MINISTÈRE DE L'ENVIRONNEMENT,
DE LA LUTTE CONTRE
LES CHANGEMENTS CLIMATIQUES,
DE LA FAUNE ET DES PARCS

Greenhouse Gas Emissions Quantification Guide

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PRODUCTION TEAM

Direction générale de la transition climatique

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3.6 GHG emissions from hydrogen production and use (New)

3.10.2 Loss of carbon sequestration capacity due to deforestation (New)

3.11 The role of forests in climate change mitigation (New)

3.12 Loss of wetlands (New)

3.13 Wetland restoration and conservation (New)

3.15.2.5 N_20 Emissions from nitrogen losses associated with inorganic and organic fertilizer application and crop residue application (New)

3.16.2 CH_4 emissions from landfill, Calculation without the LandGEM model (Amendment)

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IMPORTANT NOTE

The definitions presented in this guide are based on the definitions provided by climate change expert organizations such as the Intergovernmental Panel on Climate Change (IPCC) and the World Resources Institute (WRI). However, if a project is subject to a Quebec regulation on greenhouse gases (GHGs), the definitions in that regulation take precedence.

Biofuel

Any fuel whose energy-generating capacity is entirely derived from biomass.

Biomass

All organic matter that can become a source of energy. Organic matter includes both plant matter (food waste, wood, leaves, etc.) and animal matter (dead animals and living organisms in the soil).

Agricultural biomass

Agricultural biomass is defined as all organic matter produced by agricultural systems: meat, milk, crops, grass, crop residues, livestock manure (ADEME, 2014)[1].

Residual biomass

Organic matter of plant or animal origin, essentially from agricultural, forest, industrial, or urban sources.

Residual forest biomass

Forest biomass resulting from harvesting activities (slash [branches and tops], non-commercial tree parts, twigs, and foliage), primary or secondary processing activities (bark, shavings, sawdust, and chips), as well as sludge, pulp liquor, pellets, and compressed wood logs. Residual forest biomass also includes unadulterated, uncontaminated deconstruction wood when not used in a 3R-RD (reduction, reuse, recycling, reclamation, and disposal) waste management hierarchy. Standing trees are not considered as residual forest biomass.

Black carbon

Aerosol (airborne particles) emitted during the combustion process. Black carbon is not emitted alone; it is a component of particulate matter with a diameter of 2.5 microns or less ($PM_{2.5}$).

Carbon neutral

That has a neutral balance in terms of GHG emissions.

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[1] ADEME: https://www.ademe.fr/expertises/produire-autrement/production-agricole/chiffres-cles-observations/biomasse-agricole

Fossil fuel

Non-renewable solid, liquid, or gaseous fuel coming from the transformation of vegetable and animal mass after a very long geological process called “methanization” which produces compounds of more or less long carbon chains.

Woody crops

Trees grown on marginal agricultural land for combustion (fast-growing willow, hybrid poplar, etc.) and whose method of cultivation is more akin to agriculture than forestry.

Lignocellulosic crops

Cultivation of perennial herbaceous plants for energy production on marginal agricultural land (miscanthus, reed canary grass, switchgrass, etc.).

Carbon debt

Time required for a biomass energy project to become more attractive in terms of GHG emissions than the use of the fossil fuel it replaces. The time required is accumulated annually as a carbon debt. Benefits in terms of CO_2 emissions reduction only appear when this debt is eliminated, which can take from a few years to several decades, depending on the project parameters.

Anthropogenic GHG emissions

GHG emissions resulting from human activity.

Biogenic GHG emissions

GHG emissions produced from biomass sources.

Direct GHG emissions

GHG emissions whose source is controlled by the project owner.

Indirect GHG emissions

GHG emissions that are a consequence of project activities, but whose sources are controlled by other entities.

GHG emissions from combustion

GHG emissions related to the exothermic reaction of a fuel.

GHG emissions from industrial processes
Emissions from certain industrial processes that produce GHGs directly and whose primary purpose is not to provide energy. This category of GHG emissions includes emissions resulting from chemical reactions produced during a specific process (e.g., CO_2 from the calcination of limestone), emissions generated by the use of fossil fuels as raw materials or chemical reagents (e.g., metallurgical coke used as a reducing agent), and resulting from the direct emission of certain GHGs (e.g., SF_6 used in a variety of industrial processes or specific installation systems, or HFC emissions from industrial refrigeration systems).

Other GHG emissions
GHG emissions other than those from combustion and industrial processes.

Avoided GHG emissions
Emission reductions achieved by a company or organization’s activities, products, and/or services, when these reductions occur outside its scope of activity. They must be assessed against a baseline scenario.

GHG emission or removal factor
Factor used to convert activity data into GHG emissions or reductions.

Radiative forcing
Radiative forcing is a measure of a gas’s ability to reflect infrared light radiation. It is measured in watts per square metre (W/m^2).

Greenhouse gas (GHG)
Natural or anthropogenic gaseous atmospheric constituent that absorbs and emits infrared radiation in the wavelength emitted by the surface of the earth, the atmosphere, and clouds.

ISO 14164
International standard published by the International Organization for Standardization (ISO) that specifies the principles and requirements applicable at the organization level for quantifying and reporting GHG emissions and removals. It includes requirements regarding the design, development, management, reporting, and verification of GHG inventories.

Global warming potential (GWP)
Relative measure of the warming effect that the emission of one kilogram of a GHG has at the tropospheric surface compared to the warming effect of the emission of one kilogram of CO_2.

Process
Any method, reaction or operation by which processed materials undergo a physical or chemical change in a single production line. Processes are also defined as all successive operations performed on the same material and resulting in the same kind of physical change.

GHG sink
Any process, activity, or mechanism that removes a greenhouse gas, aerosol, or precursor to a greenhouse gas or aerosol from the atmosphere.

GHG reservoir
A component of the climate system, other than the atmosphere, capable of storing, accumulating, or emitting a substance of concern (e.g., carbon, a greenhouse gas, or a precursor). Examples of carbon reservoirs include oceans, soils, and forests.

Crop residues
Plant residues from agriculture consisting of parts of cultivated plants that are not intended for food consumption (e.g., cereal straws, corn stalks, or third-grade hay).

GHG source
Any process, activity, or mechanism that releases a greenhouse gas, aerosol, or the precursor of a greenhouse gas or aerosol into the atmosphere.

Land use, land-use change, and forestry (LULUCF)
Impact category used in GHG emissions inventories that covers GHG emissions and removals resulting directly from human activity related to land use, land-use change, and forestry, excluding agriculture, whose emissions are accounted for elsewhere.

ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
CH_4	Methane
CO_2	Carbon dioxide
ECCC	Environment and Climate Change Canada
CO_2 eq.	Carbon dioxide equivalent
g CH_4	Gram of methane
g CO_2	Gram of carbon dioxide
g CO_2 eq.	Gram of carbon dioxide equivalent
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
GJ	Gigajoule
g N_2O	Gram of nitrous oxide
LNG	Liquefied natural gas
HFC	Hydrofluorocarbons
HFO	Hydrofluoroolefins
kg CH_4	Kilogram of methane
kg CO_2 eq.	Kilogram of carbon dioxide equivalent
kg N_2O	Kilogram of nitrous oxide
kWh	Kilowatt-hour
EQA	Environment Quality Act
MELCCFP	Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs (Quebec ministry of environment, climate change)
MJ	Megajoule
N_2O	Nitrous oxide
NF_3	Nitrogen trifluoride
LHV	Lower heating value
HHV	Higher heating value
EIARP	Environmental impact assessment and review procedure

PFC	Perfluorocarbons
GWP	Global warming potential
RMRCECA	Regulation respecting mandatory reporting of certain emissions of contaminants into the atmosphere
NIR	National Inventory Report
RREIAR	Regulation respecting the environmental impact assessment and review of certain projects
SF_6	Sulfur hexafluoride
CATS	Quebec cap-and-trade system for greenhouse gas emission allowances
SSR	Greenhouse gas source, sink, and reservoir
t CO_2 eq.	Tonne of carbon dioxide equivalent
t CO_2 eq./y	Tonnes of carbon dioxide equivalent per year
tkm	Tonne-kilometre of transportation
US EPA	United States Environmental Protection Agency
LULUCF	Land use, land-use change, and forestry
WRI	World Resources Institute

1. Introduction

The purpose of this guide is to present the methodologies applicable to the quantification of greenhouse gas (GHG) emissions in sectors affected by climate change, particularly before an activity is carried out (see the cautionary note below). It is based on extensive research into the methodologies developed by recognized organizations in the field, including the Intergovernmental Panel on Climate Change (IPCC)[2] and Environment and Climate Change Canada (ECCC). Currently, quantifiers must consult several references on the websites of various organizations. This guide is therefore a first in Quebec, since it brings together in a single document the methods and references to support clients in their quantification work. It is expected that this guide will be updated periodically to reflect the changes made to the methodologies by the responsible organizations.

Many clients, including businesses, consultants, government and municipal stakeholders, as well as professionals, may need to quantify the GHG emissions attributable to an activity.

The purpose of this guide is to provide a methodology for:

- GHG emissions reduction programs (e.g., design and implementation of a climate change action plan)
- Grant applications (e.g., municipal or provincial programs, federal agreements)
- GHG emissions reporting, validation, and verification
- GHG emissions reduction measures

This guide provides:

- General information on greenhouse gases
- The general approach to assessing GHG emissions
- The main sources of GHG emissions
- Calculation formulas and methodologies for quantifying GHG emissions
- Some mitigation measures and guidelines for monitoring and tracking GHG emissions

Note to the reader: In the application of the Regulation respecting mandatory reporting of certain emissions of contaminants into the atmosphere (RMRCECA) and the Regulation respecting a cap-and-trade system for greenhouse gas emission allowances (RCATS), the regulated methods take precedence. Both regulations govern a certain number of emitters based on specified emission thresholds and apply during the operational phase of projects. The threshold for the RMRCECA is 10,000 tonnes of CO_2 equivalent per year for the covered clienteles, and the CATS threshold is 25,000 tonnes of CO_2 equivalent per year for the covered facilities and clienteles. The following figure presents a simplified diagram of the scope of this guide.

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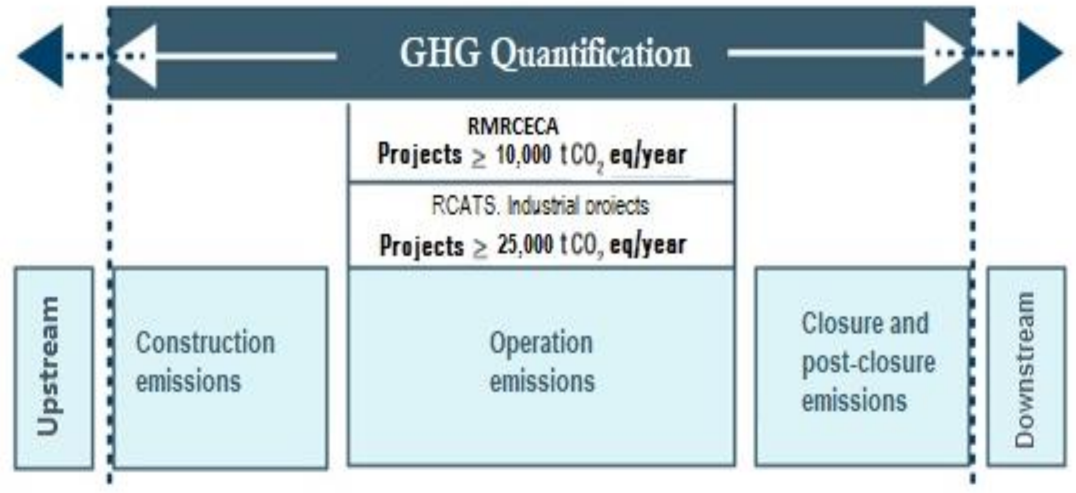
[2] IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf.

Figure 1. Simplified diagram of the scope of the guide*



*This diagram is not restrictive. Please refer to regulations for specific requirements.

2. General concepts

2.1. GHG to be considered

The GHGs that must be considered in the emissions assessment are those used by the RMRCECA, namely:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Sulphur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)
- The family of hydrofluorocarbons (HFCs)
- The family of perfluorocarbons (PFCs)

2.2. Direct and indirect GHG emissions

2.2.1. Direct GHG emissions

Direct emissions are emissions from sources that are attributable to, or controlled by, the issuer or project owner. They also include emissions from its subcontractors.

2.2.2. Indirect GHG emissions from electricity consumption

These are indirect emissions related to the third-party generation of electricity that is purchased and consumed by the project owner. It should be noted that due to Quebec's energy portfolio, which is largely hydroelectric, these emissions are generally very low. However, in some regions of Quebec not supplied by the electrical grid, they can be significant when fossil fuels are used to produce electricity.

2.2.3. Upstream, downstream or life-cycle indirect GHG emissions

Indirect GHG emissions include all other emissions that are beyond the direct control of the issuer or project owner. Several terms are used to refer to indirect emissions: “upstream”, “downstream”, or “life cycle”.

Definition of “upstream”

The term “upstream” refers to all industrial activities, from resource extraction to project completion. Upstream activities will vary depending on the resource and type of project, but in general, they include the extraction, processing, handling, and transportation of the necessary inputs. As an example, a hydrocarbon pipeline project may include the following upstream activities:

- Extraction: crude oil and gas well development, oil and gas field development, and in situ development;
- Processing: on-site processing and upgrading;
- Handling: transfer of products to terminals;
- Transportation: pre-project pipeline transportation and operation.

Definition of “downstream”

Downstream emissions are associated with subsequent activities resulting from the project. For example, GHG emissions associated with the flow of road traffic resulting from a road construction project are indirect downstream emissions.

Life cycle definition:

The life cycle approach aims to consider the impacts (environmental, social, and economic) specific to a product or service, from resource acquisition to end of life. The boundaries of the life cycle assessment can vary, with some extending from “cradle to grave,” “well to wheel,” or “well to refinery gate.”

2.3. GHG emission sources

For simplicity and to cover as many scenarios as possible, this guide is based on the definitions of emission sources proposed by the IPCC and WRI. However, if a project is subject to GHG regulations in Quebec, the definitions presented in the regulations take precedence.

2.3.1. Combustion GHG emissions

Combustion GHG emissions are caused by an exothermic reaction when fuel is burned. Combustion emissions can be from a stationary source (e.g., a boiler for heating) or a mobile source (e.g., a truck for transporting materials).

2.3.2. GHG emissions from industrial processes

This category includes emissions from the non-energy use of fuels as well as GHGs emitted as a direct by-product of industrial processes. It includes emissions involving chemical reactions other than combustion and whose primary purpose is not energy production. For example, GHG emissions from industrial processes may be generated in the manufacture of several products such as cement, iron, steel, aluminum, or nitric acid.

This category also includes GHG emissions from various purposes such as refrigeration and plastic foam manufacturing, as well as GHG emissions from the use of solvents, propellants, and anesthetics.

Where industrial process emissions are produced together with emissions from fuel burned for energy purposes, they should be separated and categorized accordingly.

2.3.3. Other GHG emissions

Other GHG emissions include all emissions that are not attributable to combustion or industrial processes. Examples include:

- Fugitive methane emissions from the decomposition of organic materials in a landfill;
- Methane emissions from enteric fermentation in ruminants
- Nitrous oxide (N_2O) emissions from fertilizer application;
- CH_4 or N_2O emissions from wastewater treatment;
- Emissions from the use of explosives in mining or road projects, for example;
- Losses of carbon reservoirs due to deforestation or land-use change.

2.3.4. The specific case of biogenic CO2 emissions

CO_2 emissions from biomass are called “biogenic emissions”. They are associated with the short carbon cycle, the decomposition or the combustion of organic matter in the presence of oxygen. These emissions are considered carbon neutral and must be considered separately from non-biogenic GHG emissions. It should be noted, however, that CH_4 and N_2O emissions from biomass are not carbon neutral. Some examples of carbon-neutral fuels are waste biomass, biogas, wood pellets, mixed liquor, ethanol, and biodiesel. These emissions should be presented separately in the quantification results. Appendix D provides more details on biogenic emissions.

2.3.5. Examples of emission sources by implementation phase

Figure 2. Examples of emission sources for each phase of an activity

Construction (C)	Operation (O)	Closure, post-closure (CL)
Stationary combustion sources (e.g. generators)	Stationary combustion sources (e.g. boilers)	Stationary combustion sources (e.g. generators)
Mobile combustion sources (e.g. transportation, machinery)	Mobile combustion sources (e.g.: same as previous)	Mobile combustion sources (e.g. same as previous)
Explosives (e.g. roads, mines)	Industrial processes, refrigeration	Fugitive emissions
Deforestation (e.g. landfills, mines, biofuels, road construction, etc.)	Electrical power	
Flooding of ecosystems (e.g. dams, dykes)	Fugitive emissions (e.g. SF_6, CH_4)	

2.3.6. Examples of emission sources associated with different GHGs

Table 1 provides a non-exhaustive list of examples of emission sources associated with different GHGs.

Table 1. Examples of GHG emissions associated with different activities

GHG	Main sources (non-exhaustive list)
Carbon dioxide (CO_2)	• Fuel combustion • Industrial processes • Deforestation
Methane (CH_4)	• Landfill sites • Oil and gas projects • Livestock rearing
Nitrous oxide (N_2O)	• Agricultural projects
Sulfur hexafluoride (SF_6)	• Electricity generation and transmission • Electronic component manufacturing • Magnesium production

Table 1. Examples of GHG emissions associated with different activities	
GHG	Main sources (non-exhaustive list)
Nitrogen trifluoride (NF_3)	• Semiconductor, solar panel, flat-panel TV and touch screen manufacturing
Hydrofluorocarbon (HFC) and perfluorocarbon (PFC) families	• Refrigeration and air conditioning equipment

2.3.7. Exclusions

All sources that cumulatively account for less than 3% of the total GHG emissions generated by the project and can therefore be considered insignificant may be excluded. The exclusion must be justified by a summary quantification based on credible and verifiable assumptions, a comparison with a similar project, or any other approach that demonstrates that the emissions are less than 3%.

2.4. Quantification approach

This guide proposes five main steps to facilitate the quantification of GHG emissions:

1. Identify the sources of GHG emissions;
2. Consider whether specific regulatory requirements apply to GHG emissions;
3. Quantify the impacts of GHG emissions;
4. Develop an impact mitigation plan;
5. Develop a GHG emissions monitoring and tracking plan.

Table 2. Steps in the GHG emissions quantification approach	
Action	Observations
1. Identify GHG emission sources	
- Identify all sources of GHG emissions related to the activity, project, or action	All sources for all phases must be identified.
- Identify the impacts of the activity, project, or action on carbon sinks and reservoirs	Carbon sinks and reservoirs (forests, wetlands, geological formations, etc.) play an important role in climate change and should not be overlooked in the quantification of GHG emissions.
2. Consider whether specific regulatory requirements apply to GHG emissions	The RMRCECA, RCATS, and Regulation respecting halocarbons are examples of regulations that address GHG emissions.
3. Quantify the impacts of the activity, project, or action on GHG emissions	
- Quantify overall GHG emissions	Determine the GHG emissions generated at all phases of the activity, project ,or measure, using recognized quantification sources and reliable, verifiable assumptions. This guide provides quantification methodologies.
- Quantify the impacts of the activity, project, or measure on the increase or reduction of carbon sinks and reservoirs	Example of a potential impact on carbon sinks and reservoirs: deforestation activities. Example of impacts on a carbon sink: CO_2 capture and sequestration.
- Comply with GHG quantification principles	**Relevance**: Consider only the sources from which GHG emissions can be quantified.

Table 2. Steps in the GHG emissions quantification approach	
Action	Observations
	Completeness: Include all relevant data. When a GHG emission source is excluded, a justification must be provided for this choice. **Consistency**: Use a consistent, accurate, and appropriate calculation methodology. **Accuracy**: Limit uncertainties. **Transparency**: Provide access to data, sources, references, and calculation methodologies used. Project documentation should include sufficient references to data sources and methodology (especially if different from this guide). **Caution**: Use reasonable assumptions, data, and methodologies so as not to underestimate GHG emissions.
4. Develop a GHG mitigation plan	The purpose of the mitigation plan is to develop ways to reduce the GHG emission impacts of the activity, project, or measure. The GHG reductions from the mitigation measures must be quantified. Section 4 of this guide provides more detail on the development of the mitigation plan.
5. Develop a GHG emissions monitoring plan	The monitoring plan is used to track GHG emissions and observe the effectiveness of mitigation measures over time. Typically, a monitoring plan will specify the types of data to be collected (e.g., equipment fuel consumption), the process and methods used to collect the data, the frequency of data collection, and the annual results. Section 4 of this guide provides more detail on this topic.

2.5. Quantification reports

Any quantification report must be filed by a person competent in the field of GHG emissions quantification (see next section for details). At a minimum, the five steps of the general quantification approach outlined above should form the basis of any quantification report. The following are examples of quantification report content.

2.5.1. To assess the impacts of GHG emissions from an activity or project

At a minimum, the report should present:

- The steps in the overall quantification approach;
- The quantification methodologies used;
- The annual GHG emissions from all project emission sources (see section on reporting);
- The mitigation measures and resulting GHG emission reductions;
- How the mitigation measures are being implemented;
- The emissions monitoring plan;
- The qualifications of the person or organization performing the quantification.

For hydrocarbon exploration and development projects (Section 3.22), this guide outlines specific requirements that must be included in the quantification report.

2.5.2. For GHG emissions reduction projects

The quantification report can be based on the GHG Report Template for the GHG CleanProjects© Registry published online by the CSA™[3] Group. At a minimum, the report must include the following information:

- The project description (project scenario);
- The baseline scenario and a justification for its choice;
- The inventory of sources, sinks and reservoirs for the project and the baseline scenario;
- The quantification and calculation of GHG emissions;
- A summary of the environmental impact analyses;
- Details on the data and information management system monitoring and data control mechanisms;
- Details pertaining to reporting and verification;
- Any aspects related to a potential program to which the emissions reduction project is linked;
- The qualifications of the person performing the quantification or a presentation of the quantifying organization;
- Any other relevant aspect.

Please note that this list is for guidance only and that program criteria, if any, take precedence over this list.

2.6. Person competent in GHG emissions quantification

A “competent quantifier” is an individual or company that can demonstrate competence in quantifying GHG emissions and who, at a minimum:

- has completed training in one of the three parts of ISO 14064[4] relating to greenhouse gases, performed quantifications as part of his or her duties, and can provide evidence of this;

OR

- is accredited to ISO 14064 for validation and verification of gases, has performed quantifications as part of their duties, and can provide proof of this (e.g., certification or proof of training on ISO 14064).

This person can be an internal or external resource of the organization. Accreditation is not mandatory but is desirable.

2.7. Presentation of results and global warming potentials

Results should be presented as follows:

- In metric units, in accordance with IPCC principles and international conventions;
- On an annual basis per calendar year;

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[3] CSA Group. https://www.csaregistries.ca/GHG_VR_Listing/

[4] 14064-1: Key Principles of Greenhouse Gas Inventories for Organizations
14064-2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements
14064-3: Specification with guidance for the validation and verification of greenhouse gas assertions

- Based on the number of years of emissions during the construction and closure or post-closure phases, if applicable;
- Individually by GHG (CO_2, CH_4, N_2O, SF_6, etc.);
- Summed up for all GHGs and expressed in tonnes of carbon dioxide equivalent (t CO_2 eq.). Carbon dioxide equivalent is calculated by multiplying the mass of a given GHG by its global warming potential (GWP). Using the GWPs for quantifying GHG emissions that are presented in Table 3;
- By distinguishing each of the applicable project phases (construction, operation, closure);
- By distinguishing the different applicable emission source categories (mobile combustion, stationary combustion, processes, and others);
- By distinguishing non-biogenic emissions from biogenic CO_2 emissions;
- In emission intensity (carbon footprint) when useful or required in a project, or for comparison with other similar projects (e.g., total GHG emissions per unit of production for an industry, total GHG emissions per kilometre of road built, GHG emissions per passenger-year for public transportation).

Table 3. Global warming potential of different GHGs (4th IPCC report)

Type of GHG	Quantity (metric tonnes)	Global warming potential (no units)	Carbon dioxide equivalent (t CO_2 eq.)
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	1	25	25
Nitrous oxide (N_2O)	1	298	298
Sulfur hexafluoride (SF_6)	1	22,800	22,800
Nitrogen trifluoride (NF_3)	1	17,200	17,200
Hydrofluorocarbons (HFC)	1	Can vary from 12 to almost 15,000	Variable, depending on the molecules considered[5]
Perfluorocarbons (PFC)	1	Can vary from 7,000 to almost 18,000	Variable, depending on the molecules considered

A complete list of GWPs for each GHG can be found in Quebec's GHG inventory, updated annually by the MELCC and available at www.environnement.gouv.qc.ca/changements/ges/index.htm.

2.8. GHG emissions intensity

GHG emissions intensity (EI) is an increasingly important piece of information in the field of climate change. For example, EI allows to compare the carbon footprint of one technology versus another in order to make more informed choices in a GHG emissions mitigation approach. EI is relevant for many projects, especially in the industrial sector. The EI will be requested by the MELCC when relevant and must be calculated using the following equation:

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[5] Environment and Climate Change Canada: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/quantification-guidance/global-warming-potentials.html

Equation 1: GHG emissions intensity

$$GHG\ emssions\ intensity = \frac{Net\ GHG\ emissions}{Units\ produced}$$

The values for “net GHG emissions” and “units produced” in Equation 1 must correspond to emissions and production at the maximum capacity of the project.

Table 4 provides some examples of EI units by project type.

Table 4 Examples of GHG emission intensity units by project type

TYPE OF PROJECT	GHG EI UNITS
Metal production	t CO_2 eq. / tonne of metal produced
Power generation	t CO_2 eq. / GWh generated
Oil production	t CO_2 eq. / barrel produced
Polystyrene production	t CO_2 eq. / tonne of polystyrene produced
Mineral extraction	t CO_2 eq. / tonne of ore
Pipeline	t CO_2 eq. / barrel transported
Gas pipeline	t CO_2 eq. / million cubic feet transported

For some types of projects, it may not be possible or appropriate to establish EIs, in which case an EI determination will not be required.

3. Quantification of GHG emissions

This section presents the equations and calculation methods to be applied when assessing GHG emissions from different emission sources. They are particularly relevant before an activity is carried out in the absence of actual data. The checklist in Appendix A provides a quick reference for identifying GHG emissions sources. Hyperlinks lead directly to the equations.

IMPORTANT NOTES

Other calculation methods than those presented in this section may be used. If so, they must be justified with supporting references and based on credible, reasonable, transparent, and conservative assumptions.

In addition, we reiterate that for a project subject to the RMRCECA and RCATS, the quantification methods in these regulations take precedence.

3.1. Emissions from stationary combustion systems

GHG emissions from the production of energy in the form of electricity, heat, or steam using stationary combustion systems (e.g., furnace or combustor, boiler, or generator) shall be calculated according to

Equation 1. The emission factors to be used are those in Tables 1-1 through 1-8 of Schedule A.2 of the RMRCECA.

GHG emissions from stationary combustion systems shall be calculated by estimating the quantity of various fuel types consumed and the GHG emission factors for each fuel type (i) as per Equation 2.

Equation 2: GHG emissions from stationary combustion sources

$$Greenhouse\ gas\ emissions = \sum_{i=1}^{i=n} Amount\ of\ fuel\ i\ consumed\ \times Emission\ factor_i$$

This equation can be used for all types of fuels, including fuels sourced from biomass.

3.2. Emissions from mobile combustion systems

The sources covered, including those used by subcontractors, are:

a) Any mobile equipment typically used at a facility or installation site for transporting or carrying substances, materials, or products;
b) Any mobile equipment (e.g., tractor, crane, grader, backhoe loader, or bulldozer) used to carry out construction, operation (e.g., ore transfer or hauling activities), or closure activities for the project;
c) Emissions from the transportation of incoming materials required for construction and operation;
d) Emissions from the transportation of outgoing excavation and backfill materials generated by construction and operation;
e) Emissions from mobile equipment used directly or indirectly by certain activities such as transportation of workers, raw materials, or finished products.

