Bisphenol A and Bis(2-ethylhexyl) Adipate releases from different facilities across Canada

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1. Executive Summary

This study aims to compare the emissions of two chemical compounds of concern, namely, Bisphenol A and Bis(2-ethylhexyl) adipate across Canada from the year 2013 to 2022. It aims to observe the emissions trends across provinces, and different environmental compartments, and source facility types. These compounds play a role in plastic industries and the possibility of using them as plastic pollution indicators is discussed along with Canada's prevention and treatment activities.

The data for compounds' release amount is accessed through the National Pollutants Release Inventory (NPRI) database. Based on the collected information, graphs were plotted, and mapping was performed for data visualization. This provided useful information about the prevalence of these compounds in different regions of the country in sync with different policies adapted at different times. For background information on these compounds, reports from Environment and Climate Change Canada were researched.

Plastics, indicators and plasticizers are discussed for Canadian context along with prevention and treatment activities. Based on the collected information, suggestions are made for improvement in data collection and database that could provide more detailed information for predicting future trends.

2. Introduction

Bisphenol A, or commonly called BPA, is a synthetic chemical compound that is used in the plastic industries for manufacturing polycarbonates and epoxy resins. Its primary function is to enhance the durability and flexibility of plastics, making it a common component in various everyday items such as food and beverage containers, thermal paper receipts, and medical devices. Polycarbonates made with BPA can resist high temperatures up to 145°C and it has impact on strength and hardness, making it widely used. Likewise, epoxy resins made from BPA can withstand chemicals and high heat (Abraham & Chakraborty 2019).

BPA finds its way into the environment through different channels, including the leaching of the compound from plastic products, industrial discharges, and improper disposal of plastic waste, especially if products are exposed to high heat (Environment and Climate Change Canada 2020). Its ubiquitous presence has led to the detection of BPA in air, water, and soil, contributing to its impact in several ecosystems and biodiversity loss. The repercussions of BPA are significant, given its classification as an endocrine disruptor capable of interfering with the hormonal systems of living organisms. Research indicates that exposure to BPA is linked to potential health risks in humans, including reproductive and developmental abnormalities, as well as an elevated risk of diseases like obesity, diabetes, and cardiovascular disorders (Rochester 2013). The impact extends beyond human health, affecting wildlife and ecosystems. Aquatic organisms, in particular, face vulnerability to BPA contamination, posing potential threats to reproductive success and overall ecosystem well-being. Addressing the environmental impact of BPA involves regulatory measures limiting its use, exploration of alternative materials, and public awareness initiatives promoting sustainable practices to minimize plastic waste and decrease BPA exposure.

BPA has been a subject of concern in Canada, as in many other countries, due to its widespread use in consumer products. Health Canada has conducted studies to assess the exposure of Canadians to BPA and has set guidelines for acceptable daily intake levels. BPA has been monitored in surface waters (2008-2018), sediments (2011-2018), wastewater (2008-2013), landfill leachate (2008-2013) etc by collecting samples from selected sampling sites across Canada. The Canadian government has implemented regulations restricting the use of BPA in certain products after biomonitoring analysis, particularly those intended for infants and young children, such as prohibiting in baby bottles and the linings of infant formula cans (Health Canada 2018).

Another chemical compound, Bis(2-ethylhexyl) adipate (DEHA) is commonly employed as a plasticizer in the manufacturing of various products, including flexible plastics, vinyl, and synthetic rubber. As a plasticizer, DEHA enhances the flexibility and durability of these materials, making them more adaptable for use in items such as food packaging, medical devices, and toys. DEHA can find its way into the environment through processes like leaching from plastic products, industrial discharges, and improper disposal practices, contributing to its presence in air, water, and soil.

While DEHA has been widely used in industrial applications, concerns have been raised about its potential impact on human health. Research is ongoing to understand the potential risks associated with exposure to DEHA, including its potential as an endocrine disruptor. DEHA, like other phthalates, including some plasticizers, has been the subject of monitoring and regulatory scrutiny in Canada. Health Canada and Environment and Climate Change Canada regularly conduct studies to assess the presence of DEHA, in the Canadian environment to limit exposure and provide a comprehensive understanding of the environmental fate and health implications. The results of these studies contribute to risk assessments and regulatory decisions.

The objectives of this study are:

- Comparing the release of Bisphenol A and Bis(2-ethylhexyl) adipate from different facilities across Canada based on regions and environmental compartments.
- Discuss the role of these chemicals as plastic pollution indicators.
- Discuss the prevention and treatment activities.

In summary, we gathered the information about emissions of Bisphenol A and Bis(2-ethylhexyl) adipate from NPRI database to predict their release trends from the year 2013 to 2022. The emissions were projected based on regions, environmental compartments and facility types. Furthermore, this data was mapped to showcase the regions with highest emissions percentage and prevalence of the source facilities across Canada. We also highlighted the gaps in database which could assist in future monitoring of contaminants to be more inclusive, especially concerning the contaminants of emerging concern.

3. Methodology

3.1. Data Collection

All the date used in this study was retrieved from the National Pollutant Release Inventory (NPRI). The data for Bisphenol A and Bis(2-ethylhexyl) adipate was collected and organized by provinces for 10-year period starting from 2013 until 2022 in a regular spreadsheet of Microsoft excel version 2020. The data for Bisphenol A was distributed in different tables for the provinces of Alberta, British Columbia, Manitoba, New Brunswick, Ontario, Quebec, and Saskatchewan, whereas for Bis(2-ethylhexyl) adipate it was organized by provinces including Ontario and Quebec according to data available in the NPRI inventory. Tables were made with information regarding the company reporting, the facility name, the type of industry, type of facility and the location (city). Moreover, data regarding the releases by the different environmental compartments (air, land, and water) were collected along with the total releases in kilograms (kg) for both pollutants. Likewise, data regarding the on-site and off-site disposals, off-site treatment and off-site treatment, and direct discharges were retrieved whenever possible for every year, province, and substance.

Additionally, a filter was used in excel to organize the releases by the type of facility. For bisphenol A, all the facilities were grouped in seven main categories including Resin and synthetic rubber manufacturing, Waste Treatment and Disposal, Paint and Coating, Electrical Equipment and Power Distribution, Iron and Steel, Aerospace products and vehicle parts and Transportation equipment. For Bis(2-ethylhexyl) adipate the releases were grouped by four main categories: chemicals, plastics and rubber, pulp and paper and other manufacturing. Moreover, another filter was required to create a table with total releases on each province by compartment. Then, the percentage of releases for each substance was calculated to estimate which compartment (air, land, water) and type of facility contribute more to the total releases. Reports of Bis(2-ethylhexyl) adipate releases with no information regarding the compartment were classified as “unspecified media”.

3.2. Digital cartographic information

To compare the release of pollutants across diverse regions, provinces, and industries emission data collected was geographically compiled considering the administrative boundaries and different types of facilities within industries contributing to Bisphenol A and Bis(2-ethylhexyl) adipate release. The framework and spatial analysis were established using Quantum GIS (QGIS 3.12.1) software. Digital boundary files were obtained from Statistics Canada (Canada, 2016) and are portrayed in Lambert conformal conic projection (North American Datum of 1983 [NAD83]). Geographic areas such as different provinces and regions were defined according to census divisions (Canada, 2016). Geolocations of reporting facilities were extracted from NPRI database and are represented according to four-digit North American Industry Classification System (NAICS) codes.

3.3. Limitations of the data collection

Data collection was very limited regarding the type of facility and compartment for Bis(2-ethylhexyl) adipate. Majority of the data comes from unspecified compartment and other type of manufacturing industry. There were no reports of releases for any of the two substances for the Atlantic region and the northern territories limiting the analysis presented here.

4. Contamination across Canada

4.1 Bisphenol A

4.1.1 Pollution by regions

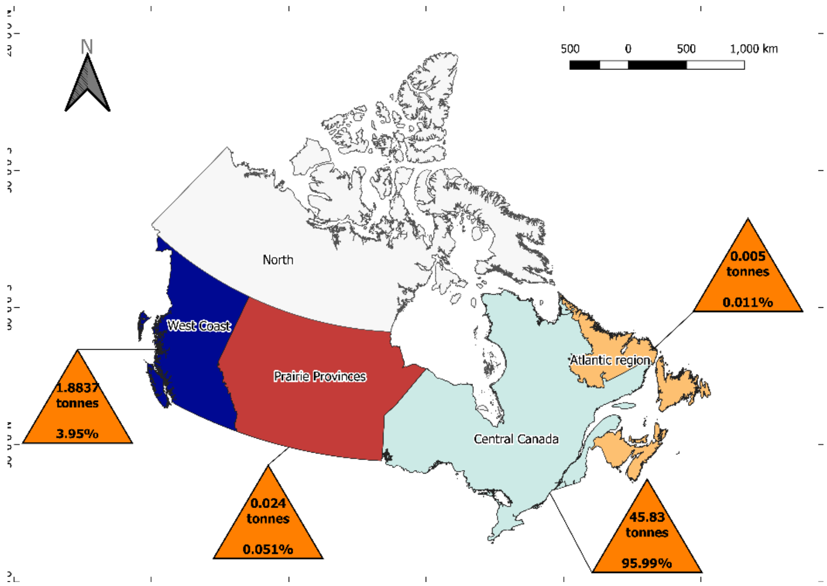
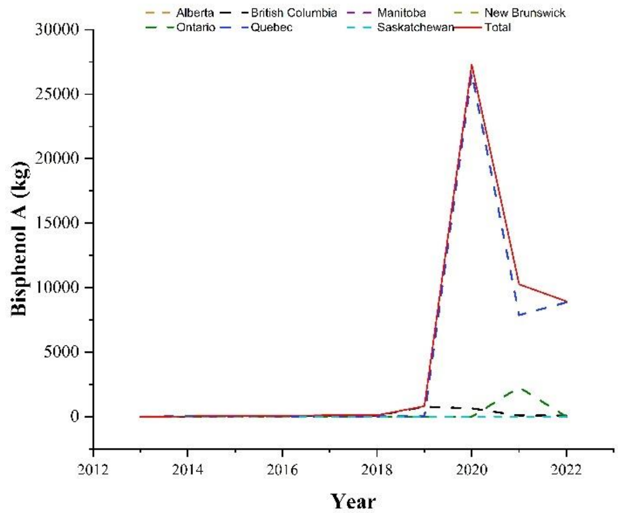


Figure 1. Cumulative Bisphenol-A emissions by region in Canada from 2013 to 2022.

