UNIVERSITÉ DU QUÉBEC À MONTREAL

IMPACTS SUR L'ENVIRONNEMENT DU TRANSPORT DE MARCHANDISES PAR CAMION : ANALYSE QUANTITATIVE DES ÉMISSIONS DE GAZ À EFFET DE SERRE DANS LA PROVINCE DU QUÉBEC

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ENVIRONMENTAL IMPACTS OF TRUCKING FREIGHT TRANSPORTATION : QUANTITATIVE ANALYSIS OF GREENHOUSE GAS EMISSIONS IN THE PROVINCE OF QUEBEC

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RÉSUMÉ

Comme il est bien connu, le secteur du transport est souvent tenu responsable d`être un secteur polluant important et un contribuant majeur à la production des émissions de gaz à effet de serre (GES) par l'utilisation massive du combustible fossile. D'autre part, vu le souci la convention-cadre des Nations Unies sur le changement climatique (CCNUCC) à mesurer les GES, tous les pays signataires de ce traité ont l'obligation de soumettre annuellement un inventaire de ces émissions, pour chaque secteur impliqué, afin d'évaluer la situation et de prévoir des solutions potentielles.

De nos jours, il convient d'étudier non seulement le volume total d'émissions de GES (CO_2, CH_4 et N_2O) mais également ceux qui proviennent du transport des marchandises par camion au Québec.

Le but de ce mémoire est d'apporter une mise à jour de la méthode, afin d'obtenir une quantification plus précise de ces émissions en termes d'équivalent de CO_2. À cette fin, nous nous servons "des enquêtes d'origine - destination" élaborées par le Ministère de transport du Québec (MTQ) comme source principale des données. À l'encontre des procédés habituelles, nous ne nous servons pas ni de Statistiques Canada, ni de l'information annuelle de CANSIM du Gouvernement du Canada.

Les recommandations et la méthodologie proposée par le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC)[1], constituent notre ressource la plus importante. Prenant en compte la disponibilité d'information, le document du GICC fournit deux genres d'approches pour évaluer les émissions provenant des véhicules routiers. La première approche ("Tier 1" ou "top-down") recommande de calculer seulement le CO_2 et d'estimer que ces émissions sont soutenues par la base des statistiques de consommation de carburant (carburant vendu) de l'autorité nationale responsable de cette information. La deuxième approche ("Tier 2" ou "bottom-up"), est appropriée pour évaluer des émissions du CO_2 et également du CH_4 et du N_2O et utilise notamment l'information concernant la distance voyagée par le type de véhicule, le type de carburant et le type de route.

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[1] GIEC - Méthodologie: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas inventories, Chapter 2 - Energy - Mobile combustions: Road vehicles.

Afin d'obtenir cette évaluation, en regardant l'information précédente et avec l'intention de ne pas employer des données statistiques, cette évaluation des émissions est effectuée sous la méthode d'évaluation "Tier 2" ou "bottom-up", parce qu'avec "les enquêtes d'Origine-destination" il est possible d'avoir l'accessibilité ou de figurer l'information comme : type de camion, distribution de la flotte, la fréquence et les distances voyagées, consommation de carburant théorique, l'efficacité de carburant, distribution des contrôles d'émissions dans la flotte et des facteurs d'émission pour des différents contrôles de pollution.

Comme résultats de cette quantification d'émission des gaz à effet de serre pour le transport de marchandise par camion, notre évaluation nommée « Q 80 + » est transformé en série chronologique de graphiques pour comparer sa tendance des émissions de 1990 à 2004 contre des émissions de la province du Québec et du Canada afin de connaitre les prévisions de l'activité du camionnage au Québec.

Mots-clés
Gaz à effet de serre (GES), secteur de transport, transport de marchandises par camion, enquêtes d'Origine - destination, Scénario d`évaluation «Q 80+».

ABSTRACT

As it is well known, the transportation sector is blamed for being a major contributor to the problem of pollution and a main contributor in the production of greenhouse gas emissions (GHG), due to the fossil fuel combustibles employed. On the other hand, considering the concern of the United Nations Framework Convention on Climate Change (UNFCCC) to quantify GHG emissions, nowadays, all the countries signatories of this treaty, must submit an inventory of these emissions on an annual basis for every sector implicated on this matter, in order to evaluate the situation and to provide potential solutions.

Nowadays, it is desirable to investigate not only the total volume of GHG emissions (CO_2, CH_4 and N_2O), but also those that proceed as result of trucking freight transportation activity on the road network in Quebec.

The aim of this thesis is to update a method to procure a quantification of these particular emissions in terms of CO_2 equivalent. As a variation to attempt in this analysis in order to find more accuracy on our GHG emissions quantification, we make use of «Origin-destination Matrix surveys» elaborated by the Transportation Ministry of Quebec (MTQ), as the key source of data, and not Statistics Canada nor CANSIM annual information from Canada Government, which are usually employed to carry out this type of analysis.

Our most important resource of support are the recommendations and methodology proposed by the Intergovernmental Panel on Climate Change (IPCC)[2], which considering the availability of information, provides two kinds of recommendations or approaches to estimate emission from road vehicles. The first approach, or Tier 1 "top-down", recommended to calculate just CO_2, estimates these emissions supported on the basis of statistics of fuel consumption (or fuel sold) from the National Authority responsible of this information. The second approach or, Tier 2 "bottom-up", which is appropriate for evaluating CO_2 emissions and also CH_4 and N_2O, basically uses information such as distance travelled by vehicle type, fuel type and road type.

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[2] IPCC - Methodology: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas inventories, Chapter 2 - Energy - Mobile combustions: Road vehicles.

In order to obtain this evaluation, considering the preceding information the aim of this evaluation is to exclude the use of statistical data. This estimation of emissions is carried out according to the method of evaluation of Tier 2 or "bottom-up", because the «Origin-destination Matrix surveys» allows the possibility of having accessibility or determining information such as: truck type, distribution of the frock fleet, frequency and distances travelled, theoretical fuel consumption, fuel efficiency, distribution of emissions controls in the fleet and Emission factors for different pollution controls.

As outcome of this quantification of emissions for trucking freight transportation, our scenario of evaluation named « Q 80 + » is transformed into a time series graph to compare the trend of emissions from 1990 to 2004 against the total volume of emissions released in the province of Quebec and Canada, in order to know the forecast of trucking freight activity in Quebec.

Keywords
greenhouse gas (GHG`s) emissions, transportation sector, trucking freight transportation, origin-destination Matrix surveys, scenery of evaluation « Q 80 + ».