Emissions from mobile combustion systems are estimated from Equation 3 for each fuel type (i). Note that Equation 3 is similar to Equation, but the emission factors differ.

Equation 3: GHG emissions from the use of mobile equipment

$$Greenhouse\ gas\ emissions = \sum_{i=1}^{i=n} Amount\ of\ fuel\ i\ consumed \times Emission\ factor_i$$

For GHG emission factors associated with fuels, refer to the tables below.

Table 5 Emission factors associated with mobile combustion equipment, in CO_2 equivalent

Mobile equipment or fuel	g CO_2 / litre	g CH_4 / litre	g N_2O / litre	g CO_2 eq/ litre	Reference
Automotive gasoline	2,307	0.14	0.022	2,317	*
Diesel fuels	2,681	0.11	0.151	2,729	*
Propane	1,515	0.64	0.028	1,539	*
Off-road 2-stroke gas vehicles	2,307	10.61	0.013	2,453	*
Off-road 4-stroke gasoline vehicles	2,307	5.08	0.064	2,576	*
Off-road diesel vehicles <19 kW	2,681	0.073	0.022	2,689	*

Off-road diesel vehicles ≥19 kW, Tier 1-3	2,681	0.073	0.022	2,689	*
Off-road diesel vehicles ≥19 kW, Tier 4	2,681	0.073	0.227	2,750	*
Natural gas vehicles	1.9	0.009	0.00006	2,143	*, **
Aviation gasoline	2,325	2.2	0.23	2,449	*
Jet fuel	2,560	0.029	0.071	2,582	*
Diesel-powered trains	2,681	0.15	1	2,983	*
Gasoline-powered vessels	2,307	0.22	0.063	2,331	*
Diesel-powered marine vessels	2,681	0.25	0.072	2,709	*
Light fuel oil vessels	2,753	0.26	0.073	2,781	*
Heavy fuel oil vessels	3,156	0.29	0.082	3,188	*

Table 6 Emission factors associated with biofuels, in CO_2 equivalent

Liquid biofuels	Biogenic emissions	Non-biogenic emissions		Reference
	Emission factor (g CO_2/litre)	Emission factor (g CH_4/litre)	Emission Factor (g N_2O/litre)	
Ethanol (100%)	1,508	0.14	0.022	*
Biodiesel (100%)	2,472	0.11	0.151	*
Gaseous biofuels	**Biogenic emissions**	**Non-biogenic emissions**		**Reference**
	Emission factor (g CO_2/m^3)	**Emission factor (g CH_4/m^3)**	**Emission factor (g N_2O/m^3)**	
Biogas	1,887	0.037	0.033	*

* National Inventory Report (NIR) 1990-2019. Part II. Table A6.1-14 – Coefficients d'émissions pour les sources de combustion mobiles du secteur de l'Énergie (Emission factors for mobile combustion sources in the energy sector).
**At standard temperature and pressure conditions.

For GHG emissions from the use of off-road mobile equipment, fuel consumption can also be estimated from the BSFC[6], factor, which represents the diesel consumption of the equipment per horsepower for each hour of operation. This factor is expressed in pounds of diesel per horsepower per hour and can be determined from Tables A4, C1, and C2 in the document "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling—Compression-Ignition" in MOVES201X, published by the United States Environmental Protection Agency (US EPA)[7].

3.3. Indirect GHG emissions from electrical energy consumption

Annual indirect GHG emissions from electricity consumption (grid-based) can be determined from the annual electricity consumption and the GHG emission factor associated with electricity generation in Quebec. Table A13-6 in Environment and Climate Change Canada's National Inventory Report[8] shows the grams of CO_2

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[6] Brake-Specific Fuel Consumption.
https://nepis.epa.gov/Exe/ZyPDF.cgi/P10005BI.PDF?Dockey=P10005BI.PDF.
https://nepis.epa.gov/Exe/ZyNET.exe/P10005BI.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2000+Thru+2005&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C00thru05%5CTxt%5C00000013%5CP10005BI.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

[7] Ibid.

[8] National Inventory Report 1990-2019- Part 3, Table A13-6. Données sur la production d'électricité et les émissions de gaz à effet de serre pour le Québec (Electricity generation and greenhouse gas emissions data for Quebec).

equivalent emitted per kilowatt-hour of electricity generated in Quebec. Since the inventory reports are annual, the factors to be used must be the most recent.

If the electricity is generated by a thermal power plant, the GHG emissions can also be calculated from the expected annual electricity consumption and the plant's GHG emissions intensity (in grams of CO_2 equivalent per kilowatt-hour).

3.4. GHG emissions from industrial processes

The RMRCECA is the main reference for the quantification of GHG emissions from the industrial sector. As a reminder, see the cautionary note in the introduction about the precedence of the standards and methods prescribed by this regulation.

Table 7 presents the list of RMRCECA protocols applicable to the quantification of GHG emissions for different emitting activities in progress. For information purposes, the table also provides a non-exhaustive list of the main sources of emissions associated with these activities.

If none of the protocols in Table 7 are applicable to the type of process or equipment used, other methods for quantifying GHG emissions should be used. Where applicable, the methodology and detailed calculations should be specified and supporting references provided. Quantification methods must be reliable, recognized, and verifiable.

Table 7 Protocols for quantifying GHG emissions from industrial sectors covered by the RMRCECA

Sector generating process emissions	RMRCECA protocols	Description and major sources of GHGs [9] [10] [11] [12] [13]
Aluminum production	QC.3	In the primary aluminum production process (Hall-Heroult), GHG emissions will vary depending on the different technologies (related to anodes and alumina feed): prebaked center-pit anodes, prebaked peripheral-pit anodes, horizontal stud Søderberg and vertical stud Søderberg. In Quebec, the last two technologies no longer exist. The most significant GHG emissions are: i) CO_2 emissions from the consumption of carbon anodes in the reaction converting aluminum oxide to aluminum metal; (ii) PFC emissions from CF_4 and C_2F_6 during anode effects.
Cement production	QC.4	Limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and other carbonates (e.g., $MgCO_3$ and $FeCO_3$) are basic raw materials with commercial applications, notably in the production of cement, lime, and glass. Carbonates are also consumed in metallurgy (e.g., steel and metallurgy), agriculture, and construction. The calcination of carbonates at high temperature releases CO_2.
Coal storage	QC.5	Coal gas consists primarily of CH_4 which is trapped in the core of the solid coal matrix. Therefore, during storage, CH_4 passively escapes, and its magnitude depends on the amount stored and the source of the coal.
Hydrogen production	QC.6	Hydrogen is mainly produced from energy sources by reforming fossil fuels (natural gas, liquid hydrocarbons, and coal). Therefore, its production is a significant source of GHG

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[9] RMRCECA and 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

[10] IPCC, 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_3_Ch3_Chemical_Industry.pdf.

[11] IPCC, 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_4_Ch4_Metal_Industry.pdf.

[12] IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_2_Ch2_Mineral_Industry.pdf.

[13] IPCC, 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/3_Volume3/V3_6_Ch6_Electronics_Industry.pdf.

Table 7 Protocols for quantifying GHG emissions from industrial sectors covered by the RMRCECA

Sector generating process emissions	RMRCECA protocols	Description and major sources of GHGs [9] [10] [11] [12] [13]
		emissions. However, the production of hydrogen by water electrolysis is excluded from the calculations.
Iron and steel production	QC.7	The production of iron and steel from iron ore generates emissions of CO_2, CH_4, and N_2O.
Lime production	QC.8	See QC.4.
Oil refineries	QC.9	The sources covered include all processes used for the production of gasoline, aromatic hydrocarbons, kerosene, light and heavy fuel oils, diesel, lubricants, bitumen, or other products obtained by distillation of petroleum or by redistillation, cracking, rearrangement, or reforming of petroleum derivatives.
Pulp and paper manufacturing	QC.10	The sources covered are GHG emissions related to: • the use of stationary combustion equipment; • biomass combustion; • electricity generation; • anaerobic wastewater treatment. Note that the QC.10 protocol is used to collect specific information and does not include calculation methods. This protocol refers to other protocols for the calculation of emissions.
Soda ash production	QC.11	Soda ash (Na_2CO_3) is used as a raw material in a wide range of industries, including glass, soap, detergent, and pulp and paper manufacturing. The GHGs emitted are CO_2, and emissivity varies depending on the type of process.
Petrochemical manufacturing	QC.12	The petrochemical industry uses primary fossil fuels (natural gas, oil, coal) and other petroleum products for non-fuel, i.e. non-energy purposes.
Adipic acid production	QC.13	Adipic acid is used in the manufacture of several products, including synthetic fibers (nylon), coatings, plastics, urethane foams, and synthetic lubricants. Adipic acid is a significant source of N_2O.
Lead production	QC.14	The main processes used in the primary production of lead (agglomeration/smelting and direct smelting) involve combustion in furnaces. Both processes generate non-energy CO_2 (e.g., use of reducing agents such as metallurgical coke and natural gas). Secondary lead production (recycling) also generates CO_2.
Zinc production	QC.15	Various primary zinc production processes (e.g. electrothermal, pyrometallurgical and hydrometallurgical) involve combustion. These processes emit non-energy CO_2 (e.g., use of reducing agents such as metallurgical coke and natural gas).
Nickel and copper production	QC.18	The processes involved are those related to the removal of impurities from the nickel or copper concentrate by adding carbonate reagents, the extraction of metals from oxidized ores with reducing agents for slag cleaning, the consumption of electrodes in electric arc furnaces, and the removal of carbon-containing raw materials, such as recycled raw materials.
Production of ferroalloys	QC.19	Ferroalloys are concentrated alloys of iron and one or more other metals such as manganese, silicon, chromium, molybdenum, vanadium, or tungsten. The production of ferroalloys involves a metallurgical reduction process that results in significant CO_2 emissions.
Magnesium production	QC.20	Primary magnesium can be produced by electrolysis or thermal reduction. Raw materials used include dolomite, magnesite, and serpentine. The processing of raw materials releases CO_2. The production and casting of any magnesium metal requires a protective system to prevent combustion, and some of these systems use SF_6, a GHG with a global warming potential approximately 23,000 times greater than CO_2.
Nitric acid production	QC.21	Nitric acid (HNO_3) is used as a raw material primarily in the manufacture of nitrogen-based fertilizers, in the production of adipic acid and explosives (e.g., dynamite), and in metal etching and ferrous metal processing. The production of nitric acid (HNO_3) can be a significant source of N_2O emissions.
Phosphoric acid production	QC.22	Phosphoric acid is generally produced by the reaction between phosphate rock and sulfuric acid. In addition, a second reaction occurs between the carbonates present in

Table 7 Protocols for quantifying GHG emissions from industrial sectors covered by the RMRCECA

Sector generating process emissions	RMRCECA protocols	Description and major sources of GHGs [9] [10] [11] [12] [13]
		the ore (mainly calcium carbonate) and sulfuric acid releasing CO_2. The amount of carbonates present in the ore depends on the region from which the ore is taken.
Ammonia production	QC.23	The production of ammonia (NH_3) requires a source of nitrogen (N) and hydrogen (H). The majority of ammonia production uses natural gas (mainly methane [CH_4]).
Electricity transmission and distribution and use of equipment to produce electricity	QC.24	Sulfur hexafluoride (SF_6) is used for electrical insulation and current interruption in equipment used for the transmission and distribution of electricity. SF_6 and CF_4 can also be used in electrical substations, circuit breakers, and high-voltage lines. GHG emissions occur at every phase of the equipment life cycle, including manufacturing, installation, use, maintenance, and disposal.
Carbonates use	QC.25	See QC.4.
Glass production	QC.26	The main raw materials used in the glass industry that emit CO_2 during the melting process are limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), both carbonates, as well as soda ash (Na_2CO_3). See also QC.4.
Electronics manufacturing	QC.28	The main GHGs emitted by this industry are NF_3 (17,200 times more potent than CO_2 in terms of global warming potential), SF_6 (nearly 23,000 times more potent than CO_2), and PFCs (7,000 to nearly 18,000 times more potent than CO_2), which are used at important stages of electronics manufacturing (plasma etching and chemical deposit cleaning).
Natural gas transportation and distribution (processes and equipment)	QC.29	The covered sources are: • compression of natural gas for land transportation; • underground storage of natural gas; • liquefied natural gas (LNG) storage; • import and export of LNG; • natural gas transmission pipelines; • natural gas distribution, which includes any equipment downstream of the shut-off valves on transmission pipelines where pressure reduction first occurs for the delivery of natural gas to consumers.
Titanium dioxide production[19]	QC.31	Titanium dioxide (TiO_2) is mainly used in the manufacture of paint, then for the manufacture of paper, plastics, rubber, etc. The CO_2 emissions of TiO_2 are associated with the chemical reaction process.
Titanium dioxide slag from ilmenite reduction and molten cast iron treatment[19]	QC.32	Titanium dioxide slag is used as material for the production of titanium dioxide (TiO_2) (see QC.31). The CO_2 emissions are mainly attributable to the reduction of ilmenite from coal.
Oil and natural gas exploration and production and natural gas processing	QC.33	These sources of GHG emissions are related to the processes and equipment used in oil and gas exploration and development in aquatic and terrestrial environments.
Iron and steel powder production	QC.34	These sources of GHG emissions are related to the following processes: • atomization of molten cast iron; • decarburization of iron powder; • steel grading; • annealing of steel powder.

Sources: RMRCECA and 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006).

3.5. GHG emissions from mining and mineral processing

The mining sector has specific characteristics that must be taken into account in the quantification of GHG emissions. Among these particularities is the location in an area not served by the main electrical grid. If the electricity is produced by a fleet of generators or by a thermal power plant, GHG emissions can be calculated from the expected annual electricity consumption and the GHG emission intensity (in grams of CO_2 equivalent per kilowatt-hour) of this electrical production. If the electricity is sourced from the main electricity grid, emissions can be calculated from the equation presented in the section on indirect emissions from electrical energy consumption.

GHG emissions from the use of stationary combustion equipment can be calculated from the equation presented in the section on stationary combustion systems. GHG emissions from the transportation of ore to the processing plant can be calculated using the equation presented in the section on mobile combustion systems. The calculation of emissions from the use of explosives is presented in Section 3.7.

In addition, some ore transformation processes vary by ore type and have specific characteristics that are presented in the following sections. Sections 3.5.1 and 3.5.2 present two transformation processes (iron pellet production and carbonate use) whose sources and quantification methodologies are based on the RMRCECA. The third section discusses mineral transformation processes that are not covered by a specific RMRCECA protocol.

3.5.1. Calculation of GHG emissions from iron pellet production

The RMRCECA protocol QC.7 ("Iron and Steel Production") can be used to calculate process GHG emissions from the production of iron pellets.

3.5.2. Calculation of GHG emissions from the use of carbonates in a process

GHG emissions from this process occur primarily in the lime kiln, where carbonates (limestone-based raw materials [$CaCO_3$, $MgCO_3$]) are calcined at high temperatures to produce quicklime (CaO) or dolomitic lime (CaO-MgO). This calcination reaction generates CO_2 emissions.[14]

The RMRCECA QC.25 protocol can be used to estimate the GHG emissions from this process.

3.5.3. Other GHG emissions from mineral processing

To calculate GHG emissions from mineral processing operations other than those mentioned, the RMRCECA quantification methodologies can be used, including QC.14, QC.15, QC.18, QC.19 and QC.32.

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[14] ECCC, 2004. Guide pour l'estimation des émissions de GES (Guidance manual for estimating greenhouse gas emissions). http://publications.gc.ca/collections/Collection/En49-2-9-5F.pdf.

3.6. GHG emissions from hydrogen production and use

3.6.1. Hydrogen production and use

As mentioned in Table 7, an industrial hydrogen producer established in Quebec is required to make its annual GHG emissions report in accordance with the RMRCECA QC.6 protocol. This calculation of GHG emissions can be done either with a continuous emissions measurement and recording system or a complete mass balance of the production plant.

To quantify GHG emissions from hydrogen acquired and used as fuel or feedstock, it is suggested to use Equation 4.

Equation 4: GHG emissions from hydrogen use

$$E_{GHG\_H2} = Q_{H2} \times EF_{H2}$$

Where:

E_{GHG_H2} = *GHG emissions associated with the use of hydrogen as a fuel or feedstock, expressed in tonnes of* CO_2 *equivalent*

Q_{H2} = *Quantity of hydrogen consumed, in tonnes*

EF_{H2} = *GHG emission factor associated with hydrogen production, in tonnes of* CO_2 *equivalent per tonne of hydrogen*

GHG emission factors for the different types of hydrogen production processes are shown in Table 8.

Table 8. GHG emission factors by type of hydrogen production process

Type of process		EF (t CO_2 eq./ t H_2)
Steam methane reforming (SMR)		10,0
Autothermal reforming (ATR)		8.98
SMR with CO_2 capture and sequestration (SMR-CCS)		5,00
ATR with CO_2 capture and sequestration (ATR-CCS)		0.45
Electrolysis	Quebec	0.075
	Alberta	33.5
	British Columbia	0.985
	Prince Edward Island	0.10
	Manitoba	0.065
	New Brunswick	13.5
	Nova Scotia	38,0
	Ontario	1.50
	Saskatchewan	35.5
	Newfoundland and Labrador	1.40
	Northwest Territories	10,0

Table 8. GHG emission factors by type of hydrogen production process		
Type of process		**EF (t CO_2 eq./ t H_2)**
	Yukon	5.65

Source: Draft technical guide related to the strategic assessment of climate change - Government of Canada, August 2021

3.6.2. Evolution of knowledge on hydrogen

In 2020, 95% of the world's hydrogen production was composed of grey hydrogen, which is produced by reforming fossil fuels (mainly methane and coal). Of the hydrogen produced, 25% is used in refineries, 65% in ammonia production, and 10% in various industrial sectors, including the steel industry.[15] [16]

Some see great potential for hydrogen in the context of the climate transition for use in heavy transport. Green hydrogen, produced from water electrolysis, could also replace grey hydrogen for industrial uses. However, knowledge on the impacts of this sector is evolving rapidly, and it is important to present the main interventions of scientists on this subject.

The IPCC[17] considers hydrogen as part of the portfolio of energy options to mitigate GHG emissions. However, the organization mentions a potential indirect impact of hydrogen emissions on the increase of the greenhouse effect while specifying that the scientific advances are not sufficiently documented at this time.

According to other experts, hydrogen is an indirect greenhouse gas. Through a series of chemical reactions, it would slow down the destruction of certain greenhouse gases in the atmosphere, such as methane, which would accelerate global warming. Fugitive hydrogen emissions would then be a problem and must imperatively be well controlled, otherwise the gains anticipated from the use of hydrogen could be cancelled out. Although these numbers are not yet endorsed by the scientific community, some authors attribute to hydrogen a global warming potential over 100 years between 11 and 15, compared to 1 for CO_2. Moreover, many question the energy balance of hydrogen production over its life cycle, which they consider to be very energy consuming, even in the case of green hydrogen production. [18] [19] [20] [21] [22] [23]

Under such circumstances and as a precautionary principle, it is necessary to take into account the evolution of knowledge on the impacts of hydrogen on climate change when carrying out projects related to this sector and to readjust if necessary. In some cases, an upstream indirect emissions assessment or life cycle analysis may be required to determine the project's carbon footprint and its actual effect on climate change.

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[15] Transition énergétique Québec, 2020. Étude sur le potentiel de la filière de l'hydrogène au Québec dans la transition énergétique (Webinaire) (Study on the potential of the hydrogen sector in the energy transition [Webinar]). https://transitionenergetique.gouv.qc.ca/fileadmin/medias/pdf/expertises/PPT_webinaire_H2_20200714.pdf

[16] Polytechnique Montréal, 2020. Étude sur le potentiel technico-économique du développement de la filière de l'hydrogène au Québec et son potentiel pour la transition énergétique, volet A : portrait régional, canadien et international actuel de l'économie de l'hydrogène (Study on the techno-economic potential of the development of Quebec's hydrogen sector and its potential for the energy transition, component A: Regional, Canadian and international portrait of the hydrogen economy). https://transitionenergetique.gouv.qc.ca/fileadmin/medias/pdf/expertises/Etude_hydrogene_Volet_A.pdf.

[17] IPCC, 2021. Climate Change 2021: The Physical Science Basis. Climate Change 2021: The Physical Science Basis | Climate Change 2021: The Physical Science Basis (ipcc.ch)

[18] Warwick N. et al, April 2022. Atmospheric implications of increased hydrogen use. Atmospheric implications of increased hydrogen use (publishing.service.gov.uk).

[19] US Environmental Defense Fund, 2022. Clean or dirty: Is hydrogen the climate-friendly energy solution we need? | Environmental Defense Fund (edf.org)

[20] US Environmental Defense Fund, 2022. https://www.edf.org/article/we-need-talk-about-hydrogen

[21] European Geosciences Union, Atmospheric Chemistry and Physics, 2022. ACP - Climate consequences of hydrogen emissions (copernicus.org)

[22] L'hydrogène est-il la solution à nos problèmes énergétiques ? (Is hydrogen the solution to our energy issues?) (futura-sciences.com)

[23] École des Hautes Études commerciales (HEC), 2022. État de l'énergie au Québec (State of energy in Quebec). EEQ2022_web.pdf (hec.ca)

3.7. GHG emissions from the use of explosives

Explosives emit GHGs during detonation. Explosives can be used in a variety of projects, including mining, road and transportation infrastructure projects (ports, airports, etc.).

The GHG emissions from the use of explosives can be calculated from Equation 5[24].

Equation 5: GHG emissions from the use of explosives

$$E_{CO2\_Exp} = \sum_{n=1}^{n=12} 3.664 \times (FFexp_n \times CC_n) \times 0.001$$

Where:

$E_{CO_2\_Exp}$ = *Annual* CO_2 *emissions from the consumption of fossil fuels used in explosives, expressed in tonnes per year*

$FFexp_n$ = *Fossil fuel mass contained in explosives used in month n, expressed in kilograms of fuel*

CC_n = *Average carbon content of the fossil fuel used in the explosive in month n, expressed in kilograms of carbon per kilogram of fossil fuel*

n = Month

3.664 = Molecular weight ratio of CO_2 *to carbon*

0.001 = Conversion factor from kilograms to tonnes

Some commonly used explosives have specific CO_2 emission factors, which are shown in Table 9.

Table 9. CO_2 emission factors for selected explosives, expressed as tonnes of CO_2 per tonne of explosive

Type of explosive	EF (tonnes CO_2 / tonne of explosive)
ANFO	0.17
Heavy ANFO	0.18
Emulsion	0.17

Source: National Greenhouse Accounts (NGA) Factors. Updating and replacing the AGO Factors and Methods Workbook. Australian Government. Department of Climate Change. January 2008. http://www.globalbioenergy.org/uploads/media/0801_Australia_-_National_Greenhouse_Accounts__NGA__factors.pdf

Therefore, if the CO_2 emission factor of the explosive is known, the GHG emissions associated with their use can be calculated very easily from Equation 6.

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[24] *A Guidance Document for Reporting Greenhouse Gas Emissions for Large Industry in Newfoundland and Labrador*. Government of Newfoundland and Labrador. Office of Climate Change. March 2017. http://www.exec.gov.nl.ca/exec/occ/greenhouse-gas-data/GHG_Reporting_Guidance_Document.pdf.

Equation 6: GHG emissions from the use of explosives

$$E_{CO2\_Exp} = M_{Exp} \times EF_{Exp}$$

Where:

$E_{CO_2\_Exp}$ = *Annual* CO_2 *emissions from the consumption of fossil fuels used in explosives, expressed in tonnes*

M_{Exp} = *Mass of explosive used, in tonnes*

EF_{Exp} = CO_2 *emission factor of the explosive, in tonnes of* CO_2 *per tonne of explosive*

3.8. GHG emissions from fugitive emissions of sulfur hexafluoride and perfluorocarbons

SF_6 emissions from magnesium production are discussed in the section on industrial processes. This activity is covered by a quantification protocol in the RMRCECA (QC.20).

Sulphur hexafluoride (SF_6) and perfluorocarbon (PFC) emissions discussed here are more likely to be associated with electricity transmission and distribution. The impact of these emissions is primarily due to their fugitive nature (meaning that they are difficult to control) and the high global warming potentials of these substances. The warming potential of SF_6 is nearly 23,000 times that of CO_2, and the warming potential of PFCs can be nearly 18,000 times that of CO_2. The other issue is that these gases have replaced deleterious substances (such as polychlorinated biphenyls, i.e., PCBs) and that there is no less emissive alternative to date. From the point of view of energy security, knowledge of the impacts of these substances, application of good practices, and research and development are desirable options.

During the operation of electricity transmission and distribution equipment, fugitive emissions of SF_6 or PFCs may occur in connection with:

- gas handling and transfer operations;
- equipment operation;
- mechanical failure of equipment.

To calculate fugitive SF_6 or PFC emissions from electricity distribution, the Canadian Electricity Association's[25] emission factor methodology can be used, according to the following equations.

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[25] Environment Canada. Canadian Electricity Association. Annex A: SF6 Emission Estimation and Reporting Protocol for Electric Utilities (Final Version). Page 32. https://publications.gc.ca/collections/collection_2013/ec/En4-229-2008-eng.pdf

Equation 7: Estimated GHG emissions from SF_6-containing equipment used in electricity transmission and distribution

$$E_{SF6} = (0.01 \times Lot_{SF6} + 0.7 \times LoiSF6_{DE}) \times GWP_{SF6} \times 0.001$$

Where:

E_{SF6} = *GHG emissions attributable to the use of* SF_6, *expressed in tonnes of* CO_2 *equivalent per year*

LotSF_6 = *Total* SF_6 *load in existing equipment during year t, expressed in kilograms of* SF_6 *per year*

Loi$SF6_{DE}$ = *Initial* SF_6 *load in discarded equipment, expressed in kilograms of* SF_6 *per year*

GWP_{SF6} = *Global warming potential of* SF_6

0.001 = Conversion factor from kilograms to tonnes

Equation 8: Estimated GHG emissions from PFC-containing equipment used in electricity transmission and distribution

$$E_{PFC} = (0.01 \times Lot_{PFC} + 0.7 \times LoiPFC_{DE}) \times GWP_{PFC} \times 0.001$$

Where:

E_{PFC} = *GHG emissions attributable to the use of PFCs, expressed in tonnes of* CO_2 *equivalent per year*

Lot_{PFC} = *Total PFC load in existing equipment during year t, expressed in kilograms of PFCs per year*

$LoiPFC_{DE}$ = *Initial load of PFCs in discarded equipment, expressed in kilograms of PFCs per year*

GWP_{PFC} = *Global warming potential of PFCs*

0.001 = Conversion factor from kilograms to tonnes

As the methodology described above may not be practical for a preliminary project, any other methodology for calculating fugitive emissions of SF_6 and PFCs may be used, as long as it is presented to the Ministère with the necessary level of detail and is based on credible and verifiable references and assumptions.

3.9. Fugitive GHG emissions from the use of refrigeration or air conditioning equipment

The fluids used in refrigeration or air conditioning equipment are gases with global warming potentials that can be 2,000 to 15,000 times higher than that of CO_2. These gases, the most well-known families of which are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) or a mixture of these substances, present problems due to leakage into the atmosphere in the form of fugitive emissions. The Regulation respecting halocarbons (Q-2, r. 29), which regulates emissions of halocarbons into the atmosphere, is intended to protect the ozone layer and minimize the enhancement of the greenhouse effect[26].

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[26] https://www.legisquebec.gouv.qc.ca/en/document/cr/Q-2,%20r.%2029.

To evaluate annual GHG emissions attributable to the use of refrigeration or air conditioning equipment, the following equation can be used by considering each GHG (i) and their addition.

