Enhancing Metro Vancouver's Emissions Inventory for Non-Road Engines: A Bottom-Up Approach

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Metro Vancouver or the University of British Columbia.

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Executive Summary

This report presents a bottom-up assessment of non-road engine (NRE) populations in Metro Vancouver to support the development of a more accurate and regionally representative air emissions inventory of greenhouse gases (GHG) and health harming contaminants. Non-road engines, used in sectors such as construction, commercial, manufacturing, and yard and garden contribute significantly to local air pollution and climate impacts, yet their emissions are not as accurately quantified compared to on-road vehicles(Hagan, 2022)

To address this gap, the study combines two primary methodologies:

- Structured interviews and data collection from regional equipment suppliers and dealers to obtain market-specific insights on equipment types, fuel distribution, sales trends, and usage characteristics.

- The use of public and institutional datasets from sources such as Environment and Climate Change Canada (ECCC), which were used to cross-validate interview data and enrich the analysis where proprietary data were unavailable.

Key findings include:

- Construction Sector: Dominated by diesel-powered equipment, this sector remains the largest contributor to NRE emissions. Electrification is in its early stage, with electric equipment representing less than 10% of new sales.
- Yard & Garden Sector: A gradual transition toward battery-powered tools is underway. However, gasoline-powered equipment, especially walk-behind lawn mowers, chainsaws, and blowers, still dominate usage and sales.
- Commercial Use: Businesses use similar equipment to households but operate them for significantly longer hours, contributing to a larger share of emissions. Gasoline remains the dominant fuel.
- Manufacturing Sector: Despite a surge in electric equipment sales since 2024, historical reliance on fossil fuels persists.. The dataset acquired for this study primarily reflects new equipment sales from certain suppliers and dealers and does not capture the broader in-use engine population within the region, warranting careful interpretation in population modeling.

To estimate equipment population, the study applies the International Council on Clean Transportation (ICCT) 's population modeling framework and simulates equipment retirement using a Weibull survival function(Neil, 2001), offering a flexible and realistic approach given limited access to EPA scrappage datasets.

The study concludes that while localized bottom-up data greatly improves the accuracy of NRE emission modeling, future work should focus on expanding supplier engagement, improving access to detailed scrappage and lifetime datasets, and applying this methodology to additional NRE categories and regions.

Introduction

Air pollution and greenhouse gas (GHG) emissions from non-road engines (NREs) in urban areas are increasingly recognized as major threats to public health and environmental sustainability. In Metro Vancouver, NREs are estimated to contribute approximately 14% of total regional GHG emissions, alongside a variety of harmful pollutants such as nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs), which exacerbate respiratory illnesses and environmental degradation.

Despite the known environmental impact of on-road vehicles, emissions from non-road engines remain understudied and insufficiently quantified. Current top-down inventory methods, often based on national-level assumptions, lack the resolution necessary for effective local policymaking. Recognizing these limitations, Metro Vancouver is exploring a bottom-up approach that leverages market data from local dealers and suppliers to better characterize engine populations and usage patterns across key sectors such as construction, yard and garden, commercial, and manufacturing.

This study aims to provide foundational data for such a bottom-up emissions inventory, focusing on estimating equipment population as a key parameter in emissions modeling. By combining supplier interviews with publicly available datasets, and by implementing the ICCT methodology and Weibull survival function, the research offers a replicable framework for future NRE emission assessments that are locally representative and policy-relevant.

Background

Air pollution and greenhouse gas (GHG) emissions in urban areas remain critical concerns for public health and environmental safety. Metro Vancouver has prioritized addressing health impacts on residents with underlying conditions and environmental hazards, such as wildfires and heat waves, as outlined in its *Clean Air Plan* (Metro Vancouver, 2021) and *Climate 2050 Strategy* (Metro Vancouver, 2019), which set a target to reduce GHG emissions by 35% below 2010 levels by 2030. Among various sources, non-road engines (NREs) contribute approximately 14% of the region's total GHG emissions (Metro Vancouver, 2022). These engines also emit health harming pollutants such as nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs), all of which negatively affect air quality, affect the health of residents in the region and contribute to climate change (Chen et al., 2023).

While emissions from on-road vehicles are relatively well understood, emissions from non-road engines (NREs) remain vastly understudied and not as accurately quantified. This gap in knowledge makes it difficult to develop effective emissions control policies for the non-road sector. Emissions are calculated using the general formula: *Emissions = Engine Population × Power × Load Factor × Activity × Emission Factor*. This highlights that engine population is one of the key parameters required for accurate emission estimations. Therefore, this project aims to improve our understanding of the number and types of NREs operating in the region, to support the development of a more accurate and representative emissions inventory.

In Metro Vancouver, the highest NRE emissions are primarily associated with the construction, manufacturing, and commercial sectors. In addition, the yard and garden sector is included in this research due to its close connection with residential and business activities (Bhatt, 2024). According to Metro Vancouver's emissions inventory, the construction sector accounts for the largest share of NRE emissions (CO2eq, SOX, NOX, VOC), followed by the commercial, and manufacturing sectors. Construction equipment often rely on heavy-duty diesel and gasoline engines, making it a significant source of air pollution (Health Canada, 2021). Diesel emissions significantly contribute to climate change by releasing black carbon, a potent short-lived climate pollutant, and pose severe risks to human health, including respiratory illnesses, cardiovascular diseases, and increased cancer risk.(WHO Regional Office for Europe., 2013)

Metro Vancouver has traditionally relied on a top-down emissions inventory approach using estimates from Environment and Climate Change Canada (ECCC). However, top-down approaches contain several assumptions and need to be cross-validated with bottom-up data. Metro Vancouver is therefore interested in applying a bottom-up method by using localized and regional data to improve and update the regional NRE emissions inventory. The bottom-up method focuses on market data collected from local suppliers and dealers, providing details that complement and verify top-down data. This study represents a crucial step toward developing a bottom-up emissions inventory by collecting essential local engine population data specific to Metro Vancouver. By accurately reflecting regional engine usage patterns, this detailed local data will significantly enhance the precision of emissions tracking and inform more effective climate and air quality policies.

Literature Review

A variety of methodologies have been developed to estimate emissions from non-road engines, ranging from top-down modeling approaches based on national fuel use statistics to bottom-up inventories relying on equipment-level activity data. These methods differ in data resolution, assumptions, and applicability, depending on regional contexts and policy needs.

ICCT's non-road emission inventory model (2016) sets a strong methodological foundation by adopting a structured bottom-up approach, where emissions are calculated as the product of five parameters: engine population, annual activity, load factor, average horsepower, and emission factors for each equipment type and scenario. It benchmarks global best practices by reviewing tools from the EPA (NONROAD), CARB (OFFROAD), and EU models, and assesses critical data needs for locally representative inventories highlighting the importance of engine age distributions, fuel types, and technology pathways in projecting future scenarios (Shao, 2016).