The accumulated release of Bisphenol-A from the year 2013 to 2022 has been majorly observed from the central region of Canada, with 95.99% equating to 45.8 tonnes (Fig. 1). The west coast follows behind with 3.95% equating to 1.8 tonnes. Ontario and Quebec are home to significant industrial sectors, including manufacturing, chemical production, and plastics industries (44% and 28% respectively). Thus, the major reported chunk of released Bisphenol-A comes from these regions. More specifically, it was found that Quebec had the highest reported load for Bisphenol-A of more than 27 tonnes during the year 2020 (Fig 2a). Percentage-wise emissions trend (Fig. 2b) also shows Quebec as the leading province until 2022, except for British Columbia from 2015-2019. The drastic reduction in emissions from British Columbia after 2019 could be correlated with the CleanBC Action Plan that established bylaws for limiting single-use plastics.



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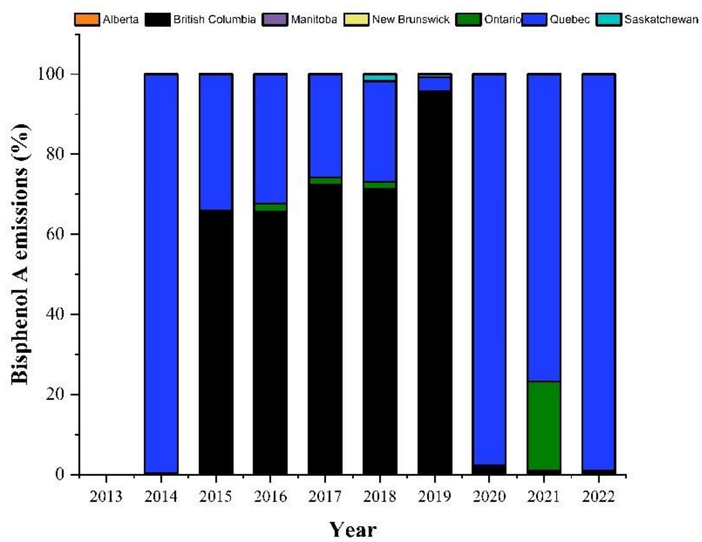


(b)

Figure 2. (a): Comparison of Bisphenol-A releases across provinces, dispersed into any medium (sum of air, land, water). (b): Percentage (%) contribution of provinces to total releases, dispersed into any medium (sum of air, land, water).

4.1.2 Pollution by environmental compartment

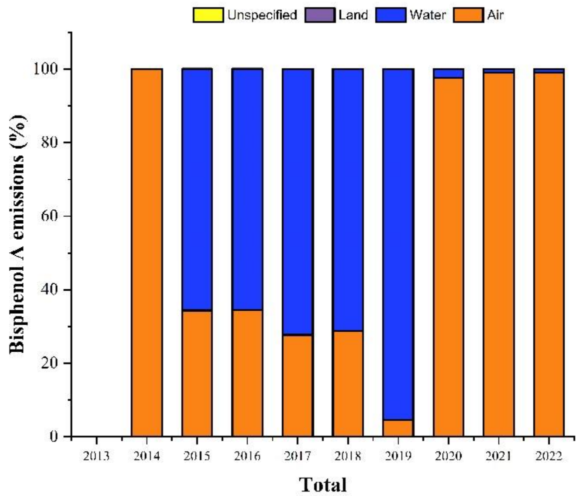
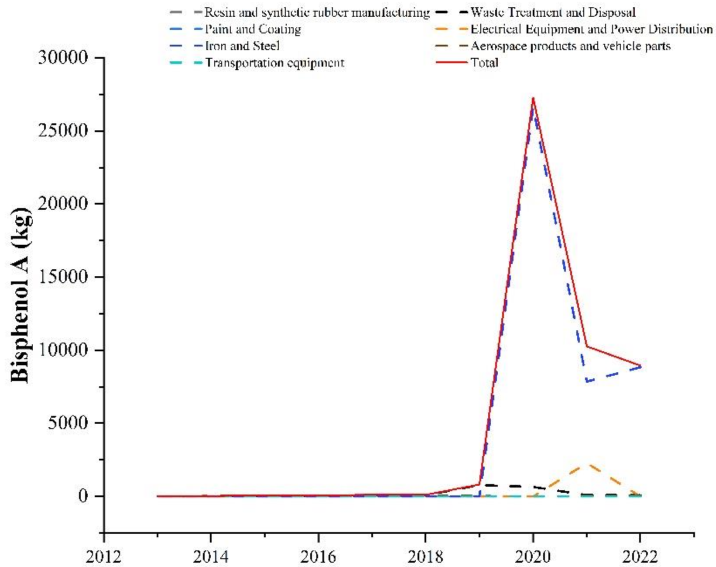


Figure 3. Percentage (%) of Bisphenol-A releases across all compartments, aggregated nationally.

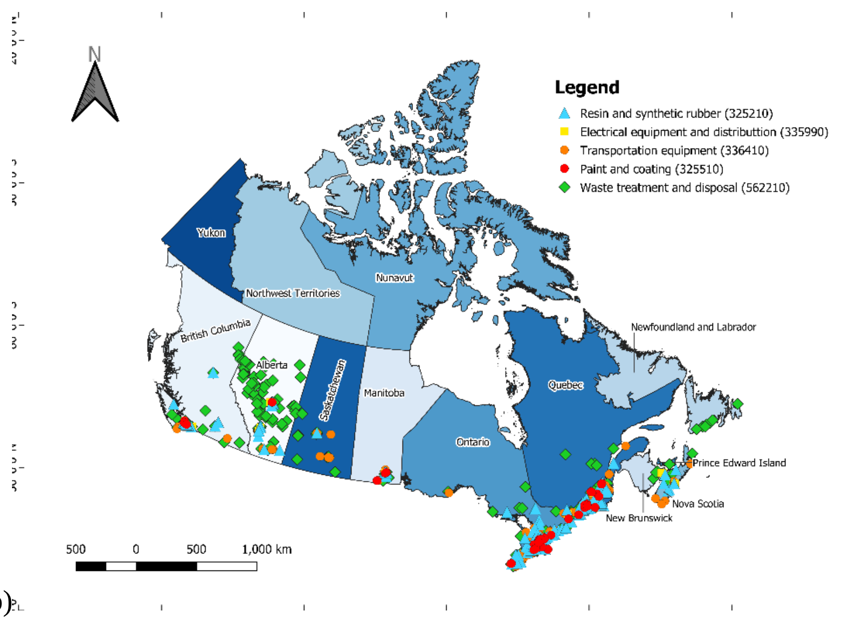
Based on the environmental compartment, i.e. air, water, land, and unspecified, the reported data shows maximum emissions in the air (Fig. 3). New Brunswick, Quebec, Ontario, Saskatchewan, Manitoba and Alberta report bisphenol-A release in the air compartment, while British Columbia reported release in the water compartment (Figures in Appendix III).

4.1.3 Pollution by facility type

The database covered different types of facilities responsible for releasing BPA into the environmental compartments. These facilities included resin and rubber manufacturing, paint, electrical equipment, wastewater treatment, iron and steel, transportation equipment, aerospace products etc. The facilities majorly responsible for releasing BPA were iron and steel, electrical equipment, and waste treatment. The iron and steel facility emissions were reported by a select few company giants having extensive services including rubber and plastic molding, mixing etc. The peak emission observed in the year 2020 (Fig. 4a) could be correlated to the Covid-19 pandemic when the demand for disposable medical equipment increased many-fold and thus the respective plastic industries workload. The other major facility types behind BPA emissions were electrical equipment situated in New Brunswick and waste treatment across Canada, concentrating in Alberta (Fig. 4b).



(a)



(b)

Figure 4. (a) Overall Bisphenol-A releases compared among industries, dispersed into any medium (aggregate of air, land, water). (b) Geolocations of bisphenol-containing facilities from 2013 to 2022 and the corresponding NAICS Codes.