Equation 9: GHG emissions from the use of refrigeration and air conditioning equipment

$$E_{GHG\_Ref} = \frac{\left[(Q_n \times k) + (C \times X \times A) + \left(Q_n \times Y \times (1 - Z)\right)\right]}{100} \times GWP_i \times 0.001$$

Where:

E_{GHG_Refr} = GHG emissions attributable to the use of refrigeration equipment, in tonnes of CO_2 *equivalent per year*

*Q_n = Amount of refrigerant added to new equipment, in kilograms**

*k = Initial emissions (%)**

C = Total capacity of equipment, in kilograms

X = Annual operating emissions (%)

*A = Number of years in operation***

*Y = Initial load remaining (%)****

*Z = Recovery efficiency (%)****

GWP_i = Global warming potential of refrigerant i (refer to Table 3 *of this document for the different GWPs to be used)*

0.001 = Conversion factor from kilograms to tonnes

** To be omitted if no equipment has been installed or if equipment has been pre-filled by the manufacturer.*

*** A = 1, since emissions are calculated on an annual basis.*

**** Omit if no equipment was retired during the year.*

Table 10 is used to estimate the load, lifespan, and emission factors for refrigeration and air conditioning systems.

Table 10 Refrigeration and air conditioning system loads and emission factors

	Q_n (kg)	k (% of initial load)	X (% of initial load/year)	Y (% of initial load)	Z (%)
Domestic refrigeration	0.05 to 0.5	0.2 to 1%	0.1 to 0.5 %	0 to 80%	0 to 70%
Independent commercial applications	0.2 to 6	0.5 to 3%	1 to 15%	0 to 80%	0 to 70%
Commercial refrigeration, medium and large industry	50 to 2,000	0.5 to 3%	10 to 35%	0 to 100%	0 to 70%
Industrial refrigeration, including food processing and cold storage	10 to 10,000	0.5 to 3%	7 to 25%	50 to 100%	0 to 90%

Table 10 Refrigeration and air conditioning system loads and emission factors					
	Q_n (kg)	k (% of initial load)	X (% of initial load/year)	Y (% of initial load)	Z (%)
Cooling	10 to 2,000	0.2 to 1%	2 to 15%	80 to 100%	0 to 95%
Commercial and residential air conditioning, including heat pump systems	0.5 to 100	0.2 to 1%	1 to 10%	0 to 80%	0 to 80%

Source: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 3: Industrial Processes and Product Use, Table 7.9.

3.10. Deforestation

Deforestation activities can have significant impacts on climate change, which are documented by the IPCC and others under the term "land-use change." The forestry sector has the capacity to sequester atmospheric carbon in biomass and therefore reduce its concentration in the atmosphere. The scientific literature suggests that forest ecosystems are carbon reservoirs, and that certain space-intensive projects (e.g., road construction, mine operation, landfill construction, or hydrocarbon development) can affect these reservoirs.

If deforestation activities are carried out (usually during the construction phase), the GHG emissions attributable to these activities must be calculated. If deforestation activities are planned for other phases of the project, they should also be taken into account.

3.10.1. GHG emissions from the loss of forest land carbon stocks

To calculate GHG emissions from deforestation, it is recommended to refer to the IPCC document "Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use" (2019)[27]. These emissions can be calculated by balancing the amount of carbon in a carbon reservoir before and after the project using the following equation.

Equation 10: CO_2 emissions from the loss of forest land carbon stocks.

$$GHG\ Emissions\ (tonnes_{CO2}) = N_H \times t_{DMh} \times (1 + T_x) \times CC \times \frac{44}{12}$$

Where:

TonnesCO_2 = CO_2 emissions due to loss of carbon stocks from deforestation, expressed in tonnes

N_H = Number of hectares deforested

t_{DMh} = Tonnes of dry matter per hectare

T_x = Ratio of below-ground biomass to above-ground biomass

CC = Carbon content of wood, expressed in tonnes of carbon per tonne of dry matter

44/12 = Molecular weight ratio of CO_2 to carbon

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[27] https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

Given the particularities of each project and since it is not possible to present all of them in this guide, Table 11 provides suggested references for determining the values of the variables in the equation above.

Table 11. Equation 10 parameters for determining CO_2 emissions from deforestation activities

Parameter	IPCC reference
t_{DMh}	Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Table 4.7.
T_X	Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Table 4.4.
CC	Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Default value = 0.47.

GHG emissions from fuel consumption by stationary or mobile equipment used in deforestation activities shall be calculated using the methodologies presented in the sections on stationary and mobile combustion systems.

In addition, where applicable, GHG emissions (or reductions) due to the use of cut wood or the decomposition of logging residues left on the site should be calculated. Any recognized methodology, based on credible and verifiable assumptions, may be used to estimate these emissions (or reductions).

3.10.2. Loss of carbon sequestration capacity due to deforestation

As mentioned in the previous section, deforestation releases a significant amount of CO_2 into the atmosphere. However, this is not the only environmental impact in terms of climate change. Deforestation is also responsible for a net loss of CO_2 sequestration capacity.

The net loss of CO_2 sequestration over 100 years due to deforestation can be calculated from Equation 11.

Equation 11: Net loss of CO_2 sequestration over 100 years

$$L_{SEQ} = N_H \times GAB \times (1 + T_X) \times CC \times 44/12 \times 100$$

Where:

L_{SEQ} = *Loss of* CO_2 *sequestration capacity over a 100-year period, in tonnes of* CO_2

N_H = *Number of hectares deforested*

GAB = *Annual growth rate of above-ground biomass, in tonnes of dry matter per hectare per year*

T_x = *Ratio of below-ground biomass to above-ground biomass*

CC = *Carbon content of wood, expressed in tonnes of carbon per tonne of dry matter*

44/12 = *Molecular weight ratio of* CO_2 *to carbon*

Table 12 shows the suggested references for estimating the parameter values in Equation 11.

Table 12. Equation 11 parameters for determining CO_2 emissions from deforestation activities

Parameter	IPCC reference
CBA	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4. Chapter 4: Forest Land. Table 4.9.
Tx	Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. Table 4.4.
CC	2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4. Chapter 4: Forest Land. Table 4.3

3.11. The role of forests in climate change mitigation

The world's forests cover 4 billion hectares, or 31% of the land surface. They contain 60 to 75% of the carbon of continental plant biomass. This represents nearly 860 gigatonnes of carbon (GtC), or nearly 3,150 gigatonnes of CO_2 ($GtCO_2$), a compartment equivalent to that of CO_2 in the atmosphere.[28]

CO_2 absorption by photosynthesis is estimated at 220 $GtCO_2$/year. At the ecosystem scale, this uptake is largely offset by a reverse flow of CO_2 related not only to the energy expenditure of plant metabolism and growth, but also to the transformation and decomposition of dead organic matter in litter and soil. [29] Wood harvesting and natural disturbances (fires, insect pests, extreme temperatures, etc.) also contribute to this outward flow due to induced plant mortality. On a global scale, the difference between CO_2 inflow and outflow remains positive, making forest ecosystems net carbon sinks.

Forests play three essential roles in climate change mitigation.

- Carbon reservoir role: this involves storing carbon in vegetation, forest soils, as well as wood products;
- Sink role: photosynthesis increases carbon stocks in the forest reservoir by removing carbon dioxide from the atmosphere;
- Reduction of fossil fuel emissions: the use of wood products as substitutes for other materials (cement, steel, etc.) and the use of wood for energy production allow significant avoidance of fossil-fuel GHG emissions.

Forest management practices can be implemented to promote carbon storage in forests. Stand aging is one option to consider. Other solutions take into account the potential for additional carbon storage through nature-based solutions[30] of afforestation or reforestation using local species. In addition to the carbon storage benefit, the objective here is also to increase the availability of wood resources for downstream user sectors, in order to reduce the pressure on natural or semi-natural forest resources.

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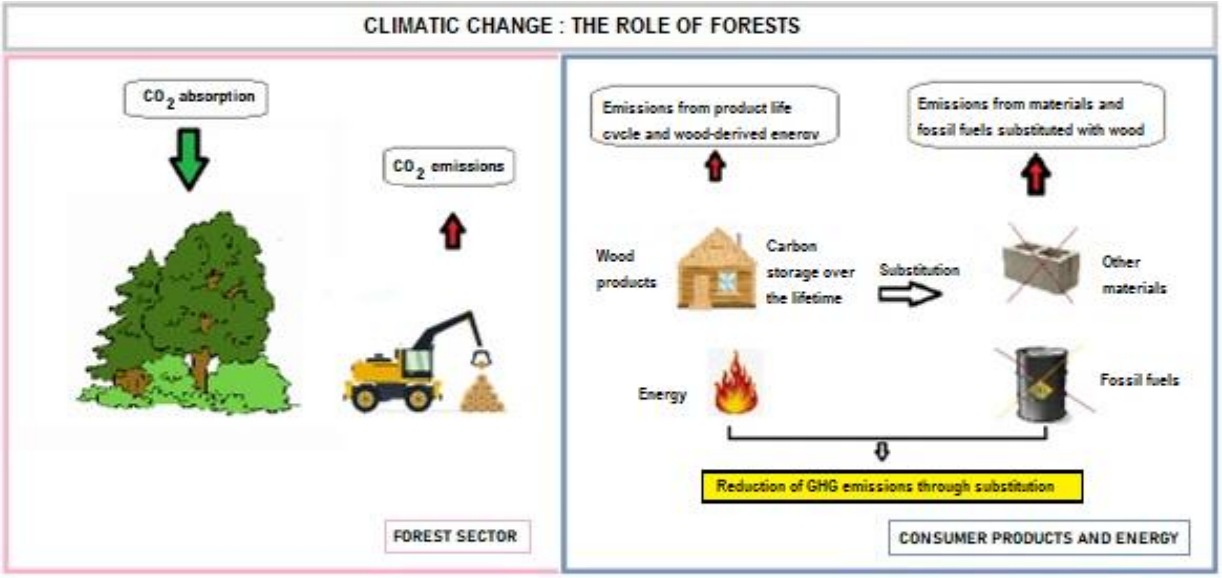
[28] Roux A. (2020). Filière forêt-bois et atténuation du changement climatique : entre séquestration du carbone en forêt et développement de la bioéconomie. Versailles, Éditions Quæ, 170 p.

[29] Gough C.M., 2011. Terrestrial Primary Production: Fuel for Life. Nature Education Knowledge, 3 (10), 28.

[30] Nature-based solutions are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature."

Figure 3. The role of forests in climate change



Improving forest management and land use reduces the vulnerability of forests and contributes to the mitigation of GHG emissions. As for the role of forests in climate change mitigation, it is inseparable from adaptation since their mitigation capacity depends on their health and the maintenance of their various ecological functions. This is why fostering the resilience of forests is a key issue for the success of GHG emissions mitigation in connection with forestry projects and, conversely, only a mitigated climate change will ensure the success of forest adaptation strategies.

There are several measures that can increase carbon storage in forests and wood products, including:

- Application of sustainable forest management practices;
- Longer rotations;
- Increasing the area covered by forests;
- Rehabilitation of degraded or damaged forests;
- Processing harvested wood into long-lasting products;
- Use of wood as a renewable energy source.

In short, to mitigate climate change, forests must sequester and store carbon. Increasing wood harvesting decreases the rate of sequestration, but promotes storage in wood products and substitution of fossil fuels or materials whose production is more GHG intensive. Therefore, in order to optimize climate change mitigation, forest management must promote effective complementarity between sequestration, storage, and substitution mechanisms.

Our two main scenarios (maximizing forest carbon storage or maximizing wood product harvesting) contribute to climate change mitigation by prioritizing different levers. In the reduced harvest scenario, the priority lever is increasing annual storage in the forest ecosystem that does not promote carbon storage in wood products or substitution effects. There are indications that this strategy may have some limits due to the decline in the forest's storage capacity as stands age. On the contrary, the scenario of harvest intensification relies more on the effects of substitution to compensate a lesser storage in forests, with a preponderant place given to the substitution of materials with a strong carbon footprint. However, this last aspect comes with the greatest uncertainties, as the substitution coefficients and their evolution in time would be particularly tricky to grasp or anticipate with precision.

Consequently, there is a high level of uncertainty regarding both the carbon sequestration mechanisms and the reductions of fossil-fuel emissions due to the use of wood products (substitution). Some studies show that an increase in harvesting would reduce sequestration in forests by 2050. However, this decrease in the rate of sequestration associated with increased harvesting could be offset over time by the benefits of increased wood use, due to the increased carbon storage in wood products coupled with material and energy substitution effects. However, the results of these studies, which extend up to the year 2050, do not fully agree on the temporal dynamics and magnitude of these mechanisms, and it is difficult to make a definitive decision on how the counterbalancing between the mechanisms favors one management strategy or the other. (Roux A. 2020). There is a consensus that more studies are needed to provide key information on the complementarity between sequestration, storage and substitution mechanisms to determine the optimal mix of strategies for forest management.

3.12. Loss of wetlands

This section is intended for all activities that may affect wetlands. Whether they be ponds, marshes, swamps or bogs, wetlands are ecosystems that play a major role in sustaining life. The ecological services they provide to society are an asset to our quality of life. Wetlands also contribute to the mitigation of GHG emissions since they are important carbon sinks, and their disappearance releases significant quantities of CO_2, CH_4, and N_2O into the atmosphere.

The GHG emissions calculations presented in this section are based on the IPCC document “2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.”[31] However, any other recognized methodology, based on credible and verifiable assumptions, can be used to estimate these emissions.

GHG emissions from wetland loss can be calculated from Equation 12.

Equation 12: GHG emissions from wetland loss

$$E_{GHG} = E_{CO2} + E_{CH4} \times GWP_{CH4} + E_{N2O} \times GWP_{N2O}$$

Where:

E_{GHG} = *GHG emissions attributable to wetland loss, in tonnes of* CO_2 *equivalent*

E_{CO2} = CO_2 *emissions attributable to wetland loss, in tonnes of* CO_2

E_{CH4} = CH_4 *emissions attributable to wetland loss, in tonnes of* CH_4

E_{N2O} = N_2O *emissions attributable to wetland loss, in tonnes of* N_2O

GWP_{CH4} = *Global warming potential of* CH_4

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[31] https://www.ipcc.ch/publication/2013-supplement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories-wetlands/

GWP_{N2O} = Global warming potential of N_2O

Equations 13, 14, and 15 are used to calculate the CO_2, CH_4, and N_2O emissions from to the loss of a certain area of wetlands.

Equation 13: CO_2 emissions from wetland loss

$$E_{CO2} = L_{WL} \times EF_{CO2} \times 44/12$$

Equation 14: CH_4 emissions from wetland loss

$$E_{CH4} = L_{WL} \times EF_{CH4}$$

Equation 15: N_2O emissions from wetland loss

$$E_{N2O} = L_{WL} \times EF_{N2O}$$

Where:

L_{WL} = *Wetland loss, in hectares*

EF_{CO2} = CO_2 *emission factor due to wetland loss, in tonnes of* CO_2 *per hectare*

EF_{CH4} = CH_4 *emission factor due to wetland loss, in tonnes of* CH_4 *per hectare*

EF_{N2O} = N_2O *emission factor due to wetland loss, in tonnes of* N_2O *per hectare*

44/12 = Molecular weight ratio of CO_2 *to carbon*

Table 13 presents the CO_2 emission factors attributable to wetland loss, while Table 14 presents the CH_4 and N_2O emission factors attributable to this wetland loss.

Table 13. CO_2 emission factors (Tier 1) attributable to the loss of forested wetlands

Climate	EF CO_2 (t C / hectare)
Boreal	0.12
Temperate	0.31
Tropical and subtropical	0.82

Source: IPCC (2013) - 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.

Table 14. CH_4 and N_2O emission factors (Tier 1) attributable to the loss of forested wetlands

Climate	EF_{CH4} (kg CH_4 / hectare)	EF_{N2O} (kg N_2O / hectare)
Boreal - Low in nutrients	7.0	0.22
Boreal - Nutrient rich	2.0	3.2
Temperate	2.5	2.8
Tropical and subtropical	4.9	2.4

Source: IPCC (2013) - 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.

3.13. Wetland restoration and conservation

In Quebec, wetlands cover approximately 17 million hectares[32], or about 10% of the province's total land area. Whether they be ponds, marshes, swamps or peat bogs, wetlands represent the essential links in the web of natural environments in Quebec. These ecosystems are all sites that are saturated with water or flooded for a sufficiently long period of time to influence the nature of the soil or the composition of the vegetation.

Wetlands play an important role in the global carbon balance, both in terms of their carbon storage capacity and their potential to release stored carbon due to drainage, drought, or rising temperatures. While they cover only about 3% of the earth's surface, they store one third of the world's soil carbon, or about 445 billion tonnes[33]. Carbon accumulates very slowly in these environments, but when they are drained, they can quickly release significant amounts of carbon dioxide.

Despite the ecological and climatic importance of wetlands, the drainage and conversion of these environments has been commonplace around the world. Several human activities can lead to wetland drainage, including:

- Peatland harvesting;
- Agricultural activities;
- Real estate developments;
- Planting of woody species;
- Development of road structures producing discontinuities that affect the wetland.

The conservation of wetlands and hydric environments is at the heart of the Ministère's mission because they fulfill essential ecological functions and are a key link in the biodiversity of Quebec. Thus, the Ministère's legal and regulatory framework reflects the importance of this issue and provides for various measures to curb the loss of these environments, and even to make gains in this area.

As for the beneficial effects in terms of carbon storage related to the restoration or conservation of wetlands, the following table presents the daily exchanges of CO_2 and CH_4 per area unit of wetlands in temperate, boreal, and subarctic regions.

Table 15. Daily fluxes of CO_2 and CH_4 in Canadian wetlands

Region	CO_2 flux ($g\ CO_2\ m^{-2}\ d^{-1}$)	CH_4 flux ($mg\ CH_4\ m^{-2}\ d^{-1}$)
Temperate	-0.55	27.45
Boreal	-2.75	23.6
Subarctic	-1.25	22.75

Source: Webster et al. Carbon Balance and Management (2018) 13:16. Spatially-integrated estimates of net ecosystem exchange and methane fluxes from Canadian peatlands.

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[32] MELCC

[33] Wang, H., Richardson, C.J.,& Ho. M.(2015). Dual controls on carbon loss during drought in peatlands. Nature Climate Change 5(6): 584-7.

In the previous table, the N_2O flux is considered negligible for non-fertilized wetlands.[34] Therefore, overall, wetlands are considered carbon sinks, and their restoration or conservation increases carbon storage.

3.14. GHG emissions from ecosystem flooding

Flooded lands are defined as bodies of water regulated by human activities, such as power generation, irrigation, navigation, or recreation, and where the regulation of water results in substantial changes in water area. Regulated lakes and rivers, where the primary ecosystem prior to flooding was a natural lake or river, are not considered flooded lands. This type of emissions is most common in projects involving flooding (e.g., dam construction).

GHG emissions from flooded lands are generated by two main mechanisms (in cold regions, CO_2 and CH_4 accumulate under the ice and are emitted during thawing):

- Molecular diffusion of CO_2, CH_4, and N_2O between air and water;
- CH_4 bubbles from sediments in the water column (bubble emissions).

In its document "Good Practice Guidance for Land Use, Land-Use Change and Forestry,"[35] the IPCC proposes three methodological tiers for estimating emissions from ecosystem flooding, with an increasing degree of precision associated with the higher tiers.

The proposed methodology for estimating GHG emissions from ecosystem flooding is Tier 1. This is a simplified methodology based on default emissions data and aggregate area data. However, Tier 2 and Tier 3 methods can also be used, which are more comprehensive and may include additional country-, province-, or region-specific data.

The calculation formulas are different for CO_2, CH_4, and N_2O emissions. They are presented separately below.

3.14.1. CO_2 emissions from ecosystem flooding

CO_2 emissions from ecosystem flooding are considered biogenic and should be accounted for separately from other GHG emissions. The estimation method to be applied is based on the change in carbon stocks resulting from conversion to flooded land and assumes that pre-conversion stocks are lost in the first year after conversion.

The annual change in carbon stocks of living biomass on land converted to flooded land can be calculated from the following equation.

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[34] Oleszczuk, R., Regina, K., Szajdak, L., Höper, H., and V. Maryganova. 2008. Impacts of agricultural utilization of peat soils on the greenhouse gas balance. In Strack, M. (ed). 2008. Peat lands and climate change. International Peat Society, Vapaudenkatu 12, 40100 Jyväskylä, Finland. Pp. 70-97.

[35] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

Equation 16: Change in carbon stocks of living biomass from land converted to flooded land

$$\Delta C_{Tflood} = \left[\sum S_i \times \left(B_{After} - B_{Before}\right)_i\right] \times CF$$

Where:

ΔC_{Tflood} = *Change in living biomass carbon stocks of land converted to flooded land, in tonnes of C*

S_i = *Surface area of land converted annually to flooded land from initial use i, in hectares*

B_{before} = *Living biomass of land before conversion to flooded land, in tonnes of dry matter per hectare*

B_{after} = *Living biomass after conversion to flooded land, in tonnes of dry matter per hectare (default value = 0)*

CF = Carbon fraction of dry matter (default value = 0.5)

For forest land converted to flooded land, the living biomass present prior to conversion can be calculated using the following equation.

Equation 17: Living biomass before conversion of forest land to flooded land

$$B_{Before} = t_{DMh} \times (1 + T_x)$$

Where:

B_{before} = *Living biomass of land before conversion to flooded land, in tonnes of dry matter per hectare*

t_{DMh} = *Tonnes of dry matter per hectare*

T_x = *Ratio of below-ground biomass to above-ground biomass*

To know the values of the parameters t_{DMh} and T_x, refer to Table 11.

Subsequently, the CO_2 emissions attributable to forest land flooding can be determined from Equation 18.

Equation 18: CO_2 emissions from forest land flooding

$$E_{CO2\_TFflood} = \Delta C_{Tflood} \times \frac{44}{12}$$

Where:

E_{CO2_Tflood} = CO_2 *emissions attributable to flooding of forest land, in tonnes of* CO_2

ΔC_{Tflood} = *Annual change in living biomass carbon stocks of forest land converted to flooded land, in tonnes of C*

44/12 = Molecular weight ratio of CO_2 *to carbon*

The loss of CO_2 sequestration capacity due to flooding of forest land can be calculated using the equations presented in Section 3.10.2.

Finally, for wildlands converted to flooded land, Table 16 associates default baseline values to the organic carbon stocks of different soil types with natural vegetation.

Table 16. Default baseline values associated with soil organic carbon stocks (COS_{REF}) under natural vegetation

(Tonnes of carbon per hectare at a depth of 0 to 30 centimetres)

Region (*likely to be present in Quebec)	Highly active clay soils	Low-activity clay soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
Boreal*	68	N/A	10	117	20	146
Cold temperate and dry*	50	33	34	N/A	20	87
Cold temperate and humid*	95	85	71	115	130	87
Warm temperate and dry	38	24	19	N/A	70	88
Hot temperate and humid	88	63	34	N/A	50	88
Tropical and dry	38	35	31	N/A	50	86
Tropical and humid	65	47	39	N/A	70	86
Tropical and rainy	44	60	66	N/A	130	86

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC, 2003. Table 3.3.3. https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

Using the soil organic carbon stock value obtained from Table 16, Equation 19 estimates the CO_2 emissions from flooding of wildlands.

Equation 19: CO_2 emissions from flooding of wildlands

$$E_{CO2_T\_WL\_flood} = S_i \times SOC_{REF} \times \frac{44}{12}$$

Where:

$E_{CO2T\_WL\_flood}$ = CO_2 *emissions attributable to flooding of wildlands, in tonnes of* CO_2

S_i = *Surface area of land converted annually to flooded land from the initial use i, in hectares*

SOC_{REF} = *Soil organic carbon stocks*

44/12 = Molecular weight ratio of CO_2 *to carbon*

3.14.2. CH_4 emissions from ecosystem flooding

The Tier 1 method for estimating CH_4 emissions from land flooding accounts for molecular diffusion and bubbling emissions of CH_4 from sediments. These emissions, expressed in tonnes of CH_4 per year, can be estimated from the following equation.

Equation 20: CH_4 emissions from ecosystem flooding

$$CH_4\ emissions = \left(ECH4_{diff} + ECH4_{bubbles}\right) \times P \times Sur_{flooded} \times 0.001$$

Where:

$ECH4_{diff}$ = Average CH_4 *emission factor per release, expressed in kilograms of* CH_4 *per hectare per day*

$ECH4_{bubbles}$ = Average CH_4 *emission factor per bubble, expressed in kilograms of* CH_4 *per hectare per day*

P = Period, expressed in days (usually 365 for annual emissions estimation)

$Sur_{flooded}$ = Total flooded surface area, expressed in hectares

0.001 = Conversion factor from kilograms to tonnes

Table 17 shows the average CH_4 emission factors for molecular diffusion and bubbles from reservoir sediments.

Table 17 Average CH_4 emission factors of reservoirs

	Average CH_4 emission factors, in kg CH_4 x ha^{-1} x day^{-1}	
	$CH4_{diff}$	$CH4_{bubbles}$
Reservoir in boreal region	0.11	0.29
Reservoir in temperate region	0.2	0.14

Source: Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry. Appendix 3a.3 Wetlands remaining Wetlands: Basis for future methodological development. Table 3A.3.5 Default Emissions Factors for Reservoirs. https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/App_3a3_Wetlands.pdf

3.14.3. N_2O emissions from flooded ecosystems

The Tier 1 method for estimating N_2O emissions from flooded lands considers only molecular diffusion emissions, since bubble emissions are not significant. These emissions, expressed in tonnes of N_2O per year, can be estimated from Equation 21.[36]

Equation 21: N_2O emissions from ecosystem flooding

$$N_2O\ emissions = P \times EN2O_{diff} \times Sur_{flooded} \times 0.001$$

Where:

EN_2O_{diff} = *Average* N_2O *emission factor per diffusion, expressed in kilograms of* N_2O *per hectare per day*

P = Time period, expressed in days (usually 365 for annual emissions estimation)

$Sur_{flooded}$ = Total flooded surface area, expressed in hectares

0.001 = Conversion factor from kilograms to tonnes

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[36] Source: Intergovernmental Panel on Climate Change *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Equation 3A.3.10 N_2O Emissions from flooded lands. http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf.

Table 18 shows the average N_2O emission factors for reservoirs.

Table 18. Average N_2O emission factors for reservoirs

	Average N_2O emission factors, in kg N_2O x ha^{-1} x day^{-1}
Reservoir in boreal region	0.008
Reservoir in temperate region	Not measured (depending on the specific project characteristics)

Source: Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry. Table 3A.3.5 Default Emissions Factors for Reservoirs. http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/GPG_LULUCF_FULL.pdf

3.15. GHG emissions from livestock and agricultural projects

Two methodologies are suggested for calculating GHG emissions from animal production projects. Calculations can be performed using either:

a) the latest update of the Holos agricultural farm GHG emissions assessment and reduction software, Section 3.13.1; or
b) the equations presented in section 3.13.2.

The agricultural community is generally familiar with the Holos software, so this option was evaluated and considered in this guide.

3.15.1. Calculation with the Holos software

The Holos software[37] was developed by Agriculture and Agri-Food Canada to estimate GHG emissions from agricultural operations. The algorithms used by the software are based on the methods proposed by the IPCC, but adapted to Canadian conditions. Holos estimates GHG emissions from enteric fermentation, animal waste management, and crop production. It also estimates emissions related to energy use during farm operations. Thus, for agricultural projects, GHG emissions from stationary and mobile combustion sources and electricity use can be estimated directly from the software or using the equations in Sections 3.1 and 3.2.

However, the Holos software is not designed to estimate GHG emissions during the construction phase. Therefore, these emissions must be calculated using the applicable formulas presented in this guide.

3.15.2. Calculation using equations (without the Holos software)

Enteric fermentation, agricultural soil management, and manure management account for about 75% of the emissions, or 39%, 29%, and 27% of the total from the livestock production sector, respectively. However, each type of livestock production has differences that must be accounted for in the calculations. The next sections present the different emission sources and types of greenhouse gases to be considered:

- CH_4 emissions from enteric fermentation;
- CH_4 emissions from manure storage and processing;
- N_2O emissions from manure storage and processing;

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[37] Agriculture Canada, 2020. https://agriculture.canada.ca/en/agricultural-science-and-innovation/agricultural-research-results/holos-software-program.

- N_2O emissions from manure application;
- N_2O emissions from fertilizer and crop residue application.