A detailed empirical case study is presented by the Oregon DEQ non-road diesel equipment inventory (2017–2020 survey), which represents one of the first state-level bottom-up inventories in the U.S. Customized field surveys and industry inputs revealed that actual fuel consumption was approximately 60 % lower than MOVES default estimates, despite fleets being older (hence higher-emitting) than assumed. This underscores how localized bottom-up data can significantly alter activity estimates while potentially balancing criteria pollutant totals due to older engine emission factors (Oregon Nonroad Diesel Equipment Survey and Emissions Inventory, 2020) The results from this report demonstrate that the bottom-up method can complement top-down NRE emissions estimates by providing more region-specific and equipment-specific data, thereby supporting more targeted regulatory decisions.

Similarly, CARB's 2022 in-use off-road diesel inventory updated equipment population, activity, and turnover data using California's reporting system (DOORS) and fleet surveys, updating emission factors and projections under regulatory scenarios including accelerated turnover and renewable diesel mandates (2022 CARB Construction, Industrial, Mining and Oil Drilling Emissions Inventory, 2022). This reflects how regulatory frameworks and reported compliance behavior can feed into more accurate and policy-relevant inventories.

Other jurisdictions like New Jersey, Alberta, and Washington State have also pursued similar inventory efforts, albeit with fewer publicly detailed methodologies, emphasizing the growing consensus on the need for locally-derived bottom-up data inputs—particularly given challenges such as lack of registration data and heterogeneous equipment usage patterns across sectors (2020 National Emissions Inventory Technical Support Document: Nonroad Mobile Sources, 2023; Winijkul, 2021).

Emission Calculation methodology

Since battery-powered equipment operates on clean electricity, it is excluded from the calculation of GHG emissions. The following analysis therefore considers only gasoline-powered and diesel-powered equipment. Based on the EPA NONROAD model(User's Guide for the NONROAD Model, 2004), the emissions from gasoline-powered equipment can be estimated using the following general formula:

$$E_p = \sum_i \sum_a [N_{i,a} \times H_i \times HP_i \times LF_i \times EF_{i,a,p}]$$

Where:

E_p = Annual emissions (g/year or tone/year)

i = Equipment type (e.g., chainsaw, lawn mower, trimmer)

a = Age group (age distribution)

p = Pollutant type (CO_2, CO, NO_x, VOC, $PM_{2.5}$, etc.)

$N_{i,a}$ = Number of equipment units for the given type and age group (unit)

H_i = Annual operating hours (hour/year per unit)

HP_i= Average horsepower (horsepower)

Population Calculation Parameters

According to the emission calculation methodology, equipment population data is essential for estimating non-road engine (NRE) emissions. In addition to population, other critical parameters such as equipment age distribution, annual operating hours, and average horsepower must also be obtained under real-world operating conditions.

This report focuses on the estimation of equipment population, which forms the foundation for bottom-up emission modeling. To achieve this, the study applies the population estimation methodology developed by the International Council on Clean Transportation (ICCT) for non-road mobile sources(Shao, 2016) The approach combines sales data, survival functions, and equipment usage characteristics to reconstruct the historical and projected in-use equipment population across categories.

PARAMETER	DESCRIPTION	EQUATION/REFERENCE
Sales	Annual sales of each equipment type	-

Population Growth Rate (PopGrw)	Estimated annual growth rate in fleet size	(2)
Median Lifetime	Median equipment lifetime in years	(1)
Annual Activity	Average operating hours per year	-
Load Factor (LF)	Ratio of actual to rated power usage	-
Survival Curve	Probability function describing equipment retirement over time	(EPA, 2005)

Table 1: Population Calculation Parameters

$$MedianLifetime = \frac{MedianLife}{AnnualActivity \times LoadFactor} \quad (1)$$

$$SalesGrowthRate = \frac{PopGrw}{(-1.4306 \times PopGrw \times MedianLife) + (-0.24 \times PopGrw) + 1} \quad (2)$$

Research Methodology

This study primarily adopts a bottom-up approach to estimating engine population for nonroad engines in Metro Vancouver, utilizing interviews and data request to collect market data on non-road engine populations from local dealers and suppliers. In parallel, publicly available datasets were reviewed and analyzed to support cross-validation and supplement the primary data. The study mainly focused on the yard and garden, construction, and commercial sectors, as the former is closely tied to residential activities, while the latter represents a major source of GHG emissions. Exploratory efforts were also made toward the manufacturing and commercial sectors. The following sections describe these two methods in detail.

Interviews and Sampling Strategy

A major component of this research involved collecting reliable first-hand market data from trusted suppliers and dealers through structured interviews and data requests. The interview questionnaire was carefully designed to capture key variables related to engine type, usage patterns, and sales volumes. A summary of the questionnaire structure is provided in Appendix A.

However, collecting equipment sales data proved to be challenging due to the large number of individual suppliers in the region and variability in their willingness or ability to share company data. This represents a major limitation of the data collection methodology and should be considered when interpreting the results.

During the research process, we conducted interviews with two experts from different sectors, both of whom are dealers representing equipment suppliers. Information was collected from another three experts through a structured questionnaire, followed by additional clarification and data gathering via email correspondence. These expert interviews provided valuable insights into market trends and power type distributions within each sector, contributing to the contextual understanding of equipment sales and usage patterns.

Public and Institutional Datasets

In addition to direct industry engagement, this research drew on public and institutional datasets as an essential secondary data source. Detailed studies from organizations such as Environment and Climate Change Canada (ECCC), particularly in the Yard & Garden sector, significantly informed this study. Moreover, open data platforms from the City of Vancouver provided valuable directional insights during the data collection phase.

These publicly available datasets played a critical role in filling key data gaps caused by limited access to proprietary information from local suppliers. Their use helped ensure a more complete understanding of equipment distribution and usage in the region.

Population Calculation methodology

The population (POP) of non-road equipment is not directly measured but calculated based on historical and projected sales, adjusted by growth rates, median lifetime, and scrappage patterns. This approach reflects the dynamic nature of fleet turnover and equipment retirement, aligning with bottom-up emission inventory frameworks. To apply the ICCT population model, the following key parameters are required:

The annual population (POP) is calculated as the sum of surviving equipment from all previous sales years, adjusted by the survival curve (Equation3):

$$POP_t = \sum_{a=0}^{L} Sales_{t-a} \times SurvivalRate_a \tag{3}$$

Where:

t = target year

a = equipment age

L = maximum age (typically 2*MedianLife)

Survival Scrappage Curve Calculation Methodology

In the EPA NONROAD model, survival scrappage curves are not expressed as simple linear or exponential functions. Instead, they are derived from empirical data or expert judgment and typically represented as "cumulative scrappage percentage versus service life ratio" in tabulated form. These values are stored discretely in lookup tables. However, due to limitations in data accessibility, this report adopts the Weibull survival function, a widely used method in equipment emission modeling and service life estimation, to simulate the scrappage curve.