4.2 Bis (2-ethylhexyl) adipate

4.2.1 Pollution by regions

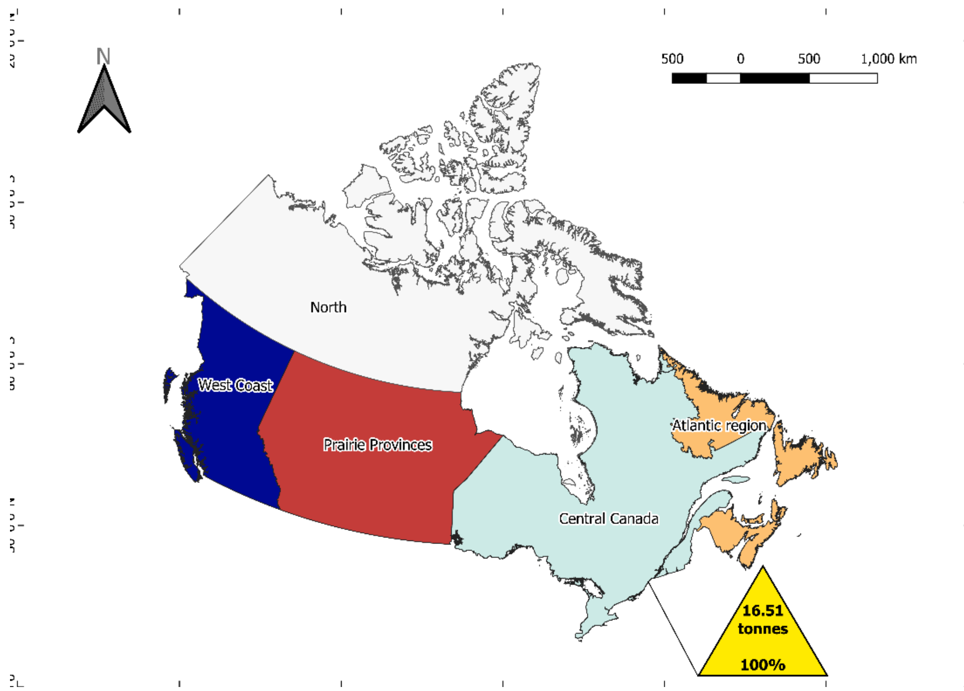
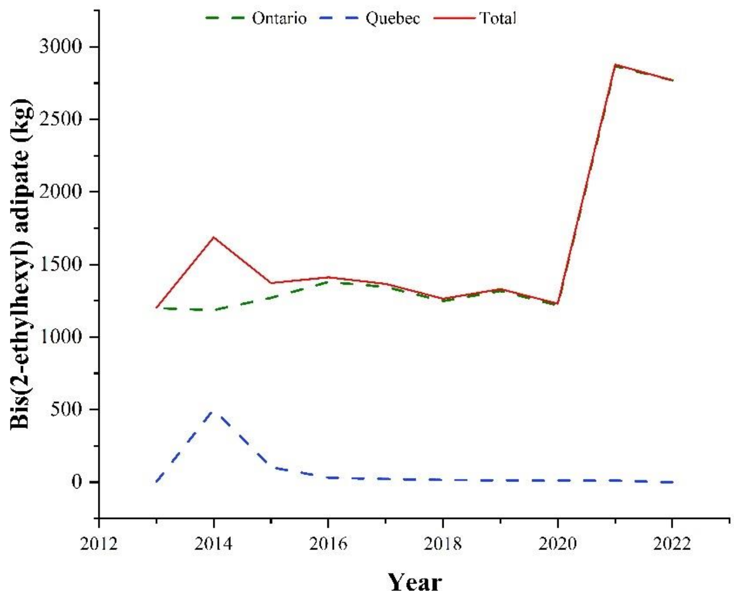


Figure 5. Cumulative bis (2-ethylhexyl) adipate (DEHA) emissions by region in Canada from 2013 to 2022.

With adipates coming under attention only recently, they haven't been reported widely, possibly due to facilities not exceeding certain threshold values. The accumulated release of adipate from the year 2013 to 2022 has been reported from the central region of Canada, with 16.5 tonnes (Fig. 5). Here, the major reported chunk of released DEHA comes from Ontario, followed by Quebec. A drastic emissions peak begins to form from 2020 to 2021 for Ontario. However, emissions in Quebec were reported in 2014, which then consistently declined (Fig. 5a).



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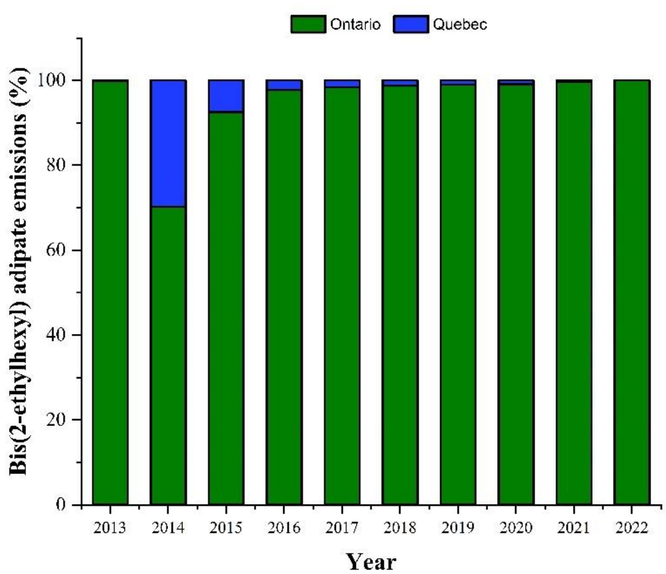


(b)

Figure 6. (a): Comparison of bis (2-ethylhexyl) adipate (DEHA) releases across provinces, dispersed into any medium (sum of air, land, water). (b): Percentage (%) contribution of provinces to total releases, dispersed into any medium (sum of air, land, water).

4.2.2 Pollution by environmental compartment

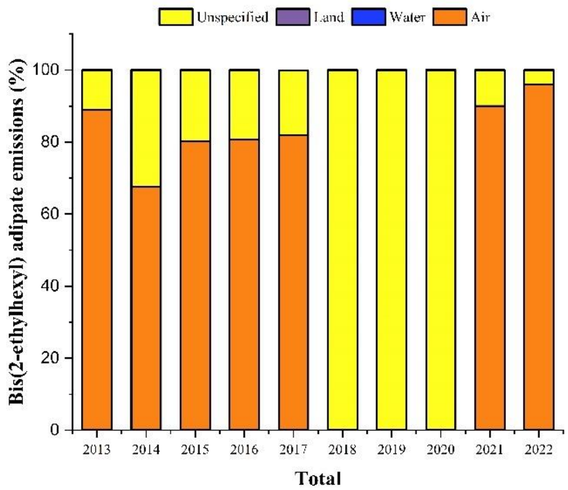
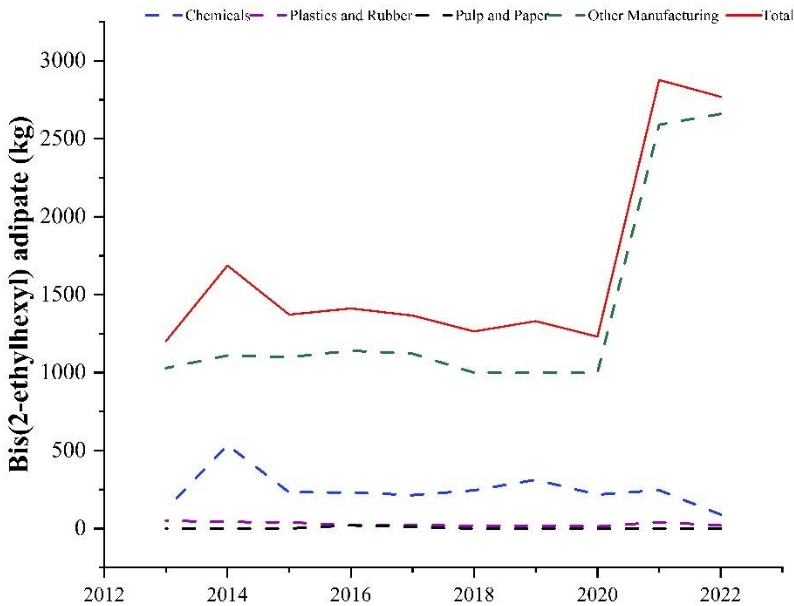


Figure 7. Percentage (%) of bis (2-ethylhexyl) adipate (DEHA) releases across all compartments, aggregated nationally.

Based on the environmental compartment, the reported data shows maximum emissions in the air followed by the unspecified compartment (Fig 6). Region-wise, Ontario reported DEHA release in the air compartment, while Quebec reported release in the unspecified compartment. There were no reported data from other provinces.

4.2.2 Pollution by Facility type

Given the role of DEHA as a plasticizer, different facility types reporting their emissions were chemicals, plastics and rubber, pulp and paper. Although, a major part of DEHA emissions came from other manufacturing facility types, followed by chemicals. The emission peak began in 2020 to reach the maximum of 3 tonnes. When correlated with region-wise emissions, plastic and rubber processing facilities were dominantly responsible in 2020 for Ontario. With the pandemic, there were reported increase in plastic packaging of which adipates form an important role.



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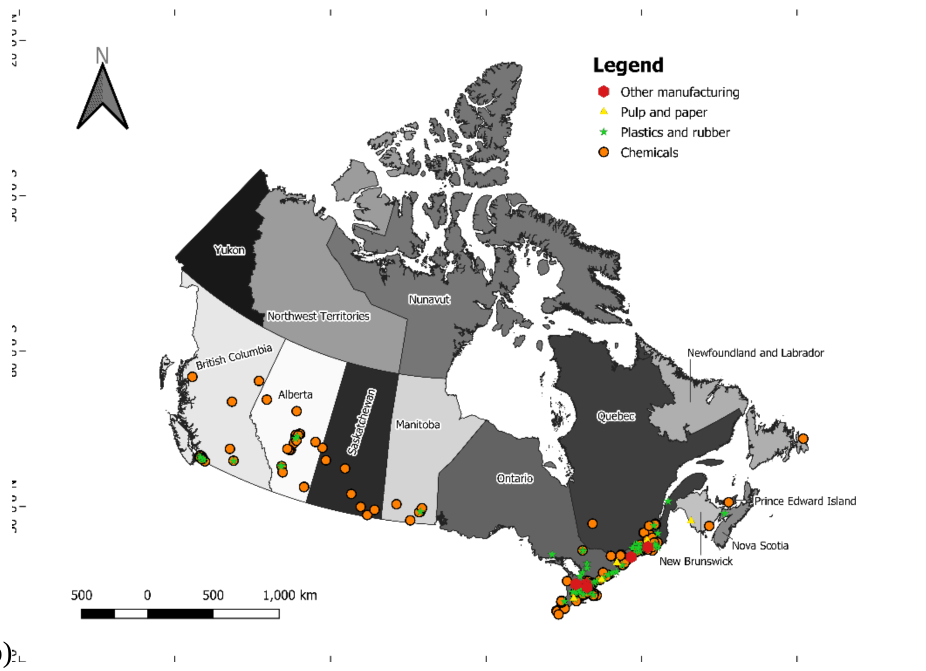

(b)

Figure 8. (a) Overall bis (2-ethylhexyl) adipate (DEHA) releases compared among industries, dispersed into any medium (aggregate of air, land, water). (b) Geolocations of DEHA-containing facilities from 2013 to 2022 and the corresponding NAICS Codes.

