the active ingredients and the ability to bind to the organic matter present in the compost (ENSP, 2002). As for metals, the concentrations at which they are found is highly dependent on the quality of the composted products. Effective source separation can reduce the risk of metal contamination of compost.

Overall, levels of organic contaminants and metals in compost are low and do not pose a significant health risk (Nie et al., 2018; Domingo and Nadal, 2009; Enviros Consulting and University of Birmingham, 2004; ENSP, 2002; Morvan and Carré, 1995; Cornelissen and Otte, 1993; Tammaddon and Hogland, 1993).

4.2. Health Risks

Published epidemiological studies of health problems in surrounding populations do not support a link between bioaerosol emissions from a composting facility and health problems in surrounding populations (Robertson et al., 2019; Giusti, 2009; Swan et al., 2003; Pheby et al., 2002; Epstein, 2002).

However, a few studies have established, based on limited qualitative data, that there may be an association between bioaerosol emissions from composting facilities and poor respiratory health of nearby residents (Robertson et al., 2019). As with other air pollutants, however, distinguishing the contribution of an individual source such as a composting site from concentrations already present in the environment is difficult (Robertson et al., 2019). For instance, a composting site could be in an area where other sources of bioaerosols are present. This can make it very difficult to assess the potential population health risk associated with bioaerosols emitted from composting sites.

Deloraine et al. (2002) suggest that if bioaerosols from composting were likely to reach a residential area with high concentrations, the theoretical risk would be allergic and mainly for immunocompromised people.

Health effects associated with dusts and bioaerosols are evaluated according to their size: the smaller the size of the dust and bioaerosols, the deeper they can penetrate the respiratory system and therefore cause health effects. Dust can cause, among other things, an increase in cardiorespiratory problems, irritation of the bronchial tree, reduced life expectancy and higher mortality rates (INERIS, 2007). Bioaerosols can cause respiratory problems such as non-allergic asthma, rhinitis, mucous membrane irritation, chronic bronchitis, organic dust toxic syndrome (ODTS), etc. (Pearsons et al., 2015; Deloraine et al., 2002; Hester and Harrison, 2002b).

Children, the elderly, asthmatics, and people with cardio-respiratory problems are the most vulnerable to dust and bioaerosols. Many studies have indicated that the main concern with bioaerosols and dust is for workers, as they are more exposed to these contaminants in concentrated form and over a long period of time, and thus more likely to develop respiratory diseases (Robertson et al., 2019; Pearson et al., 2015; Giusti, 2009; Domingo and Nadal, 2009).

5. Odours, Noise and Other Nuisances Associated with Waste Management

Activities involving the management of residual materials can result in nuisances that affect the quality of life of people living near RMTSs. This chapter describes the most common nuisances.

5.1. Foul Odours

Organic matter decomposition generates foul odours. These odours are mainly emitted by landfills, but also by recyclable waste sorting centres and composting sites.

5.1.1 Residual Materials Treatment Site Odour Sources

Many compounds resulting from the handling or treatment of waste can be a source of odour (Duan et al., 2021; ATSDR, 2021; Decottignies et al., 2009; ATSDR, 2008). Figures 4 and 5, for instance, show the odour wheels that allow an individual to identify what type of compound is associated with an odour in the context of landfill or composting sites. These odour wheels can be applied to other situations where environmental odours are likely to have an impact on the population (Suffet and Braithwaite, 2019). The most common odour compounds associated with waste treatment are sulphur compounds (hydrogen sulphide, dimethyl sulphide, ethyl mercaptan, methyl mercaptan, etc.), ammonia and other volatile organic compounds such as vinyl chloride and hydrocarbons (ATSDR, 2008). In addition to the concentration in ambient air, the different odour detection thresholds of odorous compounds must be considered to assess whether they can have an impact on some more sensitive invididuals or even on the entire surrounding population (Table 7).

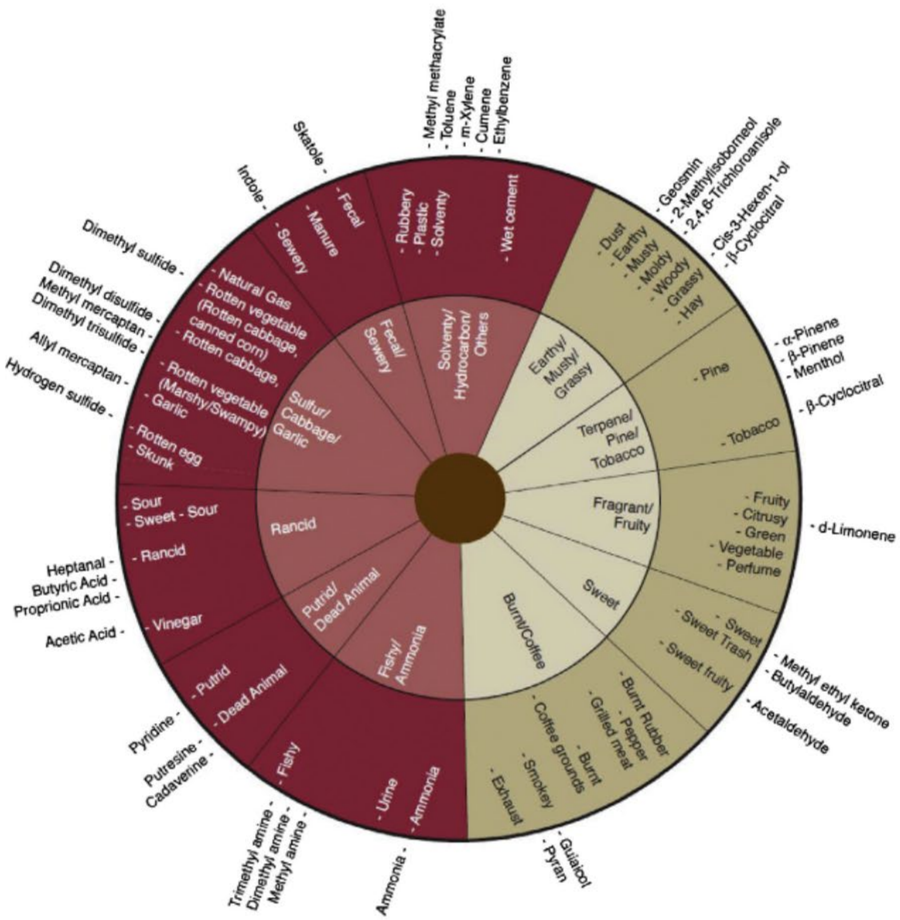

Figure 4 Odour wheel for landfills (from Decottignies et al., 2009)