CHAPTER I

INTRODUCTION

1.1 Problem statement

Since the introduction of motorized transportation systems, economic growth and advancing technology have allowed people and goods to travel farther and faster. However, these modern transportation systems powered by internal combustion engines which are fuelled by petroleum have gradually increased the use of energy and at the same time have produced nearly a third of our nation's greenhouse gas (GHG`s) emissions.

Emissions from the transportation sector in Canada have increased by about 48.8 Mt (32.8%) from 1990 to 2005. This sector represents an increase of 23.2 Mt or over 109% in emissions from light-duty gasoline trucks, reflecting the growing popularity of sport utility vehicles. Additionally, emissions from heavy-duty diesel vehicles have increased by 17.8 Mt over this period, which is indicative of greater heavy-truck transport. Offsetting these increases were reductions in emissions attributed to gasoline and alternatively fuelled cars by 6.0 Mt and 1.5 Mt respectively (Environment Canada, 2006. Canada's Greenhouse Gas Inventory 1990 – 2004).

This rise in GHG concentrations - the most important gas being carbon dioxide (CO_2) - has contributed to an increase of approximately 0.5°C in global average temperature over the past century. Climate modelling studies and climate trends during the past few decades have indicated that global warming is increasing the frequency and intensity of extreme weather events, droughts and desertification in currently inhabited areas. Moreover, continued warming can be expected if the increase in atmospheric concentrations of GHG`s - much of which is due to the burning of fossil fuels and other human activities such as industrial processes, - is allowed to continue unabated.

Canada's extreme weather conditions, geographical position and constant increase in greenhouse gas emissions, have all contributed in making Canada one of the countries most vulnerable to global climate changes. In Canada's north, for example, the extent of sea ice can be expected to decline, which will affect northern travel, wildlife distributions and traditional hunting practices. Therefore, agriculture, forestry, tourism and recreation could be affected in the future. Climate change is also expected to have an impact on human health by leading to a rise in the number of cases of heat stress, respiratory illnesses and transmission of insect and waterborne diseases, placing additional stresses on the health and social support systems.

The climate change problematic has led several international conventions and agreements aiming to limit and to stabilize GHG emissions and other harmful substances. The most recent convention was the result of the Kyoto Protocol in December 1997, under which Canada agreed to reduce its GHG emissions by 6% between the years 2008 to 2012. However, since 1990, GHG`s emissions in Canada have risen by approximately 13%.

Since the Kyoto Protocol agreement, there is an implied national commitment. Canada's Minister of the Environment and Minister of Energy have not only approved a process to examine the impacts, costs and benefits of implementing the Kyoto Protocol, but have also developed options for implementing the Protocol in Canada. This process will lead to the development of a national implementation strategy to curb climate change. Government and non-government agencies are part of this process and are working together to identify and implement initiatives to achieve the objective established in the Kyoto Protocol.

In Canada, trucking transportation is an important activity for human develops due to its flexibility, increase and spread of population and its economic dynamism. This activity has become an integrated part of production and distribution process, and considering the rapid restructuring of the global transportation system, it has brought a profound impact on processes such as globalization, in the industrialized and in the industrializing world. If Canada makes significant progress towards meeting the Kyoto commitment (reduction of GHG emissions to 6% below 1990 levels in the 2008 to 2012 period) transportation emissions, including those from trucking freight activity must become a priority, where the implementation of policies and programs in order to stabilize emissions will have a direct impact on the energy industry and on investment decisions.

The United Nations Framework Convention on Climate Change (UNFCCC) has an objective to GHG`s concentrations in the atmosphere at a level that would prevent and reduce dangerous human-induced interference with the climate system. The ability of the international community to achieve this objective is dependent on an accurate knowledge of GHG emissions trends, and on our collective ability to alter these trends. For that reason the Intergovernmental Panel on Climate Change (IPCC) has been established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. The IPCC National Greenhouse Gas Inventories Programme (IPCC-NGGIP) has helped to develop and to refine an internationally-agreed methodology and software for the calculation and reporting of national GHG emissions and removals; and to encourage the widespread use of this methodology by countries participating in the IPCC and by signatories of the United Nations Framework Convention on Climate Change (UNFCCC).

In accordance with Articles 4 and 12 of the Convention on Climate Change (UNFCCC), and the relevant decisions of the Conference of the Parties, Parties to the Convention submit national greenhouse gas inventories to the Climate Change secretariat. These inventory data are provided in the national communications under the Convention by Annex I and non-Annex I Parties, and in addition Annex I Parties submit national greenhouse gas inventories annually. In the case of Canada, Environment Canada and Statistics Canada are continuously planning and implementing refinements to the national greenhouse gas emissions inventory that will improve the accuracy of emission estimates and the quality of the indicator used. These refinements take into account the results of annual quality assurance and quality control procedures and reviews and verifications of the inventory, including an annual external examination of the inventory by an international expert review team.

In order to continue with this task to evaluate emissions, our project «Environmental impacts of trucking freight transportation: quantitative analysis of greenhouse gas emissions in the province of Quebec» which is included in the evaluation frame-work of GHG`s emissions proposed by the IPCC, it has as a primarily objective to set a first step on the quantification of gas release making use of the «Origin - destination matrix» for the trucking activity in Quebec's province. This variation to evaluate emission will allow exploring new tools in order to improve, compare and refine future gas inventories.

1.2 Context of the thesis

Nowadays, there are many reports, documents, comparisons, and inventories analyzing the current worldwide freight transportation emission, but after having analyzed this information and their final results, the outcome does not seem to offer enough and adequate information.

As matter of fact, considering the role that trucking freight transportation represents for Canada, even for the Quebec (province), and considering the actual requirements of such information, it is indispensable to improve a specific approach to quantify emission releases of carbon dioxide (CO_2), methane (CH_4) and Nitrous oxide (N_2O) in terms of CO_2 - equivalent[3] in order to dispose all elements necessary to design potential and futures measures destined to reduce this pollutant trend.

Few things are known about the contribution of trucks vehicles as economic activity and mobile source of GHG emissions. More specifically, it is desirable to investigate not only the total volume of emissions, but also emissions by link in the transportation network in Quebec (province).

The specific problematic around this subject of trucking freight transportation emissions is led by the following facts:

- There is not a specific and detailed methodology that evaluates and quantifies emissions from this sector, considering all the factors and parameters this subject could involve.

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[3] CO_2 - equivalent is defined as the amount of carbon dioxide (CO_2) that would cause the same amount of radiative forcing as a given amount of another greenhouse gas. (IPCC/TEAP. Special report)

- The undersupplied or incomplete information in order to realize these kinds of evaluations and quantifications.