5. Plastic Pollution

Plastic pollution is a pressing environmental concern characterized by the accumulation of synthetic polymers, primarily derived from petroleum, a natural resource found in the natural environment. As a versatile and durable material, plastic has become an integral part of modern life. However, the persistent nature of plastics poses a significant concern when it comes to waste management. Improper disposal, inadequate recycling infrastructure, and widespread single-use plastic consumption contribute to the proliferation of plastic debris in oceans, rivers, and terrestrial ecosystems. The environmental impact of plastic pollution is multifaceted, affecting marine life, wildlife, and human health.

Monitoring plastic pollution involves assessing indicators such as the abundance of plastic particles in water and soil, the presence of microplastics in natural habitats, and the impact on wildlife populations. There is a need for many countries that have seen a dramatic increase in plastic use in the last years to keep track of the plastic pollution to better understand the potential impact of their ecosystem and communities' health. In Canada and United States, the end use of plastic has been directed towards the manufacture of molded parts, films, pipes, and packaging, making up to 82% of the total plastic produced in these countries as of 2018 (Statista 2023). On this section, there is an attempt to describe the use of historical reports of bis(2-ethylhexyl) adipate releases found in the National Pollutant Release Inventory (NPRI) as indicator of plastic pollution in Canada by the analysis of the operation, transformation, and activity of these type of manufacturing companies present in the country.

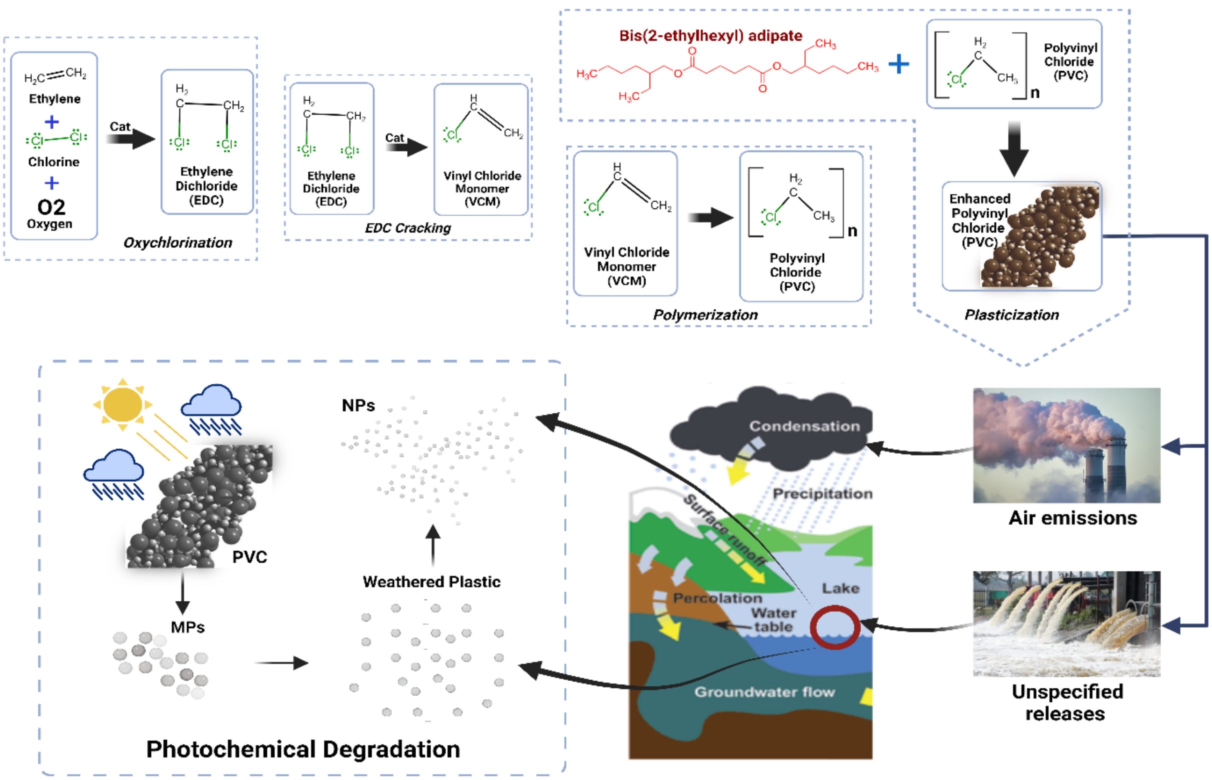

Figure 9. Schematic of PVC's manufacturing process, environmental fate, and photochemical degradation.

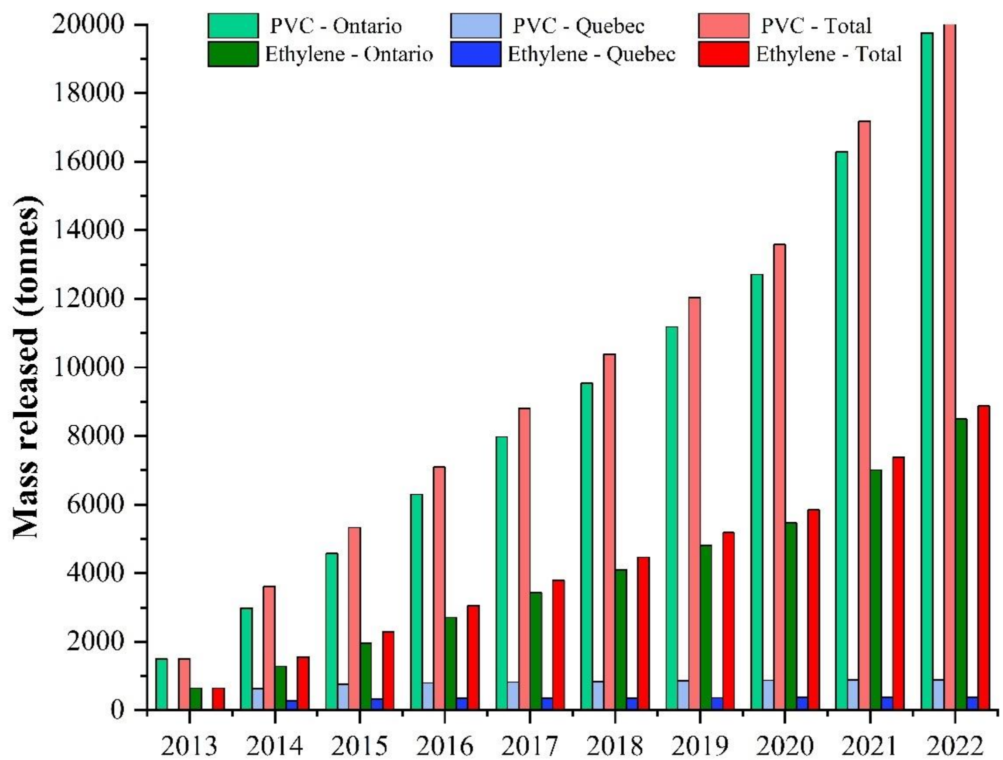

Figure 10. Total ethylene and PVC's tonnes released during the last 10 years in Ontario, Quebec, and Canada.

5.1 Indicators of Plastic Pollution

When it comes to finding an indicator that helps to see the levels of plastic pollution it is critical to first define what is plastic, understand from where the plastic is coming and once released, what is its environmental fate.

Plastic can be defined as complex substance made of organic polymers and additives that provide them specific mechanical properties and shape that make them very useful for a specific use. These polymers are always made of multiple smaller units known as monomers. For example, polystyrene and polyethylene are made of a long chain of styrene and ethylene subunits. Polyethylene's synthesis consists of the polymerization of ethylene, a hydrocarbon derived from crude oil, that undergoes this chemical reaction at specific temperatures and pressures and provides it with useful properties such as insulating properties, strength, and flexibility. However, the widely use of this substance can contribute to microplastic contamination in the environment once it is released into the environment. Plastic bags or synthetic materials made of polyethylene can undergo weathering processes and fragmentation due to exposure to sunlight, abrasion and mechanical wear that eventually break down the polymer into smaller fragments and reaching the microplastic size (< 5mm). Microplastics, including those derived from polyethylene, pose environmental concerns as they can persist in ecosystems, potentially impacting aquatic life, soil health, and even entering the food chain.

Although there are several known and unknown environmental consequences for the use of plastic as previously mentioned, only few are the alternatives available to monitor plastic. Numerical modelling, in-situ monitoring and satellite and aerial monitoring. There are particle tracking models that could help to predict the different transport pathways and dynamics of plastics in different compartments. An example of this is the Copernicus Marine Service's Ocean current models that can locate plastic particles on the ocean surface (Detecting Plastic Pollution, n.d.). Another alternative consists of collecting on-site plastic samples properly distributed; however, this can be laborious and costly for the limited analytical methods options required for microplastics identification and quantification such as Fourier-transform infrared spectroscopy (FTIR) and gas chromatography-mass spectrometry (GC-MS) that also have a limited sensitivity. Moreover, plastic pollution can be monitored by satellite by locating the floating fraction of plastics on the ocean surface. This method might be useful for tracking plastic contamination in places like the Great Pacific Garbage Patch. However, it is still a under development and can not provide information regarding the microplastics present in the subsurface.