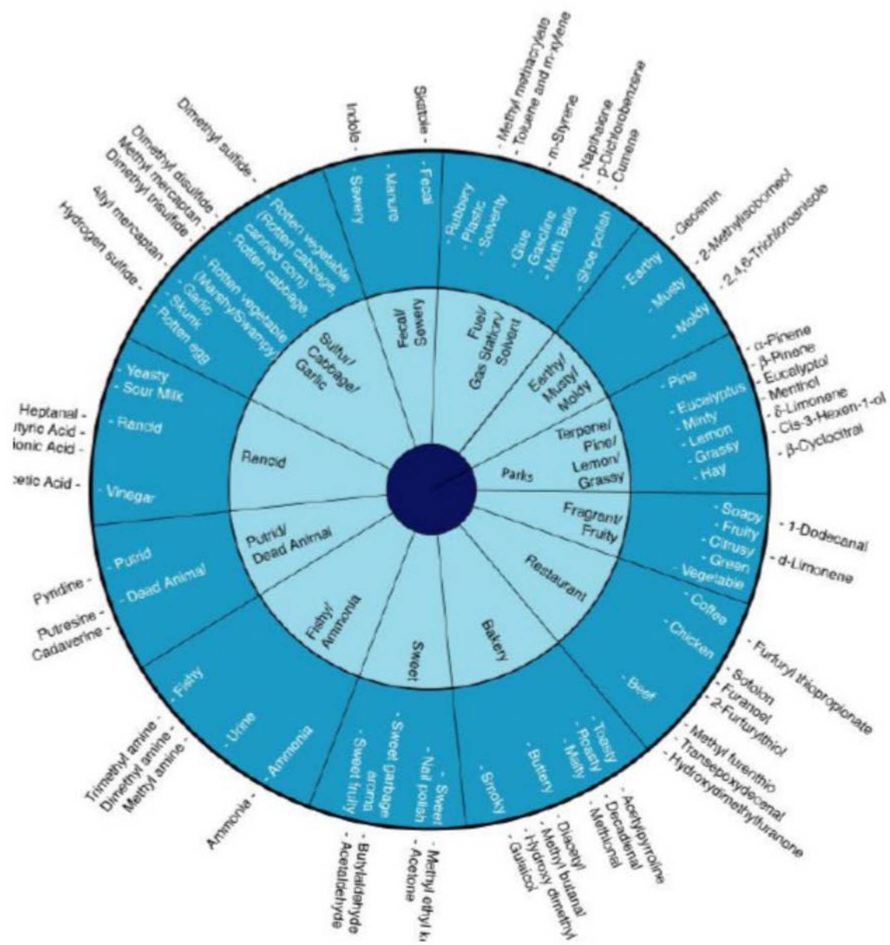

Figure 5 Odour wheel for composting sites (from Suffet et al., 2009; Rosenfeld and Suffet, 2003).

Table 7 Odour thresholds of different compounds emitted by RMTSs (adapted from ATSDR, 2008 and REPTOX, 2021)

Compound	Odour detection threshold (ppb[a])
Ammonia	1000 to 5000
Benzene	840
Dichlorethylene	85
Dichloromethane	205,000 to 307,000
Ethylbenzene	90 to 600
Toluene	10,000 to 15,000
Trichlorethylene	21,400
Tetrachlorethylene	50,000
Vinyl chloride	10000 to 20,000
Sulfur compounds	
Hydrogen sulfide	0.5 to 300
Dimethyl sulfide	0.12
Ethyl mercaptan	2.0
Methylmercaptan	1.6
Dimethyl disulphide	0.00002

[a]ppb: parts per billion

Of all these compounds, sulfur compounds are particular because their olfactory detection thresholds are very low. They can therefore be detected by humans at very low concentrations, often well below the toxicity threshold. For instance, the olfactory detection threshold of hydrogen sulfide (H_2S) varies greatly depending on the methodology and the individual. Threshold values depend, among other things, on exposure time. From all the literature consulted, it was more often found to be between 2 and 29 ppt (average threshold: 8 ppt) (Sucker et al., 2008; OEHHA, 1999). According to the Agency for Toxic Substances and Disease Registry (ATSDR), this detection threshold varies between 0.5 and 300 ppb, according to the US EPA between 3 and 20 ppb, and according to the American Industrial Hygiene Association (AIHA) around 9.4 ppb. In Québec, the MELCC sets the detection limit for H2S at 0.5 ppb (the lowest reported value). Mercaptans have an odour that is even more intense, and a detection limit up to 100 times lower than H2S (REPTOX, 2021; OEHHA, 1999).

According to Kim (2011), when dealing with a mixture of sulfur compounds, the intensity of the odour of the mixture should behave as the average of the odours of the mixture. These compounds would not act in an additive or synergistic manner.

Amoore (1985) cautions about the difference between a detection threshold under laboratory conditions and the levels at which an odour could be recognized, or at which it would be perceived as a nuisance. Analysis of various laboratory and sociological studies suggests that the threshold at which an odour is recognized would typically be a factor of 3 times the detection threshold, while the threshold at which the odour became an olfactory nuisance was 5 times the detection threshold. This discomfort was characterized based on aesthetic and behavioural responses, as well as physiological responses such as nausea and headaches.

5.1.2 Odour Perception

Odour perception is complex and is both physiological and cognitive. On the one hand, it comes from the integration of many chemical substances present in the air (combination of molecules of various gases, but also water, VOCs, etc.). It often takes only an infinitesimal quantity of molecules for an odour to be smelled (INRS, 2005). Since evolution has taught us "to avoid unpleasant smelling sources such as food (protective instinct), we can fear" a bad smell because it can represent unhealthy air while the absence of smell can represent healthy air" (Suffet et al., 2019). Physiological factors such as lifestyle habits (smoking) or qualitative alterations in olfaction can cause a variation in response to an odour.

On the other hand, apprehension, understanding and evaluation of a risk associated with an odour are cognitive activities based on collected information. This information comes from individual, socio-cultural, and external factors. According to Winneke and Neuf (1992) and Cavalini et al. (1991 and 1994), the main individual factors that can vary a response to an odour are social status, health status, prior exposure to a variety of odours, familiarity (olfactory memory) and hedonic tone (appreciation). Socio-cultural factors, such as reactions of those around (social norms) will also influence it, as will external factors, such as the context of exposure, perception of the environment near the site (notion of aesthetics) and the presence of other concomitant odours (Winneke et al., 1992; Cavalini et al., 1991). If the odour is perceived to be associated with a potential threat, then the likelihood of concern and increased discomfort is greater (Baird et al., 1990). Researchers have shown, however, that at high concentrations, the hedonic tone no longer influences the potential for nuisance; it is the frequency of reappearance of this odour that becomes the determining factor in nuisance (Both et al., 2004).

Shiffman et al. (2005) propose a hierarchy of levels of exposure to an odour:

1. Detection
2. Identification
3. Nuisance (olfactory)
4. Odour intolerance (causing somatic symptoms)
5. Perceptual irritation
6. Somatic irritation (causing a negative physical reaction)
7. Chronic toxicity
8. Acute toxicity.

Two other human reactions are well documented regarding the olfactory sense. On the one hand, for several substances, addiction to an odour raises the detection threshold and a repetitive foul odour (by recalling the olfactory memory) no longer has to be very intense to be perceived as unpleasant. On the other hand, depending on a person's state of attention (attentive, distracted, or sleepy), the threshold can vary by a factor of 1 to 100, for the same substance.