1.3 General objective

The general objective of this investigation is to bring up to date a method to evaluate and to quantify Greenhouse gas emissions produced by trucking freight transportation in Quebec's province, considering the provincial parameters that this activity involves. In order to achieve this general objective, the following specific objectives were pursued:

1. To employ the Trucking freight transportation Origin - Destination Matrix surveys from the Ministry of transportation of Quebec (MTQ), as the main data source for this quantification, in order to identifyaand to include in the evaluation information such as:

    - Trucks trips number
    - Trucks classification
    - Distances
    - Roads network (freeways (Autoroutes), highways (Routes) and Canadian highways)

2. To calculate Trucking freight transportationaemission in terms of «CO_2 – eq» from 1990 to 2004 for gasses suchaas:

- Carbon dioxide (CO_2)
- Methane (CH_4)

- Nitrous Oxide (N_2O)

3. To compare the trend obtained from this evaluation of trucking freight transportation emissions against the information of GHG emission given by Environment Canada for the province of Quebec and Canada.

4. To make suggestions for furthers evaluation and quantifications of this type.

1.4 Research hypothesis

- **Context**

Having into account factors as the introduction of new technologies used in trucks, employ of improved combustibles and the application of new environmental options to develop the trucking freight transportation activity, this research regards to demonstrate that the trend of gas emission originating from this activity, considering the actual conditions are increasing.

- **General Hypothesis**

Each year, from 1990 to 2004, the Greenhouses gas emissions as product of trucking freight transportation in the Province of Quebec are increasing.

- **Specific Hypothesis**

1- Considering the two alternatives proposed by the Guideline of the IPCC to evaluate Greenhouses gases emission from trucking freight transportation, is the

Tier 2, or <bottom-up> approach which present more accuracy in this type of evaluation and quantification for the trucking freight activity.

2- The use of annual statistics to quantify trucking freight transportation pollution does not permit to approach to a specific solution, also does not describe the problem inside Quebec's Province.

3- The use of the Origin - Destination Matrix, is the trustworthy tools which will permit to identify: particular trends, geographic areas affected and road infrastructure employ by this activity.

CHAPTER 2

LITERATURE REVIEW

Trucks play an important role in our society and are essential in maintaining our standard of living. They are responsible for practically all final deliveries of everything we buy. The industry and technology designed for trucks is often leading edge: advanced electronic controls and diagnostics, driver management systems and satellite communication are commonplace in large fleets. All this has been introduced not only for operational efficiency, but also to control the engine's performance and reduce vehicle emissions (Environment Canada. 2001).

2.1 The trucking freight activity

Freight transportation activity and communication are vital elements in the economies of nations, regions, and cities, being the movement of freight a business factor of develop (Forkenbrock, 2001). However this activity is much more complex and is not limited to the transport of people or goods. It also involves a concept about how the consumers satisfy their necessities and develop their activities.

Trucking transportation affects all kind of activities, in fact, most of the things we use or we eat in our daily lives are brought to us by truck, at least part of the way. Trucking is a major segment of the economy and is also critical for the competitiveness of Canadian business, because it is more flexible than other modes of transportation. Restricted only by the extent of the road network, trucking can provide the quality of service required to satisfy today's increasingly demanding shippers.

In Canada, trucks and trucking activity are a fundamental component of the economy because almost anything imaginable is transported by truck at some stage of its production. "If you got it, a truck brought it," is a common phrase (Transports Canada, 2003).

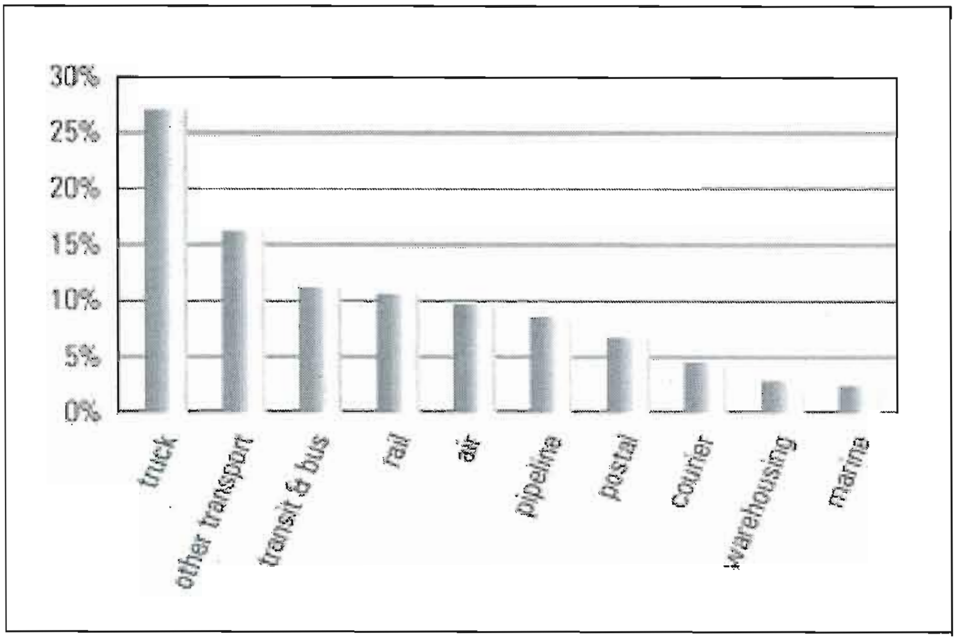
2.2 Trucking activity within the transport sector

About 90% of trucks in Canada are used to haul freight or equipment via public roads. The trucking industry in Canada, including private carriers, couriers, farm trucks and a wide range of trucks operated by trades, the service sector and governments are difficult to quantify, because so many different types of organizations use trucks in many different ways.

Trucking freight transportation is a complex activity, and this complexity derives from the pluralism of its hardware (infrastructure and vehicles) and the people and organizations involved (Forkenbrock, 2001). Its complexity is multiplied by the existence and roles of different modes, regulatory and legislative bodies, service providers, builders, financing systems, technologies, land-use patterns, and, most importantly, human behaviour. This mode of transportation basically provides over-the-road transportation of cargo using motor vehicles, such as trucks and tractor trailers. This sector is subdivided into general freight trucking and specialized freight trucking. This distinction reflects differences in equipment used, type of load carried, scheduling, terminal and other networking services. General freight transportation establishments handle a wide variety of general commodities, usually palletized and transported in a container or a van trailer. Specialized freight transportation is the transportation of cargo that requires specialized equipment because of size, weight, shape or other inherent characteristics. Each of these industry groups is further subdivided based on distance traveled. Local trucking establishments carry goods primarily within a single metropolitan area and its adjacent non-urban areas. Long-distance trucking establishments carry goods between metropolitan areas, but trucks do more than just move freight. Many trucking companies or those offering trucking services provide what is known as logistic services, whereby they manage all or a portion of a customer's distribution system.