Additionally, the use of any models or strategies for monitoring such small particles, that constitute more than 92% of the total plastic on surface water, must be always correlated with real world data (Coyle *et al* 2020). It is relevant to compared and calibrate those models with macro and microplastic measurements. Furthermore, have a better understanding of the different manufacturing processes for the different types of plastics, the operations, logistics and raw materials is necessary to assess plastic pollution.

5.1.1 Plasticizers

The use of plasticizers is in the manufacture of several plastic polymers. Plasticizers can fall in many categories; however, the most used fall into the Phthalates, Adipates, Benzoates, polyesters, citrates, and bio-based Plasticizers. They are important as additives since it greatly enhances the durability, flexibility, elasticity, and performance of different plastic materials such as rubber. Moreover, it can modify the boiling point and volatility of these materials making them more resilient and resistant to higher temperatures and more extreme conditions (Foroughi-Dahr *et al* 2017).

5.1.2 Canadian context

Multiples are the plasticizers used by the plastic manufacturing companies. In Canada, the most commonly additives are found in several reports made by companies in the National Pollutant Release Inventory (NPRI), a public inventory of releases that tracks more than 300 pollutants across the country. Several releases of phthalates and adipates are reported in the NPRI inventory, particularly, releases that correspond to bis(2-ethylhexyl) phthalate (DEHP) and bis(2-ethylhexyl) adipate (DEHA). According to the previous section, the focus of this document is DEHA which can be useful in the proposal of an indicator of plastic pollution given the important releases that at least 2770 kgs in the last two years by different companies. These companies must report to environment Canada as their releases surpass the reporting threshold of 100 kg/year. DEHA emissions are highly concentrated in the province of Ontario with an average 98% of the total, followed by Quebec with the rest and with no reports for the other provinces.

DEHA has been historically used in Canada as a solvent and plasticizer (Environment Canada 2010). It has been crucial for the manufacturing of films packaging and wrapped plastic for the food industry such as flexible polyvinylchloride (PVC) (Screening Assessment for the Challenge, 2011). The PVC food film is used for the packaging of diverse products such as beef, vegetables and cheese in grocery stores and other types of food markets. Other important uses of DEHA in the Canadian industry include the enhancement of properties of coated fabrics such as woven knit or tubes, hoses, and conveyor belts. DEHA can always leachate from these materials and be introduced into the environment. Despite that most of the emissions reported for DEHA correspond to air, it is not considered to be a concern. DEHA exists in both vapor and particulate phases in the atmosphere; the vapor phase can be rapidly degraded photochemically, and the particulate phase is deposited by the rain and the wind into surface water and soil. The dominant degradation process for DEHA is the microbial degradation which starts by its transformation into 2-ethylhexanol and hexandioic acid (NCBI, 2023).

According to section 4, the two industries with the higher DEHA releases in Canada correspond to the "chemical" and "other type of manufacturing" type of facility. This is aligned with reports of environment Canada that maintain that DEHA is mainly used as additive for packaging film since these companies are specialized in manufacturing packaging products for the food industry and for coated fabrics that are PVC-based. The DEHA releases by these two companies, one located in Ontario and the other in Quebec, makes more than 95% of the national releases during the last 10 years. Given that DEHA is, thus, mainly used as an additive for the manufacturing of PVCs this can be used to correlate and estimate the plastic pollution in Canada at least during the last 10 years.

5.2 Polyvinylchloride (PVC)

Figure 9 illustrates the different transformations that ethylene undergoes for the synthesis of polyvinylchloride (PVC). Firstly, ethylene the primary raw material, undergoes an oxychlorination in the presence of air to form a compound called ethylene dichloride (EDC). Secondly, the vinyl chloride monomer (VCM) is produced after the cracking of ethylene dichloride (EDC). Thirdly, vinyl chloride monomer (VCM) it is converted into polyvinyl chloride (PVC) by a polymerization reaction and combined with DEHA to enhanced it properties. In general, flexible PVC film used to contained 21% w/w for manual packing; however, recently research and development efforts have reduced to content to 8% w/w by promoting the addition of bio plasticizers (Peng *et al* 2020; Peterson *et al* 1998). This can help to make a direct correlation between DEHA releases in the NPRI with the amount of PVC produced. Moreover, the reported ethylene composition at the chlorination step is 43% w/w via ethylene dichloride (EDC), that can also offer a valuable reference to validate the increment on the plastic pollution levels based upon PVC (Pascoult *et al* 2012).

Since the polyvinylchloride (PVC) produced is quite persistent in the environment given that it presents a high resistance to environmental degradation, it is possible to assume that there's accumulation of these polymer for decades and even centuries. As of now, the microbial breakdown of PVC is widely acknowledged to be challenging, primarily because of its durable, resistant, and hydrophobic macromolecular structure, making it resistant to abrasion (Amass et al., 2015). Despite exposure to UV light, temperature fluctuations and other environmental interactions, this polymer can only be fragmented into smaller particles. Figure 9 shows how PVC is introduced into the Canadian environment. It is introduced only by air emissions according to the reports in the NPRI; however, there several others that were unspecified in the same and that might be posing a treat for terrestrial or water contamination. Likewise, it can be seen in figure 9 that the plastic can be deposited in surface water bodies such as lakes and rivers after being deposited by rain and water runoff. Moreover, PVC material can be fragmented and weathered by environmental degradation first in microplastics (MPs) and later in nanoplastics (NPs) posing a big concern as it is becoming a ubiquitous plastic pollution scenario.

5.3 Plastic Pollution in Canada

The levels of PVC enhanced with DEHA can be an important indicator of plastic pollution in the Canadian environment. Although this should be correlated with prediction and monitoring models, secondary datasets that offer an historical record of other types of plastics or agents that could provide key information in the correlation of plastic pollution in the country, this is a useful approach to estimate plastic pollution levels. Monitoring levels of PVC through DEHA is valid if it is still used in the same proportion in all the manufacturing companies that report to NPRI database. This can be useful to see the behaviour and demand of plastic throughout the last 10 years. A more accurate correlation could be possible if there were more data regarding the accumulation of plastics with the potential to become microplastics (MPs) beyond the 10 years scope that was selected for this analysis.

Figure 10 displays the total DEHA emissions for Quebec, Ontario, and Canada during the last 10 years with the assumption of accumulation of PVC microplastics in the environment. During the last ten years the plastic pollution in Canada has exponentially increased based on the manufacturing process of PVC films in Ontario and Quebec with more than 19000 and 887 tonnes of the same released into the environment, respectively. This exponential increase in plastic pollution is based on the tonnes of PVC released given the accumulation of plastic. The total PVC released is 14 times bigger in 2022 (20641 tonnes) compared to that of 2013 (1502 tonnes). The same exponential trend is evidence between years. For instance, from 2021 to 2022 there was an increment of 120% in the total mass introduced in the environment. This trend between years can be found for all the 10 years analyzed and can varied from 110 to 150%. A similar trend can be observed for ethylene which helps to correlate the demand for plastic manufacturing in the same period with over 8800 tonnes used as raw material for PVC production.

On the other hand, figure 10 evidence that only between the years 2020-2021 and 2021-2022 could have been added more than 3500 tonnes of PVC-based microplastics in Ontario and Quebec. A similar trend can be expected for the next few years. Moreover, most of the DEHA releases were reported in the province of Ontario (98-99% in the last 7 years) which means that there is a concern for microplastics pollution and that must be tackle promptly specifically on this province. Overall, the environmental fate for air releases and the releases with no specified compartment in the NPRI can ended up in water bodies by dry and wet deposition, and rain and water runoff. This may correspond with an increase in the risk for aquatic life and the human population to bioaccumulate plastic. As a result, there can be multiple initiatives such as creating policies that help to restrict and gradually reduce the use of plastic at industrial levels and providing funding for researching novel technologies that could help wastewater treatment plants to remove plastic pollution. This is an urgent concern and that must be addressed to guarantee the sustainable development goal (SDG #6) and make water safe to drink in Canada. Finally, more records regarding the releases of other plasticizers such as Phthalates and other reports for in-situ monitoring and predictions models are suggested to obtain a more precise correlation and understanding of plastic pollution levels in Canada.

6. Prevention and treatment activities

In April 2012, Environment Canada published a P2 Planning Notice in the Canada Gazette concerning bisphenol A in industrial effluents. According to Pollution Prevention (P2), Planning is a process by which organizations can improve their environmental protection by strategically planning to reduce or eliminate pollution before it is created. The Notice applies to any person or class of persons who owns or operates an industrial facility which, during the calendar year prior to the date of publication of the Notice, or any calendar year thereafter manufactures or uses Bisphenol A or a mixture that contains the substance in a quantity greater than 100 kg per calendar year.

Regarding DEHA, in September 2011, the Proposed Risk Management Approach for DEHA Enumerated the tasks required for the development of effective controls. These activities are geared towards enhancing the precision of identifying the origins of releases, with the ultimate goal of averting the discharge of DEHA into the environment and mitigating potential rises in exposure for Canadians. In April 2014, as a risk management action the substance was proposed to be included in the Cosmetic Ingredients Hotlist.

The prevention and treatment activities of facilities were analyzed according to the existence of a P2 Plan or P2 activities reported by the different facilities over the 10 years of data. Starting in the 2021 reporting year, facilities performing pollution prevention activities during the current reporting year were required to identify to which substance these activities pertain.

6.1 Bisphenol A

From a total of 258 reports over the 10-year span, only 8.1% reported implementing a P2 plan and P2 activities. Table 1 compiles and summarizes the pollution prevention measures that received the highest number of reports.