In his approach for the evaluation, control, and regulation of odours, Nicell (2009), for his part considers that the impacts of odours come mainly from the interactions between the following factors: frequency, intensity, duration, offence (hedonic tone) and place.

5.1.3 Exposure

Noxious odours are often seen as indicators of exposure to toxic contaminants, even though these odours may not always consist of contaminants at toxic levels. They are often the only indicators of exposure in epidemiological studies because air quality samples are rarely collected (Enviros Consulting and University of Birmingham, 2004).

Exposure to foul odours is difficult to assess. It depends on many factors such as the concentration of odorous compounds at the source, the rates of emission, dispersion and degradation of these compounds, and the distance from the exposed population. One way to estimate odour exposure is to use sensory or olfactometric analysis. This type of analysis allows an odour to be characterized in three ways: mainly by a quantitative criterion, expressing its strength and intensity; a qualitative criterion allowing its description in relation to one or more other reference odorous substances (often 1-butanol); and a temporal criterion, describing the variation in its intensity and quality over time. The results are expressed in odour unit.

5.1.4 Health Risks

Noxious odours, even without toxic properties, can be a nuisance for the exposed population and trigger various non-specific physiological and psychological symptoms. The Alberta Ministry of Health (Government of Alberta, 2017) has conducted a major literature review on the health impact of odour. Their conclusions are as follows:

> "Residents of communities located near odour-emitting facilities report a higher number of health problems compared to residents of control communities. Reported symptoms include cough, nausea, congestion, eye irritation, headaches, etc. (see Table 8). The frequency of odour perception is the measure that best correlates with health problems. Objective measures such as distance from the residence to the point of emission are not good predictors of symptoms. The relationship between odour and health seems to be influenced more by the hedonic nature of the odour than by its intensity. An element that is consistently found among epidemiological studies is that symptoms are significantly correlated with odour-related nuisance. Several studies indicate that the reported nuisance is a better predictor of symptoms than odour perception, odour concentration, or distance between the residence and the point of emission."

The presence of co-pollutants has been suggested to explain the impact of odour on health (Schiffman and Williams, 2005). An example of this is motor vehicle exhaust. This gas mixture is known to be odorous, but the carbon monoxide and nitrogen dioxide in its composition are odourless and their impact on health is well documented. However, since the reported symptoms do not always correlate with the concentration of odorous gases or the distance from the emission site, the explanation unfortunately does not always seem as clear for all situations (Government of Alberta, 2017).

Table 8 Affected organs and common symptoms of environmental odour exposure noted in epidemiological studies (Adapted from Suffet et al., 2019 and Government of Alberta 2017)

Organ	Symptoms
Brain	Headache
	Drowsiness
	Dizziness
Nose	Irritation
	Congestion
Eyes	Irritation, watery or dry
Throat	Irritation
	Hoarse voice
	Sore throat
Lungs	Cough
	Chest tightness
	Breathlessness
	Wheezing
	Sleep problems associated with coughing
Heart	Palpitation
Stomach	Nausea
Psychological, endocrine glands (hormonal)	Depression
	Stress

Assessing the risks associated with foul odours is difficult, given the variety of exposures and possible responses for each individual. Although it has not been clearly demonstrated that odours have toxic effects on health, they are nonetheless a major nuisance that can significantly affect the quality of life of populations living near waste treatment sites (Beausoleil, 2005).

In addition to physiological impacts, many psychological impacts have been associated with the presence of odours in general (Government of Alberta, 2017; Schiffman & Williams, 2005). Among the negative impacts, unpleasant odours associated with the presence of sulphur dioxide have been shown to affect the mood of those affected (Schiffman et al., 1995; Kilburn and Warshaw, 1995; Ehrlichman and Bastone, 1992). Shiffman et al. (1995) showed that people exposed to this gas were more tense, tired, angry, and more depressed. Other studies and literature reviews report effects such as loss of appetite, anxiety, sleep disorders, altered intellectual performance (learning abilities, ability to concentrate), reduced outdoor activities and social encounters, etc. (Schiffman and Williams, 2005; Gérin et al., 2003; McGinley and McGinley, 1999; Schiffman, 1998; US EPA, 1995).

Exposure to odours can also lead to immune system hyperactivity and immunosuppression (Gérin et al., 2003). People with allergies or asthma often report that odours exacerbate their symptoms (Shusterman, 2001).

5.2. Environmental Noise

Noise refers to all unwanted sounds or sounds whose level (power) is high enough to cause adverse health effects (Martin et al., 2015). Environmental noise refers to noise from all sources, but excludes occupational exposures (Martin et al., 2015). In the context of residual materials management, the transportation of these materials by truck to the treatment or final disposal site, their handling (storage, compacting, moving) on site, as well as the routine operations required for the operation of the site (addition of covering materials, use of pumping and collection equipment, etc.) are all elements that generate environmental noise that can affect the quality of life and health of the population living near residual materials treatment sites.

5.2.1 Health Effects

The nature and level of noise can have adverse effects on physical health (sleep disturbances, cardiovascular disease, etc.) as well as psychosocial effects (disturbance, also called nuisance or annoyance; learning in schools, etc.) (Martin et al., 2015).

Sleep disruption may refer to several immediate consequences of noise exposure at night: longer sleep, more frequent awakenings, increased movement, disruption of sleep structure, etc. (Martin et al., 2015). (Martin et al., 2015). Sleep disruption may also have effects the next day or in the longer term. The Institut national de santé publique du Québec (INSPQ) also noted that effects due to sleep disturbances are documented in the scientific literature: "perception of poor sleep quality; drowsiness, increased fatigue, need for compensatory rest; reduced motivation, decreased concentration, distractibility and decreased performance on specific tests; depressed mood" (Martin et al., 2015).

Disturbance is the result of noise that disrupts activities and causes an emotional reaction and a sense of helplessness (Martin et al., 2015). This means that noise levels alone cannot explain the disturbance, which depends on factors specific to the sources (e.g., low-frequency or impulse noises are generally perceived to be more disturbing), to the exposed persons and to the exposure contexts (Martin et al., 2015).

The INSPQ's analysis of the results of the 2014-2015 Québec Population Health Survey (EQSP) shows that "[...] 1 person in 6 reported being strongly disturbed by at least one noise source in the last 12 months at the provincial level, or 16.4% of Quebecers" (Lebel et al., 2019). Approximately 41.3% of the population reported being moderately or strongly bothered by at least one noise source (Lebel et al., 2019). Noise from construction work or construction sites, and road traffic noise were two of the top three sources of disturbance (Lebel et al., 2019). For sleep disruption, "...19.5% (or 1 in 5 people) reported that their sleep was disrupted by environmental noise "often" or "occasionally" in the past 12 months..." (Lebel et al., 2019). This analysis concluded that "environmental noise is a major public health problem. It unquestionably affects the quality of life of a large part of the population" (Lebel et al., 2019).

The increased risk of certain cardiovascular diseases due to noise is thought to be caused by the triggering of physiological stress reactions by noise as a non-specific stressor (Martin et al., 2015). For road transport noise, where the causal link is well established, the WHO concluded that the relative risk increases by 5% at 59 dBA Lden, with an increase of 8% for every 10 dB (WHO, 2018).