The following figure shows that trucking is the largest component of the transportation sector. Also, trucking is 2.4 times as large as the rail industry (rail includes passenger transportation and trucking excludes freight carried by private trucks, couriers, farm trucks and other truck services).

Table 2.1 Transportation sector in Canada - Components and comparison (2001) (Transports Canada, 2003 - Truck Activity in Canada - A Profile)



2.3 Environmental and economic overview of trucking freight transportation

Trucking freight transportation involves a number of identified related environmental and economics issues, including the general question of projected rise in energy use, predictions for future increases in demand for freight transport and future prospects for manufacturing in developing countries (Goldman and Gorham, 2005).

2.3.1 Economic importance

The absence of a common definition for trucking activity makes it difficult to measure its importance on the economy. Moreover, even when certain definitions are used, for example "for-hire trucking", the sense of importance changes with the measure used (tonnes of freight, tonne-kilometres of freight, revenues, employment, etc.).

In Canada, the economy is measured by its gross domestic product (GDP), which was in the order of $940 billion in the year 2001 (1997 dollars). Trucking activity accounted for 1.2%, and this takes into consideration only commercial activities of for-hire trucks (18% of the total fleet). This 1.2% of the GDP may look small, but it is about the same size as the pulp and paper industry and the primary metal manufacturing industry (all steel mills and other sources of primary metals). The trucking industry is one-third larger than arts, entertainment and recreation, and is almost twice the size of forestry (raw logs).

The rail industry, both passenger and freight, is only 42% as large as the for-hire trucking industry (Transports Canada. 2003). One-quarter of all transportation-related GDP is generated solely by trucking activity. This activity, as commercial transportation industry represents annual revenues of almost $20 billion, which is more than 40% of the transportation component of Canada's gross domestic product. Some observers estimate that the value of all this activity to be in the range of $40 billion annually (Minister of Public Works and Government Services, 2001).

On the other hand, no one truly knows how much freight trucks haul. Statistics Canada, as the most common source of information, has estimated the volume of freight handled by for-hire trucks to be 278 million tonnes for the year 2000 (204 million domestic and 74 million cross-border). But this survey of 1,711 motor carriers out of a population of at least 9,317 includes only firms domiciled in Canada that earn $1 million or more in revenue, mostly from long-distance hauls (80 kilometres or more).

The trucking freight industry is highly flexible in using Canada's 900,000 kilometres of highways and roads to bring goods to all points of the country as well as facilitating the trade of large quantities of goods with our NAFTA (North American Free Trade Agreement) neighbours (Statistics Canada, 2004). This activity has employed around 270,000 Canadians as truck drivers, and another 400,000 Canadians are employed directly by the trucking industry in the heavy vehicle industry, in the areas of manufacturing, sales, support and parts (Environment Canada 2001).

In the province of Quebec, considering the actual process of internationalization of the economy and the distribution of the economic activity, (wood, minerals, food and alimentation products), the trucking freight activity represents around 56% of all truck displacements. Also in 1997, the trucking freight industry was responsible for moving almost 66 million tons of product out of a total of 225 million tons of product moved in the same year.

2.3.2 Environment summary

Technology designed for trucks is often leading edge: advanced electronic controls and diagnostics, driver management systems and satellite communication are commonplace in large fleets. This technology has been introduced not just for operational efficiency, but also to control the engine's performance and reduce vehicle emissions. Since 1970, trucks have reduced their emissions by over 80%, decreased their fuel consumption rate by 50% and increased their payload efficiency, as measured in litres/tonnes per kilometre (L/t-km), by 300% (Environment

Canada. 2001). On the other hand, the latest statement from Environment Canada reports that total emissions in Canada grew in 2004. Emissions from the energy sector increased 13% between 1990 and 2004. Transportation emissions increased 25% during the same period, with light-duty gasoline trucks and heavy-duty diesel vehicles contributing to 53% and 43% of the increase, respectively. These increases can be attributed to not only the increase in the number of passenger-kilometres travelled (more people drove further), but also to the increase of merchandise-kilometres travelled to supply and satisfy all kind of necessities.

Heavy-duty diesel vehicles (HDDV, large transport trucks), light cars and trucks consisting of light-duty gasoline vehicles (LDGV), or automobiles, and light-duty gasoline trucks (LDGT), or pickup trucks, sport utility vehicles (SUVs), and some vans showed emission increases of 2.6 Mt and 2.1 Mt respectively, between 2003 and 2004. This growth is a continuation of long term trends in road transport. Emissions from HDDV (large freight trucks) rose by about 20 Mt between 1990 and 2004, an 83% increase. Spurred by free trade and the deregulation of the trucking industry, the amount of freight shipped grew rapidly over the period. In addition, the quantity shipped by truck, as opposed to other modes of transport, such as rail, increased as a result of customer requirements for just-in-time delivery and cross-border freight (Environment Canada, 2006).

2.3.3 Sustainable development

As is well known, CO_2 emissions from trucking freight transportation are supposed to be the one of the largest contributors to the problem of global warming. It is feared that this warming might lead to a non-sustainable development of the earth (Kessel, 2000). Nevertheless, in response to this issue, a notion and a number of measures under the term "Sustainable Mobility" has emerged as the key challenge for the 21st Century and the future (Downing *et al.*, 2003).

When the Sustainable Mobility notion was created, it was defined as "the ability to meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values today or in the future" (WBCSD, 2001), and it was subsequently modified by the Brundtland Commission's definition of sustainability for the planet. A new definition of sustainable transportation was derived and defined as "the ability to meet today's transportation needs without compromising the ability of future generations to meet their transportation needs" (Black, 1996), (United Nations, 1987) referenced to economic, environmental, and social equity sustainability, but in not many ways is considered a strong connection among: economic growth, transportation, environments impacts and the future and welfare of the human being.

The most notorious disconnection concerning the concept of Sustainable Mobility has been motivated by a lack of vision and an overall view of transport having as result not only that sustainable development and freight transportation interact in a circular way (Grubb, 2003) but also these issues are in grand part responsible for climate change.

Among the disconnections of this activity it is possible to mention the following aspects:

- Truck freight transportation is the main consumer of fossil fuels, which ecologically is the primary worldwide source of consumed energy including oil and natural gas.

- Truck freight transportation has become each of the transportation modes (air, inland water, ocean, pipeline, rail, and road) and through a technological evolution has functioned separately under a modally based regulatory structure for most of the 20th century.