Table 1. Reported pollution prevention measures implemented by facilities to decrease the releases of Bisphenol A

Pollution prevention measure	Details
ISO 14001 Standards	Revised goals for 2014-2015 and 2015-2016, seeking a rubber recycler, and internal recycling of vinyl and rubber products.
Equipment or Process Modifications	Added equipment for improved product distribution, water meters in the paint workshop, and new, more efficient spray guns.
Good Operating Practice or Training	Continued optimization of PM completion and record-keeping, training on potential environmental impacts, and monitoring VOCs.
Inventory Management or Purchasing Techniques	Monitoring/manage materials with shelf life and replenishing as necessary.
On-site Recovery, Re-use or Recycling	Continued recirculation within the process and a plan for recycling waste materials.
Product Design or Reformulation	Optimized packaging materials for improved seal.
Spill and Leak Prevention	Adjusted setpoint for auto shutdown of cooling systems and continued monitoring of processes for leaks.
Materials or Feedstock Substitution	Increased purity of materials and substitution of materials.

The introduction of new preventive measures to diminish bisphenol A levels is primarily attributed to the Pollution Prevention Planning Notice in Industrial Effluents. Under this notice, four industrial users of BPA were mandated to formulate and execute a plan aimed at reducing the concentration of BPA in their wastewater to below 1750 ng/L. Facilities implemented various measures, such as on-site treatment of raw water containing BPA before reaching the final discharge point. Additionally, disposal strategies included evaluating the recovery of BPA-contaminated water for off-site disposal as hazardous waste. Furthermore, efforts were made in product design or reformulation, involving the assessment and utilization of non-BPA products. A comprehensive 94% reduction in BPA sent to off-site wastewater systems has been accomplished. As of now, there has been an overall 83% reduction in the average concentration of BPA in effluents. Notably, since 2013, there has been no transfer of BPA to landfills (Environment and Climate Change Canada, 2018).

6.2 Bis (2-ethylhexyl) adipate

From a total of 133 reports over the 10-year span, only 11.3% reported implementing a P2 plan and P2 activities. Table 2 compiles and summarizes the pollution prevention measures that received the highest number of reports.

Table 2. Reported pollution prevention measures implemented by facilities to decrease the releases of Bis (2-ethylhexyl) adipate.

Pollution prevention measure	Details
ISO 14001 Certified	ISO 14001 certification for environmental management.
Equipment or Process Modifications	1 - Maintained a schedule of inspections to manage potential environmental concerns, including effluent quality, dam inspections, dust abatement practices, and waste rock management. 2 - Installed particulate filter systems; purchased and installed new dust collection equipment in 2018; installed new vacuum dust collection equipment in 2019; installed a new aspiration dust removal system in 2020 (fully operational).
Good Operating Practice or Training	1 - Maintained a schedule of inspections to manage potential environmental concerns, including effluent quality, dam inspections, dust abatement practices, and waste rock management. 2 - ISO 900 certified; ongoing operator training program.
Materials or Feedstock Substitution	1 - Maintained a schedule of inspections to manage potential environmental concerns, including effluent quality, dam inspections, dust abatement practices, and waste rock management. 2 - Replaced Bis(2-ethylhexyl)adipate with an alternate product.
Spill and Leak Prevention	Maintained a schedule of inspections to manage potential environmental concerns, including effluent quality, dam inspections, dust abatement practices, and waste rock management.
On-site Recovery, Re-use or Recycling	Utilization of 85% of scrap material back into the operation, avoiding municipal landfill.
Program to clean up spills within the plant site	Recycling water in equipment.
Reduction of the use of phthalate plasticizers	DEHP continues to be replaced; participate in the Tin Stabilizer Agreement and apply material handling and waste management program to all metal stabilizers.
Inventory Management or Purchasing Techniques	Old stock processed into finished product and sold for use.

Other Pollution Prevention Activities	Participate in the Tin Stabilizer Agreement and apply material handling and waste management program to all metal stabilizers.
Product Design or Reformulation	Water contaminated with phenols isolated for special disposal; DEHP and DEHA tested for and addressed.

While DEHA does not currently have a Pollution Prevention Planning Notice in Industrial Effluents, similar to Bisphenol A, there are noteworthy measures worth highlighting. As mentioned earlier, DEHA is predominantly employed as a plasticizer in the flexible vinyl industry, including its use in flexible polyvinyl chloride (PVC). Vinyl compounding facilities have reported adherence to the Guideline for the environmental management of tin stabilizers in Canada, which has aided in reducing the utilization of DEHA plasticizers. The objective of this guideline is to mitigate the release of tin stabilizers into the environment by ensuring responsible handling, storage, usage, and disposal of these substances and their packaging materials (Environment and Climate Change Canada, 2020). Given the parallels, a comprehensive guide encompassing more specific plasticizers would be valuable as a reference for DEHA compounding facilities.

7. Prediction of emissions trends

Predicting future trends for chemical compounds involves complex factors, regulatory changes, technological advancements, and shifts in consumer behaviour. For instance, a sudden shift towards increased demand of disposable plastics and packaging during the year 2020 with Covid-10 pandemic was evident with the increase in BPA and DEHA release in Canada. Furthermore, the decline and following stagnancy observed in BPA from past years was observed with new research on BPA and its health effects which then led to changes in government's regulatory changes. With adipates now coming under research limelight and advancing information, it can impact future regulations by the government. Although, at present the increase from 2020 is now at a decline.

8. Conclusions and recommendations

Since the implementation of the Canadian Environmental Protection Act, 1999 (CEPA 1999) proposed risk management actions for both health and the environment were developed against Bisphenol A and DEHA. The National Pollutants Release Inventory (NPRI) database presents values which outline the releases of these contaminants from various sources. Utilizing data encompassing multiple years enabled the generation of visual representations illustrating the concentrations of contaminants released into different environmental compartments. The information that facility owners and operators must report to the inventory is a valuable source of information and helps inform decisions on protecting the environment. The comparison of the release of these pollutants from different facilities across Canada provided a comprehensive understanding of their occurrence and sources. Considering the analysis presented in this document, we can derive the following conclusions and recommendations:

- The central region of Canada dominates Bisphenol A emissions with Quebec maintaining a leading role in percentage-wise emissions until 2022. The existence of provincial programs suggests a decline in emissions in recent years.
- Due to a lack of data, there was limited differentiation among facilities in terms of the environmental compartment to which emissions were released or transferred.

- Many industries not reporting any emission of the respective contaminant despite it being accumulative in nature and of emerging concern. Perhaps there is time to reconsider the minimum threshold of such compounds in sync with developing research.
- For both bisphenol A and DEHA, a sudden increase in their release was observed from 2020 when the Covid-19 pandemic began. Given their role in plastic industries, there were reported studies showing increased adipates in food packaging (Cohen *et al.* 2023).
- PVC can be a preliminary indicator of plastic pollution in Canada given that the main companies releasing DEHA have focused on its production for the food industry. In the next five years there can be an increase in the plastic pollution in the form of PVC-based microplastics by at least 3500 tonnes.
- More records regarding the releases of other plasticizers such as Phthalates and other reports for in-situ monitoring and predictions models are suggested to obtain a more precise correlation and understanding of plastic pollution levels in Canada.
- During the last ten years the plastic pollution in Canada has exponentially increased based on the manufacturing process of PVC films in Ontario and Quebec with more than 19000 and 887 tonnes of the same released into the environment, respectively.
- Over the last decade, only 8.1% and 11.3% of facilities reporting on Bisphenol A and DEHA, respectively, executed Pollution Prevention (P2) plans and activities for these contaminants. The irregular updating of plan activities information suggests a potential deficiency in monitoring the performance of P2 plans. In response, it is highly recommended the organization of public workshops encouraging facilities to establish and monitor P2 plans.
- Although there is no dedicated Pollution Prevention Planning Notice for DEHA, efforts have been made, including adherence to guidelines established by industrial partners. These initiatives potentially played a role in reducing DEHA plasticizer usage and fostering alternative pollution prevention activities. Encouraging such partnerships is prudent, as the proximity among industrial collaborators facilitates the implementation of effective prevention measures.

9. Acknowledgement

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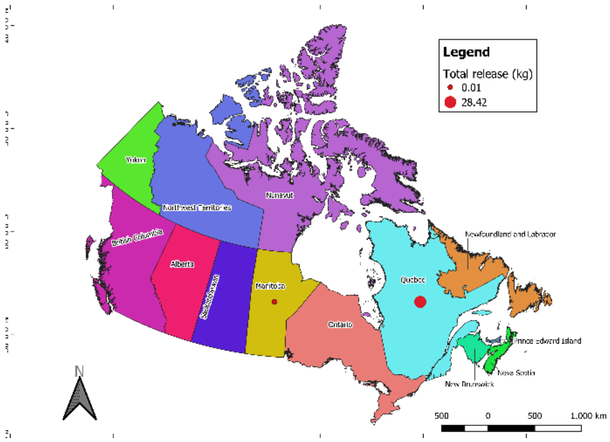
10. Appendix I: Maps for Bisphenol A emissions across Canada

2014:



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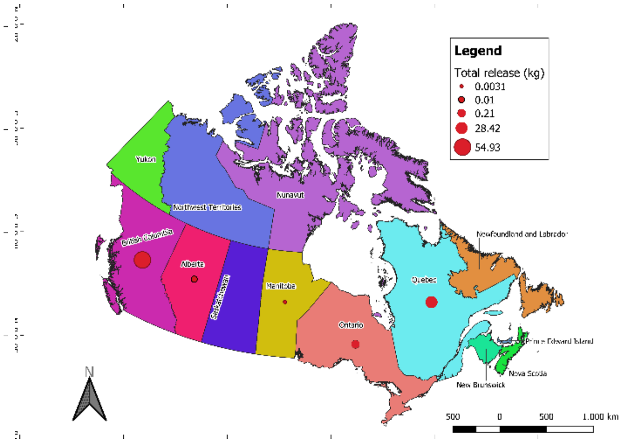