The Weibull survival distribution (Neil, 2001)estimates the probability that a piece of equipment will remain operational beyond a certain age, considering the gradual wear and failure patterns observed over time. Its mathematical expression is:

$$S(a) = \exp\left(-\left(\frac{a}{\lambda}\right)^k\right) \quad (4)$$

In this formula:

S(a) is the survival probability at age a;

λ is the scale parameter, often associated with median or characteristic life;

k is the shape parameter, which determines how failure rates evolve with age.

In practical Excel modeling, this function is embedded into cells to dynamically compute the survival rate by equipment age. Integrating it into the equipment population model enables a more accurate representation of equipment turnover, improving the precision of non-road emission estimations.

Findings

Yard and Garden

ECCC Public Dataset

Based on the 2021 ECCC report on Small Mobile Outdoor Power Equipment in Yard and Garden sector (Prairie Research Associates (PRA), 2021), which analyzed data from over 4,000 surveys conducted across Canada, Figures 1 − 5 and 11 − 15 were generated to describe key findings. The types of household equipment owned by more than 10% of households belong to 12 categories. The specific types are illustrated in the figure below.

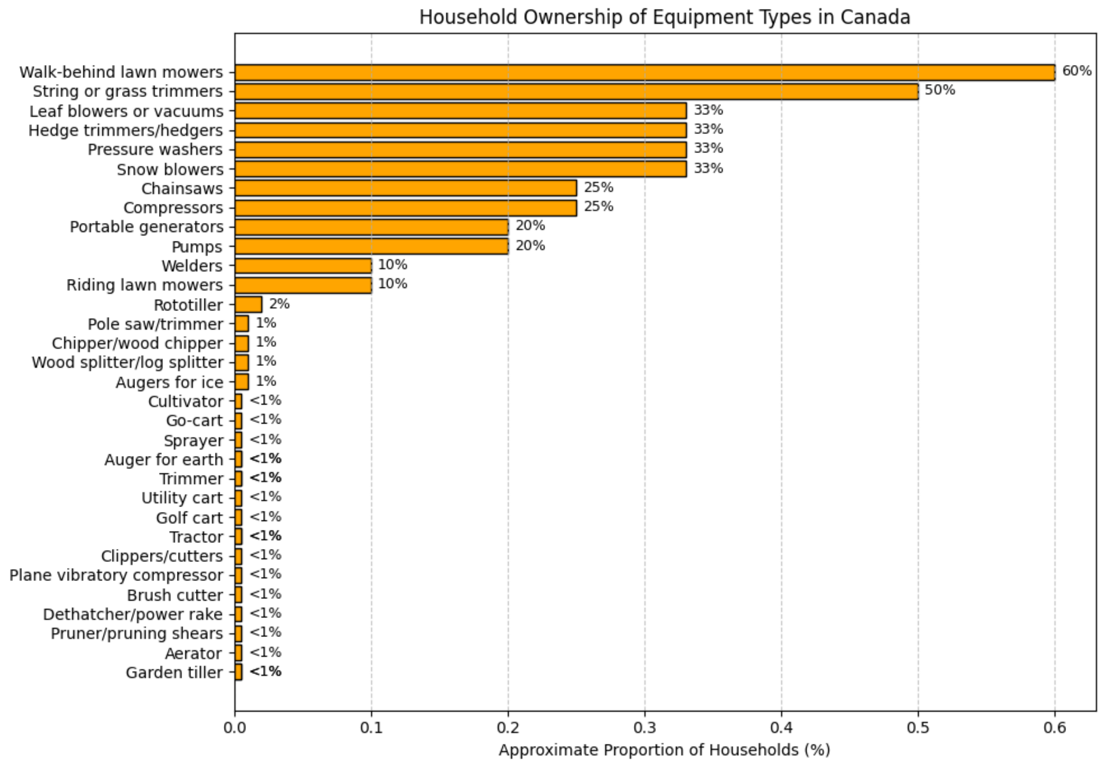

Figure 1: Household Ownership of Equipment Types in Canada

According to Figure 1, household equipment with an ownership rate of 10% or higher mainly includes walk-behind lawn mowers (60%) and string or grass trimmers (50%), reflecting the widespread need for basic lawn maintenance. A cluster of tools including leaf blowers or vacuums, hedge trimmers, pressure washers, and snow blowers (each at around 33%) are associated with seasonal or aesthetic property care. Chainsaws and compressors (25%) are versatile tools often used for heavier-duty maintenance in garden. Portable generators and pumps (20%) suggest preparedness for power outages or water-related maintenance, while welders and riding lawn mowers (10%) are typically associated with rural or semi-rural households that require more robust equipment for larger properties or personal fabrication needs.

Figure 2 and 3 below illustrate average euipment number per household and fuel type distribution for the 12 most commonly owned yard and garden equipment types among Canadian households (i.e., those with ≥10% household ownership).

Figure 2 shows the average number of equipment units per household. Notably, walk-behind lawn mowers and string or grass trimmers are owned at a ratio of approximately one for every two households. Hedge trimmers, leaf blowers, and pressure washers are each owned by roughly one in three households, reflecting their role in routine seasonal maintenance.

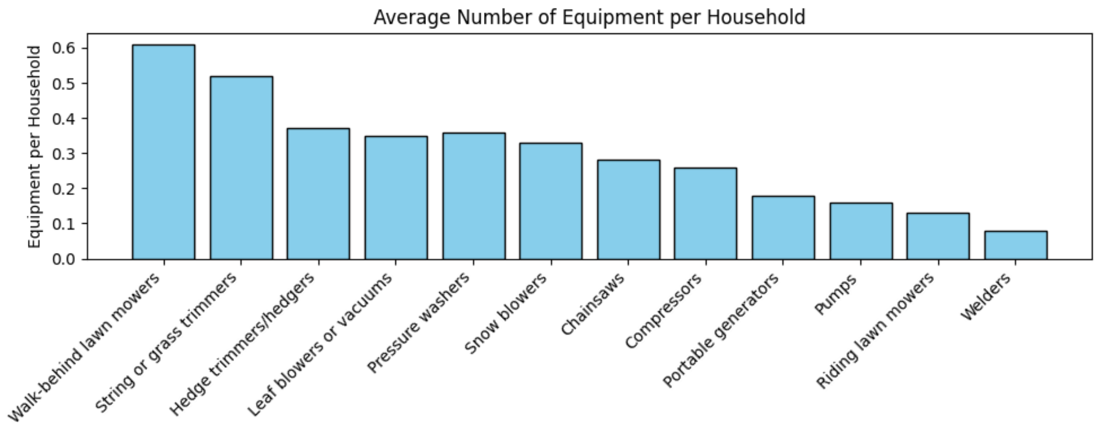

Figure 2: Average Number of Equipment per Household

Given that yard and garden equipment is primarily powered by either gasoline or electricity, with a small amount of number using bio-fuel power or diesel, which is also confirmed during expert interviews. Greenhouse gas (GHG) emissions are largely attributed to gasoline-powered units. Figure 3 presents the proportion of gasoline-powered equipment among the top 12 types. The data reveal that over 50% of walk-behind lawn mowers, snow blowers, chainsaws, portable generators, and riding lawn mowers are gasoline-powered. In contrast, compressors, pumps, and welders have largely transitioned to electric power, suggesting a broader electrification trend in lower-load or stationary equipment categories.