- The strong expansion of truck freight transportation is a consequence of safety and congestion. Also, constitutes an important disturbing activity, and in particular freight road transport throughout world is an important source of congestion and pollution, as well as a cause of many accidents (DeWitt and Clinger, 1997).

- Congestion and city traffic are synonymous of slow velocity, associated with pollution, gas emission, extra fuel consuming, traffic jams, roads congested and accidents. The congestion is caused not only by the traffic demand approaches but also by the capacity of the roads system. On the other hand when there are many users of the infrastructure its capacity is not enough to support then. Through this concept is easy to understand, that the congestion can vary significantly from day to another due to the traffic demand and the availability of the road capacity that are in a constant change. However traffic demand varies significantly by hour, day of week, and also by the season of the year and they are also subjected to significant fluctuations due to recreational travel, special events, and emergencies (Paniati, 2002).

- Noises, even in rural areas where fewer people live and work, (defined as unwanted or detrimental sound) is bothersome. Even where noise levels are generally quite low, intermittent noise can adversely affect people, especially when they need to concentrate, rest or maintain tranquility. While the psychological effects of noise are very difficult to monetize, noise tends to have an adverse impact on residential property values (Hokanson *et al.*, 1981).

- Deterioration of road network infrastructure, every time, when a vehicle or truck, is using or passing on the road (pavement structure), it is producing a small alteration in the internal composition of such structure, having as result deterioration and fatigue of the road system, that is represented on constantly maintenance and money investing to keep the infrastructure in normal condition. Also it is important to consider, when road infrastructure is constructed, a series of alterations are created and associated with the environment surrounded like changes in vegetation properties, soils and animal's behaviors.

- Production of waste, as a normal result of a regular use of any vehicle or trucks, a production of oil, tires, auto parts are the consequence of this process. It is important to consider that some of these remaining or waste are difficult to incorporate to the environment, because its storage or reusability is complicated or simply because its recycling is complex and expensive.

- In developed and non developed countries, the main air pollution problem has typically been high levels of smoke and sulphur dioxide arising from the combustion of sulphur-containing fossil fuels. The major threat to clean air is now posed by traffic emissions and trucking freight transportation. Freight transportation petrol and diesel-engined motor vehicles emit a wide variety of pollutants, principally carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds (VOCs) and particulates, which have an escalating impact on urban and rural air quality. In addition, photochemical reactions resulting from the action of sunlight on nitrogen dioxide (NO_2) and VOCs from vehicles leads to the formation of ozone, a secondary long-range pollutant, which impacts in rural areas often far from the original emission site.

But in contrast, economic, social and environmental situation have been well responded by the truck freight transportation activity:

- Freight transportation activity has grown with the increase and spread of population and economic activity and with the increasing interdependence of economies across the globe, reflecting unprecedented global interconnectivity.

- Freight transportation has become an integrated part of the production and distribution system and the rapid restructuring of the global transport system taking place at present. Therefore is likely to have a profound impact on processes of globalisation, not only in the industrialised and industrialising world.

- Freight transportation as an integrated part of the actual changing trends of mobility also aims to influence forces behind mobility and to pressure the transport industry.

2.4 Strategies to meet sustainable development objectives in trucking freight transportation

Reducing pollution from trucking freight transportation represents a complex set of policy choices. Much effort has focussed on improving the technology that is embedded in vehicles and transportation systems, changing the content of fuels, or/and developing alternative fuels. A wide range of regulations are in place governing fuel quality, combustion, and operating practices. Increasing efforts are being made to change the design of transportation systems, to influence transportation behaviour, and to reduce transportation fuel demand.

Being identified both positive and negative issues concerning to the truck freight transportation activity, now it is important to link the climate change and sustainable transportation to create a better and efficient way to frame the mitigation of climate change in order to find a better adaptation to the impacts and its linkages between population, lifestyles, environment and development (Swart *et al.*, 2003).

2.4.1 Quebec's province perspective solutions

In the activity of trucking transportation in Quebec is important to take into account many factors and context as: internalization of the economies (international market), internal structural changes of the economies in Quebec, distribution economical activity, legislatives frameworks, and actual freight transportation situation in order to get a balanced and reasonable solution.

Nowadays, there is many approximations concerning to find an appropriate and a concrete explanation to the trucking transportation problematic, being possible to mention three levels of solution to explore:

1. **First level**

It consist to focus and to work at level of trucks user. The Government on local or national level has to teach and instructing the population about this problem and its challenges. It is not possible that everyone blame or makes responsible the vehicle or truck as the main source of gas emission, if the vehicle it is just a tool to satisfy necessities of the human being, the vehicle it is an inert instrument that depends on somebody else's manipulation to make a specific task.

At this first level, the most important idea is the attitude change regarding to the vehicle or truck use, and to let everybody know what is going to happen in a future not too far about our life quality if this tendency continues.

2. **second level**

It regards to how the local and provincial governments have to support initiatives against the gas emissions, Reduce pollution and noise; Contribute reaching the Kyoto targets; Improve living conditions of city inhabitants (Crainic *et al*, 2004). These measures consist basically of initiatives to optimize the truck use.

Among the main measures of this initiative is possible to mention:

- Better urban planning and connection between common freight transportation, reduction of congestion and increasing of mobility (Crainic *et al*, 2004).

- Logistic efficiency, with the aim of increasing the load factor, choosing the optimum vehicle category or optimising the entire transportation chain from origins to final delivery (Léonardi et Baumgartner, 2004)

- Promotion of freight transportation modes which have lesser negative effects as rail and waterway, and their intermodal combination with road, in order to substitute these modes to the use of direct road transports. One way to achieve this substitution could be to set up a pricing policy that would include the external effects of each mode (Beuthe M. *et al*. 2002).

- Driver efficiency, with training or assistance from on-board units used for measuring components of driving behaviour that influence fuel use (Léonardi et Baumgartner, 2004).

- Route efficiency: information on itinerary, road conditions or traffic can help to optimise routing (Haughton, 2002).

At this level, the emergent ideas and solution deploys: "creative new technologies" (fuel and vehicle technology) and business models to provide competitive alternatives to the truck vehicle, also these strategic policies visions might take different forms if applied in different cities, where local needs, levels of economic development, cultures, urban forms, economic structures, and transportation systems must be taken into account (Goldman and Gorham, 2005).

3. Third level

It concerns to the implementation of measures at level of federal governments and worldwide industry in developed countries or companies or entities uncharged to develop new freight vehicles and fuel technologies, consumption efficiency, resistance of tires (Côte, 1998).

The main idea of this third type of solution it is to establish truth and real measures, policies, programmes regarding to new technologies to reduce GHG emissions, where the central point is the investment decision with ethical, moral and environmental criteria.