5.2.2 Noise Issues

5.2.2.1. Complaints

Noise can represent a significant percentage of complaints associated with RMTS. For instance, for the Lachenaie engineered landfill site, noise was responsible for 11% to 28% of complaints when activities were close to residential neighbourhoods, only to become practically non-existent when activities on the RMTS moved to another sector (BAPE, 2021; BAPE, 2008). However, complaints are not as representative of the impact of noise as data from rigorous disturbance studies.

5.2.2.2. Applicable Noise Limits

The MELCC's note d'instructions NI 98-01 on noise (MDDEP, 2006) applies to noise generated on RMTSs (considered "stationary sources"). The BAPE's investigation and public hearing report on the Sainte-Sophie engineered landfill expansion project shows that the limits of the note d'instructions NI 98-01 may be exceeded by this type of facility (BAPE, 2020).

However, the limits of the MELCC's note d'instructions NI 98-01 on noise do not apply to moving sources on public roads (BAPE, 2020). Nor does the consideration of trucking noise generated by an LTMR explicitly fall within the two-noise management approaches[2] employed by the Ministère des Transports (MTQ)'s Traffic Noise Policy, which applies to its road network (MTQ, 1998). Therefore, there are no clearly established limits for considering the trucking noise associated with the LTMR.

Both the MELCC's note d'instructions NI 98-01 (MDDEP, 2006) and the MTQ's Traffic Noise Policy (MTQ, 1998) impose limits that must not be exceeded, but do not guarantee the absence of harmful effects on the health of the population. For certain quiet environments where ambient noise levels are often low (e.g., rural environments, remote regions, or convention territories), compliance with the limits of the Instruction Note 98-01 or the Traffic Noise Policy may nevertheless lead to an increase, sometimes significant, in noise levels.

2 These two approaches are the corrective approach, which allows the MTQ "[...] in consultation with the municipalities, to mitigate the main noise pollution problems by implementing corrective measures in areas where the outdoor noise level is equal to or greater than 65 dBA Leq, 24 h" and the integrated planning approach, as part of the revision of the development plans, which requires the MRCs to "[...] determine the traffic lanes that are present, in a place makes the occupation of the land near that place subject to major constraints [...] "because of noise and also asks the MRCs to "[...] establish minimum rules for zoning or subdivision in order to oblige the municipalities on their territory to adopt regulatory provisions to mitigate noise impacts [...]" (MTQ. Politique sur le bruit routier au Québec, [online], [Québec], Ministère des Transports du Québec (MTQ), Service de l'environnement; 1998. Available: https://www.transports.gouv.qc.ca/fr/ministere/role_ministere/Documents/politique _bruit.pdf).

For instance, the project to develop an engineered landfill at Hébertville-Station expected an increase of more than 10 dBA in noise during the construction phase, as well as an increase of up to 7.5 dBA during the operation phase (BAPE, 2013). The investigation and public hearing report also noted: “The fact remains that the project fits into a calm environment where the ambient noise climate is low. Noise from human activities that becomes perceptible may be more disturbing for people who are used to silence or the sounds of nature” (BAPE, 2013).

5.2.2.3. Nature of Noise

Acoustic Study

For noise during the construction phase as well as during the operation phase, it is important to remember that it is the conduct of an acoustic study that can help characterize the initial sound environment, identify, and evaluate the impact of potential project-related noise, and identify the mitigation measures to be planned (Martin and Gauthier, 2018). However, this analysis must consider all the activities associated with the project, whether they take place on site (choice of equipment, choice of access routes to the construction site and to the RMTS during operation, etc.) or off site (noise from the transportation of construction materials, covering material, equipment, and residues, etc.). Factoring in all project-related noise and local particularities that affect noise propagation (topography, local meteorological conditions, etc.) makes it possible to adapt the measures to be implemented at each site and reduce noise-related impacts.

Construction Phase

The construction phase of projects can expose local residents to noise generated by the transportation of equipment or materials, as well as noise generated by construction activities on the RMTS. Under certain situations where noise is a major issue, in addition to acoustic studies prior to project completion, monitoring of the noise climate during construction, i.e., an acoustic study conducted during the work, may be necessary. For even more critical situations, continuous noise level monitoring, which allows for the very rapid implementation of mitigation measures, may be considered.

Operation Phase

The exact nature of noise during operation varies from one RMTS to another, but generally includes transportation noise and industrial noise.

Noise generated by the transportation of residual materials or covering materials can vary greatly depending on the number of passages, which can range from a few dozen to a thousand passages per day (BAPE, 2020; BAPE, 2005). Moreover, the impact of trucking noise on the noise climate can be caused by travel inside or outside the RMTS.

Traffic noise is likely to impact all environments. For rural areas, remote regions, and territories under agreements, truck traffic noise may become the main source of transportation noise or may significantly add to other trucking generators already present in an area (BAPE, 2005). In an urban environment, when road traffic flow is already high, an increase in noise from people already exposed may lead to additional effects (increased disturbance, sleep disturbance, cardiovascular disease, etc.). In the absence of applicable limits that could consider all the factors that influence the adverse effects of noise on health and quality of life, trucking noise becomes an important issue that is difficult to address. For instance, the BAPE's investigation and public hearing report on the Projet d'agrandissement du lieu d'enfouissement technique de Sainte-Sophie notes that the route that vehicles should take to reach the LTMR while minimizing disturbance is known, but that "[...] there are still some reluctant individuals who access the landfill by [a different route], on which transit trucking is prohibited" (BAPE, 2020).

The commission of inquiry rightly noted that "... given the high number of trucks accessing the landfill site every day, even a small percentage of offending drivers can be an irritant for residents..." (BAPE, 2020).

Industrial noises on MRLs include truck and machinery traffic, noise from machinery operation, pumping station and biogas destruction, aeration lagoon, etc. (BAPE, 2013). Some noises are emitted continuously, while others have limited emission schedules during the day (BAPE, 2013). Opening hours for the reception of residual materials and recovery materials, as well as the hours of operation on the RMTS also vary according to the project. In some cases, activities take place mainly during the day or in the early evening (BAPE, 2020), which may help limit some of the effects of noise. In other cases, activities also take place during part of the night (BAPE, 2008), which increases the risk of sleep disturbance for residents living near the RMTS or the routes used to transport residual materials or cover materials. Finally, activities also take place on weekends on certain RMTSs (BAPE, 2021), which increases the risk of harmful effects of noise for local residents and gives them little or no respite.

Pyrotechnics used to scare birds away sometimes generate high noise levels, but only for a short time. They can be used once or several times per hour to scare birds away and are sometimes only used at certain times of the year (BAPE, 2008).

In certain situations where noise is a major issue, in addition to an acoustic study prior to project completion, a follow-up of the noise climate during the operating phase, i.e., an acoustic study carried out when the RMTS is in operation, may be necessary.

5.2.3 WHO Recommendations

WHO recommendations vary according to the nature of the noise. The following sections provide an overview of these recommendations for traffic and industrial noise.