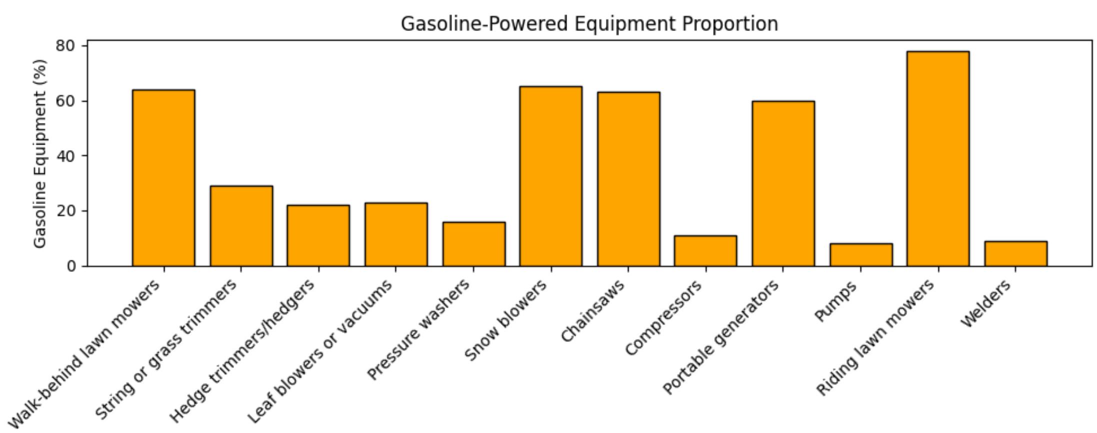

Figure 3: Gasoline-Powered Equipment Proportion

Figure 4 illustrates the approximate annual working time per equipment type for the 12 most owned yard and garden tools in Canadian households. The data shows that walk-behind lawn mowers, riding lawn mowers, and snow blowers have significantly higher annual usage compared to other equipment types. Among all equipment types shown, riding lawn mowers have the highest average annual working time, approaching 600 minutes. While most of the remaining tools—including hedge trimmers, compressors, and portable generators—show average annual working times below 300 minutes.

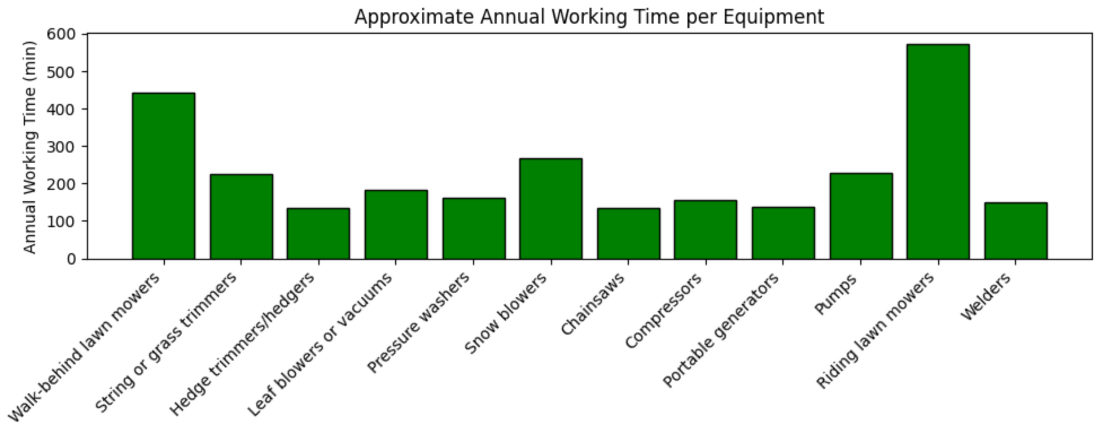

Figure 4: Approximate Annual Working Time per Equipment (minutes)

Figure 5 illustrates the average actual age of various types of equipment. The average actual service life of the equipment is approximately 6.5 years. When comparing this with Figure 4, we observe that riding lawn mowers and walk-behind lawn mowers, despite being used more intensively each year, do not exhibit a notably shorter lifespan.

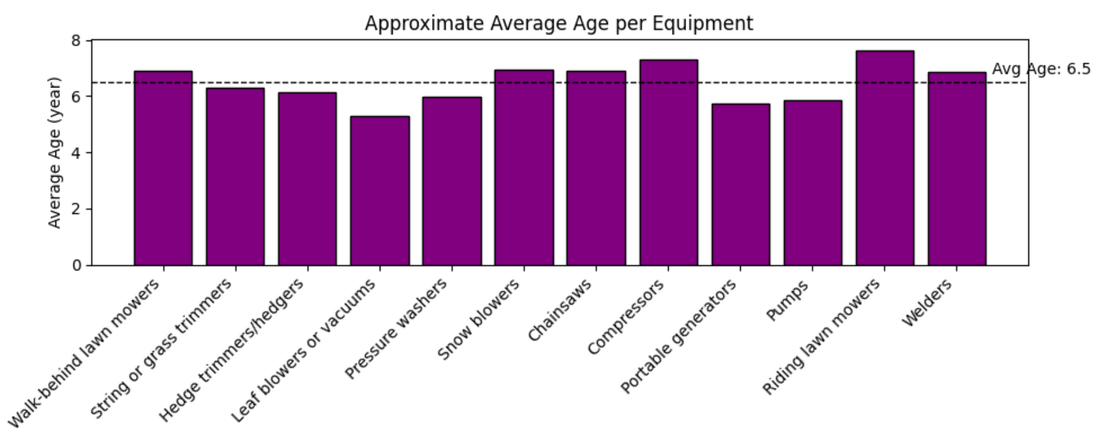

Figure 5: Average Age of Equipment (year)

Expert Interview

Through interviews with two suppliers in the yard and garden sector in Metro Vancouver, we obtained detailed regional equipment data and valuable insights into market trends. The suppliers reported experiencing a gradual shift in both residential and commercial (professional) customer preferences toward battery-powered equipment in recent years.

Figures 6 and 7 present the total number of gasoline-powered and battery-powered equipment sold from 2022 to 2024. Unlike the gasoline-powered models, which mostly show a steady decline, especially for blowers, chainsaws, and engines, the sales of battery-powered equipment such as blowers, pole pruners, and lawn mowers either remained stable or even increased during the same period. As mentioned in expert interviews, although gasoline-powered equipment still dominates in absolute numbers, the upward or consistent trend in battery-powered equipment indicates a growing market preference for electric alternatives. This reflects an emerging shift toward cleaner, quieter, and potentially more sustainable power sources in residential and commercial landscaping.