CHAPTER 3

GREENHOUSE EMISSIONS FROM TRUCKING FREIGHT TRANSPORTATION

The rapid growth of world population, strongly increasing energy demand of emerging economies and the high CO_2 production in industrialized countries are issues to aboard rapidly in order to reduce or even stabilize global GHG emissions (Kessel, 2000). However transportation is the single largest contributor of greenhouse gas emissions (GHG), accounting for about 25% of Canada's total emissions.

This sector also accounts for the largest share of the growth of emissions on the last decade. (Minister of Public Works and Government Services, 2001, Chapter 17, page 278.).

The following Table 2.1 presents the GHG`s trends and forecast from 1990 to 2020 according to different transportation activities.

Table 3.1 Greenhouse gas emissions trends and forecast 1990 – 2020

(M t - CO_2 eq)

Activity	1990	1997	2010	2020
Road transport	123.7	146.4	165.7	191.8
Rail	7.1	6.4	7.1	7.4
Aviation	10.6	13.0	17.6	21.1
Marine	6.1	6.2	7.0	7.4
Total Transport	147.5	172.0	197.4	227.7
Total Canada	601.0	682.0	764.0	845.0

Source: National Climate Change Strategy Development, Analysis and Modeling Group, Canada's Emissions Outlook: An Update, December 1999.

3.1 The greenhouse phenomenon

Human beings need specific environmental conditions to stay alive on this planet. One of those situations refers to the requisite to live under a natural greenhouse effect that provides a series of particular about weather conditions in order to obtain all the supplies necessaries to keep going in the planet.

Briefly, this phenomenon could be described as when the earth receives radiant energy from the sun it must be re-radiate back into space or our world would become progressively hotter. This solar energy arrives at the earth's surface at wavelengths lying predominantly within the visible part of the electromagnetic spectrum. The earth re-radiates energy, however, at longer wavelengths which concentrate in the far infrared or "heat" end of that spectrum. The energy of these longer wavelengths is more readily absorbed by naturally occurring carbon dioxide (CO_2) and water vapor in addition to other infrared-absorbing gases such as nitrous oxide, methane, chlorofluorocarbons and ozone. This absorption occurs primarily in the troposphere, the region from the earth's surface up to an altitude of 10 to 15 km (Labelle, 2000). When these molecules absorb energy, they cause general atmospheric warming, a phenomenon commonly called the "greenhouse effect." These gases thus act like a "thermal blanket" around the earth, and as their atmospheric concentration increases, together with the absorption of energy in the infrared, incoming radiation temporarily exceeds outgoing radiation. The temperature of the atmosphere rises, and a new radiation balance is established. This "natural greenhouse effect" is an important phenomenon to biological life on Earth. The average surface temperature is maintained at approximately 15°C because of this effect. If all the radiant energy were to escape out of the atmosphere, the global temperature would be -18°C, a difference of 33°C (Hobbie *et al.*, 1984). However, any alteration on this natural greenhouse effect will be represented in an imbalance on the human being welfare.

3.2 The balance of greenhouse gases

Carbon dioxide (CO_2) is the vehicle that transports carbon through the carbon cycle. It is removed from the air by plants during photosynthesis to make solid organic compounds, and when these compounds are respired, CO_2 is again released to the atmosphere. Carbon dioxide dissolves in the oceans as bicarbonate and can be converted to the solid, calcium carbonate, by shellfish. In the very long term, CO_2 can be converted to fossil fuels. This is the role of carbon dioxide in carbon circulation (a biogeochemical cycle), which consists of both living and nonliving components (Labelle, 2000).

Over the past half-billion years of our planet's more than 4.5-billion-year history, a small percentage of the carbon circulating through the earth's surface environment has been diverted and stored in sedimentary rocks as fossil fuels. In mankind's recent history there is believed to have been an approximate balance in the exchange of carbon between the atmosphere and the oceans. In the course of a century or two, however, industrial activity has returned to the atmosphere a portion of the carbon that nature had been storing in fossil fuels over many millions of years.

Worldwide human activity or anthropogenic activities such transportation, industrial activities, are producing more than 24 billion tonnes of CO_2 every year, being the direct combustion and non-energy uses of fossil fuels are responsible for some 98% of total carbon dioxide emissions and 78% of total greenhouse gas (GHG) emissions, producing as result an unbalance due that the system it is not re-radiating back into space the radiant energy from the sun (IPCC, 1990). Of the six gases covered by the Kyoto protocol, CO_2 is the most significant, counting for some 80% of potential global warming. CO_2 comes first among the GHG,s produced (81% of emissions, or 500 million tones), followed by methane (12%), nitrous oxide (5%), and perfluorocarbons (1%). The industrial production, transport and consumption of fossil fuels account for 89% of emissions being the energy industries the main producers of such emissions (34%), followed by the transportation industry (27%), other industries (20%), residential sector (10%), the commercial and industrial sector (5%), and agriculture (5%) (Environment Canada, 2006).

As a result of these human being activities, the atmospheric concentration of CO_2 has augmented by 31% since 1750 and continues to increase, on average, by 1.5 ppm or 0.4% per year. About 80% of the anthropogenic emissions of CO_2 in the past 20 years are due to fossil fuel burning, cement production and deforestation. Since approximately 1750, the atmospheric concentrations of CH_4 and N_2O have increased by 151% and 17%, respectively (Environment Canada, 2003).

Table 3.2 Atmospheric changes in concentration of GHG

Atmospheric Indicator:	Pre-industrial Concentration (1000 - 1750)	Concentration year 2000	Increase
Carbon dioxide CO_2	280 ppb	368 ppb	31 ± 4%
Methane CH_4	700	1750	151 ± 25%
Nitrous oxide N_2O	270	316	17 ± 5%
Tropospheric O_3	Increases by 35 ± 15% from 1750, varies with region		
Hydrofluorocarbons HFC Perfluorocarbons PFC Sulphurhexafluoride SF_6	Increased globally over last 50 years		

Source: Environment Canada. 2003. Science of Climate Change. Greenhouse Gas Concentration Trends in the 20th Century.

Future levels of Greenhouse gas emissions are conjectural, depending upon the assumptions made regarding population growth, technological change, the global economy, energy conservation, fuel costs and the evolution in the mix of energy sources to satisfy energy requirements (IPCC, 1990).