3.15.2.1. CH_4 emissions from enteric fermentation

CH_4 is produced by enteric fermentation during the normal digestion process of herbivores. CH_4 emissions from livestock production can be estimated from Equation 22.

Equation 22: Methane emissions from enteric fermentation

$$E_{CH4\_EF} = \sum_{i=1}^{i=k} N_i \times f_{CH4\_EF_i} \times 0.001$$

Where:

E_{CH4_EF} = *Annual* CH_4 *emissions from enteric fermentation, in tonnes of* CH_4 *per year*

i = Animal category

N_i = *Number of heads of animal category i*[38]

f_{CH4_EFi} = CH_4 *emission factor for enteric fermentation associated with animal category i, in kg CH4/head/year*

0.001 = Conversion factor from kilograms to tonnes

Table 19 shows the CH_4 emission factors for enteric fermentation associated with the different animal categories.

Table 19. CH_4 emission factors associated with enteric fermentation

ANIMAL CATEGORY	CH_4 emission factor (kg CH_4/head/year)	Reference
Dairy cows	142.2	*National Inventory Report 1990-2019.* Part 2. Table A3.4-8. CH_4 emission factors for enteric fermentation from cattle, selected years, 1990-2019. Values from 2019.
Dairy heifers	76.6	
Bulls	124.0	
Beef cows	120.3	
Beef heifers	91.0	
Heifers for slaughter	53.9	
Steers	49.0	
Calves	43.7	
Bison	55	*National Inventory Report 1990-2019.* Part 2. Table A6.4-2. Methane emission factors (EF) for enteric fermentation from non-bovine animal species.
Sheep	8	
Lambs	8	
Goats	5	
Horses	18	
Mules and donkeys	10	
Swine:		
Boars	1.5	

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[38] Note: the number of heads applies to a single type of animal and differs from the number of animal units, which takes into account all types of animals reduced to a common denominator. Examples: 1 dairy cow = 1 animal unit; 1 laying hen = 175 animal units. Source: Regulation respecting the environmental impact assessment and review of certain projects.

Sows	1.5	
Pigs < 20 kg	1.5	
Pigs 20-60 kg	1.5	
Pigs > 60 kg	1.5	
Llamas and alpacas	8	
Elk and deer	20	
Wild boars	1.5	
Foxes	ND	
Mink	ND	
Rabbits	ND	
Chickens	ND	
Chickens	ND	
Turkeys	ND	

3.15.2.2. CH_4 emissions from manure storage and processing

Equation 23 is used to calculate CH_4 emissions from manure storage and processing.

Equation 23: CH_4 emissions from manure storage and processing

$$E_{CH4\_MS} = \sum_{i=1}^{i=k} N_i \times f_{CH4\_MS_i} \times 0.001$$

Where:

E_{CH4_MS} = *Annual* CH_4 *emissions from manure storage and processing, in tonnes of* CH_4 *per year*

i = Animal category

N_i = *Number of heads of animal category i*

f_{CH4_MSi} = CH_4 *emission factor associated with manure storage and processing of animal category i, in kg* CH_4*/head/year*

0.001 = Conversion factor from kilograms to tonnes

CH_4 emissions from manure storage and processing can be estimated from the emission factors presented in Table 20.

Table 20 CH_4 emission factors associated with manure storage and processing		
ANIMAL CATEGORY	CH_4 emission factor (kg CH_4/head/year)	Reference
Dairy cows	27.8	Environmental Quality Act (chapter Q-2, r. 46.1) Regulation respecting a cap-and-trade system for greenhouse gas emission allowances (RCATS) https://www.legisquebec.gouv.qc.ca/en/document/cr/Q-2,%20r.%2046.1
Dairy heifers	19.1	
Bulls	3.3	
Beef cows	3.2	
Beef heifers	2.4	
Steers	1.6	
Semi-finished cattle	1.8	
Dairy calves and heifers	1.5	
Piglets	1.66	
Pigs	6.48	
Sows	7.71	
Boars	6.40	

3.15.2.3. N_2O emissions from manure storage and processing

N_2O production during manure storage and processing occurs during nitrification and denitrification of the nitrogen in the manure.

N_2O emissions from manure storage and processing can be calculated from the N excretion rate, depending on the animal category, and the N_2O emission factor per kilogram of N, depending on the manure management type. Equation 24 is used to calculate N_2O emissions from manure storage and processing.

Equation 24: N_2O emissions from manure storage and processing

$$E_{N2O\_MS} = \sum_{i=1}^{n} N_i \times T_{exc_{Nitrogen_i}} \times f_{N2O/N} \times 0.001$$

Where:

E_{N2O_MS} = N_2O *emissions attributable to manure storage and processing, expressed in tonnes of* N_2O *per year*

N_i = *Number of heads of animal category i*

$T\_exc\_Nitrogen_i$ = *Annual nitrogen excretion rate from manure for animal category i, expressed in kg N/head/year*

$f_{N2O/N}$ = N_2O *emission factor associated with manure storage and processing, expressed in kilograms of* N_2O *per kilogram of nitrogen excreted*

0.001 = Conversion factor from kilograms to tonnes

Table 21 presents the annual nitrogen excretion rate from manure for different categories of farm animals.

Table 21. Annual nitrogen excretion rate from manure, expressed in kg N/head/year

Animal category	$\frac{kg_N}{head \times year}$	Animal category	$\frac{kg_N}{head \times year}$	Animal category	$\frac{kg_N}{head \times year}$
Dairy cows	122	Pigs	7.1	Broilers	0.4
Dairy heifers	76	(20-60 kg)	17.2	Turkeys	1.8
Bulls	107	Pigs (> 60 kg)	4.1	Elk and deer	13.6
Beef cows	74	Sheep	4.1	Farm-raised wild boars	17
Beef heifers	57	Lambs	10.5	Wild boars	11.1
Heifers ready for slaughter	66	Goats	49.3	Foxes	7.9
Steers	68	Horses	17.2	Mink	3.0
Calves	26	Llamas and alpacas	67.7	Rabbits	4.7
Sows	17	Bison	0.5	Mules and donkeys	26.8
Pigs (> 20 kg)	1.7	Chickens	17		

Source: National Inventory Report 1990-2019, Part 2. Tables A3.4-20, A3.4-21, and A3.4-22

Table 22 shows the N_2O emission factors for all animal categories based on the type of manure management practised.

Table 22. N_2O emission factors by manure management approach

	Manure storage systems		
	Liquid manure management systems	Solid and dry manure storage	Other systems
kg of N_2O per kg of nitrogen excreted	0.001	0.02	0.005

Source: National Inventory Report 1990-2019, Part 2. Table A6.4-10.

3.15.2.4. N_2O emissions from manure application

N_2O emissions from manure application can be calculated from Equation 25.

Equation 25: N_2O emissions from manure application

$$E_{N2O\_AP} = \sum_{i=1}^{i=n} Q_{MA_i} \times CON_{Nitrogen_{MA_i}} \times EF_{N2O_{MA_i}} \times 0.001$$

Where:

E_{N2O_AP} = *Annual* N_2O *emissions from manure application, expressed in tonnes of* N_2O *per year*

Q_{MA_i} = *Tonnes of manure of type i applied in the year*

$CON\_Nitrogen_{MA_i}$ = *Nitrogen content of manure for type i, expressed in kilograms of nitrogen per tonne of manure*

$EF\_N_2O_{MA_i}$ = N_2O *emission factor associated with manure type i, expressed in kilograms of* N_2O *per kilogram of manure nitrogen*

0.001 = Conversion factor from kilograms to tonnes

For Quebec and Ontario, an N_2O emission factor of 0.012 kilograms of N_2O per kilogram of manure nitrogen can be used.[39]

The nitrogen content of different types of manure is shown in Table 23.

Table 23. Nitrogen content of different types of manure and slurry

Type of manure or slurry	Nitrogen content (kilograms/tonne)
Dairy cattle - solid manure	5.7
Dairy cattle - slurry	3.1
Beef cattle (intensive farming) - manure	7.1
Cows and calves - manure	4.8
Sheep - solid manure	11
Pigs - fattening, slurry	2.7 to 4.9
Poultry - chicken manure	28
Poultry - laying hen manure	31

Sources: Centre de référence en agriculture agroalimentaire et du Québec (CRAAQ), 2003[40] and 2007[41]; ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec (MAPAQ), 1997[42].

3.15.2.5. N_2O emissions from nitrogen losses associated with inorganic and organic fertilizer application and crop residue application

N_2O emissions from the application of inorganic and organic fertilizers and crop residues to agricultural soils can be calculated from Equation 26.

Equation 26: N_2O emissions from application of inorganic and organic fertilizers and crop residues.

$$E_{N2O\_Fer} = Q_{Nitrogen} \times EF_{N2O\_N} \times 0.001$$

Where:

E_{N2O_Fer} = *Annual* N_2O *emissions from application of inorganic and organic fertilizers and crop residues, in tonnes of* N_2O *per year*

$Q_{Nitrogen}$ = *Tonnes of nitrogen applied per year*

EF_{N2O_N} = N_2O *emission factor, in kilograms of* N_2O *per tonne of nitrogen applied to soil*

0.001 = Conversion factor from kilograms to tonnes

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[39] Gregorich, E.G., P. Rochette, A.J. VandenBygaart and D.A. Angers, 2005. *Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada.* Soil & Tillage Research 76:120.

[40] CRAAQ. Guide de référence en fertilisation (Fertilization reference guide), 2003b.

[41] CRAAQ. Caractéristiques des effluents d'élevage – validées – (porc et poule pondeuse), 2007, 7 pages. http://pub.craaq.qc.ca/transit/validees/tdm.pdf.

[42] MAPAQ. Guide régional sur la composition des fumiers et lisiers sur les fermes de la Montérégie-Est (Regional guidance on manure and slurry composition for farms in the Montérégie Est region), Bureau des renseignements agricoles de Saint-Hyacinthe, 1997.

Table 24 presents the N_2O emission factor per tonne of nitrogen associated with fertilizer and crop residue application, in kilograms of N_2O per tonne of nitrogen.

Table 24. Annual N_2O emission factor per tonne of nitrogen from fertilizer and crop residue application

Province	EF_{N2O_N} (kg N_2O per tonne of nitrogen per year)
Alberta	13
British Columbia	16
Prince Edward Island	21
Manitoba	14
New Brunswick	25
Nova Scotia	24
Ontario	23
Quebec	26
Saskatchewan	12
Newfoundland and Labrador	26

Source: National Inventory Report 1990-2019, Part 2. Table A6.4-20.

3.16. CH_4 emissions from landfill

Landfilling of waste materials results in the decomposition of organic matter in the absence of oxygen (anaerobiois) and the generation of biogas consisting primarily of CH_4 and CO_2. As mentioned, CO_2 emissions from biomass are considered biogenic (carbon neutral), but CH_4 emissions are not. Most of the emissions are released in the first few years, and the remaining emissions decline over time until after the site is closed. Since CH_4 has a global warming potential 25 times higher than CO_2 and considering the temporal process of emissions, it is important to include mitigation measures in the design of a project.

For the quantification of GHG emissions, it is important to know that :

- CH_4 production at a landfill is dependent on several variables, including the composition of the organic material being landfilled and the temperature and moisture content resulting from precipitation;
- CH_4 emissions to air will subsequently depend on the efficiency of the landfill's gas capture and destruction system and the rate of oxidation of the emissions by the landfill cell cover;
- For landfill expansion, consideration should be given to ongoing and future methane emissions, including those associated with materials landfilled in previously permitted areas;
- The time period to be considered for these emissions includes the operational phase and extends beyond the post-closure phase; it is recommended that methane emissions be taken into account for a minimum of 100 years after closure of the site.
- The calculation of CH_4 emissions can be performed using either:
  - (a) the US EPA Landfill Gas Emissions Generation Model (LandGEM); or
  - (b) the equations presented in the following section.

3.16.1. LandGEM calculation

The Landfill Gas Emissions Generation Model (LandGEM), which is the latest model developed by the US EPA, can be used to calculate CH_4 emissions from landfilling of waste materials. Where applicable, the important information used in the model should be provided. The calculation parameters should be consistent with those in the following section.

3.16.2. Calculation without the LandGEM model

The CH_4 emissions from landfilling of waste for a given year can be estimated with Equation 27. These emissions correspond to the quantities generated minus those recovered and those that could be oxidized to CO_2.

Equation 27: CH_4 emissions from landfilling of waste

$$E_{CH4Landf} = \left[\sum CH_4\ gen_{x,T} - R_T\right] \times (1 - OX_T)$$

Where:

$E_{CH4Landf}$ = *CH_4 emissions in year T, in tonnes of CH_4 per year*

T = *Year*

x = *Type of waste material (e.g., yard waste, paper)*

CH_4 $gen_{x,T}$ = CH_4 generated from decomposable material x in year T, in tonnes of CH_4 per year

R_T = CH_4 recovered in year T, in tonnes of CH_4 per year

OX_T = *Oxidation factor in year T, fraction. By default, this factor is 0.1.*

The methane generated over the years can be estimated based on the quantities and composition of the waste materials buried in the landfill and the management practices of the site.

As shown in Equation 27, the potential for methane generation at landfills is based on the mass of organic carbon that will decompose under anaerobic conditions at the landfill (CODDm), which depends on the following:

- The tonnage and type (x) of waste material that is landfilled annually;
- The degradable organic carbon (DOC), which represents the portion of organic carbon in the waste that is available for decomposition and is determined by the composition of the waste entering the landfill;
- The fraction of DOC that is likely to decompose under anaerobic conditions (DOCf). The DOCf is an estimate of the amount of DOC in the waste material that actually decomposes in the landfill;
- The CH_4 correction factor (CCF), which accounts for the decomposition of the waste under different management practices. The CCF can vary between 0 and 1. 0 corresponds to completely aerobic

conditions, while 1 corresponds to completely anaerobic landfill conditions. Quebec uses a CCF of 1 for anaerobic landfills, as recommended in the 2006 IPCC Guidelines.

The methane emissions generated from Equation 27 are the sum of the methane emissions for each of the landfill waste types presented in Table 25.

Equation 28: Calculation of degradable and decomposable organic carbon (DDOCm)[43]

$$\mathrm{DDOCm}_{x,T} = WM_{x,T} \times DOC_x \times DOC_{fx} \times MCF$$

Where:

$DDOCm_{x,T}$ = Mass of degradable and decomposable organic carbon from material x deposited in year T (in tonnes)

x = Type of waste material deposited (e.g., food waste, paper) or sector (residential, CRD, IC&I)

T = Year

$WM_{x,T}$ = Mass of waste material x deposited in year T (in tonnes)

DOC_x = Degradable organic carbon in waste material type x

DOC_{fx} = Fraction of DOC that is likely to or does decompose for waste material type x

MCF = CH_4 correction factor for aerobic decomposition in the landfill year, fraction. The default is 1.

The basis for calculating CH_4 emissions is a first-order decomposition model based on an exponential factor that describes the fraction of degradable material that decomposes into CH_4 and CO_2 each year. Equations 29 and 30 are used to calculate, for a given year, the amount of degradable and decomposable organic carbon accumulated and decomposed by waste material type.

Equation 29: Calculation of accumulated DDOCm[44]

$$DDOCma_{\ x,T} = \quad DDOCmd_{\ x,T} + \ (DDOCma_{\ x,T-1} \times \ e^{-k_x})$$

Equation 30: Calculation of decomposed DDOCm[45]

$$DDOCm\ decomp_{x,T} \ = \ DDOCma_{\ x,T-1} \times \ (1 - e^{-k_x})$$

Where:

T = Year

$DDOCma_{x,T}$ = DDOCmx accumulated in the landfill at the end of year T, in tonnes

$DDOCmd_{x,T}$ = DDOCmx deposited in the landfill during year T, in tonnes

$DDOCma_{x,T-1}$ = DDOCmx accumulated in the landfill at the end of year (T-1), in tonnes

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[43] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3, Equation 3.2.

[44] Modified from Equation 3.5 of the 2006 IPCC Guidelines.

[45] Modified from Equation 3.5 of the 2006 IPCC Guidelines.

2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3.

$DDOCm\ decomp_{x,T}$ = DDOCmx decomposed in the landfill during year T, in tonnes

k_x = Reaction constant of material x

$t_{1/2}$ = Half-life time (in years)

$$k = \frac{\ln(2)}{t_{1/2}}$$

Equation 31 calculates CH_4 emissions from landfilled waste as a function of the degradable and decomposable organic carbon in material x.

Equation 31: CH_4 emissions from landfilled waste as a function of degradable and decomposable organic carbon[46]

$$CH_4\ gen_{x,T} = DDOCm\ decomp_{x,T} \times F \times 16/12$$

Where:

$CH_4\ gen_{x,T}$ = Amount of CH_4 generated from decomposable material x in year T, expressed in tonnes of CH_4

$DDOCm\ decomp_{x,T}$ = $DDOCm_x$ decomposed in the landfill during year T, expressed in tonnes of CH_4

F = Fraction of CH_4, by volume contained in the gas produced at the landfill. The default factor is 0.5.

16/12 = Molecular weight ratio of CH_4/C

Table 25 presents the descriptions of the main parameters of the waste decomposition model, and Tables 26, 27, and 28 present the parameters and factors to be used with Equations 26, 27, 28, 29, 30, and 31 for CH_4 emissions from landfilling of municipal waste and other waste types. The values for k, DOC and DOCf are presented by waste type in Table 26. These same parameters have been grouped by sector according to time periods, based on characterization data, balances, or MELCC estimates and are presented in Tables 26 or 27 and 28. The use of any values other than those presented in Tables 26 and 27 should be justified. The CH_4 recovered during year T (R_T) must be determined and justified according to the biogas capture, destruction (e.g., flare) or upgrading system, and the landfill site.

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[46] Modified from Equation 3.5 of the 2006 IPCC Guidelines.
2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3.

Table 25. Parameters of the first-order decomposition model for landfill waste

Parameter	Description
Degradable organic carbon (DOC)	DOC represents the amount of organic carbon in the waste material that is available for decomposition and is determined by the composition of the waste material deposited in the landfill. DOC is generally measured as a fraction of the wet weight of the waste.
Fraction of DOC that decomposes (DOC_f)	DOC_f is an estimate of the amount of DOC in waste materials that actually decomposes in landfills. The DOC_f values by material are taken primarily from the 2019 Revision of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019).[47]
Methane correction factor (MCF)	The MCF accounts for the decomposition of waste materials under different management practices. It is used to account for the fact that unmanaged landfills produce less CH_4 from a given amount of material than managed landfills in an anaerobic environment (IPCC, 2006). **For sanitary and engineered landfills in Quebec, the recommended value is 1**.
Reaction constant (k)	k represents the rate at which CH_4 is generated in the first-order decomposition reaction after the waste material is deposited in the landfill. The value of k is influenced by moisture content, nutrient availability, pH, and temperature, among other factors. The 2006 IPCC Guidelines decay rate constants , k, for the boreal-temperate wet and dry climate zones are used (IPCC 2006). The "wet" and "dry" climates are defined by the ratio of mean annual precipitation to potential evapotranspiration: wet climates have a mean annual precipitation that is greater than the potential evapotranspiration, while dry climates have a mean annual precipitation that is less than the potential evapotranspiration.
Fraction of CH_4 in biogas (F)	F is the volume fraction of methane in the biogas produced by the decomposition of waste materials. **The 2006 IPCC Guidelines (IPCC 2006) recommend a default value of 0.5.**
Oxidation factor (OX)	OX represents the amount of CH_4 that is oxidized to CO_2 by methanotrophic microorganisms as it passes through the landfill cover material. **The default value of 0.1 from the 2006 IPCC Guidelines (IPCC, 2006) for managed landfills covered with a CH_4-oxidizing material is recommended**.

Source: National Inventory Report 1990-2020: Greenhouse Gas Sources and Sinks in Canada. Part 2 - Section A3.6.1.2.1.

Based on characterizations of the types of waste materials landfilled, covering various periods, the MELCC has developed default values for the parameters DOC x DOC_f and k according to sectors and periods. These parameters can be used for the purposes of calculating emissions from landfilling of waste materials.

Table 26. DOC, DOCf and k parameters by type of waste

	Types of waste	DOC	DOCf	k
A	Paper	0.4	0.5	0.06
B	Garden waste	0.2	0.7	0.1
C	Table scraps	0.15	0.7	0.185
D	Layer	0.24	0.5	0.185
E	Textiles	0.24	0.5	0.06
F	Other organic materials	0.4	0.5	0.1
G	Building materials	0.22	0.1	0.03
H	Wood	0.43	0.1	0.03
I	Sludge	0.13	0.5	0.185

*Sludge is considered to be 29% dry.

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[47] The values for materials F and G (Table 25) were adapted by the Direction de l'expertise en réduction des émissions de GES of the MELCC.

Table 27. DOC x DOCf parameters according to sectors and sludge				
	Parameters: $DOCxDOC_f$			
	Sectors			Input
Periods	Residential	CRD	ICI	Sludge
1941–1969	0.1298	0.0311	0.1413	0.065
1970–1989	0.1234	0.0311	0.1413	0.065
1990–2006	0.1173	0.0311	0.1413	0.065
2007–2011	0.1105	0.0311	0.1413	0.065
2012–2015	0.1099	0.0306	0.0938	0.065
2016–2019	0.1034	0.0306	0.0938	0.065
2020 and after	0.0935	0.0316	0.0866	0.065

Table 28. Parameter k according to sectors and sludge				
	Parameter: k			
	Sectors			Input
Periods	Residential	CRD	ICI	Sludge
1941–1969	0.0661	0.0555	0.0659	0.185
1970–1989	0.0735	0.0555	0.0659	0.185
1990–2006	0.0806	0.0555	0.0659	0.185
2007–2011	0.0930	0.0555	0.0659	0.185
2012–2015	0.0988	0.0366	0.0814	0.185
2016–2019	0.0972	0.0366	0.0814	0.185
2020 and after	0.0878	0.0340	0.0688	0.185

3.16.3. Biogas upgrading and calculation of associated GHG reductions

For all landfill projects subject to environmental authorization, the Regulation respecting the landfilling and incineration of residual materials (REIMR) requires, at a minimum, the installation of a system to capture the biogas generated and, if the landfill site receives 50,000 tonnes of residual materials or more per year or has a maximum capacity of more than 1.5 million m^3 of residual materials, it is also required that the captured biogas be sent to an upgrading (e.g., gas network) or destruction (e.g., flaring) facility. The MELCC encourages the use of biogas as a substitute for fossil fuels whenever possible. Where biogas upgrading is planned as an alternative to flaring, the GHG emission reductions from the project can be quantified. Biogas upgrading could reduce the project's fossil fuel bill or reduce GHG emissions from users outside the project. The calculation of GHG reductions can be done using the equations presented in the sections on stationary and mobile combustion systems, depending on the type of biogas use.

3.17. GHG emissions from energy use in biogas cleaning operations

GHG emissions attributable to energy consumption in biogas cleaning operations are calculated in the sections on stationary and mobile combustion systems.

3.18. CH_4 emissions from biogas destruction (Amendment)

CH_4 emissions from this operation can be estimated from Equation 32, which considers the amount of CH_4 sent to the flare and the CH_4 destruction efficiency factor in the flare (DE).

Equation 32: Methane emissions from biogas combustion

$$E_{CH4Comb} = Q_{CH4Comb} \times (1 - DE)$$

Where:

$E_{CH4Comb}$ = *Methane emissions attributable to biogas combustion, expressed in tonnes of* CH_4 *per year*

$Q_{CH4Comb}$ = *Total amount of* CH_4 *sent to the flare per year, expressed in tonnes of* CH_4 *per year*

DE = *Biogas destruction efficiency*

Table 29 shows the DE factor associated with the different biogas destruction devices.

Table 29. Biogas destruction efficiency

System, equipment or process for the destruction or upgrading of biogas	Efficiency factor
Visible flame flare	0.96
Invisible flame flare	0.995
Internal combustion engine	0.936
Boiler	0.98
Micro or large gas turbine	0.995
Use of gas as CNG/LNG fuel	0.95
Injection into a natural gas transmission and distribution system (Factor takes into account system losses and distribution leakage.)	0.98
Off-site gas use under a direct-use agreement	Factor according to the agreement

Source: RCATS, Protocol 2, landfills – CH_4 destruction or processing, Table 1.

3.19. Fugitive CH_4 emissions from biomethanization of organic waste (Amendment)

Biomethanization is a biological process (anaerobic fermentation) that allows the recovery of organic materials by producing biogas (mainly methane), a renewable energy source, and a digestate, which can be used as fertilizer. Biomethanization reduces the quantity of organic materials destined for disposal, thereby helping to achieve the environmental objectives set out in the Quebec Residual Materials Management Policy and reducing GHG emissions. The MELCC is responsible for the implementation of Quebec's biomethanization and composting program. It is mainly the very large cities that choose this method of managing organic materials, given the infrastructure required.

Although biomethanization is a GHG emission reduction measure, some fugitive CH_4 emissions may be generated during the process. According to Equation 33, fugitive CH_4 emissions from the biomethanization process can be calculated from the amount of methane produced annually and the leakage rate from the process. For the CH_4 leakage rate from digesters, the Climate Action Reserve proposes a value of 0.02 in its "Organic Waste Digestion" protocol.[48].

Equation 33: Fugitive methane emissions from biogas processing

$$E_{CH4BIOMET} = Q_{CH4BIOMET} \times T_{FCH4}$$

Where:

$E_{CH4BIOMET}$ = *GHG emissions attributable to the organic waste biomethanization process, in tonnes of* CH_4 *per year*

$Q_{CH4BIOMET}$ = *Amount of methane produced, in tonnes of* CH_4 *per year*

T_{FCH4} = *Methane leakage rate from the biomethanization process*

3.20. GHG emissions from biogas compression and liquefaction

For GHG emissions from methane compression and liquefaction, it is suggested to refer to the RMRCECA Protocol QC.29 on emissions from processes and equipment used to transport and distribute natural gas.

3.21. CH_4 and N_2O emissions from the treatment of organic waste by composting

Composting is a measure used to reduce organic waste and GHG emissions. Small and medium-sized municipalities are the most likely to choose this method of organics management. Composting is a biological treatment process (aerobic fermentation, i.e., in the presence of oxygen) of organic materials. The organic materials are mixed with a structuring material that promotes aeration (e.g. wood chips) and placed in windrows, piles, or reactors. Compost is obtained after fermentation and maturation. Composting generates mostly CO_2 and small amounts of CH_4 and N_2O.

However, since the CO_2 emissions released during composting result from the decomposition of organic materials from biomass sources, they are considered biogenic, and these emissions are not included in the

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[48] Climate Action Reserve (Reserve), Organic Waste Digestion (OWD) Project Protocol Version 2.1, table B6.

Quebec GHG inventory. Therefore, estimates of GHG emissions from composting include only CH_4 and N_2O emissions.

GHG emissions from composting can be quantified using the following equations and factors.

Equation 34: Methane emissions from waste composting

$$E_{CH4} = EF_{CH4} \times Qt_{OWM} \times 0.001$$

Where:

E_{CH4} = *Annual* CH_4 *emissions from composting treatment, expressed in tonnes of* CH_4 *per year*

EF_{CH4} = *CH_4 emission factor associated with composting treatment, expressed in kilograms of* CH_4 *per tonne of organic waste materials (OWM)*

Qt_{OWM} = *Quantity of OWM processed by composting, expressed in tonnes*

0.001 = Conversion factor from kilograms to metric tonnes.

Equation 35: N_2O emissions from waste composting

$$E_{N2O} = EF_{N2O} \times Qt_{OWM} \times 0.001$$

Where:

E_{N2O} = *Annual* N_2O *emissions from composting treatment, in tonnes of* N_2O *per year*

EF_{N2O} = N_2O *emission factor associated with composting treatment, in kilograms of* N_2O *per tonne of OWM*

Qt_{OWM} = *Amount of OWM processed by composting, in tonnes*

0.001 = Conversion factor from kilograms to metric tonnes.

The table below presents the CH_4 and N_2O emission factors associated with waste composting.