5.2.3.1. Daytime Noise

The WHO recommends limiting traffic noise measured outdoors to less than 53 dBA L_{den}[3] on average (WHO, 2018). At this level, about 10% of the population will report being highly disturbed by traffic noise (WHO, 2018). For industrial-type noise, the WHO recommends limiting average levels to 50 dB L_{Aeq} in outdoor living spaces (balcony, terrace, courtyards, etc.) to reduce the percentage of people moderately disturbed by noise (Berglund et al., 1999). These recommendations consider relatively constant noise sources in all cases (Berglund et al., 1999). Consequently, like the limits of the MELCC's Instruction Note NI 98-01 on noise (MDDEP, 2006) and the MTQ's Traffic Noise Policy (MTQ, 1998), these recommendations do not necessarily make it possible to consider certain specific noise characteristics, such as distinguishing low-flow automobile traffic (which produces constant noise) from intermittent trucking traffic (which produces noise whose level fluctuates as it passes) and can also generate dust and significant vibrations.

5.2.3.2. Nighttime Noise

The WHO recommends limiting road noise measured outdoors to less than 45 dBA L_{night} on average (WHO, 2018). At this level, about 3% of the population report having sleep that is severely disturbed by traffic noise (WHO, 2018).

The WHO also recommends limiting industrial noise at night outside homes to 40 dBA, which is the minimum threshold for observable adverse effects (WHO, 2009). Above 55 dBA, the WHO considers that the risk to public health is increasingly important and that, in addition to being responsible for a significant proportion of the population that is severely disturbed, or whose sleep is severely disturbed, there are indications of the presence of a risk of cardiovascular disease (WHO, 2009). The WHO also recommends limiting noise inside bedrooms to 30 dBA and noise events to 45 $L_{Amax,\ fast}$, for all sources, which corresponds to levels of 45 dBA and 60 $L_{Amax,\ fast}$ outside residences, assuming attenuation of 15 dBA when windows are partially open (Berglund, 1999).

Table 9 Overview of some WHO recommendations for environmental noise

Environment	Criterion	Period	Recommendations
Outside houses	Disturbance, traffic noise	24 h	53 dBA L_{den}
	Disturbance (moderate disturbance), noise industrial	Day, 16hrs	50 dBA
	Sleep disturbance, traffic noise	Night	45 dBA L_{night}
Inside houses	Sleep disturbance from all sources	Night	30 dBA L_{night}
		Night, measurement "Instant"	45 $L_{Amax,\ fast}$
Outside the rooms	Sleep disturbance from all sources open windows	Night	45 dBA L_{night}
		Night, measurement "Instant"	60 $L_{Amax,\ fast}$

3 " Lden: An indicator of the equivalent continuous "A" weighted equivalent (cumulative exposure) sound level for a 24-hour period (one day) [d = day (6:00 a.m. - 6:00 p.m.), e = evening (6:00 p.m. - 10:00 p.m.), and n = night (10:00 p.m. - 6:00 a.m.)] with the noise level corrected for two of the three periods, evening, and night. The noise levels for these periods are increased by 5 and 10 dBA respectively to consider the greater degree of nuisance felt. "Martin R, Deshaies P, Poulin M. Avis sur une politique québécoise de lutte au bruit environnemental : pour des environnements sonores sains [Online]. Institut national de santé publique du Québec; 2015.

Available: https://www.inspq.qc.ca/pdf/publications/2048_politique_lutte_bruit_environnemental.pdf

5.2.4. Other Factors and Measures to Consider

Increased telework (due to COVID-19 or for other reasons) will likely have an impact on residents' perception of the noise generated by RMTS projects. Even when operators concentrate RMTS operations on weekdays, it is now more likely that local residents will be present at their homes and be adversely affected.

The disturbance caused by environmental noise may be greater during summer. Opening windows facilitates the propagation of noise inside homes. Outdoor spaces where noise is higher than indoors (yards, balconies, parks, etc.) may also be used more by people at this time of year.

Noise sources with special characteristics (intermittent, impulsive, with a high proportion of low frequencies, etc.) may cause greater disturbance (see Table C-1 “Summary of factors influencing the degree of noise disturbance”, in Martin et al., 2015). In such cases, while average noise levels may remain relatively low, they are not necessarily a good indicator of disturbance. For instance, noise levels produced by pyrotechnics used at low frequencies (1 hour) will not be perceptible by indicators of average noise levels. However, in some situations they may be high enough to wake children during their nap or cause disturbance. Even the limits proposed by the Ministère de l'Environnement's Instruction Note 98- 01, which use an indicator that considers some of the peculiarities of noises, may not necessarily consider all the peculiarities of all noises. Instruction note 98-01 also states that: “[…] the acceptability criteria and the measurement methodology are not adapted to all types of noise or to all the variety of noise sources. As a result, it may be justified to recommend the use of different or complementary criteria or methods in certain cases" (MDDEP, 2006).

The noise level decreases as the distance between the source and exposed individuals increases. The use of a separating distance, sometimes called a "buffer zone", between sources and exposed people is therefore a good way to reduce noise exposure (Martin et al., 2015). However, the appropriate distance to sufficiently reduce environmental noise is difficult to predict, since noise levels depend on the nature of the sources (intensity, emission spectrum, etc.) and the local propagation conditions (topography, weather conditions, presence of noise barriers, etc.) Moreover, in the case of RMTSs, part of the effects come from traffic. It is then necessary to analyze all sources, including transport routes, to assess the effects that could even be present at a very great distance from the RMTSs.

The application of the concept of reciprocity is important in the fight against environmental noise (Martin and Gauthier, 2018). The Ministère des Affaires municipales et de l'Habitation (MAMH) provides a good definition of this concept: “In land-use planning, the concept of reciprocity implies that the standards applying to establishments or activities that may generate constraints on nearby uses apply reciprocally when sensitive uses are implemented. For instance, if an industrial activity is required to be established at least 400 metres from a residential neighbourhood, by reciprocity, residential uses should not be allowed to be established less than 400 metres from this industrial activity” (MAMOT, 2016). The development of RMTS must be accompanied by an acoustic study when sensitive uses are in proximity to such a stationary source (Martin and Gauthier, 2018).

The INSPQ also considers that “By reciprocity, the installation of sensitive uses near noisy industries or businesses [...] requires an assessment of the acoustic impacts" (Martin and Gauthier, 2018). The analysis of noise levels only in the event of complaints, after the implementation of new uses (BAPE, 2021), even if it could correct problematic situations, does not prevent them.

Vibrations, particularly those associated with blasting during the construction phase, may require the implementation of additional mitigation measures.

In both the construction and operation phases, the management of complaints, through a clear and transparent process and in collaboration with citizens (Martin and Gauthier, 2018), is one of the measures that can allow for adequate consideration of the harmful effects of environmental noise. Communication and collaboration with citizens in the planning of noisy activities, both in the construction and operation phases, are also effective ways to reduce the impacts of noise once all other necessary mitigation measures have also been put in place.

5.3. Vermin

Vermin include all animals, usually rodents and birds, that frequent waste disposal sites. They are found primarily at landfill sites but can also be found in any easily accessible waste disposal area (outdoor depot, open building, composting site).