Figure 6 show that the highest-selling gasoline-powered equipment types are concentrated in blowers, chainsaws, engines, brush cutters, cut-off machines, and hedge trimmers, which are largely consistent with patterns observed in public datasets from ECCC(Prairie Research Associates (PRA), 2021). Among these, blowers, chainsaws, and engines consistently rank in the top three. This dominance can be attributed to their broad application across both residential and commercial settings, frequent year-round usage, and essential role in routine property maintenance.

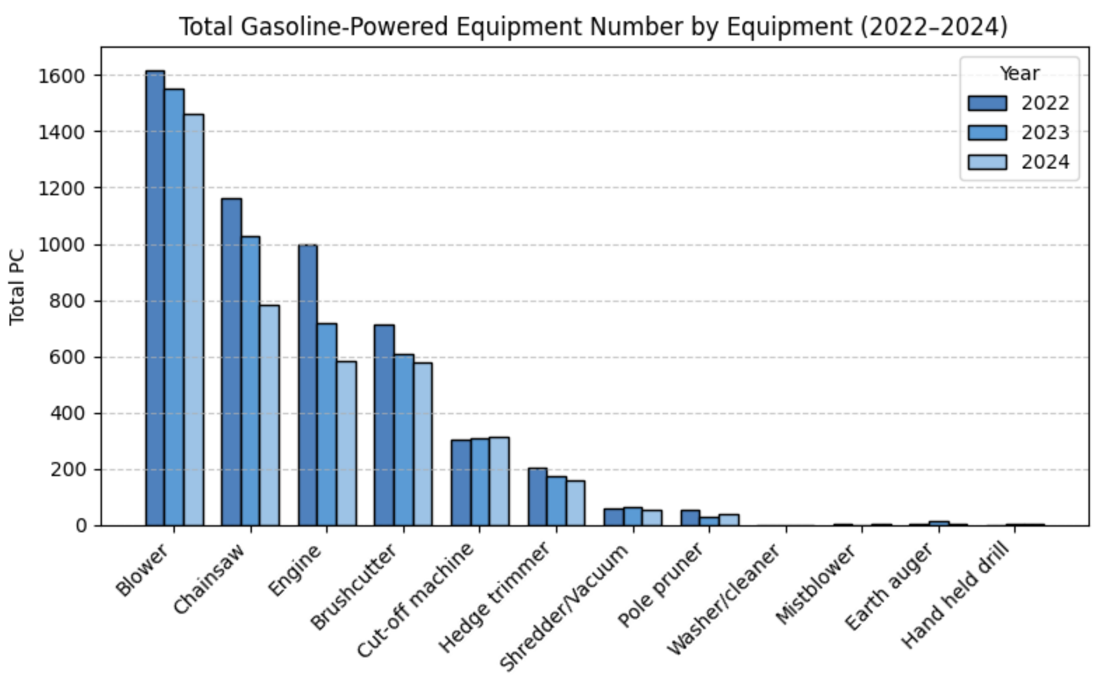

Figure 6 Total Gasoline-Powered Equipment Number by Equipment (2022–2024)

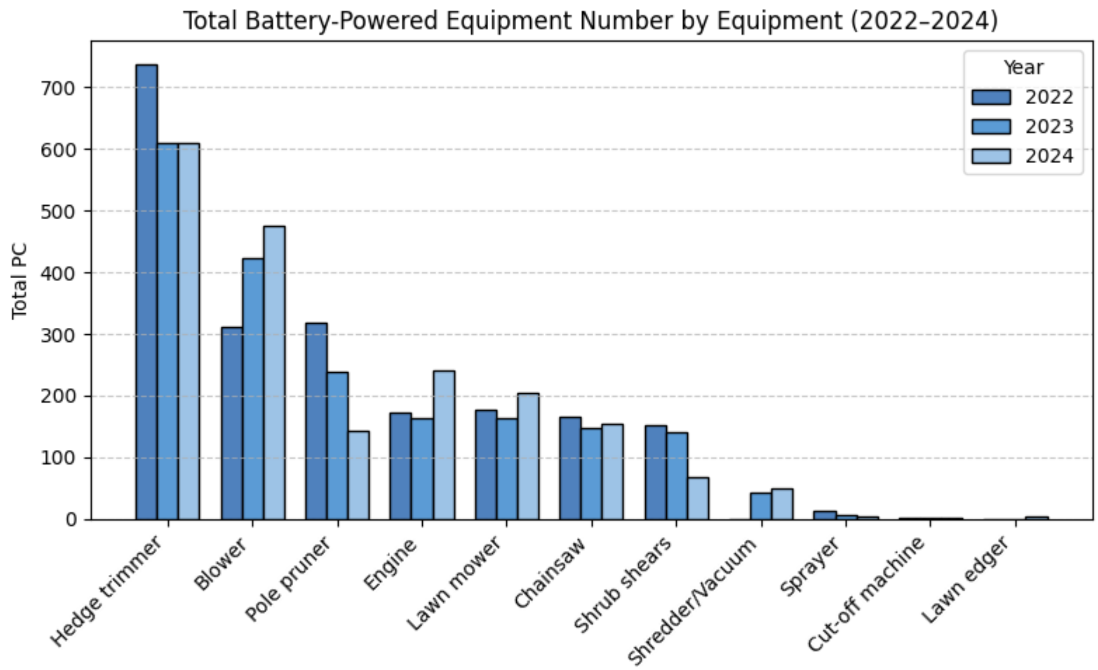

Figure 7 Total Battery-Powered Equipment Number by Equipment (2022–2024)

Construction

Through interviews and data requests with experts that supply NRE to the region, we obtained the data shown in Figure 8, which illustrates the power type distribution of construction equipment sold in the past whole year (from August 2024 to August 2025). It is evident that diesel-powered equipment continues to dominate both sales and market application in the construction sector. This is one of the main reasons why the construction sector contributes the largest share of non-road engine (NRE) emissions in Metro Vancouver.

Furthermore, the data show that electric equipment accounts for less than 10% of the market, indicating that electrification in this sector remains at an early stage. Although LP (liquefied petroleum gas) is considered a relatively cleaner fuel, it still emits significant amounts of greenhouse gases, including carbon dioxide (CO_2) and methane (CH_4).(C2ES, n.d.)

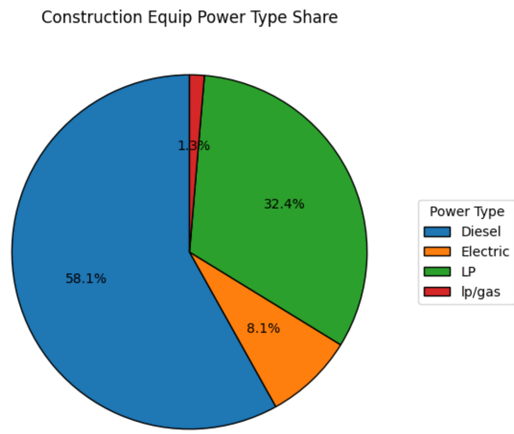

Figure 8: Construction Equipment Power Type Share

Figure 9 shows that the peak season for equipment sales occurs in spring (March–May), while autumn (September–November) tends to be a low-sales period. Diesel-powered equipment dominates all seasons, with the highest seasonal PC in spring. And LP-powered equipment also exhibits significant seasonal variation, showing higher counts in spring and summer. Electric equipment shows lower but consistent sales across all seasons, with a slight increase in winter. LP/gas and natural gas equipment have minimal presence, with only slight seasonal activity visible for LP/gas types.