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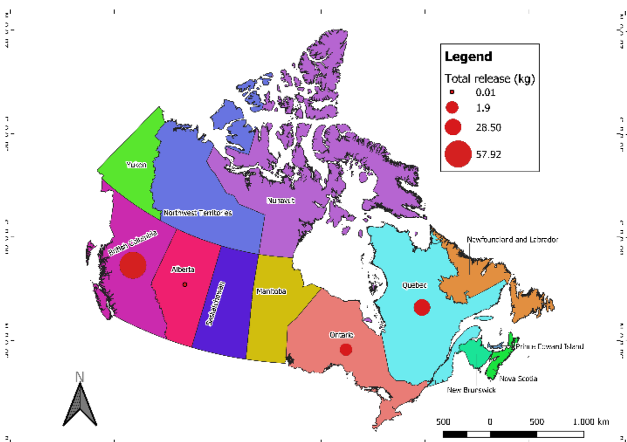

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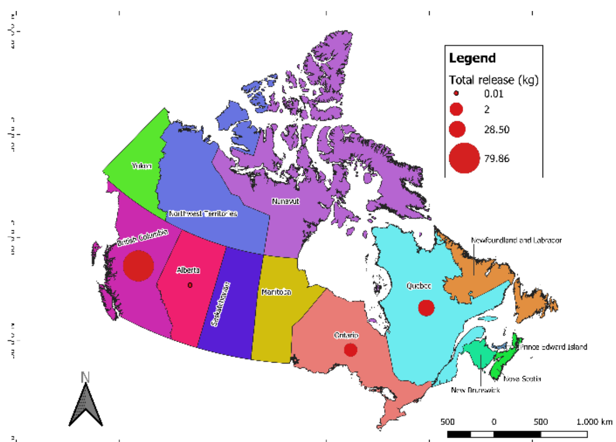

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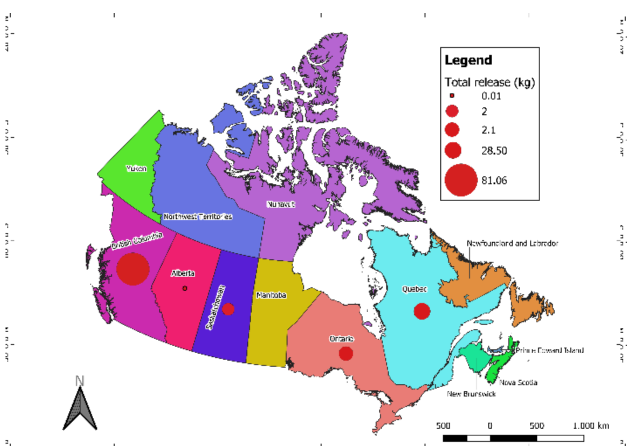

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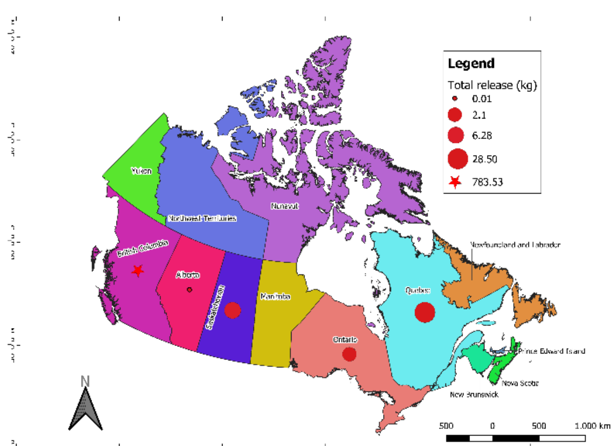

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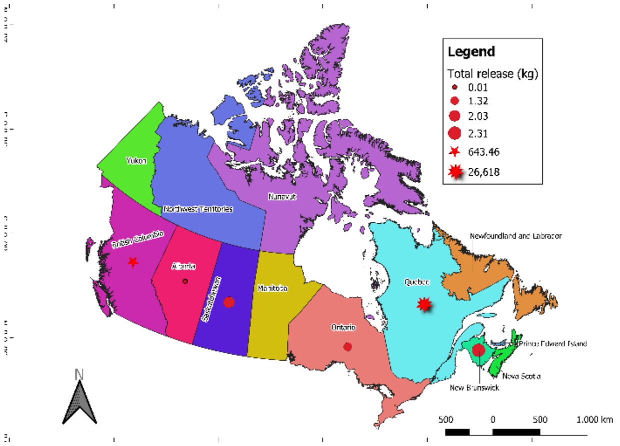
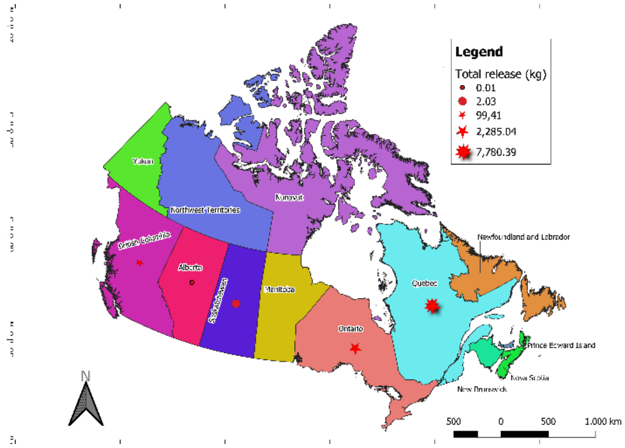
2021:





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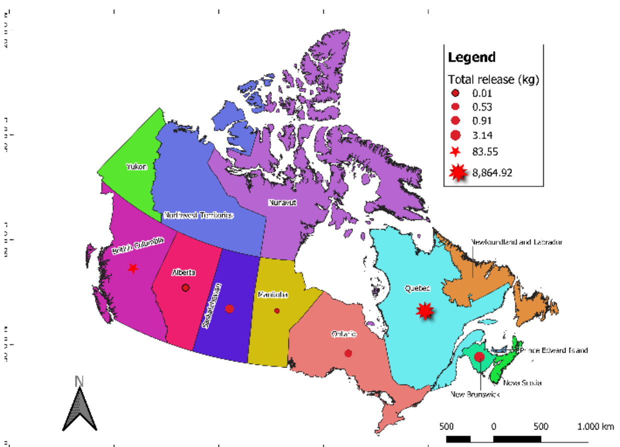

Appendix II: Maps for Bis(2-ethylhexyl) adipate across Canada

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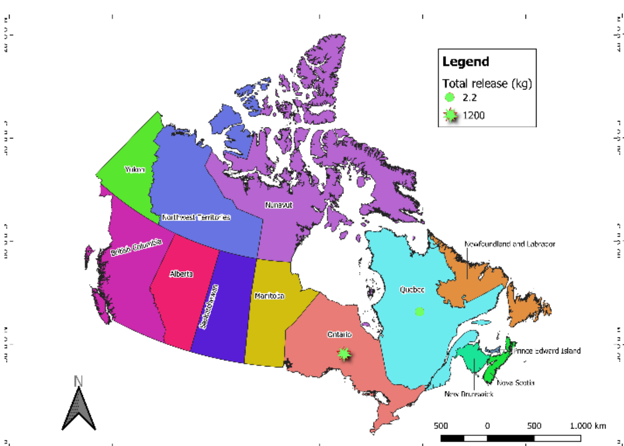

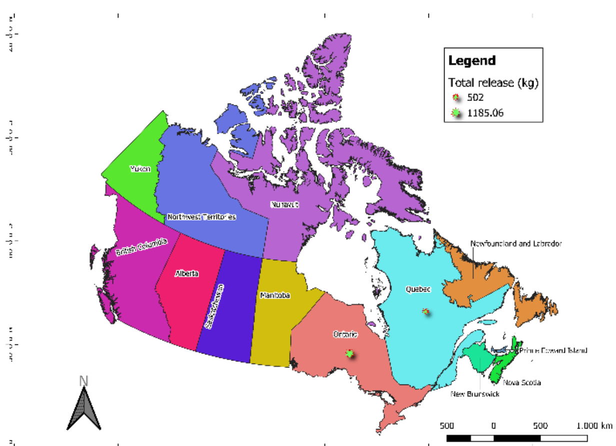

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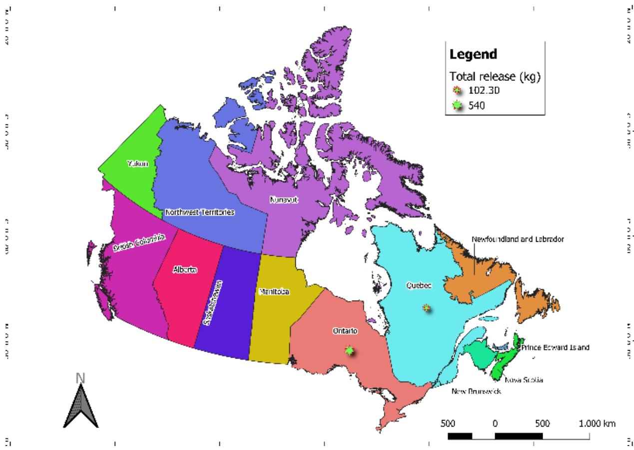

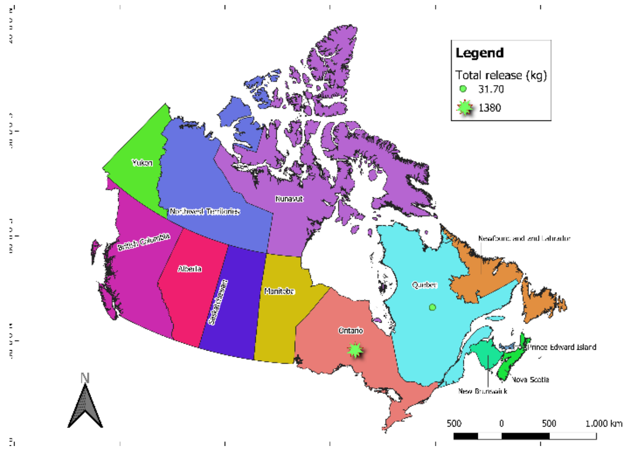

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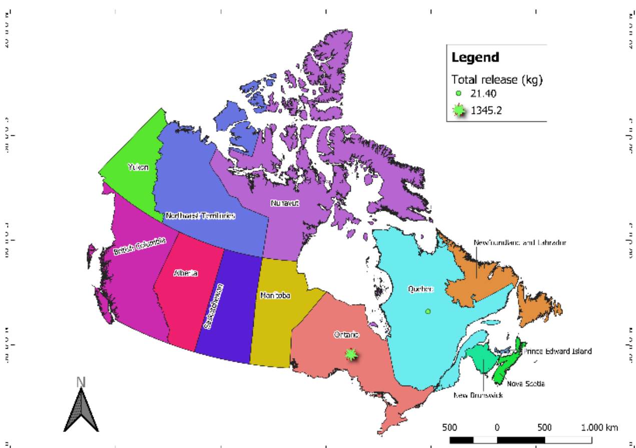