Table 30. CH_4 and N_2O emission factors associated with OWM composting

Type of material	EF_{CH4} (kg CH_4 /t OWM)	EF_{N2O} (kg N_2O /t OWM)	Reference
Yard waste	1.72	0.25	NIR 1990–2019, Part 2, Table A6.7-4
Municipal solid waste	1.51	0.18	
Biosolids or manure	3.54	0.18	
Mixture of the above co-composted wastes	1.09	0.11	

3.22. GHG emissions from waste incineration or thermal treatment of hazardous materials or contaminated soil

Waste incineration or thermal treatment of hazardous materials or contaminated soils can be sources of CO_2, CH_4, and N_2O emissions. The following sections present the equations for calculating GHG emissions from these activities.

3.22.1. Fossil-based CO_2 emissions from municipal waste incineration (other than sludge)

The incineration of municipal waste generates CO_2 emissions from the fossil carbon it contains. For the non-biomass (i.e. non-biogenic) portion of municipal waste, emissions can be quantified using Equation 36 below[49]. Sludge incineration is discussed in the next section.

Equation 36: Non-biogenic CO_2 emissions from municipal waste incineration, other than sludge

$$E_{MW}\, CO_{2f} = MW \times (1 - PAB) \times EF_{MW} \times HHV_{MW} \times OF \times 0.001$$

Where:

$E_{MW}\, CO_{2f}$ = *Annual* CO_2 *emissions from municipal waste incineration in tonnes of* CO_2 *equivalent per year*

MW = *Total mass of municipal waste (wet weight) incinerated, expressed in tonnes per year*

PAB = *Biomass fraction of municipal waste*

EF_{MW} = CO_2 *emission factor associated with municipal waste (85.6 kg/GJ)*

HHV_{MW} = *Higher heating value of municipal waste, default value = 11.57 GJ/tonne of municipal waste*

OF = Oxidation factor, default value = 1 (100%)

0.001 = Conversion factor from kilograms to metric tonnes.

3.22.2. Fossil-based CO_2 emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge

Incineration and thermal treatment of waste materials generate non-biogenic CO_2 emissions from the fossil carbon contained in these materials. Equation 37 below is used to quantify these emissions[50].

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[49] Adapted from RMRCECA Equation 1-1.

[50] 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Equation 37: Non-biogenic CO_2 emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge

$$E_W\ CO_2 = \sum_i (W_i \times dm_i \times FC_i \times FFC_i \times OF_i) \times {}^{44}/_{12}$$

Where:

$E_W CO_2$ = *Annual non-biodegradable* CO_2 *emissions from the incineration or thermal treatment of non-municipal waste, in tonnes of* CO_2 *equivalent per year*

W_i = *Total amount of waste type i (wet weight) incinerated, in tonnes per year*

dm_i = *Dry matter content of waste (wet weight) incinerated, (fraction)*

FC_i = *Fraction of carbon in dry matter (total carbon content)*

FFC_i = *Fraction of fossil carbon in total carbon, (fraction)*

OF_i = *Oxidation factor, default value = 1 (100%)*

44/12 = Conversion factor of C to CO_2

i = Type of waste incinerated or thermally treated: municipal, industrial or hazardous waste, biomedical waste, or sewage sludge

Table 31 presents the carbon factor (CF) and fossil carbon factor (FCF) in waste materials to be used in Equation 37. These factors are taken from best practice guides, the 2006 IPCC[51] Guidelines, and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Table 31. Default factors for the calculation of CO_2 emissions

Types of non-municipal waste incinerated or treated	FC: Fraction of carbon in dry matter (%)	FCF: Fraction of fossil carbon in total carbon (%)	References
Industrial	50	90	1
Hazardous	50	90	2
Biomedical waste	60	40	1
Sludge:			
• Municipal	31	0	3
• Food industry	44	0	3
• Paper industry (process sludge)	28	0	3
• Paper industry (sewage sludge)	31	0	3

1. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste, Chapter 5, Table 5.2.
2. 2006 IPCC Guidelines. Volume 5: Waste. Chapter 5. Table 5.6.
3. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste, Chapter 2, Table 2.4A.

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[51] IPCC (2000). IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.

3.22.3. CH_4 emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge

CH_4 emissions from incineration or thermal treatment are mainly the result of incomplete combustion of waste materials. They are influenced by the following parameters: the technology used, the operating mode, the temperature, the residence time, and the air index. The following equation quantifies these emissions[52].

Equation 38: CH_4 emissions from incineration or thermal treatment of waste

$$E_W CH_4 = \sum_i (W_i \times EF_i CH_4) \times 0.001$$

Where:

$E_W CH_4$ = *Annual* CH_4 *emissions, expressed in tonnes of* CH_4 *per year*

W_i = *Amount of waste material of type i incinerated or thermally treated annually, expressed in tonnes per year*

$EF_i CH_4$ = CH_4 *emission factor associated with waste type i, expressed in kilograms of* CH_4 *per tonne of waste*

10^{-6}= *Conversion factor from grams to tonnes*

i = Category or type of waste incinerated or thermally treated, specified as follows:
MW: municipal waste; IW: industrial waste; HW: hazardous waste; BW: biomedical waste; and SS: sewage sludge.

The table below shows the CH_4 and N_2O emission factors for the incineration of different types of waste depending on the type of facility. These factors can be used in Equations 38 and 39.

Table 32. Default CH_4 and N_2O emission factors for incineration facilities

Type of waste	Type of feed	Type of incinerator	EF CH_4 (g/t)	EF N_2O (g/t)
Municipal solid waste	Continuous	Mechanical furnace	0.2	50
Municipal solid waste	Continuous	Fluidized bed	0	50
Municipal solid waste	Semi-continuous	Mechanical furnace	6	50
Municipal solid waste	Semi-continuous	Fluidized bed	188	50
Municipal solid waste	Batch	Mechanical furnace	60	60
Municipal solid waste	Batch	Fluidized bed	237	60
Hazardous waste	Continuous	Mechanical furnace	169.49	3,163.84
Hazardous waste	Batch	Mechanical furnace	169.49	3,163.84
Sewage sludge	Continuous	Fluidized bed	9.70	990
Sewage sludge	Continuous	Mechanical furnace	9.70	990
Medical waste	Continuous	Mechanical furnace	0.20	50
Medical waste	Batch	Mechanical furnace	60	60
Medical waste	Semi-continuous	Mechanical furnace	0.20	50
Other sludge	Continuous	Mechanical furnace	0.20	450

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[52] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Table 32. Default CH_4 and N_2O emission factors for incineration facilities

Type of waste	Type of feed	Type of incinerator	EF CH_4 (g/t)	EF N_2O (g/t)
Other sludge	Batch	Mechanical furnace	60	450
Fossil-based liquid waste	Continuous	Mechanical furnace	0.20	100
Fossil-based liquid waste	Batch	Mechanical furnace	60	100
Industrial waste	Continuous	Mechanical furnace	0.20	50
Industrial waste	Continuous	Fluidized bed	0	50
Industrial waste	Semi-continuous	Mechanical furnace	6	50
Industrial waste	Semi-continuous	Fluidized bed	188	50
Industrial waste	Batch	Mechanical furnace	60	60
Industrial waste	Batch	Fluidized bed	237	60

Source: National Inventory Report 1990-2019. Part 2. Table A3.6-12.

3.22.4. N_2O emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge calculated from emission factors

Nitrous oxide emissions are influenced by the temperature of the combustion process, the air pollution control device, the type and nitrogen content of the waste, and the air index. Equation 39 below is used to quantify these emissions.[53]

Equation 39: N_2O emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge calculated from emission factors

$$E_W N_2O = \sum_i (W_i \times EF_i N_2O) \times 0.001$$

Where:

$E_W N_2O$ = N_2O *emissions, in tonnes of* N_2O *per year*

W_i = *Amount of waste type i incinerated or thermally treated, in tonnes per year*

$EF_i N_2O$ = *N_2O emission factor associated with waste type i, in kilograms of N_2O per tonne of waste*

0.001 = Conversion factor from kilograms to tonnes

i = Category or type of waste incinerated or thermally treated, specified as follows:
MW: municipal waste; IW: industrial waste; HW: hazardous waste; BW: biomedical waste; and SS: sewage sludge.

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[53] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

3.22.5. N_2O emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge, based on flue gas concentration data

Where flue gas concentration data for N_2O is available, N_2O emissions from waste incineration can be calculated from Equation 40[54].

Equation 40: N_2O emissions from incineration or thermal treatment of municipal, industrial and hazardous waste, biomedical waste, and sewage sludge, based on flue gas concentration data

$$E_W N_2 O = \sum_i (W_i \times CE_i \times VFG_i) \times 10^{-9}$$

Where:

$E_W N_2O$ = *Annual* N_2O *emissions, in tonnes of* N_2O *per year*

W_i = *Amount of waste type i incinerated or thermally treated, in tonnes per year*

CE_i = *Concentration of* N_2O *emissions in the flue gas from the incineration of waste type i, in mg* N_2O/m^3

VFG_i = *Volume of flue gas per quantity of waste type i incinerated, in* m^3*/tonne*

10^{-9}= *Conversion factor from milligrams to tonnes*

i = Category or type of waste incinerated or thermally treated, specified as follows:
MW: municipal waste; IW: industrial waste; HW: hazardous waste; BW: biomedical waste; and SS: sewage sludge.

3.22.6. Energy recovery and associated GHG emissions reduction

If waste energy is recovered to replace fossil fuels, this contributes to reducing GHG emissions. In Quebec, there are several examples of energy being sold to nearby industries (e.g. steam network). In the case where it is planned to recover the residual energy generated, it is suggested to quantify the related GHG emission reductions. To do so, the equation provided in the section on stationary combustion systems can be used.

3.23. Emissions from wastewater treatment and discharge

These include CH_4 and N_2O emissions from municipal and industrial wastewater treatment, as well as CH_4 and N_2O emissions from untreated wastewater discharge.

3.23.1. CH_4 emissions from wastewater treatment or discharge

The methodology for estimating CH_4 emissions from wastewater treatment or discharge presented in this guide follows the recommendations of the IPCC guidelines. CH_4 emissions are estimated based on the organic matter load in the wastewater, the maximum methane production capacity (Bo), and the methane

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[54] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

correction factor (MCF), which is a function of the type of wastewater treatment performed. Equation 41 presents the methane emissions from wastewater treatment in tonnes of CH_4 per year.

Equation 41: CH_4 emissions from wastewater treatment or discharge

$$CH_4 = (EF_{CH4(treat)} \times Lo_{Org} \times Eff + EF_{CH4(dis)} \times Ch_{Org} \times (1 - Eff)) \times 0.001$$

Where:

CH_4 = CH_4 *emissions attributable to wastewater treatment and discharge, expressed in tonnes of* CH_4 *per year*

$EF_{CH4(treat)}$ = *Methane emission factor associated with wastewater treatment, expressed in kg* CH_4*/kg BOD5*

Lo_{Org} = *Total annual organic load from the wastewater treatment plant, expressed in kilograms of* BOD_5 *per year*

$EF_{CH4(dis)}$ = *Methane emission factor associated with direct wastewater discharge, expressed in kg* CH_4*/kg BOD5. Since the types of receiving water bodies may be unknown, this guide uses the Tier 1 emission factor from the 1990-2019 NIR, which is 0.0396 kg* CH_4*/kg BOD5.*

Eff = Wastewater treatment efficiency. Fraction of wastewater organic load removed during treatment.
0.001 = Conversion factor from kilograms to tonnes

Organic load is determined from the organic load rate per capita per day and an industrial and commercial input correction factor of 1.25.[55]

Equation 42: Calculation of annual organic load

$$Ch_{Org} = Pop \times BOD_{Cap.day} \times 1.25 \times 365$$

Where:

Lo_{Org} = *Total annual organic load from the wastewater treatment plant, expressed in kilograms of* BOD_5 *per year*

Pop = Population that is connected to the wastewater treatment system

BODcap.day = Organic load per capita per day = 0.06 kg BOD_5*/person/day*

1.25 = Correction factor for industrial and commercial inputs

365 = Days/year correction factor

The table below presents the methane emission factors associated with the different types of wastewater treatment.

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[55] Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste. Chapter 6. Wastewater treatment and discharge.

Table 33. Methane emission factors associated with different types of wastewater treatment		
Type of treatment	**$EF_{CH4(treat)}$ (kg CH_4/kg BOD)**	**Eff**
No treatment	0	0
Primary treatment	0.0108	0.4
Aerobic lagoon	0	0.85
Anaerobic lagoon	0.288	0.85
Facultative lagoon	0.072	0.85
Other / “unspecified” type of lagoon	0.072	0.85
Anaerobic secondary treatment	0.288	0.85
Secondary activated sludge treatment	0.0108	0.95
Bacterial bed	0.0108	0.85
Bacterial bed (high load)	0.0108	0.85
Biological discs	0.0108	0.85
Sequential biological reactors (SBR)	0.018	0.9
Secondary treatment by biofiltration	0.0108	0.95
Secondary treatment with biological nutrient removal	0.0108	0.98
Septic tank	0.18	1
Septic tank with ocean discharge	0.18	0.625
Wetlands	0.0612	0.975
Other / unknown	0.072	0.85

Source: National Inventory Report 1990-2019. Part 2. Table A3.6-14.

3.23.2. N_2O emissions from wastewater treatment or discharge

N_2O emissions can originate directly from wastewater treatment facilities or be generated indirectly from wastewater after the effluent is discharged to streams, lakes, or the sea. Direct emissions, resulting from nitrification and denitrification, at wastewater treatment facilities can be considered minor sources and therefore negligible, except for more sophisticated facilities with the capacity to nitrify and denitrify effluent (IPCC, 2006).

Equation 43 presents the N_2O emissions from wastewater treatment, expressed in tonnes of N_2O per year.

Equation 43: N_2O emissions from wastewater treatment or discharge

$$E_{N2O} = EF_{N20} \times N \times \frac{44}{28} \times 0.001$$

Where:

EN_2O = N_2O *emissions from wastewater treatment, expressed in tonnes of* N_2O *per year*

EFN_2O = N_2O *emission factor from wastewater, use Table 34*

N = Amount of nitrogen in wastewater, in kilograms of N per year

44/28 = Stoichiometric factor used to convert molecular nitrogen to N_2O

0.001 = Conversion factor from kilograms to tonnes

Therefore, according to Equation 43, N_2O emissions are directly proportional to the amount of nitrogen in the wastewater and the N_2O emission factor. The latter is characteristic of each type of treatment or discharge and can be estimated from Table 34 below.

Table 34. N_2O emission factors associated with different types of residential and industrial wastewater treatment

Type of treatment or disposal route for wastewater	Observations	EF_{N2O} (kg N_2O/kg N)
Untreated wastewater		
Discharge to freshwater, estuaries, and the sea (Tier 1)	Based on limited field data and specific assumptions regarding the occurrence of nitrification and denitrification in rivers and estuaries.	0.005
Discharge to eutrophic or hypoxic environments (Tier 3, if required)	Higher emissions are associated with hypoxic or nutrient-enriched waters, such as those in eutrophic lakes, estuaries, and rivers, or where stagnant conditions prevail.	0.019
Treated wastewater		
Centralized aerobic treatment plants	N_2O is variable and can be significant.	0.016
Anaerobic reactor	N_2O is not significant.	0
Anaerobic lagoon	N_2O is not significant.	0
Engineered wetland	Refer to the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC 2014).	
Septic tank	N_2O is not significant.	0
Septic tank and disposal field	N_2O is emitted by the disposal field.	0.0045
Latrine	N_2O is not significant.	0
Anaerobic sludge digester	N_2O is not significant.	0

Source: Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5: Waste. Chapter 6. Wastewater treatment and discharge. Table 6.3.

The total amount of nitrogen to be treated can be estimated based on the population served by the treatment plant (municipal wastewater) or the nitrogen load to be treated at the industrial wastewater treatment plant (industrial wastewater). Equations 44 and 45 are used to estimate the total amount of nitrogen to be treated for domestic wastewater and industrial wastewater, respectively.

Equation 44: Total nitrogen in municipal wastewater

$$N = Proteins \times Population \times F_{NPR} \times F_{household} \times F_{NC}$$

Where:

N = Total nitrogen in municipal wastewater, in kilograms of N per year

Proteins = Annual protein consumption per person = 69.85 kilograms per person per year[56]

Population = Population served by wastewater treatment facilities

F_{NPR} *= Fraction of nitrogen in protein = 0.16 kilogram of N per kilogram of protein*[57]

$F_{household}$ *= Additional fraction of nitrogen from household products = 1.17*[58]

F_{NC} *= Fraction of protein not consumed = 1.13*[59]

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[56] NIR 1990-2019. Part 2. Table A3.6-17.

[57] 2009 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5, Chapter 6, page 6.38.

[58] 2009 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5, Chapter 6, Table 6.10A.

[59] 2009 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5, Chapter 6, Table 6.10A.

For industrial wastewater treatment plants, Equation 45 estimates the total amount of nitrogen treated at the treatment plant by multiplying the annual flow of treated wastewater by the total influent nitrogen concentration.

Equation 45: Total amount of nitrogen present in industrial wastewater

$$N = Annual_{flow} \times CNitrogen_{Inf}$$

Where:

N = Total nitrogen in municipal wastewater, in kilograms of N per year

$Annual_{flow}$ = Annual flow of treated wastewater at the treatment plant, in cubic metres per year

$CNitrogen_{Inf}$ = Total concentration of nitrogen in the treated influent at the treatment plant, in kilograms of N per cubic metre

In the event that the type of treatment and its rate of nitrogen removal is known, Equation 46 can be used to determine the total amount of nitrogen sent to the effluent.

Equation 46: Total amount of nitrogen sent to effluent

$$N_{EFF} = N \times (1 - N_{REM})$$

Where:

N_{EFF} = Total amount of nitrogen sent to the effluent, expressed in kilograms of N per year

N = Amount of nitrogen present in industrial wastewater, expressed in kilograms of N per year

N_{REM} = Fraction of nitrogen removed during wastewater treatment, obtained from Table 35 below

Table 35. Fraction of nitrogen removed during wastewater treatment (N_{REM})

Type of treatment	Default value for nitrogen removal	Range of values for nitrogen removal
No treatment	0	0
Primary treatment (mechanical)	0.10	0.05 to 0.20
Secondary treatment (biological)	0.40	0.35 to 0.55
Tertiary treatment (advanced biological)	0.80	0.45 to 0.85
Septic tank	0.15	0.10 to 0.25
Septic tank and disposal field	0.68	0.62 to 0.73
Latrine	0.12	0.07 to 0.21

Source: Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 5, Chapter 6, Tableau 6.10c.

3.24. Hydrocarbon exploration and development

3.24.1. Context in Quebec

The adoption, on April 12, 2022, of Bill 21, an Act mainly to end petroleum exploration and production and the public financing of those activities, puts an end to hydrocarbon exploration and development activities as well as production of brine in Quebec. Historically, more than 900 oil and gas wells have been drilled in Quebec since 1860, but the industry has not developed much in the province. Three hydrocarbon exploration and development projects in Quebec have received media attention over the past decade. These projects include the potential development of shale gas in the St. Lawrence Valley, the potential development of shale gas and oil in Anticosti and Quebec, and the development of hydrocarbons from the Old Harry formation in the Gulf of St. Lawrence near the Magdalen Islands. These projects served as references for the development of the GHG emissions quantification methodologies in this guide. Despite the adoption of Bill 21, this section has been retained because some of the methodologies could be applicable to other sectors, such as the closure of orphan hydrocarbon wells in Quebec.[60]

For the quantification of GHG emissions, this section is based on the numerous reports and studies produced in the context of the various strategic environmental assessments (SEAs), on the regulations in force in Quebec (RMRCECA), in the United States (United States Environmental Protection Agency [US EPA]), and in Canada, as well as on the MELCC's Interim Guidelines for Oil and Gas Exploration[61]. In addition, some methodologies from the American Petroleum Institute (API) are used as references. Finally, among the references concerning the impacts of hydrocarbon exploration and development on GHG emissions applicable to the Quebec context, we can cite the studies of the International Reference Center for Life Cycle Assessment and Sustainable Transition (CIRAIG)[62] (2013), WSP[63] (2015), and the MELCC[64] (2013).

As the state of knowledge on this sector is not very advanced in Quebec, the precautionary principle must be applied for this type of project, and a specific process is applied to determine the sources of GHG emissions. This section as well as Appendix B present applicable methodologies to assess GHG emissions from hydrocarbon exploration and development activities.

3.24.2. Description of the sequence of operations

Appendix B presents the general sequence of operations for a typical shale oil exploration and development project (Ref: WSP, 2015). Due to the wide variability of activities related to hydrocarbon exploration and development (e.g., drilling with hydraulic fracturing or "conventional" drilling), some elements may not be

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[60] Ministère de l'Énergie et des Ressources naturelles, March 2021. Rapport sur l'état des puits d'hydrocarbures inactifs au Québec (Status report on inactive hydrocarbon wells in Quebec).

[61] MELCC, 2014 : Lignes directrices provisoires sur l'exploration gazière et pétrolière. 200 pages

[62] CIRAIG, 2013. Rapport synthèse des résultats du CIRAIG sur l'impact des émissions de GES de la filière du gaz de schiste au Québec (Summary report on the CIRAIG's findings about the impact of GHG emissions from Quebec's shale gas industry). http://www.bape.gouv.qc.ca/sections/mandats/gaz_de_schiste-enjeux/documents/PR3.6.24.pdf.

[63] WSP, October 2015. Élaboration d'un projet type concernant les activités d'exploration et d'exploitation du pétrole et du gaz à Anticosti (Sample project preparation regarding oil and gas exploration and development activities in Anticosti). Study AENV17, https://mern.gouv.qc.ca/energie/filiere-hydrocarbures/etudes/AENV17.pdf.

[64] MELCC, December 2013. Rapport synthèse des résultats du CIRAIG sur l'impact des émissions de GES de la filière du gaz de schiste au Québec (Summary report on the CIRAIG's findings about the impact of GHG emissions from Quebec's shale gas industry). http://www.bape.gouv.qc.ca/sections/mandats/gaz_de_schiste-enjeux/documents/PR3.6.24.pdf.

identified in the guide or, alternatively, may cover a broader spectrum. In any case, it is important to identify all phases, activities, and equipment that have GHG emissions impacts as part of the project.
The following is a summary of the main phases and activities to be considered in the quantification of GHG emissions (non-exhaustive list).

A. RAW MATERIAL SUPPLY (UPSTREAM)

B. PRELIMINARY WORK
  - Geophysical and other surveys, sampling and testing
  - Site preparation

C. EXPLORATION
  - Drilling of boreholes and wells
  - Hydraulic fracturing
  - Production testing

D. PILOT PROJECT/DEVELOPMENT
  - Well drilling
  - Hydraulic fracturing
  - Production testing

E. HYDROCARBON PRODUCTION
  - Oil-water separation
  - Pumping of hydrocarbons
  - Gas compression
  - Gas dehydration
  - Gas decarbonation
  - Natural gas transfer
  - Natural gas liquefaction
  - LPG storage
  - Condensate storage
  - CO_2 sequestration

F. TRANSPORTATION AND DISTRIBUTION
  - Transport by pipeline, gas pipeline, ship, train, or truck

G. FINAL CLOSURE
  - Decommissioning of surface equipment
  - Closing of wells
  - Site reclamation

H. WASTE AND TAILINGS MANAGEMENT
  - Sludge and spoil

- Wastewater
- Air emissions
- Accidental releases
- Equipment management

I. POST-CLOSURE MONITORING

- GHG emissions monitoring program, including fugitive emissions

3.24.3. Equation-based GHG emissions calculations

GHG emission sources should be identified in a clear and detailed manner, and GHG emissions should be quantified for each phase and activity. This allows for a clear identification of the most GHG-emitting activities and potentially gives an overview of possible mitigation measures. In particular, activities related to hydrocarbon extraction and well production testing (Phases D and E) should be detailed, given their associated emission potential.

The table below provides examples of emission sources that must, at a minimum, be considered. The formulas and methodologies proposed are for illustrative purposes. Other methodologies or references could be used depending on the specific needs of the project. If so, they must be well documented and based on reliable and verifiable sources.

Table 36. GHG emission sources and references for quantification

No.	SOURCES - COMBUSTION	REFERENCES - QUANTIFICATION
1	Internal combustion engine, diesel or otherwise, for transporting materials, equipment or process-specific inputs, including air, sea, and land transport by rail or truck	RMRCECA Protocol QC.27
2	Internal combustion engine, diesel or otherwise, for mobile equipment (off-road machinery, pumping trucks, mixing equipment, etc.)	RMRCECA Protocol QC.27
3	Internal combustion engine, diesel or otherwise, for passenger transportation if applicable, including air, sea, and land (rail or truck)	RMRCECA Protocol QC.27 (methodology applicable even if transportation of people is initially excluded) and API Guide Section 4.8
4	Internal combustion engine, diesel or otherwise (including natural gas or ethane) for generator sets (local power generation) or other stationary equipment such as compressors and pumps	RMRCECA Protocols QC.1 and QC.16 (generators)
5	Oil, diesel, natural gas, ethane, or other fuel-fired boilers and heaters (heat production - e.g., for frac water or gas heating or glycol regeneration)	RMRCECA protocol QC.1
No.	SOURCES - COMBUSTION	REFERENCES - QUANTIFICATION
6	Flare or other gas destruction equipment (burn pit)	RMRCECA Protocol QC.33.3.13 or API Guide Section 4.6 for flares and RMRCECA Protocol QC.1 for all other equipment
7	Incinerator, thermal or catalytic oxidizer	RMRCECA Protocol QC.1 (incinerator) and API Guide Section 4.7
8	Oil, ethane, natural gas, diesel or other fossil fuel-fired power plant for local electricity generation (including cogeneration)	RMRCECA Protocol QC.16 and API Guide Section 7.2
	SOURCES - PROCESSES	

Table 36. GHG emission sources and references for quantification

No.	SOURCES - COMBUSTION	REFERENCES - QUANTIFICATION
9	Process micro-leaks - flanges and fittings (piping or equipment), manual or control valves, instruments, etc.	RMRCECA Protocol QC.33.3.16/17 and API Guide Section 6.1.3
10	Safety valve openings (one-time events)	Sections 5.7 and B7.3 of the API Guide
11	Compressor vents (centrifugal or reciprocating)	RMRCECA Protocols QC.33.3.14/15
12	Well gas or natural gas pneumatic actuator vents	RMRCECA QC.33.3.1/2 protocols and API Guide Section 5.6.1
13	Well gas or natural gas air pump vents	RMRCECA Protocol QC.33.3.1 and API Guide Section 5.6.2
14	End product or transfer tank vents (oil, condensate, etc.)	RMRCECA Protocol QC.33.3.9 and API Guide Section 5.4.1/2/4
15	Fuel tank vents (diesel or other)	Chapter 7 of the US EPA AP42 Guide
16	Flowback water storage tank vents	API Guide Section 5.4.3
17	Drilling mud degassing	API Guide Section 5.6.3
18	Emissions from water treatment or flowback tanks	API Guide Section 6.2.1
19	H_2S (acid gas) scrubbing equipment	RMRCECA Protocol QC.33.3.3 and API Guide Section 5.1.5
20	Glycol regenerator vents (dehydrators)	RMRCECA Protocol QC.33.3.4 and API Guide Section 5.1/3/4
21	Gas separators	See references associated with the following sources, as applicable: process micro-leaks - flanges and fittings, fugitive emissions from completion and flaring
22	Equipment blowdowns for maintenance or other purposes	RMRCECA Protocol QC.33.3.7 and API Guide Section 5.7.2
No.	SOURCES - OTHER LOSSES	REFERENCES - QUANTIFICATION
23	Fugitive emissions during completion (including fracturing), workover, or production testing (CO_2 or methane)	RMRCECA Protocols QC.33.3.6 and QC.33.4.6 and API Guide Section 5.7.2
24	Venting of gas from wells into the atmosphere (no flare or not operating) during production testing	RMRCECA Protocol QC.33.3.11 and API Guide Section 5.7.2
25	Fugitive emissions from wellhead vents (CO_2 or methane)	RMRCECA Protocols QC.33.3.5 and QC33.3.11
No.	SOURCES - COMBUSTION	REFERENCES - QUANTIFICATION
26	Fugitive emissions with flowback water during fracturing	See references for the following sources: flowback tank and gas separator
27	Losses during filling (truck, train or ship) and ballasting operations	Sections 5.5.1 and 5.5.2 of the API Guide
No.	SOURCES - OTHER	REFERENCES - QUANTIFICATION
28	Emissions from the use of explosives	Section 3.7 of this guide
29	Deforestation during construction	Sections 3.10.1 and 3.10.2 of this guide
30	Off-site electricity generation (indirect)	Section 3.3 of this guide
31	Off-site heat (steam) or cold (chilled water) generation (indirect)	Sections 7.1.5 and 7.1.6 of the API Guide
32	Emissions from construction activities (buildings, related facilities, oil and gas pipelines, tanks, etc.)	See the references associated with the following source: mobile or stationary combustion equipment
33	Fugitive emissions due to the use of refrigeration or air conditioning equipment	Section 3.9 of this guide and Section 6.4.1 of the API Guide
34	Any other source associated with the project	To be specified in the calculation

3.24.4. Calculation of GHG emissions based on emission rates

If the project includes an air dispersion study for contaminants, the emission rate method could be used for the project-specific greenhouse gases from each source. Studies conducted as part of strategic environmental assessments can be referenced for methodological examples (WSP, 2015[65] and SNC-Lavalin, 2013[66]). Details of the methodology used must be provided.