Vermin can contribute to the dispersal of pathogens by displacing detritus or by becoming carriers themselves. The presence of human pathogenic bacteria (Salmonella spp., Campylobacter spp. and Yersina spp.) in the droppings of several gull species was documented by Lévesque and Brousseau (1992). The most likely exposure scenario begins with the contamination of land or objects used by humans by pathogenic organisms present in feces. Secondly, there must be contact between humans and a sufficient quantity of viable pathogens. The potential for infection can therefore be limited by the possibility of avoiding contact. Children are most at risk of exposure to pathogens since they play on the ground, often carry objects, or have their hands in their mouths.

Health risks associated with vermin are assumed, but not assessed, nor clearly demonstrated in the literature. For instance, the presence of birds on landfills is well documented and recognized as an important issue. However, the literature suggests that their impact on pathogen transmission is low and easily managed. Studies linking birds to health have focused on issues related to the transport of human pathogens via feces, primarily in water contamination (Alm et al., 2017; Hatch, 1996). Birds are key vectors for Campylobacter, a pathogen endemic to the species, and Salmonella (Hatch, 1996). These two bacteria have similar symptoms when ingested: diarrhea, vomiting, headache, abdominal pain (Public Health Agency of Canada, 2020; 2018). Another possible hazard presented in the literature is the transmission of more antibiotic-resistant microorganisms in connection with their exposure to anthropogenic inputs via landfills (Ahlstrom et al., 2021). However, the risk remains low. Nevertheless, their presence is annoying to the surrounding population in terms of aesthetics, noise, and landfill employees.

For small mammals such as rats and mice, their presence does not appear to have a significant impact on health, since studies suggest that they are found in small proportion on landfill sites (Allen et al., 2011; Gabrey, 1997). However, as noted above, they are thought to play an important role in the spread of antibiotic-resistant microorganisms (Allen, 2011). Through their presence in water pipes, they are believed to contribute to the transmission of Escherichia Coli bacteria, which cause symptoms such as fever, abdominal cramps, nausea, and other symptoms (Public Health Agency of Canada, 2017).

In conclusion, whether for birds or small mammals, the health risk remains low and can be reduced by the implementation of techniques to control them.

6. Social and Psychological Dimensions

The WHO defines health not only as the absence of disease, but also as the state that enables the full development of individuals and communities. Therefore, public health authorities in Québec are looking into the well-being of communities living near proposed and ongoing final waste disposal or incineration sites, and the social and psychological effects of these projects on communities.

A literature review is currently underway at the INSPQ to assist the BAPE in its current mandate and to inform the public. The purpose of this review is to document the social and psychological impacts, and the nuisances to quality of life associated with final waste disposal activities. At present, a few relevant, high-quality documents comparable to the Québec context have been identified in the scientific literature. Coupled with the BAPE's main reports on the subject, which provide evidence of recent Québec cases, the exercise makes it possible to draw a portrait of the main social and psychological issues related to the advent or expansion of a landfill or incinerator project.

As the literature review exercise is ongoing, this content is likely to be updated in the coming weeks. Moreover, as underlined in the preamble of this summary document, the data collected is indicative of the pre-pandemic situation and therefore does not consider the potential increase in teleworkers.

6.1. Social Acceptability

Theoretically, social acceptability is:

> “a process of political evaluation of a project that involves interaction between multiple stakeholders involved at various levels and from which institutional arrangements and rules are gradually built that are recognized as legitimate because they are consistent with the vision of the territory and the development model favoured by the stakeholders concerned (Bouchard-Bastien et al., 2020, p.8; Caron-Malenfant and Conraud, 2009).”

Social acceptability is often understood by social stakeholders as the population's consent or not to a project likely to have repercussions on its activities and living environment (Bouchard-Bastien et al., 2020). Therefore, we prefer to use the notion of social acceptance in the context of this document, so as not to create confusion.

Taking social acceptance factors into account is relevant insofar as these factors modulate the social and psychological impacts, and thus provide a better understanding of, for instance, the sources of conflict, stress, or feelings of hope. However, the identification of these factors does not replace an assessment of the potential or proven risks of the project under study, since a socially acceptable project is not synonymous with a project without health or social risks (Vanclay et al., 2015).

Social acceptance factors can take various forms, such as “social norms, values, beliefs, perceptions, emotions, habits, previous experience, knowledge,” etc. (Vanclay et al., 2015). (Bouchard- Bastien et al., 2020, p.8). They are dynamic and multi-scale, hence the importance of identifying them at each stage of the project, and according to the changes in social systems (political, economic, and territorial) that are underway.

Prior to listing the factors uncovered in the scientific literature consulted, it is important to clarify the markers of the "not in my backyard" or NIMBY phenomenon. This notion, which dates to 1980, is historically associated with the landfill industry, and is therefore widely used in the literature on the subject. The NIMBY phenomenon can be defined as “an attitude of individually motivated and egocentric opposition to development projects for the common good of society” (Bouchard-Bastien et al., 2020, p.8; Sébastien, 2017; Wolsink and Devilee, 2009). Corroborating the INSPQ Guide (Bouchard-Bastien et al., 2020), most of the articles consulted warn against this notion which would be used too often to explain the non-acceptance of a project, while the opposition citizenry is rarely selfish, but rather stems from a perception of injustice or inequity (Wolsink & Devilee, 2009). Therefore, a growing scientific consensus seems to be tending towards the invalidity of this notion, which can be potentially denigrating for the population (Bouchard-Bastien et al., 2020; Wolsink and Devilee, 2009).

Social acceptance (public consent) may vary within a community once a final waste disposal project is announced. Studies to date document factors that influence social acceptance prior to eight Alabama landfill projects in the United States (Solheim et al., 1997), one Ontario landfill project in Canada (Elliott and McClure, 2009), one incinerator project in France (Rocher, 2006), and six various final waste disposal projects (landfill, composting, and incinerator) in the Netherlands (Wolsink and Devilee, 2009):

- The industrial and socio-political history of the community (Elliott and McClure, 2009; Solheim et al., 1997)
- Attachment to place and landscape (Solheim et al., 1997);
- Negative financial impacts (loss of home value) and positive financial impacts (job creation; lower taxes) (Solheim et al., 1997)
- Change in the rural character of the community (increased traffic) (Solheim et al., 1997)
- The process by which the company establishes the site (lack of consultation; perceived inequity in profits; lack of transparency) (Wolsink and Devilee, 2009; Solheim et al., 1997; Rocher, 2006)

- Risks of pollution and contamination of drinking water (Elliott and McClure, 2009; Solheim et al., 1997; Rocher, 2006));
- Potential health risks (Rocher, 2006).

A few factors were also collected in relation to operating landfills in France (Praznoczy et al., 2020) and Canada (Elliott and McClure, 2009), as well as an operating incinerator in Spain (Subiza-Pérez et al., 2020). The factors uncovered are:

- The historical and socio-economic context of the territory (Praznoczy et al., 2020)
- Direct financial benefits (job creation) (Praznoczy et al., 2020)
- The company's attitude towards communication and risk management (transparency, management of nuisances (odours) and consultation with the population and elected officials) (Praznoczy et al., 2020; Subiza-Pérez et al., 2020; Elliott and McClure, 2009)
- Potential health risks (Subiza-Pérez et al., 2020).