3.3 Greenhouse emissions and climate change

Climate changes are more than a warming trend. Increasing temperatures will help to change the weather (wind patterns, the amount and type of precipitation and the types and frequency of severe weather events that may be expected to occur). Also greenhouse gasses and climatic change are motivating several changes and impacts into all three aspects of sustainable development: environmental, social and economic as human health, ecosystem alterations, forestry, fishery, water resources affecting the human welfare. (Prades et al., 1998)

3.3.1 Environmental impacts

3.1.1.1 Climate change

The Intergovernmental Panel on Climate Change (IPCC) has predicted an average global rise in temperature of 1.4°C (2.5°F) to 5.8 °C (10.4°F) between 1990 and 2100, but climate changes are more than a warming trend.

The increase in the mean global temperature of the lower atmosphere could result from a doubling of the current CO_2 concentration lay between 1.5°C and 4.5 °C. More complex model takes into account predicts maximum global mean annual surface air warming in the range of 1.9 to 2.5 °C (Hengeveld, 1997).

Environment Canada suggested that in 1997 a doubling of CO_2 levels would cause the average global temperature to rise by a minimum of 0.98 °C. Over the past century, the average global temperature is believed to have increased by approximately 0.3 to 0.6 °C, and it could continue to increase over the next 100 years.

3.1.1.2 *Stratospheric ozone depletion*

The GHG`s from road transportation and mobility processes like Halocarbons such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have led to the reduction of the ozone layer, also as a response to this problematic Hydrofluorocarbons (HFC's) has been created to substitute CFCs and HCFC's to not deplete stratospheric ozone, but on the other hand contributing to global warming.

The stratospheric ozone depletion processes leads to a cooling of the troposphere, thus offsetting climate warming, through decreased downward infrared radiation, and through increased UVB radiation, which enhances the oxidation of methane producing some climate change that may also change temperature and wind conditions in the stratosphere, enhancing further ozone depletion (Noreen *et al.*, 2002).

3.1.1.3 *Oceans flows*

Oceans are the main heat distribution factor between continents and are controlled by a massive combination process involving deep ocean currents displacing enormous quantities of hot and cold water, this process has a direct effect on coastal air temperature that comes in contact with it (Oppenheimer, 1998).

A higher greenhouse gas levels and increased temperatures could have an impressive effect on ocean flows. Scientists estimate that sea levels could rise by an average of 5 cm per decade over the next 100 years. Some estimates suggest that sea levels could rise by almost a full meter by the year 2100. Now this temperature has increased only few degrees and it could result in the melting of icecaps, which in turn supply a considerable quantity of additional, freshwater to the oceans. Seawater density and salinity levels would both decrease, and ocean movement would be slowed. If the oceans stopped moving completely, coastal regions would be deprived of a major heat source; as well, some continents - notably the western part of continental Europe - would become cooler. On the other hand, in the absence of ocean movement, the sea would stop absorbing CO_2, a phenomenon that currently takes care of half of the CO_2 produced in the world. If current consumption patterns continue, atmospheric CO_2 levels will double with extreme and unforeseeable climatic consequences.

Canada is the perfect example of this situation; scientists suggest that the disappearance of cod from the Gulf of St. Lawrence may not only be due to overfishing, but also to oceanic heat loss. Northern Quebec is now colder and drier than before, and is currently experiencing greater climatic variation. It is thus not difficult to imagine that with more pronounced climatic change, water levels in natural reservoirs such as the St. Lawrence River and the Great Lakes would drop even further. Such a development would particularly affect the hydroelectric and marine transportation sectors, as has already happened in the past: in 1994, these two sectors suffered losses of million of dollars a result of the drop in the water levels of the Great Lakes (Labelle, 2000).

3.1.1.4 Urban air pollution

Fossil fuels used in cities and roads for transportation produces air pollutants such as particulate matter, sulphur compounds, carbon monoxide, and ozone precursors such as nitrogen oxide and volatile organic compounds (VOC's) besides climate changes can also affect the chemical processes involved in urban air pollution through changes in temperature, cloud cover, winds, and the impacts of this pollution on public health (Noreen *et al.*, 2002). Principally this use of fossil fuels to feed engines is the principal source of air pollution (Environment Canada, 2001).

The Internal combustion of these engines is producing the following GHG`s:

- Hydrocarbons (HC), which are partially, burned fuel – these are also called volatile organic compounds (VOC).
- Carbon monoxide (CO), which is a product of an incomplete combustion of carbon.
- Nitrogen oxides (NOx), which are the product of high-temperature combustion of nitrogen (present in air).
- Particulates or particulate matter (PM), which are agglomerations of fuel soot and sulphur particulates caused by incomplete combustion.
- Carbon dioxide (CO_2), which is the complete combustion product of carbon in the fuel.
- Sulphur oxides (SOx), which are created by the combustion of the sulphur contained in fuel, especially diesel fuel.

3.1.1.5 Land degradation

Greenhouse gas emission is the most significant environmental problem in several regions deteriorating land quality and varying the properties physic and chemical of the soil (Agriculture and Agri-Food Canada, 1999).

The new weather and climatic pattern not always do match with the existing land, affecting the production of food and other agricultural crops. In many regions, such as sub-Saharan Africa, the projected changes in temperature and especially precipitation due to climate change would lead to additional stresses on agricultural productivity. Also food production can also be a cause of global warming by the application of nitrogenous fertilizers for intensive agriculture thus increasing emissions of the GHG`s nitrous oxide (Noreen *et al.*, 2002).

3.1.1.6 Land use and biodiversity

Climate change and the release of GHG`s to the atmosphere have created a big impact on vulnerable ecosystems affecting not only the ecosystem composition and biological diversity (Noreen *et al.*, 2002) but also due to new agricultural or urban usages by the new climatic changes patterns (Agriculture and Agri-Food Canada, 1999).

3.1.1.7 Agriculture and forestry

GHG`s and Climatic changes can influence the species distribution and productivity of forest and agriculture ecosystems, impacting their operations (Noreen *et al.*, 2002). Day by day forecast prediction it is weaker to use on agricultural and forestry proceedings, the temperature and precipitation calculations are more difficult to use on planting decisions (Gielen et Yagita, 2002), besides the probability to get more dry soil conditions is expected.

3.1.1.8 Water resources

Greenhouse gases and climate change have modified precipitation patterns, snowfall and ice cover (including glaciers) and affecting water supply. High temperatures have increased and affected water demand for agriculture and water quality, as well as the sources to produce energy form hydropower plants. Therefore these climatic have affected agriculture, industry water users and aquatic ecosystems like fisheries (Noreen *et al.*, 2002).

3.3.2 Social economic impacts

Factors such as human well being, human consumption and social organization are vulnerable factors on developing countries regarding to extreme weathers events and climatic variability. These variables have produced an economical damage and enormous pressure on poor economies, making poorest countries more vulnerable (Monirul et Qader, 2003).