3.24.5. Presentation of results

At a minimum, the following elements should be included in the description of the GHG assessment methodology:

- The detailed sequence of operations;
- The list of equipment required to carry out the activities and their operating parameters;
- The GHG emission sources, including fugitive emissions;
- The emission factors and models;
- The duration of the activities and use of the equipment;
- The physical characteristics of the site that impact GHGs (e.g., number of well pads and pad size);
- The properties and characteristics of the hydrocarbons considered in the calculations (e.g., heating value, gas composition, liquid hydrocarbon composition, CO_2 concentration in the gas or liquid hydrocarbon, sulfur composition, and production rate);
- The references and data sources used for quantification (e.g., RMRCECA, US EPA, API).

For the presentation of results, a table of GHG emissions must be provided for each phase of the project. Emissions must be broken down by emitting activities or equipment, by type of gas, and in CO_2 equivalent. Appendix B provides sample tables of results that the quantification report should minimally include.

3.25. Direct GHG emissions from natural gas processing, transportation and distribution

The primary sources of GHG emissions involved in natural gas processing (operations) are:

- hydrocarbon or condensate extraction;
- water extraction;
- separation of liquefied natural gas;
- extraction of hydrogen sulfide (H_2S) and CO_2;
- liquid fraction present in natural gas;
- capture of CO_2 extracted from natural gas for delivery outside the facility;
- gathering or auxiliary stations and natural gas from multiple wellheads;
- any other treatment process.

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[65] WSP, October 2015. Élaboration d'un projet type concernant les activités d'exploration et d'exploitation du pétrole et du gaz à Anticosti (Sample project preparation regarding oil and gas exploration and development activities in Anticosti). Study AENV17, https://mern.gouv.qc.ca/energie/filiere-hydrocarbures/etudes/AENV17.pdf.

[66] SNC-Lavalin, 2013. Détermination des taux d'émission et modélisation de la dispersion atmosphérique pour évaluer l'impact sur la qualité de l'air des activités d'exploration et d'exploitation du gaz de schiste au Québec (Emission rate determination and air dispersion modelling to assess the impact of shale gas exploration and development on air quality in Quebec). https://voute.bape.gouv.qc.ca/dl/?id=00000362189

For all these sources, annual emissions of CH_4, CO_2 and N_2O can be determined using Protocol QC.33 of the RMRCECA.

Natural gas transportation and distribution activities emit mainly CH_4 and, to a lesser extent, CO_2 and N_2O. The emission sources targeted in the operational phase are all the processes and equipment used to transport and distribute natural gas. The main sources include:

- compression of natural gas for land transportation;
- storage of natural gas and liquefied natural gas (LNG);
- import and export of LNG;
- natural gas transmission pipelines;
- natural gas distribution;
- flares associated with the transmission and distribution system.

Annual emissions of CH_4, CO_2, and N_2O can be determined using Protocol QC.29 of the RMRCECA.

Recent advances have shown that fugitive methane emissions could be more significant than initially anticipated. This is why several countries, including Canada, have decided to establish a specific framework for this issue. In 2020, the Canadian government adopted the Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector)[67]. In addition to GHGs, these regulations also aim to control emissions of volatile organic compounds (VOCs) that are found with methane. Thus, fugitive methane emissions must be clearly identified and detailed in the calculations. If no formula provided by RMRCECA allows for an exhaustive calculation, another methodology can be used. The RMRCECA also lists several alternative methodologies, such as the one published by Clearstone Engineering Ltd. or the Canadian Gas Association's methodology. Where appropriate, the methodology should be detailed and based on reliable and verifiable assumptions. For example, it may be possible to use emission factors per kilometre of pipe from existing networks in Quebec, based on the type of pipe material and gas pressure. In the absence of local data, IPCC emission factors can be used.[68]

For emissions in the construction phase, refer to sections on stationary and mobile combustion systems.

NOTE: Indirect emissions from naturel gas pipeline transportation are presented in the section on indirect upstream or downstream emissions attributable to certain projects.

3.26. Direct GHG emissions from the transportation of liquid hydrocarbons by pipeline

Direct emission sources during the operational phase are related to all processes and equipment used for transportation and distribution.Table 36 in the previous section presents the different activities that can take place during the transportation of hydrocarbons by pipeline and provides the related quantification

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[67] Canada's methane regulations for the upstream oil and gas sector – Canada.ca. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/proposed-methane-regulations-additional-information.html

[68] IPCC, 2019. https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/2_Volume2/19R_V2_4_Ch04_Fugitive_Emissions.pdf

references. Several of the calculation methods refer to the RMRCECA or the American Petroleum Institute (API) guide. Due to the variability of activities and since the list provided is not necessarily exhaustive, the emission sources and calculations must be detailed for each activity. If there is no formula provided in Table 36 that allows for a comprehensive calculation, an alternative methodology may be used. If so, the methodology must be detailed and based on reliable and verifiable assumptions.

For emissions in the construction phase, refer to sections on stationary and mobile combustion systems.

NOTE: Indirect emissions attributable to the transportation of hydrocarbons by pipeline are presented in the section on indirect upstream or downstream emissions attributable to certain projects.

3.27. Indirect upstream or downstream emissions attributable to certain projects

Indirect emissions, as mentioned in the general concepts in Section 2.2.3, belong to a different category of GHG emissions than those presented in the previous sections. They differ in that they are neither generated within the project nor controlled by the project owner. These emissions can be generated "upstream" or "downstream" of a project or "over the life cycle."
When is it required to consider upstream or downstream indirect emissions? It depends on each case.

Example 1: To achieve social acceptability, a project conducted within Quebec may require an upstream GHG emissions assessment if citizens or organizations are concerned that it may cause damage outside of Quebec. The substitution of gasoline with bioethanol from palm oil obtained through clear-cutting in Asia would be a good example.

Example 2: Downstream indirect emissions are especially relevant to transportation projects, whether it be to know the emissions from additional users once the project is completed (e.g., new highway) or those that the project will help avoid in the future (e.g., public transit or modal shift, decreased road congestion, etc.).

The following sections provide examples of how indirect upstream or downstream emissions attributable to specific projects can be calculated. The life cycle assessment approach is also presented.

3.27.1. Upstream GHG emissions from hydrocarbon pipeline projects[69]

The calculation of GHG emissions can be done using one of the two methodologies presented below. The use of another methodology must be supported by appropriate justifications and detailed references.

3.27.1.1. Methodology for calculating upstream emissions proposed by Environment and Climate Change Canada (ECCC)

According to ECCC's approach[70], the upstream GHG assessment consists of two parts: (A) a quantitative estimate of GHG emissions associated with the project; and (B) an assessment of the potential impact of

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[69] The term "pipeline" used in this guide refers to both oil and gas pipelines. The term "hydrocarbons" includes oil, gas, and other petroleum products.

[70] Environnement and Climate Change Canada-ECCC, 2016. Estimating upstream GHG emissions. https://gazette.gc.ca/rp-pr/p1/2016/2016-03-19/html/notice-avis-eng.html

the project on Quebec, Canadian and global GHG emissions. For the purposes of an assessment in Quebec, only part (A) is required. Part (B) is optional.

The quantitative GHG estimate (A) will focus on emissions from upstream activities exclusively associated with the project. This estimate will consider emissions from combustion, fugitive emissions, venting, and flaring. It will not consider indirect emissions such as those associated with equipment manufacturing, land use change, grid electricity, and fuels produced elsewhere, unless they are indistinguishable from upstream emissions.

(Optional) Discussion component (B) will assess the conditions under which the upstream emissions estimated in Part A may occur even if the project is not carried out. This may require an assessment of projected hydrocarbon production with and without the project, under different price scenarios, possible transportation scenarios and "alternative" markets, costs, and other Canadian and global market conditions. The discussion will also explore the potential impact of GHG emissions associated with the project on GHG emissions in Quebec, on overall emissions in Canada, and, where possible, on global GHG emissions.

For example, for a hydrocarbon pipeline project, which requires an upstream GHG emissions assessment, see the equations in the referenced ECCC document available on the ECCC website (https://gazette.gc.ca/rp-pr/p1/2016/2016-03-19/html/notice-avis-eng.html).

3.27.1.2. Calculation methodology based on the estimated intensity of GHG emissions from upstream oil and gas operations

GHG emissions intensity can be expressed in grams of CO_2 equivalent per megajoule of energy produced, kilograms of CO_2 equivalent per barrel of oil equivalent, kilograms of CO_2 equivalent per cubic metre of natural gas, etc. In the literature, several studies present the intensity of GHG emissions from the production of "conventional" and "unconventional" hydrocarbons. By estimating the proportion of each type of hydrocarbon transported by the pipeline, it is possible to calculate the GHG emissions upstream of the project. The calculation methodology used must be detailed and based on reliable and verifiable assumptions.

3.27.2. Modal shift in passenger transport and reduction of associated GHG emissions

Transportation projects can influence the mode of transportation chosen by users. For example, the creation of a dedicated public transit lane can be an incentive to change modes. Public transit produces fewer GHG emissions per passenger per kilometre than private cars.

Therefore, once the reduction in car travel or trucking resulting from the project has been determined, it is possible to estimate the reduction in GHG emissions from the modal shift achieved by the project.

The reduction in GHG emissions associated with the modal shift resulting from the project can be determined from Equation 47[71]

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[71] Golder Associates. Rapport de quantification des émissions de GES évitées par le transport collectif dans la région métropolitaine de Montréal (Quantification report on GHG emissions avoided through public transit in the greater Montreal area). November 2016.

Equation 47: GHG emissions attributable to project impacts on a modal shift

$$ER_{GHG\_PT} = Passenger\_km(km/year) \times t_{TM}(\%) \times t_{FC}\left(\frac{l}{km}\right) \times EF_{fuel}(\frac{kgCO_{2e}}{l}) \times 0.001$$

Where:

ER_{GHG_PT} = Reduction of GHG emissions from passenger transportation, expressed in tonnes of CO_2 *equivalent per year*

Passenger_km = Total distance travelled by passengers per year, expressed in kilometres per year

t_{MS} = Modal shift rate (%)

t_{FC} = Average fuel consumption rate of cars, expressed in litres per kilometre

EF_{fuel} = Emission factor associated with fuel, expressed in kilograms of CO_2 *equivalent per litre*

0.001 = Conversion factor from kilograms to tonnes

The modal shift rate can be determined in three different ways: from a user survey, based on a regional transportation model, or by default values based on the size of the population served.

3.27.3. Indirect emissions or emission reductions due to traffic flow and road congestion

The methodologies presented in this section can be applied in two different contexts. In the first context, the calculations are used to assess the additional emissions induced by a road project if there is an increase in light and heavy vehicle flows. In the second context, the same methodologies are used to assess the reduction in GHG emissions attributable to a transportation project if there is a decrease in traffic flow (public transit, dedicated lane, etc.). **In other words, the same methodologies can be applied in both contexts, but, depending on the case, they will be used to calculate emissions or emission reductions.**

Some road projects modify the flows and performance of roadway systems. Tools leveraging GHG emission models through a representation of the transportation supply and demand system, at a given territory scale, help paint a picture of the impact of a project on GHG emissions from the movement of people.

The drivers of GHG emissions from road projects can be grouped into two main categories:

- Fleet data: vehicle types (passenger cars, light-duty vehicles, heavy trucks, two-wheelers, etc.), engines and fuels (gasoline, diesel, or electric, etc.), equipment, age of the fleet, and so on.
- Conditions of use (traffic data): annual distance traveled, average trip length, networks used (which may affect traffic speeds), weather conditions, driving behavior, etc.

Using fleet and traffic data, it is possible to model current and future GHG emissions. Several tools can be used to model traffic and GHG emissions. For example, the Emme software[72] allows to model traffic congestion, and the MOVES software[73] from US EPA allows to model associated GHG emissions.

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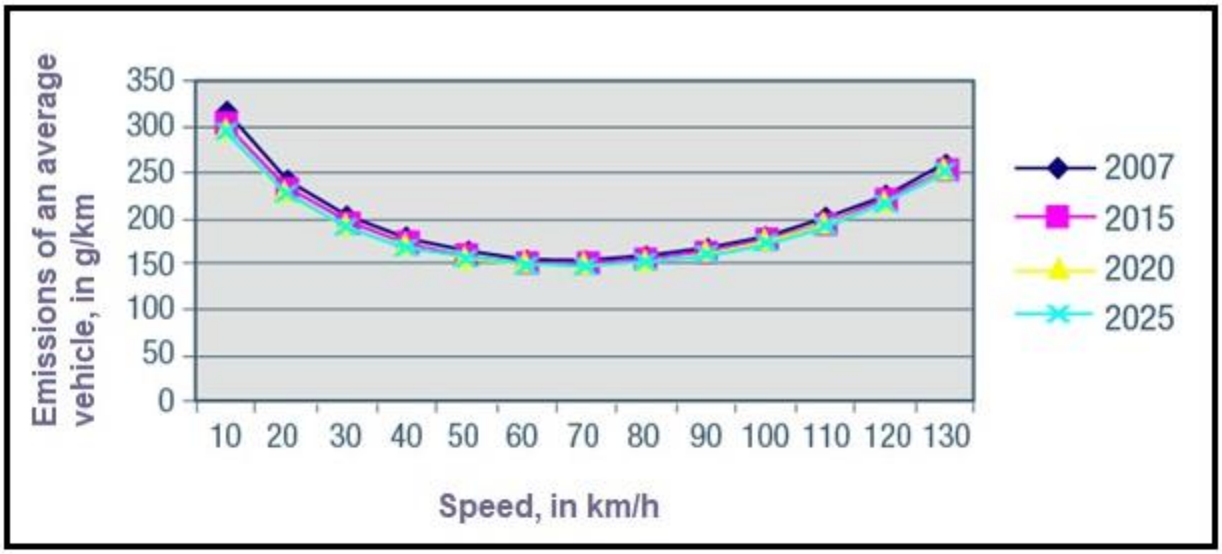
[72] Emme software: https://www.inrosoftware.com/en/products/emme//.

[73] MOVES2014a: http://www.epa.gov/otaq/models/moves/index.htm.

In addition, traffic congestion influences vehicle fuel consumption. Therefore, the impact of projects on traffic congestion must also be presented. The latter category of emissions may be significant in cities where traffic congestion is already high. Several models and approaches have been designed to determine the relationship between the level of congestion and GHG emissions.[74,75 and 76]

Figure 4 presents a graph of the effects of congestion on GHG emissions, and Figure 5 presents a simplified diagram of modeling performed with the Emme and MOVES software.

Figure 4. Effects of traffic congestion and vehicle speed on GHG emissions



Source: Adapted from the Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME)[77]

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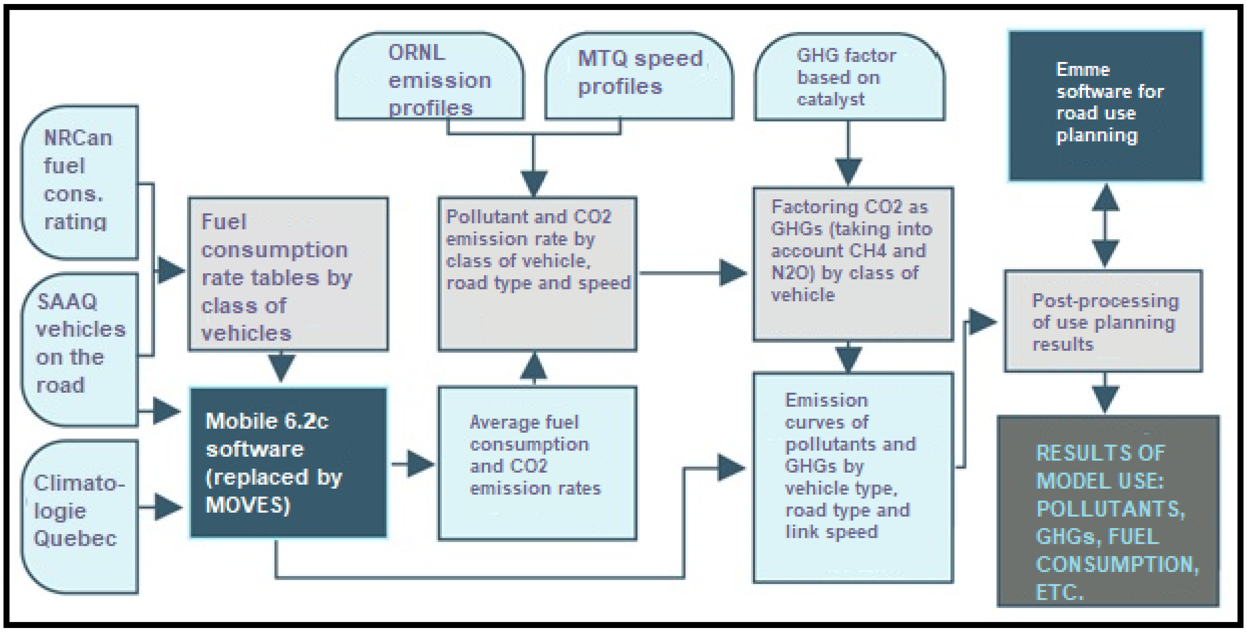
[74] APTA Climate Change Standards Working Group. Recommended Practice for Quantifying Greenhouse Gas Emissions from Transit. APTA 2009. http://www.apta.com/

[75] INRIX GLOBAL TRAFFIC SCOREBOARD, February 2018. http://inrix.com/scorecard//.

[76] MOVES2014a (Motor Vehicle Emission Simulator). US EPA. https://www.epa.gov/moves.

[77] ADEME, 2014. Impacts des limitations de vitesse sur la qualité de l'air, le climat, l'énergie et le bruit (Impacts of speed limits on air quality, climate, energy, and noise). https://www.ademe.fr/sites/default/files/assets/documents/adm00013623_synthese_etude-limitation-de-vitesse_fev2014.pdf.

Figure 5. Simplified diagram of the use of traffic models



Source: Adapted from the Ministère des Transports du Québec

3.27.3.1. Indirect emissions associated with urban sprawl

With the current state of knowledge, it is not yet possible to confidently estimate GHG emissions associated with urban sprawl. As knowledge is quickly expanding, if reliable, rigorous and well-documented methods exist to assess the impact of commuting on urban sprawl, an assessment of the resulting GHG emissions shall be presented. This assessment should describe the methodology in detail and present detailed calculations with supporting assumptions and references.

3.27.4. Indirect emissions from various modes of freight transportation (truck, train, and ship)

If a project may result in a change in freight transportation patterns, the indirect GHG emissions (or reductions) can be determined by the difference between the GHG emissions of the freight transportation scenario proposed by the project (future scenario) and the freight transportation scenario without the project (current scenario).

As previously shown, Equation 48, developed by Natural Resources Canada (NRCan), calculates the difference between the freight GHG emissions associated with the project and those of the current scenario.

Equation 48: Indirect emissions from project impacts on freight transportation

$$\Delta E_{PMS} = E_{PFT} - E_{CFT} = \left[\left(t_{truck} \times d_{truck} \times EF_{truck} + t_{rail} \times d_{rail} \times EF_{rail} + t_{ship} \times d_{ship} \times EF_{ship}\right)_P - \left(t_{truck} \times d_{truck} \times EF_{truck} + t_{rail} \times d_{rail} \times EF_{rail} + t_{ship} \times d_{ship} \times EF_{ship}\right)_{BFP}\right] \times 0{,}001$$

Where:

ΔE_{PMS} = Change in GHG emissions attributable to the project's modal shift impacts in the freight sector, expressed in tonnes of CO_2 *equivalent per year*

E_{PFT} = Freight transportation GHG emissions expected after project implementation, expressed in tonnes of CO_2 *equivalent per year*

E_{CFT} = GHG emissions from freight transportation in the current scenario (before project implementation), expressed in tonnes of CO_2 *equivalent per year*

P = Scenario with project

BFP = Scenario before the project

t_{truck} = Total annual tonnage transported by truck

t_{rail} = Total annual tonnage transported by train

t_{ship} = Total annual tonnage transported by ship

d_{truck} = Total annual trucking distance, expressed in kilometres

d_{rail} = Total annual distance of transport by train, expressed in kilometres

d_{ship} = Total annual distance of transport by ship, expressed in kilometres

EF_{truck} = Emission factor associated with trucking, expressed in kilograms of CO_2 *equivalent per tonne per kilometre*

EF_{rail} = Emission factor associated with rail transportation, expressed in kilograms of CO_2 *equivalent per tonne per kilometre*

EF_{ship} = Emission factor associated with shipping, expressed in kilograms of CO_2 *equivalent per tonne per kilometre*

Table 37 presents GHG emission factors associated with different modes of freight transportation.

Table 37. GHG emission factors associated with different modes of freight transport, in kilograms of CO_2 equivalent per tonne transported per kilometre

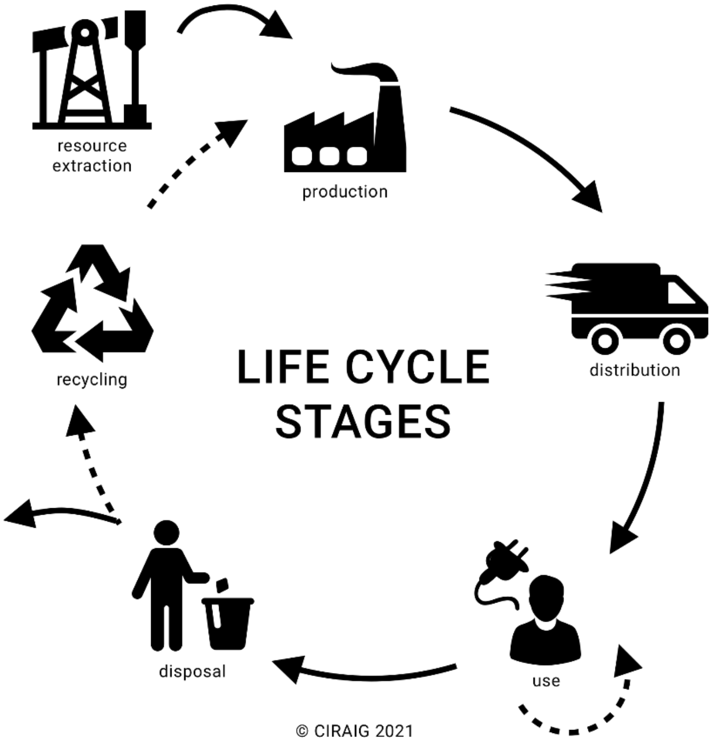
Mode of transportation	Emission factor (kg CO_2 eq./tkm*)	Source: Natural Resources Canada
Truck	0.1873	Heavy-duty diesel trucks. GHGenius, version 4.03 or later, "Freight Emissions" page.
Rail	0.0191	GHGenius, version 4.03 or later, "Freight Emissions" page.
Ship	0.0057	GHGenius, version 4.03 or later, "Freight Emissions" page.

**Tonne-kilometre of transportation*

3.27.5. Life cycle assessment

Life cycle assessment (LCA) is a methodology used to evaluate a product or service's environmental impacts during all or a part of its life cycle. This encompasses all the steps from extraction and transportation of raw materials to manufacturing, distribution, consumption or use, and ultimately disposal (including the reuse and recycling phases, if applicable). The LCA approach is illustrated below.

Figure 6. Simplified diagram of life cycle assessment steps



Source : adapted from the International Reference Centre for Life Cycle Assessment and Sustainable Transition (CIRAIG) (https://ciraig.org/index.php/life-cycle-assessment/).

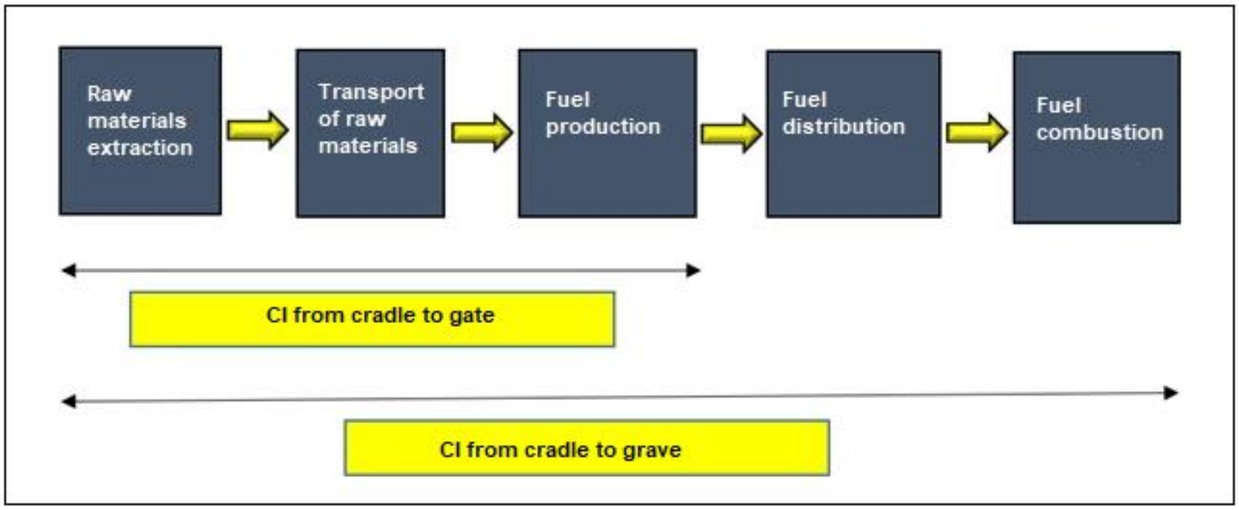
Applied in the field of GHG emissions, the LCA is used to estimate the carbon footprint of a product or a service.

Some examples where life cycle assessment has been conducted in Quebec are oil and gas development, pipeline projects, and road or public transportation projects.

3.27.6. Carbon footprint of fuels used in Canada (New)

This section presents the carbon footprint, expressed in terms of carbon intensity (CI), of different fuels used in Canada, assessing GHG emissions at different stages of the life cycle, as illustrated in Figure 7.

Figure 7. Life cycle steps considered in the calculation of the CI of fuels



According to Figure 7, depending on the life cycle stages of the fuel, two types of CI values can be calculated:

- Well-to-gate[78] CI: This CI value includes emissions at the life cycle stages of feedstock production and transport, as well as fuel production at the plant;
- Well-to-wheel CI: This CI value is also referred to as the CI value for the full life cycle of the fuel. In addition to the life cycle stages included in the well-to-gate CI, the well-to-wheel CI value also includes emissions from the distribution and combustion stages of the fuels.