6.2. Nuisances to Quality of Life and Risk Perception

Activities related to the management and disposal of final residues, such as infrastructure construction, waste transportation, landfill capping and combustion, are likely to generate nuisances to the quality of life.

As documented in Chapter 5, the magnitude of the effects of odours, noise or vermin will vary depending on the activity and characteristics of the site. The risk perception of the local population, which is “the process by which individuals become aware of their environment on the basis of the information collected”, is also a factor that can magnify or mitigate its effects (Bouchard-Bastien et al., 2020, p.9). Risk importance is assessed based on individual factors (health status, age, trust in experts, etc.), social factors (socioeconomic environment, collective values, religious groups, etc.) and external factors (media, public consultations, landscape change, etc.) (Bouchard-Bastien et al., 2020). As a result, a broad spectrum of risk perceptions within a population and in the face of an apprehended effect are confronted, and it is important to consider them without prioritization (idem).

BAPE reports on landfill expansion projects in operation frequently name bad odours as the most disturbing nuisance to quality of life (BAPE, 2020; BAPE, 2012; BAPE, 2009; BAPE, 2008). Along with the physical effects identified, these odours may be associated with a health threat and pollution, which negatively modulates perceived quality of life (Elliott and McClure, 2009). Secondly, this apprehension of risk is associated with very tangible social and psychological impacts, such as the erosion of social capital or anxiety (Elliott and McClure, 2009; Wakefield and Elliott, 2000).

6.3. Social and Psychological Impacts

Based on the few scientific documents available to date, it is possible to identify the social and psychological impacts associated with the planning and operation of a final waste disposal site. BAPE reports on EL implementation or expansion projects confirm these effects. As the INSPQ is currently conducting a literature review, this content is likely to be updated in the coming weeks.

From the time the project was announced and planned, two scientific studies and a doctoral dissertation selected to date described effects on the social fabric, particularly about socio-political dynamics (Sébastien, 2017; Rocher, 2006; Wakefield and Elliott, 2000).

These three studies of an incinerator project in France (Rocher, 2006) and the planning of landfill sites in Ontario, Canada (Wakefield and Elliott, 2009), and France (Sébastien, 2017) note the spontaneous creation of citizen groups and the emergence of social cleavages. Faced with the uncertainty of the upcoming project, coalitions of residents fight to preserve their quality of life and ensure the fairness of the implementation process (Sébastien, 2017; Wakefield and Elliott, 2009). Conflicts in the community, neighbourhood, and families, arising from the polarization between people for and against the project, can be exacerbated by the mediatization of the conflict and social networks (Wakefield and Elliott, 2000). Citizen mobilization can also strengthen the social capital of citizens in opposition, particularly when there is technical, legal, or institutional consolidation of the group (Sébastien, 2017; Rocher, 2006).

Some of the cases studied in the articles reviewed also report psychological impacts as soon as the project is announced and planned. Stress, anxiety, fears, and anger among residents were identified, as well as feelings of powerlessness, loss of trust in authorities and injustice (Wakefield & Elliott, 2000; Elliott & McClure, 2009; Wolsink & Devilee, 2009; Solheim et al., 1997). These manifestations and feelings are believed to be associated with:

- the process of implementing the business, particularly when the process is staggered over time or there is a lack of transparency about decisions (Wakefield & Elliott, 2000; Wolsink & Devilee, 2009)
- the nuisances associated with the future project, particularly for people who are already ill or when there are scientific uncertainties about environmental and health impacts (Wakefield and Elliott, 2000; Solheim et al., 1997)
- Anticipated lifestyle changes, particularly in rural or quiet areas (Elliott and McClure, 2009; Solheim et al., 1997).

According to a longitudinal study conducted in Ontario (Canada), the social and psychological impacts associated with the planning phase of the project would not diminish during the operations phase, suggesting that anticipating impacts would be as harmful as the actual experiences (Elliott and McClure, 2009). In this case, contextual elements associated with risk management, namely the appearance of illegal dumping of toxic waste, modulated the impacts, demonstrating the importance of focusing on the project implementation process, monitoring, and follow-up (idem).

Specifically, regarding the psychological dimensions, a study of landfill sites in France (Praznoczy et al., 2020), as well as certain BAPE reports on LET expansion projects, describe manifestations of stress, fear and anger among residents living near a site in operation (BAPE, 2012; BAPE, 2008). These manifestations would be related to operating activities, and more specifically to odour nuisances and environmental risks.

6.4. Health Risk Management

Most of the articles collected to date are unanimous on the importance of respecting the guiding principles of public health risk management, which are the primacy of the protection of human health, prudence, equity, scientific rigour, transparency, openness, and appropriation of power (Ricard, 2003). Respecting these principles helps improve the overall health of populations, including social and psychological health. However, in the few cases collected to date, including some BAPE reports, examples of lack of transparency, lack of access to clear and neutral information, lack of opportunity to dialogue with the authorities, perception of inequity, lack of listening and feelings of powerlessness have been experienced, generating negative impacts on the well-being of individuals and communities. To improve current practices, some of these authors suggest actions, such as the following:

- Implementing a mechanism for citizen participation from the outset of the project, allowing impacted residents to share decision-making power more equitably and to increase their sense of control over their environment and their sense of trust in the authorities (Elliott and McCure, 2009; Wakefield and Elliott, 2000; Solheim, et al., 1997)
- Improve dissemination and quality of information about environmental and health risks (or not) (Praznoczy et al, 2020; Wakefield and Elliott, 2000; Solheim et al, 1997)
- Significantly reduce odour nuisance (Praznoczy et al., 2020

According to the few Québec cases investigated by the BAPE, the establishment of a vigilance committee seems to be a promising means of ensuring concerted action. However, this committee must respect the rules of the trade to be functional; otherwise, it may rather accentuate the polarization of stakeholders, as was the case for the citizens' committee of the LET in Lachenaie, prior to the 2008 expansion project (BAPE, 2008).

7. Issues Specific to the Nordic Territory

7.1. Landfill

Owing to the specific climatic challenges, and the presence of near-annual permafrost, communities north of the 55th parallel face significant logistical problems with respect to waste management. In these regions, landfilling as a waste management practice is in most cases impossible (Dessureault et al., 2014). As a result, waste accumulates on the surface, is mostly burned, or is sent to the southern regions of Québec. The inability to landfill waste properly, however, raises important issues.

An important issue concerns facilities related to northern landfills (NLs). The composition of these sites differs from landfills in the south and their management is a significant issue in itself. Given that, in most cases, the various types of residual materials are not sorted, they are exposed to bad weather, except for the Kangiqsujuaq site, which has a specific section for storing household hazardous waste (Cogut, 2018; BAPE, 1990). The NLs therefore represent a mixture of wastes from both domestic residual materials and any other residual material. Waste thus accumulates and causes the gradual release of toxic compounds through leaching. There are also issues related to spontaneous fires and open burning.