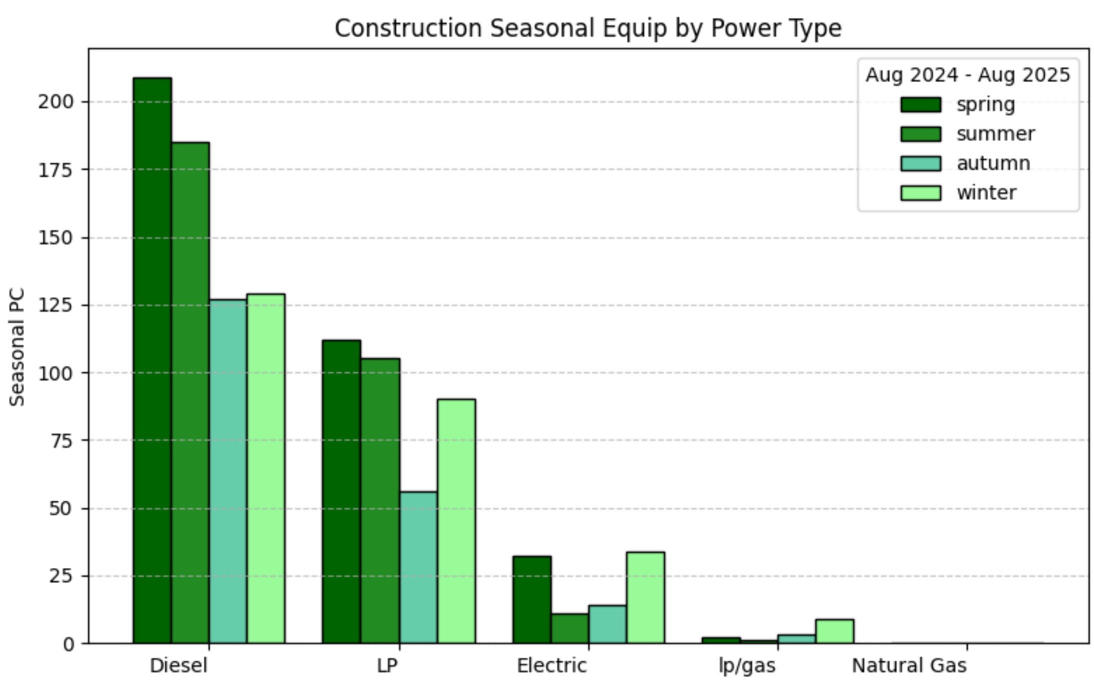

Figure 9: Construction Seasonal Equipment Number by Power Type

Figure 10 presents the seasonal number of construction equipment units sold by type and seasons in the past year (August 2024 to August 2025). Pneumatic Forklift has been the supplier's top-selling product, especially in spring. This equipment is primarily used for material handling in construction sites, warehouses, and distribution centers, where outdoor mobility and lifting capacity are essential. And mid-tier equipment types like Aerial Platforms, Telehandlers, and Scissor Lifts show relatively consistent sales across all seasons, with a slight peak in spring, suggesting stable demand not heavily influenced by seasonality. While specialized equipment such as Container Handlers, Truck Forklifts, and Yard Trucks record minimal seasonal sales, reflecting limited or niche market demand.

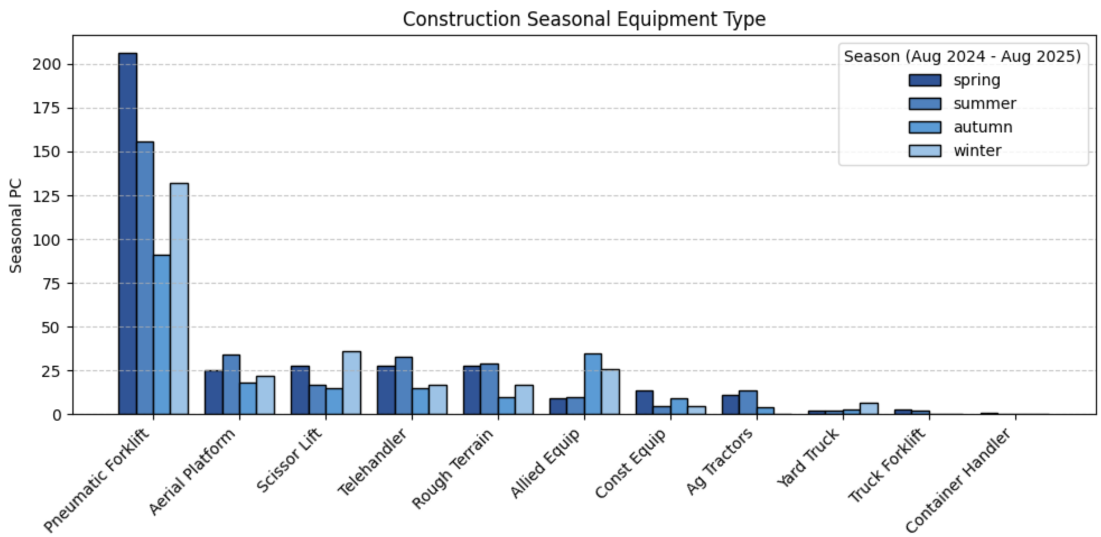

Figure 10: Construction Equipment Seasonal Type Share

Commercial (Yard and Garden)

ECCC Public Dataset – Business

Among the 30 major categories of commercial yard and garden equipment in Canada, those with ownership shares of 5% or more can be considered widely adopted. As shown in Figure 11, there are 12 such equipment types.

These widely adopted commercial tools closely mirror those most commonly found in residential settings, suggesting a high degree of overlap between household and business needs in the yard and garden equipment sector. This alignment reflects how small landscaping businesses and individual homeowners often rely on similar equipment types for routine property maintenance. It also highlights the shared emissions and electrification challenges across both user groups, making these equipment types key targets for policy or incentive programs aimed at reducing non-road emissions.