The table below shows the CIs, expressed in grams of CO_2 equivalent per MJ, for most fuels produced or distributed in Canada. For liquid fossil fuels, the Oil Production Greenhouse Gas Emissions Estimator (OPGEE) version 2.0 model was used to estimate GHG emissions from the extraction, processing, and transportation of crude oil. The natural gas CI was estimated using a weighted average based on natural gas production in Alberta and British Columbia and natural gas imported from the United States.

Table 38. Carbon intensity (CI) of fuels produced or distributed in Canada, expressed in grams of CO_2 equivalent per MJ

Fuel	Total CI from cradle to gate (mean value)	Total CI from cradle to grave (mean value)
Biodiesel, camelina	16	16
Biodiesel, canola	24	24
Biodiesel, yellow grease	7.6	7.6
Biodiesel, soy	29	29
Biodiesel, beef tallow	21	21
Bioethanol	45	45
Non-marketable round wood, dry basis	6.9	6.9
Aviation fuel	19	88
Coal	6.5	100
Petroleum coke	22	101
Wood chips, dry basis	6.9	6.9

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[78] The term “gate” refers to the gate of the production plant.

Table 38. Carbon intensity (CI) of fuels produced or distributed in Canada, expressed in grams of CO_2 equivalent per MJ

Fuel	Total CI from cradle to gate (mean value)	Total CI from cradle to grave (mean value)
Diesel	25	96
HPRD, canola[79]	54	54
HRDC, palm oil[80]	24	24
Gasoline	24	96
Cellulosic ethanol, corn stover	-6.4	-6.4
Cellulosic ethanol, wheat straw	-8.8	-8.8
Ethanol, corn	42	42
Natural gas	15	65
Compressed natural gas (CNG)	19	67
Liquefied natural gas (LNG)	27	77
Liquefied petroleum gas (LPG)	16	83.6
RNG, anaerobic digestion of organic matter	26	26.3
RNG, landfill	5.9	6.2
Wood pellets, dry basis	20.9	20.9
Kerosene	19	87
Fuel oil, light	24	95
Fuel oil, heavy	23	98
Fuel oil for stoves	24	92
Propane	16	75

Source : Fuel Life Cycle Assessment Model. ECCC (2021)

3.28. Emissions from black carbon

Black carbon is an aerosol (airborne particles) emitted during the combustion process that has a short atmospheric lifetime and has global warming and health effects (refer to Appendix E). Black carbon is not emitted on its own; it is part of particles with a diameter of 2.5 microns or less ($PM_{2.5}$), along with other components.

To date, black carbon emissions are not accounted for in national GHG emissions inventories under the United Nations Framework Convention on Climate Change (UNFCCC). However, the climate impact of black carbon emissions is very significant. After CO_2, black carbon is considered the second most important anthropogenic source of global warming.[81]

Appendix E provides more detail on black carbon and its impacts. This section will focus on quantifying the associated GHG emissions.

For the calculation of black carbon emissions, two important assumptions are made: 1) black carbon is emitted primarily as $PM_{2.5}$; and 2) only $PM_{2.5}$ emissions from combustion contain a significant amount of black carbon. Therefore, black carbon emissions are calculated by the amount of $PM_{2.5}$ emitted from the combustion process, multiplied by the proportions of black carbon specific to each source.[82]

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[79] Renewable diesel produced by hydrogenation

[80] Without taking into account land use change

[81] Greene S., Smart Freight Centre Adviser. Black Carbon Methodology for the Logistics Sector. https://www.ccacoalition.org/en/resources/black-carbon-methodology-logistics-sector.

[82] Canada's Black Carbon Inventory Report—2019 Edition. https://publications.gc.ca/collections/collection_2019/eccc/En81-25-2019-eng.pdf.

Diesel engines have both significant $PM_{2.5}$ emission rates and relatively high proportions of black carbon in these $PM_{2.5}$. They are, therefore, one of the major sources of black carbon emissions. Other combustion sources with high $PM_{2.5}$ emissions include solid fuel combustion units such as coal and wood boilers and residential combustion equipment (fireplaces, wood stoves, etc.).

The commercial-, residential-, and institutional-sector black carbon emission sources include firewood burning and fossil fuel burning in commercial establishments, institutional establishments, and homes.

The transportation and mobile equipment category includes air, marine, road, off-road, and rail transportation. On-road and off-road diesel engines are the largest source of black carbon emissions in this category.

In terms of methodology for calculating black carbon emissions, this guide follows the recommendations from the report "North American Black Carbon Emissions Estimation Guidelines: Recommended Methods for Estimating Black Carbon Emissions," developed in November 2015 by the Commission for Environmental Cooperation (CEC)[83].

The guidelines adopt the three-tier structure used by the IPCC and adopted by the European practice community to establish best practices. In the IPCC and European inventory guidance documents (IPCC, 2006; EMEP/AEE, 2013[84]), these three tiers differ in the level of detail required for the activity and emission factors, and in the level of detail of the resulting inventory, with Tier 1 being the most general and Tier 3 being the most detailed. The tiers provide estimation options that depend on the available data and the purpose of the inventory. Typically, a Tier 1 method uses national fuel data and $PM_{2.5}$ and black carbon speciation factors grouped by activity type. A Tier 2 method is similar to a Tier 1 method, but the emission factors are characterized by technology type. Tier 3 methods, where they can be applied, are generally considered the most accurate and are characterized by a much higher level of detail than the other two methods.

In general, these methods are based on an estimate of $PM_{2.5}$ emissions, which is then converted to an estimate of black carbon emissions using a speciation factor. This speciation factor represents the fraction of $PM_{2.5}$ that is black carbon, and its value depends on the fuel type and technology used.

Tier 1 and Tier 2 calculation methods are suggested in this guide.

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[83] http://www.cec.org/files/documents/publications/11629-north-american-black-carbon-emissions-recommended-methods-estimating-black-en.pdf.

[84] EMEP/AEE (European Monitoring and Evaluation Programme [Cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe] and European Environment Agency). 2013. EMEP/EEA air pollutant emission inventory guidebook 2013. Technical report No 12/2013. Doi: 10.2800/92722. Online: www.eea.europa.eu/publications/emep-eea-guidebook-2013.

3.28.1. Calculation of black carbon emissions from stationary combustion systems

Stationary combustion systems generating black carbon emissions are used for the following purposes: power generation; oil and natural gas production, processing and refining; and manufacturing (including systems employing stationary diesel engines and industrial, commercial, and institutional boilers).

Fine particles ($PM_{2.5}$) and black carbon are emitted into the atmosphere as a result of the use of different types of fuels (coal, fuel oil, diesel, natural gas, LPG, biomass, etc.).

Black carbon emissions from stationary combustion systems are estimated based on the activity's fuel consumption multiplied by a $PM_{2.5}$ emission factor per unit of fuel consumed, as well as a speciation factor that converts $PM_{2.5}$ emissions to black carbon emissions.

3.28.1.1. Tier 1 calculation of black carbon emissions from stationary combustion systems

The Tier 1 method estimates black carbon emissions based on fuel consumption and a default emission factor determined according to the type of fuel used in the industry. The Tier 1 method is based on Equation 49 below.

Equation 49: Black carbon emissions from stationary combustion sources (Tier 1)

$$E_{BC} = \sum_{i,j} \left(Q_{i,j} \times EF_{i,j,PM2,5} \times SF_{i,j,BC/PM2.5} \right) \times 0.001$$

Where:

E_{BC} = *Annual black carbon emissions from fuel combustion, in kilograms per year*

i = *Type of fuel*

j = *Type of industry*

$Q_{i,I}$ = *Quantity of fuel type i consumed annually in industry j*

$EF_{i,j,PM2.5}$ = *$PM_{2.5}$ emission factor associated to fuel "i" and industry "j"*

$SF_{i,j,BC/PM2.5}$ = *Speciation factor to convert $PM_{2.5}$ to black carbon for fuel type i*

0.001 = Conversion factor from grams to kilograms

Table 39 and Table 40 present Tier 1 $PM_{2.5}$ emission factors and speciation factors associated with different fuel types used in stationary combustion systems.

At the time of publication of this guide, a compilation of Tier 2 $PM_{2.5}$ emission factors was not available for stationary combustion systems. However, if such factors are available for a specific type of technology, the user could perform the Tier 2 black carbon emissions calculation according to Equation 50.

Table 39. Emission factors (EF$_{i,j,PM2.5}$), Tier 1

Fuel	Emission source	EF$_{i,l,PM2.5}$	Units	Reference
Bituminous/sub-bituminous coal	Electricity generation	2,820.0	g $_{PM2.5}$/tonne	(1)
Oil distillate		185.8	g $_{PM2.5}$/m^3	(1)
Lignite		236.2	g $_{PM2.5}$/tonne	(1)
Liquefied petroleum gas (LPG)		101.6	g $_{PM2.5}$/m^3	(1)
Natural gas		0.122	g $_{PM2.5}$/m^3	(1)
Solid waste		17.5	g $_{PM2.5}$/GJ	(1)
Wood waste		5,000.0	g $_{PM2.5}$/tonne	(1)
Low-sulfur diesel		30	g $_{PM2.5}$/m^3	(2)
Ultra-low-sulfur diesel		30	g $_{PM2.5}$/m^3	(2)
Light fuel oil		30	g $_{PM2.5}$/m^3	(2)
Heavy fuel oil		30	g $_{PM2.5}$/m^3	(2)
Bituminous/sub-bituminous coal	Industrial	2,820.0	g $_{PM2.5}$/tonne	(1)
Oil distillate		185.8	g $_{PM2.5}$/m^3	(1)
Kerosene/naphtha (jet fuel)		4.8	g $_{PM2.5}$/GJ	(1)
Lignite		337.4	g $_{PM2.5}$/tonne	(1)
Liquefied petroleum gas (LPG)		132.5	g $_{PM2.5}$/m^3	(1)
Natural gas		0.122	g $_{PM2.5}$/m^3	(1)
Process gas/refinery gas		0.139	g $_{PM2.5}$/m^3	(1)
Process gas/blast-furnace gas		0.138	g $_{PM2.5}$/m^3	(1)
Process gas / coke oven gas		0.143	g $_{PM2.5}$/m^3	(1)
Wood waste		5,000.0	g $_{PM2.5}$/tonne	(1)
Low-sulfur diesel		30	g $_{PM2.5}$/m^3	(2)
Ultra-low-sulfur diesel		30	g $_{PM2.5}$/m^3	(2)
Light fuel oil		30	g $_{PM2.5}$/m^3	(2)
Heavy fuel oil		30	g $_{PM2.5}$/m^3	(2)
Anthracite and lignite	Commercial - residential - institutional	398	g $_{PM2.5}$/GJ	(3)
Oil distillate		47.9	g $_{PMFiltrables}$/m^3(*)	(1)
Kerosene		47.9	g $_{PMFiltrables}$/m^3(*)	(1)
Natural gas		0.1	g $_{PM2.5}$/m^3	(1)
Wood		17,300.1	g $_{PM10}$/tonne (**)	(1)
Light fuel oil		99.5	g $_{PM2.5}$/m^3	(2)
Heavy fuel oil		99.5	g $_{PM2.5}$/m^3	(2)

(*) No EF associated with PM$_{2.5}$ for residential combustion of oil distillate and kerosene. Detailed PM fractions from the California Air Resources Board (CARB 2014) may be used.

(**) No EF associated with PM$_{2.5}$ for residential wood combustion. Detailed PM fractions from the CARB (CARB 2014) may be used.

(1) WebFIRE (US EPA 2015b)

(2) ECCC 2021- Boiler and heaters emissions calculator: guide to reporting.

(3) EMEP/AEE, 2013

Source: North American Black Carbon Emissions Estimation Guidelines. Part 3.2.

Table 40. Speciation factors (SF), Tier 1

Source/fuel type	Emission source	EC (% mass)	Reference
Combustion of bituminous coal	Power and industrial production	1.696%	SPECIATE (US EPA 2011)
Combustion of oil distillate		10%	
Combustion of lignite		1.43%	
Combustion of natural gas		38.4%	
Combustion of liquefied petroleum gas (LPG)		38.4%	
Combustion of process gases		14.57%	
Combustion of waste oil		1%	
Combustion of solid waste		1.52%	
Combustion of sub-bituminous coal		4.28%	
Combustion of wood/bark		3.3%	EMEP/AEE, 2013
Low-sulfur diesel		10%	CBCIR*
Ultra-low-sulfur diesel		10%	
Light fuel oil		10%	
Heavy fuel oil		10%	
Combustion of anthracite and lignite	Commercial - residential - institutional	6.4%	EMEP/AEE, 2013
Combustion of natural gas		6.7%	SPECIATE (US EPA 2011)
Combustion of petroleum		3.90%	
Combustion of wood		5.58%	
Light fuel oil		10%	CBCIR*
Heavy fuel oil		1%	

Note: The speciation factor refers to the percentage of $PM_{2.5}$ that is elemental carbon (EC). Elemental carbon is recognized as a proxy for black carbon until improved measurement methods and data become available.

**Canada's Black Carbon Inventory Report 2013-2019.*

Source: North American Black Carbon Emissions Estimation Guidelines. Part 3.2.

3.28.1.2. Tier 2 calculation of black carbon emissions from stationary combustion systems

The Tier 2 method estimates emissions for each combination of fuel and technology types used. The Tier 2 methodology is based on Equation 50.

Equation 50: Black carbon emissions from stationary combustion sources (Tier 2)

$$E_{BC} = \sum_{i,j} \left(Q_{i,j} \times EF_{i,j,PM2,5} \times SF_{i,j,BC/PM2.5} \right) \times 0.001$$

Where:

E_{BC} = *Annual black carbon emissions from stationary combustion systems, in kilograms per year*

i = *Type of fuel*

j = *Type of technology/equipment (e.g., natural gas-fired boiler, diesel engine, or oil-fired boiler)*

$Q_{i,j}$ = *Amount of fuel type "i" consumed annually in technology/equipment type "j"*

$EF_{i,l,PM2.5}$ = $PM_{2.5}$ *emission factor associated with fuel type "i" and industry "l"*

$SF_{i,l,BC/PM2.5}$ = *Speciation factor to be applied to convert* $PM_{2.5}$ *to black carbon for fuel type "i"*

0.001 = *Conversion factor from grams to kilograms*

3.28.1.3. Estimating the climate impact of black carbon emissions from stationary combustion systems

Once the black carbon emissions have been determined, Equation 51 is used to estimate their impact on global warming.

Equation 51: Black carbon emissions from stationary combustion sources (Tier 2)

$$E_{GHG\_BC} = E_{BC} \times GWP_{100\_BC} \times 0.001$$

Where:

E_{GHG_BC} = *Annual GHG emissions from black carbon emissions attributable to stationary combustion systems, in tonnes of* CO_2 *equivalent per year*

E_{BC} = *Black carbon emissions from fuel combustion, in kilograms of black carbon per year*

0.001 = Conversion factor from kilograms to tonnes

3.28.2. Calculation of black carbon emissions from mobile combustion systems

Mobile sources can be subdivided into five broad categories:

- On-road vehicles: cars, trucks, buses, motorcycles, etc.;
- Off-road equipment: equipment used in construction, agriculture and industry (excavators, bulldozers, tractors, cranes, off-road trucks, graders, dump trucks, etc.);
- Rail transportation;
- Marine transportation;
- Aviation.

Because of the prevalence of diesel engines in most of these categories, mobile sources are among the largest emitters of black carbon.

3.28.2.1. Tier 1 calculation of black carbon emissions from on-road mobile sources

On-road mobile sources use a diverse range of fuels, including gasoline, diesel, ethanol fuels, liquefied petroleum gas (LPG), and compressed natural gas (CNG). The largest contributors to black carbon emissions from on-road mobile sources are by far heavy-duty diesel trucks. For these vehicles, incomplete combustion of long-chain hydrocarbons in diesel fuel is the main contributor to black carbon emissions.

Detailed inventories of $PM_{2.5}$ emissions from on-road vehicles are being conducted in Canada and the United States, and models have been developed to estimate the amount of $PM_{2.5}$ emitted per kilometre driven in the different vehicle categories. Of these models, the most widely used in North America today is the MOVES model, developed by the US EPA. This model has the advantage of incorporating a considerable amount of new data on $PM_{2.5}$ emissions from cars, light trucks, and heavy trucks that are more realistic than previous estimates and lead to more accurate estimates of total $PM_{2.5}$ emissions. In addition, MOVES produces direct estimates of elemental carbon (EC), which is a better proxy for black carbon than $PM_{2.5}$.

The calculation of Tier 1 black carbon emissions from on-road mobile sources is based on the fuel consumption of the activity under consideration, multiplied by an EC emission factor specific to the fuel type. (Here, the EC emission factor is assumed to be the same as the black carbon emission factor.)

Equation 52 estimates black carbon emissions from mobile sources based on fuel type and consumption.

Equation 52: Black carbon emissions from on-road mobile sources (Tier 1)

$$E_{BC} = \sum_{i} \left(Q_i \times EF_{i,EC} \times 0.001 \right)$$

Where:

E_{BC} = *Annual black carbon emissions from on-road mobile sources, in kilograms per year*

i = Type of fuel

Q_i = *Quantity of type "i" fuel consumed annually*

$EF_{i,EC}$ = *EC emission factor for fuel type "i" in grams per litre of fuel*

0.001 = Conversion factor from grams to kilograms

Table 41 presents the EC emission factors associated with diesel and gasoline.

Table 41. Elemental carbon emission factors for diesel and gasoline

Fuel	Emissions source	Pollutant	Factor	Units	Reference
Diesel	All diesel vehicles (Canada and United States)	EC	0.391%	g/l	MOVES 2014
Gasoline	All diesel vehicles (Canada and United States)	EC	0.132	g/l	MOVES 2014

Source: North American Black Carbon Emissions Estimation Guidelines. Section 3.3.1.

3.28.2.2. Tier 1 calculation of black carbon emissions from off-road mobile sources

Black carbon emissions from off-road mobile sources are primarily from the combustion of diesel fuel and, to a lesser extent, from the combustion of gasoline and other fuels such as LPG or natural gas. The off-road sources discussed in this section include fossil fuel-powered mining, agricultural, construction, logging and airport support equipment.

Annual black carbon emissions from off-road mobile sources can be calculated from the specific black carbon emission rate multiplied by the expected service life, based on Equation 53.

Equation 53: Annual black carbon emissions from off-road mobile sources (Tier 1)

$$E_{BC} = \sum_i \left(t_i \times P \times LF \ \times EF_{i,PM10} \times \frac{PM_{2.5}}{PM_{10}} \times SF_{BC} \right) \times 0.001$$

Where:

E_{BC} = Annual black carbon emissions from off-road mobile sources

i = Type of off-road mobile source

t_i = Time of use per year of off-road mobile source i, expressed in hours per year

P = Power of mobile source, in kW

LF = Equipment load factor [85]

$EF_{i,PM10}$ = Emission factor for particulate matter less than 10 microns in diameter for mobile source type i, in grams per kW per hour [86]

$PM_{2.5}/PM_{10}$ = fraction of particles smaller than 2.5 microns in diameter in proportion to total particles = 0.97[87]

SF_{BC} = Speciation factor to convert $PM_{2.5}$ to black carbon for diesel fuel = 0.771241[88]

0.001 = Conversion factor from grams to kilograms

Table 42 below shows the exhaust emission standards that establish a maximum level for emissions of particulate matter less than 10 microns in diameter from off-road equipment. The emission standards are divided into categories based on engine power and are defined as the mass of particulate matter per unit of power output expressed in grams per kilowatt-hour.

Table 42. PM_{10} emission standards for off-road machinery

Power (kW)	Tier	Model years	PM (g/kWh)	Note
kW<8	0	Prior to 2000	1	
	1	2000–2005	1	
	2	2006–2011	0.8	
	4	2012 +	0.4	
8<kW<19	0	Prior to 2000	0.95	
	1	2000–2005	0.8	
	2	2006–2011	0.8	
	4	2012 +	0.4	

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[85] Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling-compression-ignition, US EPA 2008, Appendix A, Table A4 and Appendix C, Table C2.

[86] Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling-compression-ignition, US EPA 2008, Appendix A, Tables A1 to A4 and Appendix C, Table C2.

[87] Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling-compression-ignition, US EPA 2008. Page 25.

[88] 2019 Canada's Black Carbon Inventory Report 2013-2017. Environment and Climate Change Canada, 2019. Table B-5. Fractions of Black Carbon to Particulate Matter Less Than or Equal to 2.5 Micrometres in Diameter, Transportation and Mobile Equipment.

Table 42. PM_{10} emission standards for off-road machinery

Power (kW)	Tier	Model years	PM (g/kWh)	Note
19<kW<37	0	Prior to 1999	0.95	
	1	1999–2005	0.8	
	2	2006–2011	0.6	
	4	2012 +	0.03	
37<kW<56	1	1998–2005	0.8	
	2	2006–2007	0.4	
	3	2007–2011	0.3	
	4	2012 +	0.03	
56<kW<75	1	1998–2005		
	2	2006–2007	0.4	
	3	2007–2011	0.4	
	Interim 4	2012	0.02	
	4	2013+	0.02	
75<kW<130	1	1998–2005		
	2	2006	0.3	
	3	2007–2011	0.3	
	4	2012 +	0.02	
130<kW<560	1	1998–2005	0.54 +	
	3	2006–2011	0.2	
	4	2012 +	0.02	
>560kW	1	1998–2005	0.54 +	
	2	2006–2011	0.2	
	Interim 4	2012–2014	0.1	
	4	2015 +	0.04 +	*All except gen-set drive engines
	4	2015 +	0.03**	**Gen-set drive engines

Source: Guidance document on Off-Road Compression-Ignition Engine Emission Regulations: chapter 6. (https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/guidance-document-engine-emission-regulations/chapter-6.html)

3.28.2.3. Calculation of black carbon emissions from locomotives

Black carbon emissions from locomotives are caused by the combustion of diesel fuel associated with passenger and freight rail transportation.

Annual black carbon emissions from locomotives can be estimated from annual diesel fuel consumption and a default emission factor established for locomotives. The calculation can be made using Equation 54 below.

Equation 54: Annual black carbon emissions from locomotives (Tier 1)

$$E_{BC} = Q \times EF_{PM2.5} \times SF_{BC/PM2.5} \times 0.001$$

Where:

E_{BC} = Annual black carbon emissions from locomotives, in kilograms per year

Q = Amount of diesel fuel consumed annually, in litres

$EF_{PM2,5}$ = $PM_{2.5}$ emission factor = 1.204 $g_{PM2.5}$/l (*)

$SF_{BC/PM2.5}$ = Speciation factor to be applied to convert $PM_{2.5}$ to black carbon for locomotives = 0.6767 (*)

0.001 = Conversion factor from grams to kilograms

(*) North American Black Carbon Emissions Estimation Guidelines. Section 3.3.3

3.28.2.4. Calculation of black carbon emissions from marine vessels

Black carbon emissions from marine vessels are attributable to the combustion of diesel fuel or the combustion of residual fuel blends for marine transportation.

Annual black carbon emissions from marine vessels can be estimated from annual fuel consumption and a default emission factor for ships. The calculation can be made using Equation 55 below.

Equation 55: Annual black carbon emissions from marine vessels (Tier 1)

$$E_{BC} = \sum_{i} \left(Q_i \times EF_{i,PM2.5} \times SF_{i,BC/PM2.5} \right) \times 0.001$$

Where:

E_{BC} = Annual black carbon emissions from marine vessels, in kilograms per year

i = Fuel type (i.e., diesel or residual fuel blend)

Q_i = Quantity of type "i" marine fuel consumed annually, in litres

$EF_{i,PM2.5}$ = PM2.5 emission factor associated with fuel type "i", in gPM2.5/l

$SF_{i,BC/PM2.5}$ = Speciation factor to convert $PM_{2.5}$ to black carbon for fuel type "i"

0.001 = Conversion factor from grams to kilograms

Table 43 presents $PM_{2.5}$ emission factors and speciation factors associated with the different types of fuels used in marine vessels.

Table 43. $PM_{2.5}$ emission factors and speciation factors associated with different fuel types used in marine vessels

Fuel	$EF_{i,PM2.5}$ ($g_{PM2.5}$/l)	$SF_{i,BC/PM2.5}$	Reference
Diesel	1.998 (1)	0.77 (3)	▪ US EPA Regulatory Impact Analysis (Category 1 and 2, EPA 2007; Category 3, EPA 2009c) ▪ International Maritime Organization (IMO) study on the reduction of GHG emission from marine vessels (2014) ▪ US EPA, 2013a
General blend of residual fuels for marine vessels	6.271 (2)	0.06 (3)	

Source: North American Black Carbon Emissions Estimation Guidelines. Section 3.3.4.

3.28.2.5. Calculation of black carbon emissions from aircraft

Black carbon emissions from aircraft are attributable to the combustion of jet fuel associated with passenger and freight transportation and other aviation activities.

Annual black carbon emissions from aircraft can be estimated from annual jet fuel consumption and a default emission factor. The calculation can be made using Equation 56, shown below.

Equation 56: Annual black carbon emissions from aircraft

$$E_{BC} = Q \times EF_{PM2.5} \times SF_{BC/PM2.5} \times 0.001$$

Where:

E_{BC} = Annual black carbon emissions from aircraft, in kilograms per year

Q = Amount of fuel consumed annually, in litres

$EF_{PM2.5}$ = Jet fuel $PM_{2.5}$ emission factor = 0.164 $g_{PM2.5}$/l (*)

$SF_{BC/PM2.5}$ = Speciation factor to be applied to convert $PM_{2.5}$ to black carbon = 0.13 (*)

0.001 = Conversion factor from grams to kilograms

(*) North American Black Carbon Emissions Estimation Guidelines. Section 3.3.5.

3.29. Emissions from activities not presented in this guide or emerging quantification issues

If an activity not presented in this guide (e.g., CO_2[89] capture and sequestration) is likely to emit GHGs, a GHG emissions assessment based on recognized methodologies and credible and verifiable assumptions must be conducted. The MELCC is always available to provide support for assessments.

As mentioned in the introduction, knowledge in the field of climate change is rapidly evolving, and some issues may be addressed in a future update of this guide. These issues include the concept of best available technology, GHG sequestration in wetlands, biological, chemical, and geological CO_2 capture and

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[89] ISO 27914:2017 - Carbon dioxide capture, transportation and geological storage — Geological storage, https://www.iso.org/standard/64148.html.

sequestration, deep geothermal power, carbon debt from forestry projects, and the development of a framework for life cycle assessments of certain projects.

4. Mitigation measures for GHG emissions reduction

4.1. Types and examples of GHG emissions reduction measures

Mitigating GHG emissions is an essential action for the development of a sustainable project and is part of the quantification approach presented in this guide. Measures to reduce GHG emissions can be physical, organizational, or behavioral. Table 44 presents the main characteristics of each of these types. The selection of optimal GHG emissions reduction measures for each project should be guided by:

- The reduction in GHG emissions achieved by the implementation of the measure;
- Applicability to the Quebec context;
- Financial considerations.