In 2014, the city of Iqualuit experienced numerous spontaneous combustions within its landfill site that resulted in a critical increase in VOCs such as benzene and dioxin-furans that could have significant health impacts (Weichenthal et al., 2015). Other significant issues were noted during this occurrence, such as an increase in soil contaminants, inconveniences related to smoke and odours escaping from the fire, and safety issues surrounding fire control (Weichenthal et al., 2015). These events constitute a major health and safety issue for the populations living near the NLs. These situations, mostly isolated, will tend to increase over the years with the global warming of northern regions, population growth and the proximity of fuels and flammable materials within the NLs (Weichenthal et al., 2015, Balthazard and Hacker-B., 2019).

Second, the lack of leachate treatment (see Section 2.1.2 for health risks associated with leachate) remains an issue of concern for some communities. Contaminated water flowing from the NLs enters streams and water tables directly, without initial treatment. As a result, a significant quantity of pollutants such as lead, mercury and cadmium are absorbed by marine mammals and fish, which remain a significant source of food in the region, in addition to contributing to the precariousness of existing drinking water sources in the region (Schaffer et al., 2008; BAPE, 1990).

Finally, according to section 96 of the RLIRM: “Northern landfills must be surrounded by a fence or any other device (...)” (R.S.Q., c.Q-1,r.19), however, studies have shown that in most cases, this regulation is not respected, and monitoring is minimal (Sanschagrin, 2016; Dessureault et al., 2014; BAPE, 1990).

As a result, the public can easily deposit waste and use it without supervision and without respecting safety standards. This situation represents a real danger since many of the compounds present are toxic and/or can represent a major source of accidents.

7.2. Open Incineration

Section 47 of the RLIRM (R.S.Q., c.Q-1,r.19) prohibits the incineration and/or burning of residual materials on an EL. However, section 99 (R.S.Q., c.Q-1, r.19) of the same regulation exempts NLs from this rule. Thus, section 99 stipulates that: "Combustible residual materials deposited in northern landfills must be burned at least once a week, when weather conditions permit (R.S.Q., c.Q-1, r.19)". Open Incineration: means "any fire or burning that is not carried out in a building" (Canadian Council of Ministers of the Environment, 2016).

This open burning of waste produces a significant amount of air emissions and residual solids such as carbon dioxide, methane, VOCs, and dioxins/furans (Cogut, 2016; CCME, 2016) and others. These same compounds are emitted during conventional incineration, however, the lack of capture mechanisms and adequate infrastructure to manage releases makes open burning even more harmful to health and the environment than the use of incinerators (Cogut, 2016). Apart from the lack of VOC and bottom ash capture, the lack of sorting within the NLs promotes the spread of multiple toxic compounds through the presence of all types of waste, including domestic, demolition, tires and certain hazardous residues that would have been deposited within the NLs (Cogut, 2016; Weichenthal et al., 2015). Finally, the lack of adequate infrastructure to store the waste and protect it from the elements reduces the effectiveness of open burning, which often contains wet or damp compounds, thus reducing the heat of the fires. Materials burning with insufficient heat will release contaminants over a longer period of time, contributing to increased pollutant concentrations. Moreover, incrustation, which occurs very close to the ground, makes natural dispersion of contaminants very difficult (Cogut, 2016). Thus, these two elements combined create clouds of particles and toxic fumes (Cogut, 2016; Balthazard and Hacker-B., 2019).

The health effects are like those presented in section 3.3 since the components emitted remain the same. However, their presence due to the absence of a filtering system implies a greater health risk (Cogut, 2016, CCME, 2016). The lack of information in the scientific literature regarding the exact quantity of contaminants released during open burning makes the estimation of health risks difficult. The study by Schaffer et al. however, demonstrated the significant presence of PCBs in animal meats, in water treatment systems and in water surrounding landfills. PCBs are known to be a carcinogenic substance in addition to being a persistent organic pollutant (Département Cancer et environnement, 2018). Furthermore, members of the Kuujjuaq community have strongly expressed their discomfort during burning in terms of odour, aesthetics, and respiratory difficulties associated with black smoke (Balthazard and Hacker-B., 2019).

7.3. Nuisance Management

The fences not only prevent people from accessing the site, but also serve to keep animal populations away from the site. The presence of edible food on these sites represents a significant source of calories for species such as black and polar bears. Once accustomed to human food, studies have shown that bears will venture closer and closer to communities and proximity to humans increases the risk of attack and/or accident (Gehring, J, 1990; Herrero et al. 1990). Tyrrell (2006) discusses this issue of polar bears' proximity to certain villages on Hudson Bay and the health risks to the population, such as attacks, fear, stress, and trauma caused by their presence. Furthermore, bears, like most other animals, tend to scatter waste outside of the NWAs, which negatively affects the beauty of the landscape (Tyrrell, 2006).

7.4. Other Issues Specific to the Nordic Territory

The presence of residual sites related to former mining, archaeological or military operations have generated large quantities of hazardous waste scattered over the territory, including used oil, waste rock piles, electronic and electrical equipment, diesel power plants and others (Keske et al., 2018; BAPE, 1990). All these materials have been abandoned on the territory and release numerous contaminants that can be toxic: PCBs, hydrocarbons, metals such as lead, cadmium, arsenic, mercury, nickel, cyanide effluents and other compounds harmful to human health (Keske et al., 2018; Schaffer et al., 2018; BAPE, 1990).

Apart from the presence of unrecovered hazardous waste on the territory,

dumping is also a common practice in the region. This phenomenon consists of the disposal of residential or other waste by different members of the community anywhere in the territory (Keske et al., 2018). These two phenomena generate toxic contaminants that are not captured or filtered by specialized waste treatment facilities, thus there is a significant risk of leaching and contamination of water and surrounding wildlife, in addition to representing a safety issue for individuals (Schaffer et al., 2018; Keske et al., 2018; BAPE, 1990).

8. Conclusion

The need to limit contaminant discharges and nuisances from MRLs is widely recognized and accepted. This has contributed to improving waste management, both in terms of management methods (landfilling, incineration, recovery, composting) and in terms of controlling discharges and nuisances (stricter standards, more frequent monitoring over longer periods, etc.). However, these various waste management methods are interrelated. For instance, improved air quality controls reduce the toxicity of incinerator emissions but increase the toxicity of ashes to be landfilled. Encouraging composting and recovery reduces the amount of final waste to be treated but involves more direct contact with waste for workers. This transfer of risk must be considered when assessing the health risks associated with different waste management methods.

Overall, the literature available to date provides little support for concerns about the potential health effects associated with RMTSs, although significant results are reported. Two interpretations are therefore possible: exposure to the contaminants emitted by RMTSs is too low for health effects to be observed, or the studies are not sensitive enough to link the contaminants present to the health problems observed. However, the difficulty in demonstrating a causal link between exposure to RMTS contaminants and health effects does not imply an absence of risk, as these effects remain biologically plausible. Reducing the health risks associated with RMTSs therefore involves reducing waste generation at the source.

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Appendix 1:

Determinants of Health (MSSS, 2016)