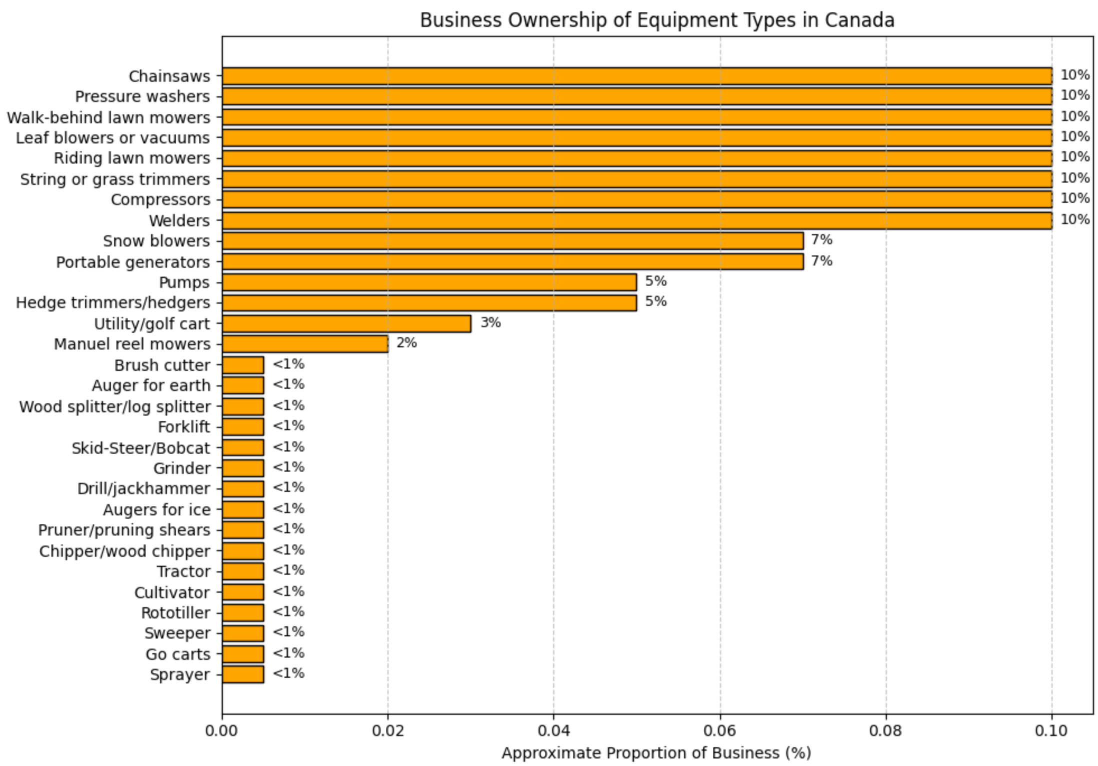

Figure 11: Business Ownership of Equipment Types in Canada

Figure 12 shows the average number of each equipment type owned per business. Compared to households (Figure 2), businesses tend to own a smaller quantity of equipment on average for most types.

This divergence highlights how commercial and residential users have overlapping needs in some areas (e.g., lawn care, trimming) but diverge significantly in others due to differences in task intensity, professional requirements, and operational scale.

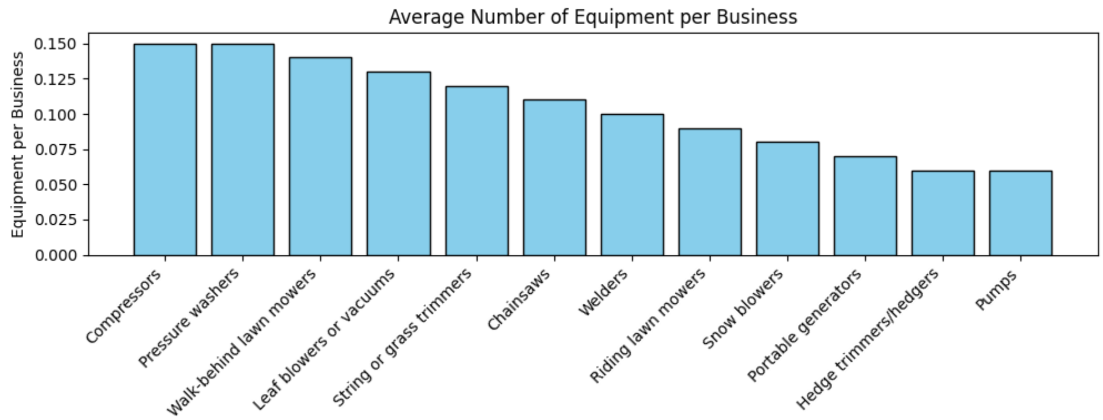

Figure 12: Average Number of Equipment per Business

Comparing Figure 13 and Figure 3, which illustrate the proportion of gasoline-powered equipment across different types for business and household ownership respectively.

Notable differences emerge for certain equipment types. For example, walk-behind lawn mowers and leaf blowers or vacuums exhibit significantly higher gasoline dependency in commercial use compared to household use.

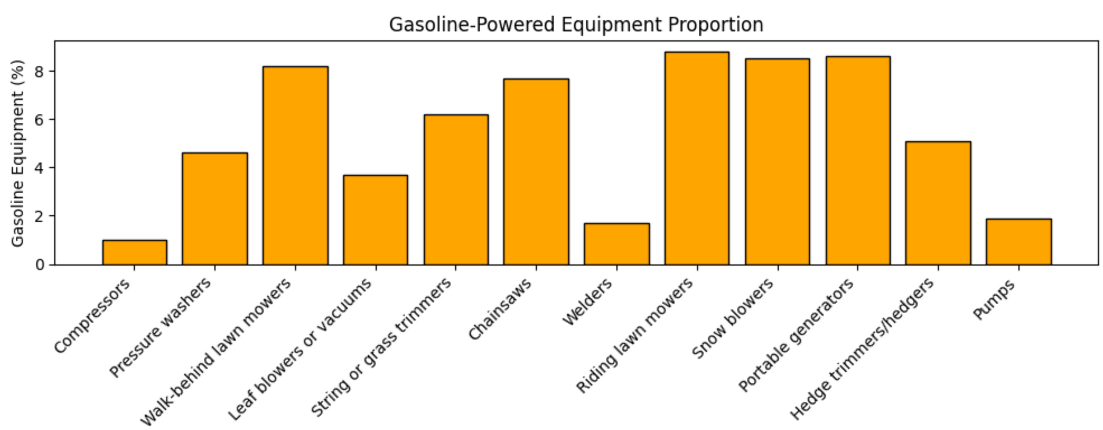

Figure 13: Gasoline-Powered Equipment Proportion

Figure 14 presents the approximate annual working time for various equipment types in business use. When compared with Figure 4, which shows the same data for residential users, it is evident that commercial equipment is operated for significantly longer durations, roughly 10 times more on average.

As with household use, riding lawn mowers remain the most intensively used equipment in the business sector. However, compressors, pressure washers, and welders also exhibit notably high annual working times in commercial applications, in contrast to their relatively limited use in residential settings.