Table 44. Types of GHG emissions reduction measures (non-exhaustive list)		
PHYSICAL MEASURES	MODIFICATION OF EQUIPMENT OR SYSTEMS. THIS TYPE OF MEASURE IS USUALLY LINKED TO AN INVESTMENT.	
	TECHNOLOGY	Use equipment or technologies that reduce energy consumption or use renewable energy with low GHG emissions. Examples: • Use the best available technology from a techno-economic feasibility standpoint; • Use alternative energy sources with low carbon footprints; • Use more efficient equipment; • Replace combustion equipment with electric equipment; • Replace oil-fired boilers with residual biomass-fired boilers; • Use grid-connected equipment instead of generators when conditions permit; • For buildings, adopt green certification practices that help reduce energy consumption and GHG emissions. Use geothermal energy where possible; • Take advantage of existing funding programs to reduce GHG emissions; • Examine the feasibility of sustainable GHG capture and sequestration.
	PROCESSES	Optimize industrial production processes to minimize GHG emissions. Examples: • Minimize or eliminate sources of GHG emissions in industrial processes; • Implement energy efficiency measures that are sustainable over time and a continuous improvement process; • Optimize heat (or cold) recovery and reduce thermal waste; • Implement process integration (Pinch analysis);[90]

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[90] According to Canmet Energy (RNCan), process integration is a systemic approach to identify and remedy inefficiencies in industrial processes by analyzing interactions between operations as a whole, rather than individually. Process integration accounts for technical and financial constraints before detailed design. (Pinch analysis). https://www.nrcan.gc.ca/energy-efficiency/data-research-insights-energy-efficiency/commercial-industrial-innovation/industrial-systems-optimization/process-integration-and-pinch-analysis/5497

Table 44. Types of GHG emissions reduction measures (non-exhaustive list)

		• Replace HFCs in industrial refrigeration equipment with other refrigerants that are less emissive or have a low GWP; • Minimize SF_6 losses during operations; • Take advantage of existing funding programs to reduce GHG emissions; • Practise circular economy, i.e., use a company's waste materials as raw materials (e.g., sell the steam generated by a waste incinerator to a nearby industry).
ORGANIZATIONAL MEASURES	CHANGES IN ORGANIZATIONAL PROCESSES	
	SUSTAINABLE PURCHASING POLICY	Integrate sustainable development criteria into the organization's purchasing policies. Examples: • Establish specific GHG requirements in the company's raw material purchases, specifications, or performance requirements; • Buy locally; • Know the carbon footprint of products.
	FLOW OPTIMIZATION	Optimize the flow of materials, people and goods to reduce related GHG emissions. Examples: • Optimize passenger and freight transportation logistics through intermodal options (train, boat, truck); • Use raw materials located closer to the site (e.g., borrow pit materials); • Reduce empty returns in trucking; • Use transportation methods that emit less GHGs.
	RESEARCH AND DEVELOPMENT	Conduct research and development to design products, materials, practices, or technologies that reduce GHG emissions in the way they are produced or used. Examples: • Eco-design; • Design of processes that emit less GHGs.
BEHAVIOURAL MEASURES	CHANGES IN EVERYDAY BEHAVIOR	
	INFORMATION AND AWARENESS	Inform and educate employees, suppliers, customers, and users on ways to reduce GHG emissions. Examples: • Carry out information or awareness campaigns; • Promote best practices for reducing GHG emissions.
	TRAINING	Enable the various stakeholders to acquire good practices that promote energy savings or the reduction of GHG emissions. Examples: • Training on responsible waste management; • Training on process integration, energy efficiency, renewable energy, etc.; • Training on circular economy; • Training on fuel-efficient driving for employees.
	VOLUNTARY COMMITMENTS OR AGREEMENTS	Commit to voluntary GHG emissions reduction targets. Examples: • Establish annual GHG emission intensity reduction targets per unit produced; • Establish a procedure to limit HFC emissions from refrigeration systems;

Table 44. Types of GHG emissions reduction measures (non-exhaustive list)

		• Establish a responsible energy consumption policy; • Contribute to third-party reduction measures (e.g., installation of electrical charging stations); • Promote circular economy and industrial symbiosis.

4.2. Quantification of GHG emissions reduction from mitigation measures

To quantify the reduction potential of a mitigation measure, the difference is calculated between the GHG emissions of the baseline scenario and the GHG emissions of the project including the proposed measure. The baseline scenario is defined as the scenario most likely to occur in the absence of mitigation measures. Typically, the baseline scenario represents business as usual or the current situation. Two examples are presented in Table 45 and 46 below.

Table 45. Example of reduction calculation for stationary combustion sources

Emissions source	**Baseline scenario** (Oil-fired boiler, 75% efficiency)	**Proposed scenario** (Oil-fired boiler, 90% efficiency)	**GHG emissions reduction** (Baseline scenario minus proposed scenario)
	GHG emissions (tonnes CO_2 eq./yr)	GHG emissions (tonnes CO_2 eq./yr)	(tonnes CO_2 eq./yr)
Boiler	10,000	8,000	2,000

Table 46. Example of reduction calculation for mobile combustion sources

Emission source	**Baseline scenario** (Borrow pit 40 km from the site)	**Proposed scenario** (Borrow pit 10 km from the site)	**GHG emissions reduction** (Baseline scenario minus proposed scenario)
	GHG emissions (tonnes CO_2 eq./yr)	GHG emissions (tonnes CO_2 eq./yr)	(tonnes CO_2 eq./yr)
Transport of materials by truck	50	20	30

The preferred tools for determining reduction measures are the GHG emissions mitigation plan and the accompanying GHG monitoring plan. These tools are used to identify the most emissive activities and determine the mitigation measures to be taken, with quantification. Both are presented below.

4.3. GHG emissions mitigation plan

The GHG emissions mitigation plan, a lever for internal engagement

Experience shows that the implementation of such a plan is an excellent internal communication tool to engage stakeholders involved in the project around sustainable development goals shared by all. This plan can be part of a GHG management system or integrated into a pre-existing management system, whether it be an environmental (e.g., ISO 14001), quality (e.g., ISO 9001), or energy (e.g., ISO 50001) management system. This plan can help the organization to:

- Reduce its operating costs;
- Innovate and stand out;
- Improve its image;
- Anticipate new constraints;
- Prepare for changes in energy prices;
- Motivate the team;
- Act for the planet and the climate;
- Establish new partnerships.

In concrete terms, when developing the mitigation plan, it is important to draw up a more or less exhaustive list of measures and select the most promising in terms of reducing GHG emissions, taking into account their technical and economic feasibility. It is important to adopt measures with a high potential for reducing GHG emissions, without neglecting those which, despite having a lower reduction potential, have a strong power to mobilize teams.

In particular, the plan should include:

- A description of the GHG emissions reduction measures planned for the different phases of the project;
- A description of the baseline scenario and the proposed scenario;
- A quantification of the GHG emission reductions attributable to the different measures. To perform the quantification, methodologies other than those proposed in this guide can be used to establish the baseline scenario and the scenario with the proposed measure (see examples in the tables in the previous section);
- An explanation of how GHG emissions reduction opportunities are incorporated into the design or subsequent operations of the project;
- Where applicable, mitigation measures that would result in indirect GHG emission reductions or avoided emissions, along with their quantification (e.g., dedicated lane for public transit).

If it appears that mitigation measures with high reduction potential cannot be implemented for economic, social, or environmental reasons, this must be documented.

Monitoring the effectiveness of mitigation measures should be included in the GHG emissions monitoring plan, described below.

4.4. GHG emissions monitoring plan

The monitoring plan makes it possible to quantify the GHG emissions generated by the project and to follow their evolution over time. In general, a monitoring plan indicates the type of data to be collected (e.g., fuel consumption, the process and methods for collecting this data, the frequency of data collection, etc.). It is intended to facilitate the quantification of GHG emissions and may evolve over the life of the project.

For an ongoing project submitted to the RMRCECA, the GHG emissions report is an excellent tracking tool. However, not all projects are subject to the RMRCECA, and this regulation does not cover construction emissions or post-closure emissions. In this context, the ISO 14064 standard and the GHG Protocol's Mitigation Goal Standard (World Resources Institute, 2018) can be used as references. An example of a GHG emissions monitoring plan is presented in Appendix C.

4.5. Avoided emissions

Beyond reducing their own GHG emissions, companies and organizations can participate in the transition to a lower-carbon economy through the solutions they can develop. These solutions contribute to reducing emissions downstream of the value chain, in comparison with other existing and usual solutions.

The avoided emissions of a company, organization, or project refer to the emission reductions achieved by its activities, products, and/or services, when these reductions occur outside its scope of activity. These emissions are assessed against a baseline scenario as defined in Section 4.2.

Examples of avoided emissions are listed below:

- Production of renewable energy or steam from cogeneration, for the benefit of third parties;
- Recovery of materials (recycling) or energy (energy recovery) from waste for the benefit of others;
- Sale of products or services whose use reduces GHG emissions outside the scope of the project, company, or organization;
- Financing of third-party projects that reduce GHG emissions outside the scope of the project, company, or organization;
- Financing of third-party projects that increase carbon sinks outside the scope of the project, company, or organization;
- Emissions avoided when the company or organization implements projects that contribute to reducing GHG emissions in the value chain (e.g., production of low-carbon intensity fuels, production of zero-emission vehicles, etc.)

Main references

Regulation respecting mandatory reporting of certain emissions of contaminants into the atmosphere.
https://www.legisquebec.gouv.qc.ca/en/document/cr/Q-2,%20r.%2015

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Appendix A – Checklist of GHG Emission Sources to Consider by Sector

Table 47. Checklist of GHG emission sources to consider by sector

GHG emission sources	Project types and phases (C = Construction; O = Operation; D = Decommissioning or closure)																					
	Guide section	Industries (Note 1)			Energy (Note 2)			Water (Note 3)			Agriculture (Note 4)			Transportation			Waste materials and contaminated soils			Hydrocarbons (Section 3.24)		
		C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D
Stationary combustion systems	3.1	X	X	X	X	X		X				X		X	X		X	X				
Mobile combustion systems	3.2	X	X	X	X	X	X	X	X[3b]	X[3b]	X	X		X	X	X	X	X	X	X	X	X
Electrical energy consumption	3.3	X	X	X	X	X	X	X	X	X[3a]	X	X		X	X		X	X		X	X	X
Industrial processes	3.4		X																			
Mining and mineral processing	3.5		X																			
Hydrogen production	3.6	X	X	X	X	X								X	X						X	
Explosives use	3.7	X	X		X			X						X			X					
Fugitive emissions of sulfur hexafluoride and perfluorocarbons	3.8					X			X[3a]													
Refrigeration and air conditioning equipment	3.9		X	X								X			X							
Deforestation	3.10	X			X			X			X			X			X			X	X	
Loss of wetlands	3.12	X			X			X														
Flooding of ecosystems	3.14							X[3a]														
Agricultural production	3.15											X										
Landfill of waste materials	3.16																	X	X			
Biogas cleaning	3.17																	X	X			
Biogas destruction	3.18																	X	X			

Table 47. Checklist of GHG emission sources to consider by sector

GHG emission sources	Project types and phases (C = Construction; O = Operation; D = Decommissioning or closure)																					
	Guide section	Industries (Note 1)			Energy (Note 2)			Water (Note 3)			Agriculture (Note 4)			Transportation			Waste materials and contaminated soils			Hydrocarbons (Section 3.24)		
		C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D
Biomethanization of waste materials	3.19		X															X				
Compression and liquefaction of biogas	3.20		X															X				
Composting of waste materials	3.21		X															X				
Waste incineration or thermal treatment of hazardous materials or contaminated soil	3.22																	X				
Wastewater treatment and discharge	3.23		X															X		X	X	X
Hydrocarbon exploration and development	3.24																			X	X	X
Natural gas processing, transportation and distribution	3.25					X														X	X	X
Transportation of hydrocarbons by pipeline	3.26				X	X	X													X	X	X
Indirect upstream emissions of hydrocarbon transportation by pipeline	3.27.1					X														X	X	X
Indirect emissions from modal shift	3.27.2														X							
Indirect emissions from traffic flow and congestion	3.27.3								X[3b]						X							
Indirect emissions from different modes of freight transportation	3.27.4								X[3b]						X							

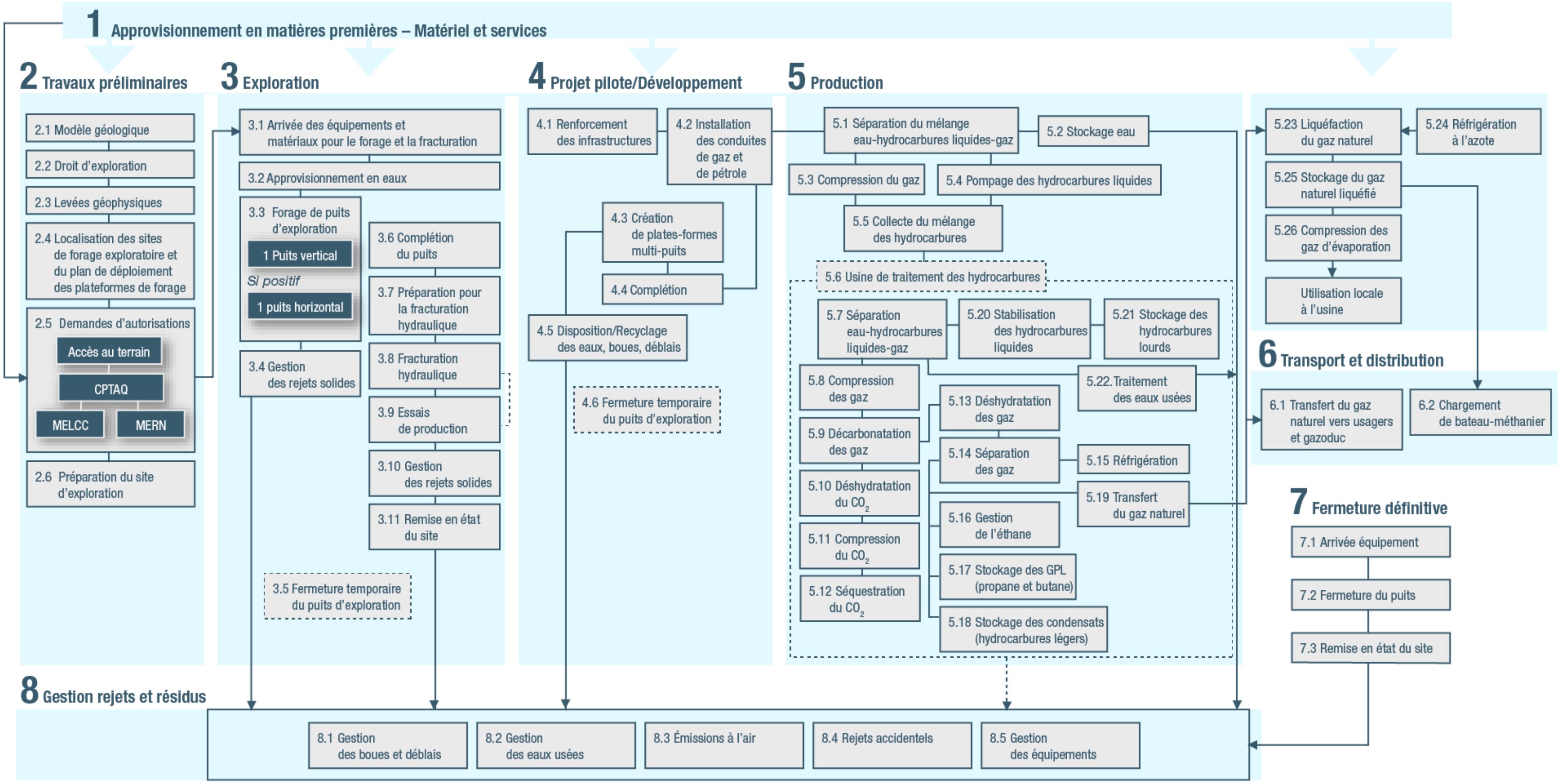
Table 47. Checklist of GHG emission sources to consider by sector

GHG emission sources	Project types and phases (C = Construction; O = Operation; D = Decommissioning or closure)																					
	Guide section	Industries (Note 1)			Energy (Note 2)			Water (Note 3)			Agriculture (Note 4)			Transportation			Waste materials and contaminated soils			Hydrocarbons (Section 3.24)		
		C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D	C	O	D
Life cycle analysis	3.27.5																			X	X	X
Black carbon	3.28																			X	X	X
Activities not presented in this guide and emerging issues	3.29	Emission sources may vary depending on the type of activity or issue.																				

Note 1: The industrial sector corresponds to economic activities whose purpose is the transformation of materials into finished products or exploitation of the mineral wealth of the soil and energy sources. The mining sector is part of the primary sector of resource development (Government of Quebec, Thesaurus). Several emission sources are common to both sectors, which is why they have been grouped together.
Note 2: The decommissioning phase should be considered only when applicable.
Note 3: The “Water” sector covers all water-related activities. 3a) Identified sources apply to water retention activities only. 3b) The sources identified apply to activities carried out in aquatic and port environments.
Note 4: The processing of agricultural products is not part of animal production but rather of the agri-food industry. It is therefore necessary to refer to the emission sources associated with the "Industries" sector.

Appendix B – Additional information on hydrocarbon exploration and development projects

Figure 8. Example of an operational sequence for a typical hydrocarbon exploration and development project



Source: adapted from WSP, October 2015. "Élaboration d'un projet type concernant les activités d'exploration et d'exploitation du pétrole et du gaz à Anticosti" (Sample project preparation regarding oil and gas exploration and development activities in Anticosti, French only).

Table 48. Inventory of GHG emissions generated during the exploration phase (example)

GHG type / source of GHG emissions	Generator sets	500-kW motors	1,000-kW motors	Boilers	Flare	Trucks	Diesel tanks	Other	Total
Quantity	2	2	3	2	1	6	1		N/A
CO_2 (kg)									
CH_4 (kg)									
N_2O (kg)									
Other									
CO_2 eq. (kg)									

Table 49. Inventory of GHG emissions attributable to hydraulic fracturing in the exploration phase (example)

GHG type / source of GHG emissions	Boilers	Frac pumpers	Frac blenders	Hydration units	Sand conveyors	Water pumps	Other	Total
Quantity	2	12	10	3	2	10		N/A
CO_2 (kg)								
CH_4 (kg)								
N_2O (kg)								
Other								
CO_2 eq. (kg)								

Table 50. Inventory of GHG emissions attributable to production testing in the exploration phase (example)

GHG type / source of GHG emissions	Gas venting before flaring	Enclosed flares	Flowback ponds	Other	Total
Quantity	2	2	3		N/A
CO_2 (kg)					
CH_4 (kg)					
N_2O (kg)					
Other					
CO_2 eq. (kg)					

Table 51. Summary of GHG emissions attributable to the entire project, by phase (example)

GHG type/phase	Preliminary work	Exploration			Pilot project/development			Hydrocarbon production			Transportation and distribution	Permanent closure	Waste management	Post-closure	Other	Total
Activity	Site preparation	Drilling	Fracking	Other	Drilling	Fracking	Other	Oil-water separation	Hydrocarbon treatment	Other	Pipeline	Sealing of wells		Fugitive emissions		
CO_2 (kg)																
CH_4 (kg)																
N_2O (kg)																
Other																
CO_2 eq. (tonnes)																

Appendix C – GHG emissions monitoring plan

Table 52. Examples of data to be included in a GHG emissions monitoring plan (not exhaustive)

Category	Data type	Units	Data source	Frequency
Motorized equipment	Fuel consumption of each vehicle	Litres	Invoices	Monthly/annually
	Mileage of each vehicle	Kilometres	Odometer	Monthly/annually
	Hours of operation of off-road vehicles	Hours	Operations registry	Monthly/annually
	Acquisition of new vehicles	Litres/100 kilometres	Invoices	Annually
Buildings and processes	Natural gas consumption	Cubic metres	Invoices	Monthly
	Electricity consumption	Kilowatt-hours	Invoices	Monthly
	Fuel oil consumption	Litres	Invoices	Monthly
	Refrigerant refill	Kilograms	Invoices	Monthly
	Consumption of carbonates	Tonnes	Invoices	Monthly
	Consumption of carbon electrodes	Tonnes	Invoices	Monthly
Waste management projects	Percentage of emitted biogas captured at the technical landfill site (TLS)	Percentage	Measure	Monthly
	Quantity of biogas combusted at the TLS	Tonnes	Measure	Monthly
	Quantity of recovered biogas	Tonnes	Measure	Monthly
	Quantity of organic waste treated by composting	Tonnes	Measure	Monthly
	Quantity of compost produced	Tonnes	Measure	Monthly
	Quantity of waste incinerated	Tonnes	Measure	Monthly
	Dry matter content of incinerated waste	Fraction	Measure	Monthly

Category	Data type	Units	Data source	Frequency
	Composition of incinerated waste	Percentage	Operations registry	Monthly
	Carbon fraction in incinerated waste	Fraction	Measure	Monthly
	Fraction of fossil carbon in incinerated waste	Fraction	Measure	Monthly
Livestock production projects	Number of heads per animal type	Units	Operations registry	Monthly
	Quantity of manure stored	Tonnes	Measure	Monthly
	Quantity of manure spread	Tonnes	Measure	Monthly
	Quantity of synthetic fertilizer applied	Tonnes	Operations registry	Monthly

Appendix D – Complementary Information on Biogenic Emissions

According to the French agency for the environment and energy management (ADEME)[91], there are two possible scenarios for biogenic CO_2 emitted by humans:

- Case 1: Either it is part of an overall change in ecosystems that does not contribute to increasing the atmospheric concentration of CO_2 because the increased emissions by humans are offset by a carbon sink (typical case of forest management); or
- Case 2: It is part of an emissions pattern not offset by carbon sinks (as in the case of deforestation or land-use change).

In general, in industrialized countries, where there is little deforestation, CO_2 emissions are offset by annual forest growth (case 1).

In addition:

- "Carbon-neutral" biogenic CO_2 emissions, even if not considered in GHG balances according to international conventions, nevertheless affect the climate and the quality of the atmosphere, which indiscriminately receives CO_2 of biogenic and non-biogenic origin.
- The IPCC, which is increasingly concerned with this issue and the carbon debt (see definition), recommends accounting for biogenic CO_2 emissions, particularly if a project is part of a pattern of emissions not offset by carbon sinks (case 2).
- In the Regulation respecting mandatory reporting of certain emissions of contaminants into the atmosphere (RMRCECA), a person or municipality operating a facility in Quebec must report its annual non-biogenic and biogenic GHG emissions separately.

i) Biogenic CO_2 emissions resulting from biomass combustion

CO_2 emissions from the combustion of biomass or biomass-derived products (biodiesel, construction, renovation and demolition wood, agricultural residues, etc.) are considered biogenic. However, CH_4 and N_2O emissions from biomass combustion are not considered biogenic and must be quantified with emissions from fossil fuel combustion.

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[91] Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME), 2018. Base Carbone database (http://www.bilans-ges.ademe.fr/documentation/UPLOAD_DOC_FR/index.htm?co2_biogenique.htm).

ii) Biogenic CO_2 emissions not resulting from biomass combustion

Waste disposal, composting, wastewater treatment, and other activities can produce CO_2 emissions due to biomass decomposition, and these emissions are considered biogenic. However, CH_4 and N_2O emissions from this biomass decomposition are not biogenic and must be reported in their respective categories (waste, water treatment, etc.).

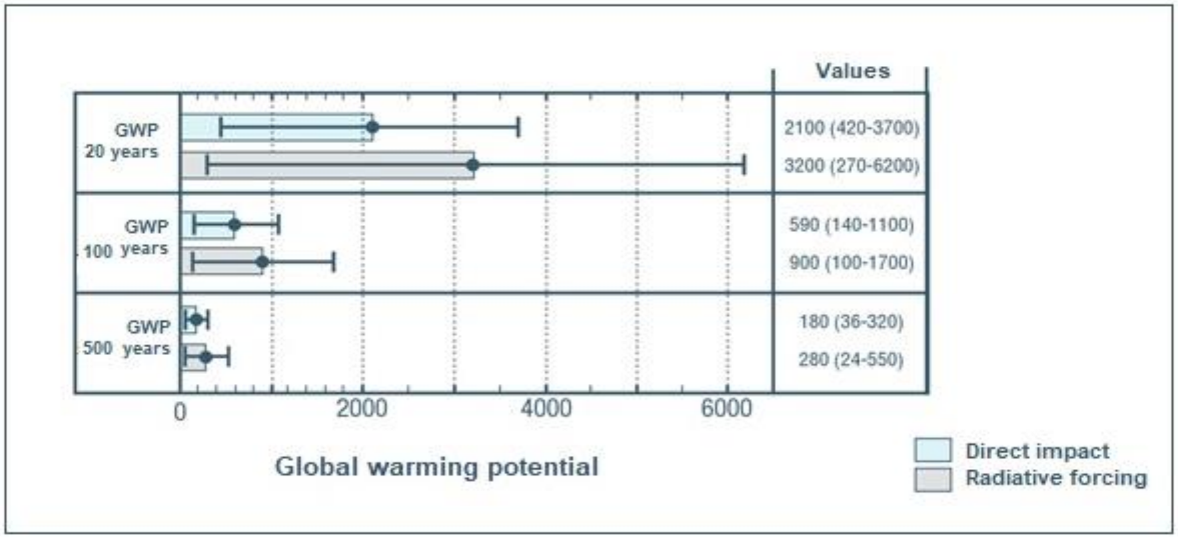
Appendix E – Complementary Information on Black Carbon

Airborne black carbon absorbs and scatters sunlight, increases temperatures, melts snow and ice, and impacts cloud formation and distribution. It can also influence air circulation and precipitation. The impact of black carbon is especially high in polar regions, such as the Arctic, where black carbon particles turn black as they settle on snow and ice, increasing their ability to absorb solar radiation and therefore accelerating the rate of melting.

Once emitted, black carbon remains in the atmosphere for a few days or weeks until it returns to the earth's surface as rain or by atmospheric deposition. Carbon dioxide, on the other hand, remains in the atmosphere for decades.

Figure 9 below shows the GWP of black carbon over periods of 20, 100, and 500 years. The most frequently used period is 100 years. Over this period, the GWP of black carbon is estimated to be 900 times greater than that of CO_2.[92]

Figure 9. Global warming potential of black carbon over periods of 20, 100 and 500 years



Source: Bond et al. 2013[76]

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[92] Bond et al. 2013. Bounding the role of black carbon in the climate system – A scientific assessment. https://www.researchgate.net/publication/312193003_Bounding_the_role_of_black_carbon_in_the_climate_system_-_A_scientific_assessment.

On November 28, 2017, Canada ratified the Gothenburg Protocol and its 2012 amendments under the Convention on Long-Range Transboundary Air Pollution (CLRTAP). Among the amendments to the Gothenburg Protocol are new commitments to reduce particulate matter emissions, with a priority focus on sources of particulate matter that are also significant sources of black carbon. At the 2017 Ministerial meeting of the Arctic Council, Canada, along with other Arctic states, renewed its commitment to take action to reduce black carbon emissions. At this meeting, Canada committed to continue to improve the quality and transparency of information on black carbon emissions and to publish an annual inventory of black carbon emissions. All emissions in this inventory are from anthropogenic (human) sources. Natural sources of black carbon, such as forest fires, are excluded.

The Gothenburg Protocol: an international consensus on black carbon[93]

The Gothenburg Protocol is an outcome of the Convention on Long-Range Transboundary Air Pollution. It was established to address pollutants that cause acidification of the biophysical environment and the formation of ground-level ozone, with the understanding that air pollutants cross borders and affect air quality far beyond their place of origin. This protocol sets limits for air pollutants, including sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds that are hazardous to health and the environment. It was updated in 2012 to include particulate matter and black carbon (a constituent of particulate matter) as well as new commitments for 2020.

According to Canada's Black Carbon Inventory Report, 8,809 tonnes of black carbon were emitted in Quebec in 2017 as shown in the table below.

Table 53. Quebec black carbon emissions by sector

Sector	Black carbon emissions (tonnes per year)
Transportation and mobile equipment	3,216
Commercial - residential - institutional	5,405
Ore and mineral Industries	75
Manufacturing	64
Electric power generation	45
Oil and gas industry	2.1
Agriculture	1.1
Total	8,809

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[93] Environnement and Climate Change Canada. https://www.canada.ca/en/environment-climate-change/corporate/international-affairs/partnerships-organizations/gothenburg-protocol-air-pollution.html

Table 53 highlights that the commercial-residential-institutional sectors and the transportation sector are by far the largest sources of black carbon in Quebec, accounting for 61% and 36% of total Quebec emissions respectively.

Health impacts of black carbon

As for the health impacts of these particles, it is scientifically proven that they cause serious problems in the lungs and cardiovascular system. Because of their small size, black carbon and other fine particles can enter the lungs. People with pre-existing lung or heart disease, as well as the elderly and children, are particularly vulnerable to the effects of fine particles. Furthermore, there is no evidence of a safe level of exposure or a threshold below which no adverse health effects would occur. Furthermore, in June 2012, the World Health Organization (WHO) reclassified diesel exhaust emissions as a human carcinogen and the International Agency for Research on Cancer (IARC), part of the WHO, found sufficient evidence that exposure to diesel exhaust causes lung cancer (IARC, 2012).