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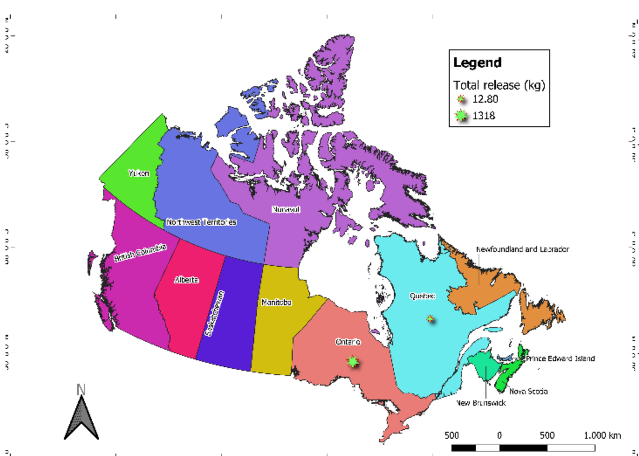

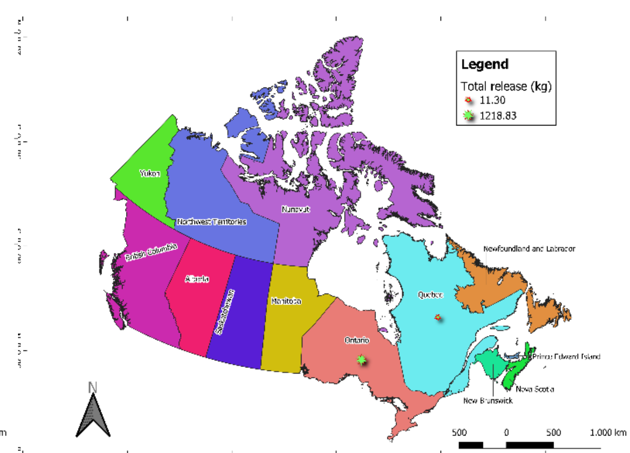

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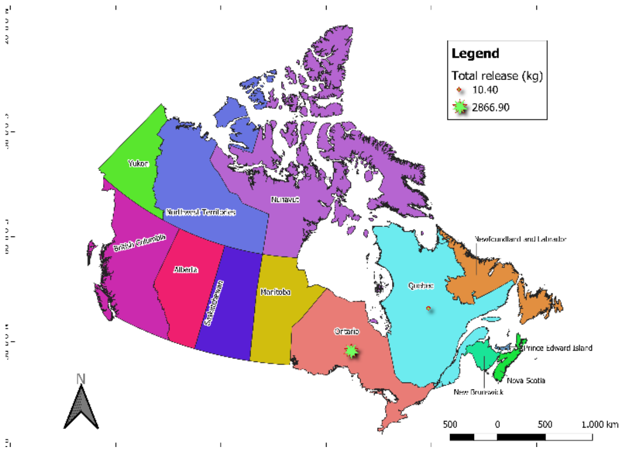
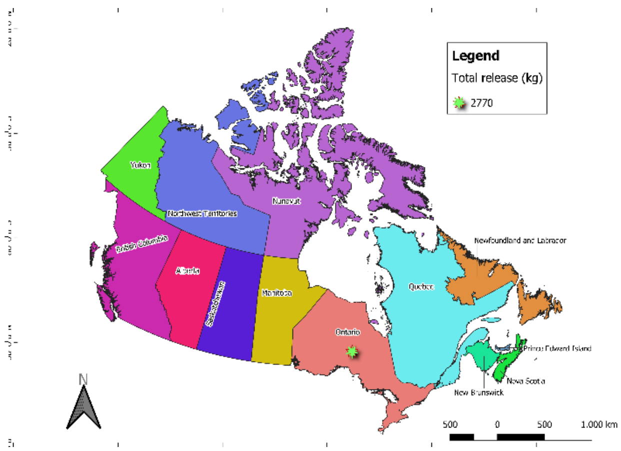
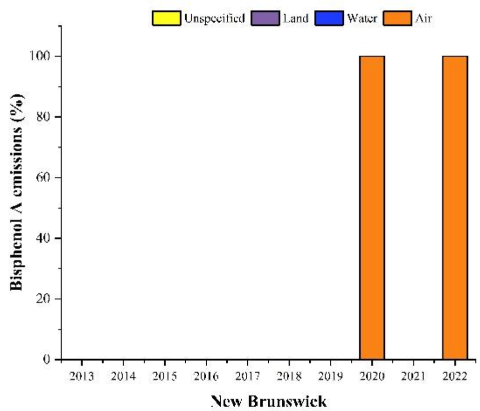
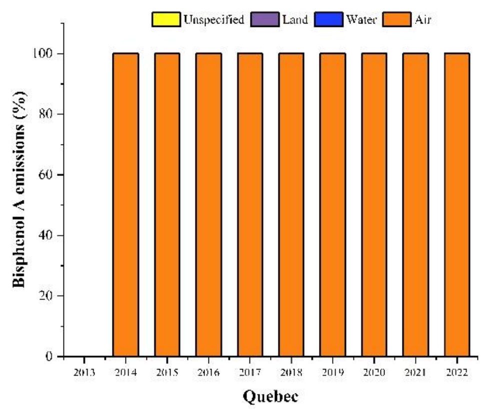
2022:

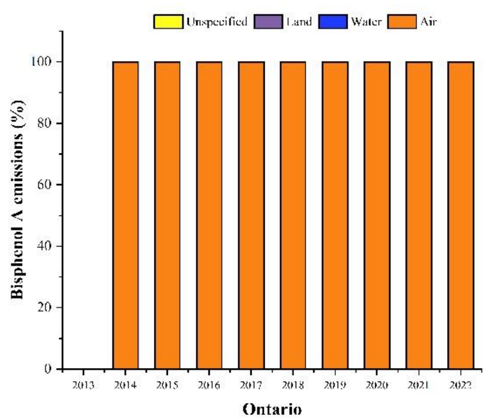


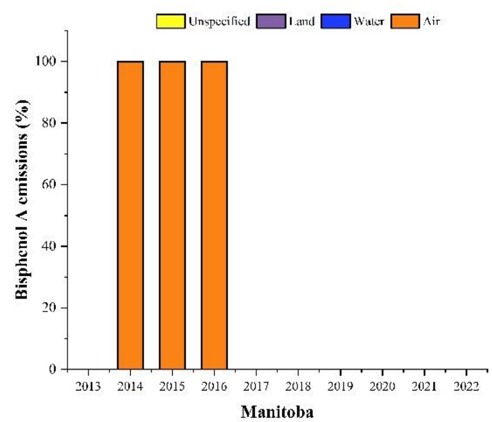


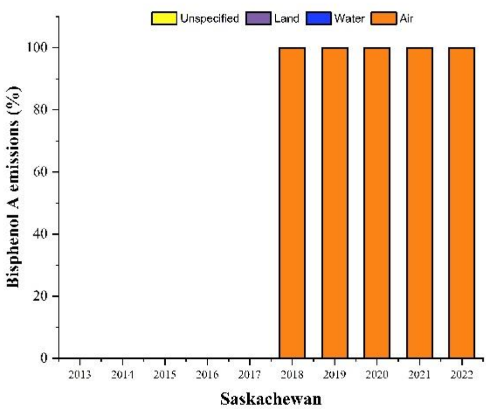
Appendix III: Bisphenol A emissions (%) in different provinces of Canada

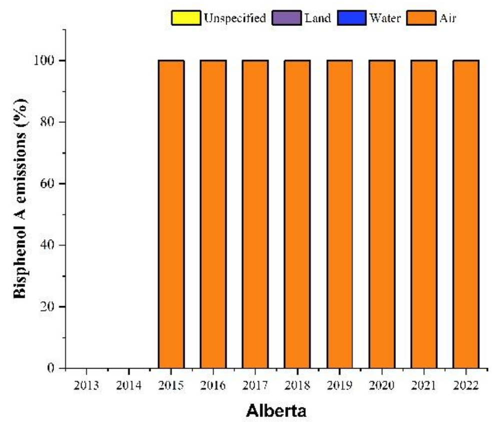


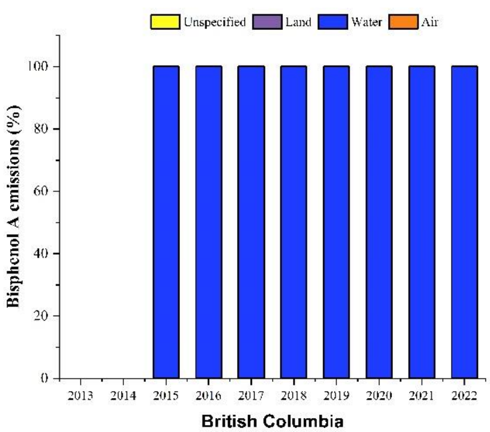












Appendix IV: Bis(2-ethylhexyl) adipate emissions (%) in different provinces of Canada