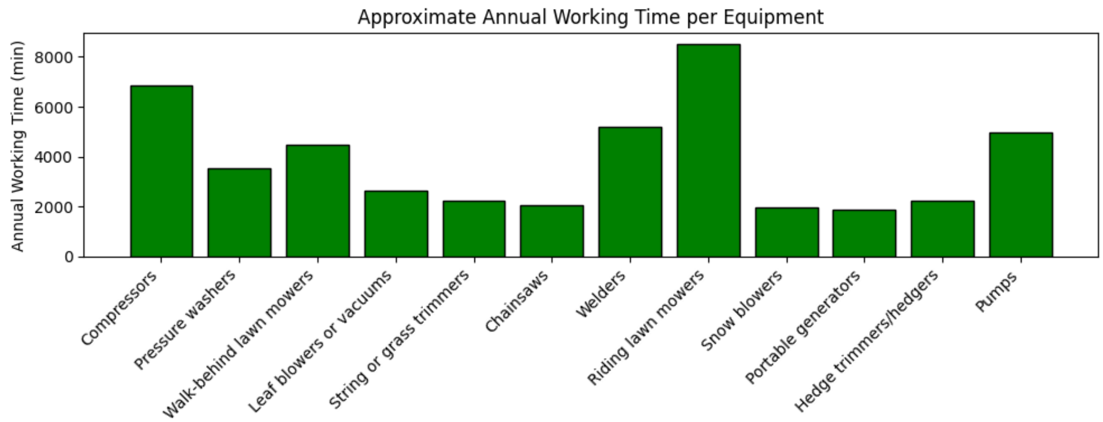

Figure 14: Approximate Annual Working Time per Equipment

Figure 15 shows that business-owned yard and garden equipment generally has a shorter average age compared to residential-owned equipment in Figure 5, indicating faster equipment turnover in commercial use.

Specifically, business-use tools such as Chainsaws and Riding lawn mowers exceed 7 years but still tend to be younger than their residential counterparts. On the other hand, Pressure washers, Walk-behind mowers, and String trimmers are noticeably newer in business applications than in household settings.

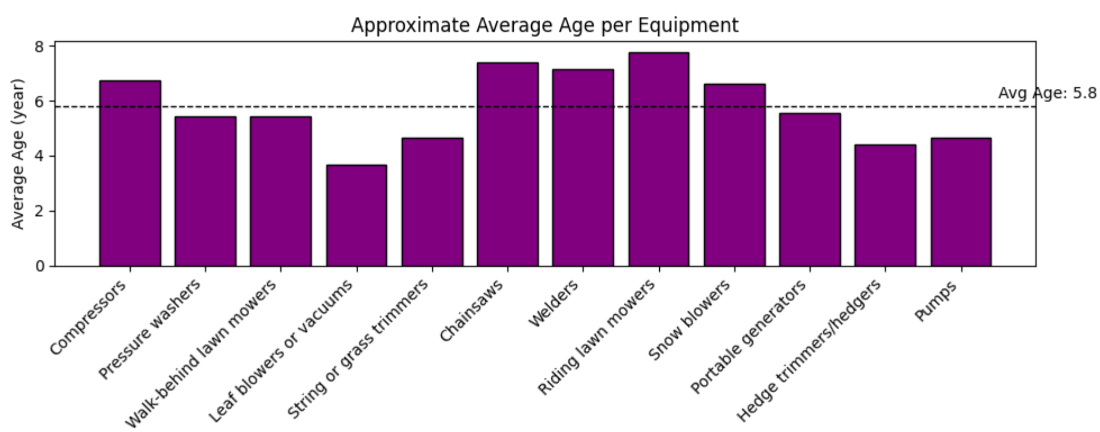

Figure 15: Average Age of Equipment (year)

Summary

This report presents a bottom-up assessment of NRE) populations in Metro Vancouver to support the development of a more accurate and regionally representative air emissions inventory of greenhouse gases (GHG) and health harming contaminants. Non-road engines, used in sectors such as construction, commercial, manufacturing, and yard and garden contribute significantly to local air pollution and climate impacts, yet their emissions are not as accurately quantified compared to on-road vehicles(Hagan, 2022)

To address this gap, the study combines two primary methodologies. To estimate equipment population, the study applies the International Council on Clean Transportation (ICCT) 's population modeling framework and simulates equipment retirement using a Weibull survival function(Neil, 2001), offering a flexible and realistic approach given limited access to EPA scrappage datasets.

The study concludes that while localized bottom-up data greatly improves the accuracy of NRE emission modeling, future work should focus on expanding supplier engagement, improving access to detailed scrappage and lifetime datasets, and applying this methodology to additional NRE categories and regions.

Future Direction and Limitation

This project faced several limitations in data collection, primarily due to restricted access to comprehensive datasets. In future studies, the methodology established in this report can serve as a foundation for expanding data sources by collecting more comprehensive information from additional suppliers and dealers. The limited availability of data channels currently constrains both the coverage and the accuracy of population and emission estimates.

During the four-month duration of this project, considerable effort was made to contact suppliers across various NRE sectors. However, there was a low response rate partially attributed to the summer season, which coincides with peak sales periods, leaving suppliers with limited availability and capacity to participate in interview-based data collection. Notably, several of the experts who did respond mentioned that they had previously engaged with Metro Vancouver (MV) or similar organizations and had maintained a good relationship with them. This highlights the importance of ongoing relationship-building with key stakeholders as a long-term strategy.

Furthermore, regarding the estimation of equipment retirement, future work could aim to obtain complete scrappage curve datasets from the U.S. EPA. Alternatively, researchers may continue applying the Weibull survival function method to simulate equipment retirement behavior where official data is unavailable. Both approaches will help improve the robustness and credibility of equipment lifetime and emission modeling.

It is also recommended that Metro Vancouver and other local or regional governments undertaking similar tasks of estimating non-road engine (NRE) populations adopt consistent and well-validated methods across regions. Applying either complete EPA datasets or statistically grounded models like the Weibull function will enhance transparency, replicability, and consistency.

This consistency across jurisdictions will also support more meaningful interregional comparisons and facilitate integration into broader national emission inventories.

Finally, based on the data already collected, further detailed analysis tailored to the specific characteristics of the Metro Vancouver region could yield additional insights. Expanding future data collection to include more suppliers would help construct a more complete and representative picture of equipment population and enable more accurate emissions modeling at the regional level.

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Appendix A Questions for experts

1. **Sales Numbers by Equipment Category and Fuel Type**
   - Could you provide data on number of equipment sold in recent years by equipment category (e.g. manufacturing, construction, etc.) and fuel type (e.g., diesel, gasoline, battery-electric) or?
   - If you cannot provide sales data by fuel type, can you share what proportion of your equipment sales are gasoline-powered, diesel-powered, and battery/electric?
   - If available, could you provide equipment sales or inventory data further disaggregated by:
     - Emission tier group or model year
     - Horsepower range
2. **Market Share**
   - Do you track estimated market share in [field] equipment sector in Metro Vancouver different geographic areas?
   - If so, could you share the data with us?
3. **Lifespan & Replacement**
   - Do you track the average lifespan or replacement rate of the equipment?
   - If so, could you share the data with us?
4. **Equipment Activity**
   - What is the estimated average number of operating hours per year for the equipment in the Metro Vancouver area?
   - If possible, please break this down by:
     - Season or month
5. **Supplier Contacts**
   - Would you be willing to share contact information for your equipment suppliers or distribution.