3.3.2.1 Poverty

One of the most worrying aspects of climate change impacts it is that they are projected to fall disproportionally on poverty, increasing the existing development inequalities.

Poverty often coincides with limited technological development, inadequate institutions, unequal access to resources and information, and poor levels of participation in decision-making. However, it is no surprising that the impacts of climate change can especially affect poor concentrations of human beings, who are much more vulnerable and have less capacity to adapt to climate changes. At the same time, the poverty contributes to climate change as well, because of the conversion of forests and marginal lands by poor farmers and the usage of inefficient technologies (Noreen et al., 2002). The most vulnerable communities and countries are those which are already the poorest and least able to adapt to these changes (Adil et al., 2003).

3.3.2.2 Health

The main problems related to traffic and transportation, GHG`s and air pollution are concentrated in central cities with high density of populations and activities.

Respiratory, cardiovascular diseases, asthma, intoxication caused by chemical and biological contaminants, skin damage and skin cancer, cataracts, disturbed immune function and premature mortality are the most frequent air pollution consequences of private car use, having very elevated cost to the health sector (Rabl et Spadaro, 2000).

3.3.2.3 Economic growth and development

GHG`s emission and climatic changes have directly affected the economic development structure. Countries where their economies depends basically of activities such as agriculture, fisheries, coastal system, etc or countries with economies service-oriented with less consumptive lifestyle will suffer more impacts than countries with economies that depends basically on the energy andamaterial goods production (Noreen *et al.*, 2002).

3.3.2.4 Security

Greenhouse gases released and climate change can also have connection with security issues such as: political tensions and conflicts between countries by means of water resource deficiency, also projected reductions in Arctic sea ice could affect Arctic security by making high latitude waterways more accessible for longer periods. Finally the overdependence on fossil fuel resources (the most important source of GHG`s), concentrated in a limited and politically unstable region (such as oil in the Middle East), has proven to be a source of conflict and military activities. (Noreen *et al.*, 2002).

3.4 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (UNFCCC) is the result of an international environmental treaty or agreement produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro in 1992. This treaty aimed to stabilize the emissions of GHG release even its potential reduction in order to combat global warming.

On June 12, 1992, 154 nations signed the UNFCCC that upon ratification committed signatories' governments to a voluntary "non-binding aim" to reduce atmospheric concentrations of greenhouse gases with the goal of "preventing dangerous anthropogenic interference with Earth's climate system." These actions, as gathering and sharing information on greenhouse gas emissions, national policies and best practices, cooperating in preparing for adaptation to the impacts of climate change and cooperate in preparing for adaptation to the impacts of climate change, were aimed primarily at industrialized countries, with the intention of stabilizing their emissions of greenhouse gases at 1990 levels by the year 2000 and other responsibilities would be incumbent upon all UNFCCC parties.

The parties agreed in general that they would recognize "common but differentiated responsibilities," with greater responsibility for reducing greenhouse gas emissions in the near term on the part of developed/industrialized countries, which were listed and identified in Annex I of the UNFCCC and thereafter referred to as "Annex I" countries.

The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases.

On December 4 of 1992, Canada ratified the United Nations Framework Convention on Climate Change and in March of 1994, the Convention entered into force (Government of Canada, 2005).

3.5 Canadian measures to stop the actual emission trend

There is not doubt that awareness of the need to preserve the environment has grown worldwide during the last decades, though in many parts of the world this awareness is hidden behind more urgent needs to be satisfied.

As previously mentioned, the world is facing a big environmental challenge represented by the rapid growth of world population, strongly increasing energy demand of emerging economies and the slow progress of international harmonization of CO_2-reduction measures that are serious obstacles, in order to reduce or even stabilize global CO_2-emissions. But if mankind turns out to be unable to solve these problems, the actual impacts and the so far undetectable anthropogenic greenhouse effect may become very real, and it might then be too late for a "no regret policy".

During the Kyoto Conference, Canada made commitments to reduce its greenhouse gas emissions by 3% from 2008 to 2012 and by a further 5% from 2013 to 2017. Also, in order to meet these commitments, and from the perspective of sustainable development, Canada has to help developing countries by transferring technology that encourages both emission reduction and economic growth.

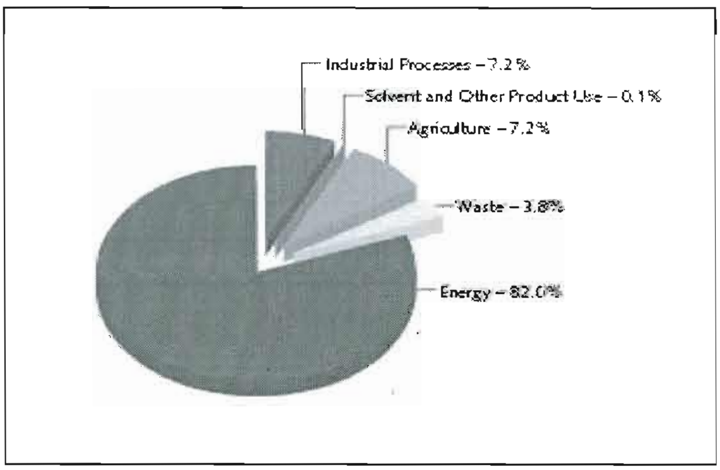
3.6 Canadian and Quebec emissions

Canada, the United States and Japan are responsible for 85% of emissions leading to the GHG increases observed on the latest years. In 2004, Canada contributed about 758 Mt CO_2 - eq of GHGs to the atmosphere, an increase of 0.6% over the 754 Mt recorded for the year 2003. Approximately 73% of total GHG emissions in 2004 resulted from the Energy sector. Figure 2.1 presents the percentage of Greenhouse Gas by the Canadian industry.

In the case of the province of Quebec, it represents 23.6% (7.5 million) of the total country's population and accounted for 12.3% (91.8 Mt) of Canada's GHG totals in 2004. In the same year, it has registered a 9.4% increase in HDDs (heating degree-day) compared with 1990 (Environment Canada, 2006).

Figure 3.1 Sectoral Breakdown of Canada's GHG.

(Environment Canada, 2006. Canada's Greenhouse Gas Inventory 1990 - 2004)



3.7 Reduction of Greenhouse gas

Measures to reduce greenhouse gas emissions are a major issue for governments and industry around the world. All developed countries, and many developing ones, are actively putting into place policies and programme to reduce emissions. The implementation of these policies and programmes has a direct impact on the energy industry and on investment decisions (World Energy Council (WEC), 2004).

Among the measures and strategies to reduce Greenhouse gas emission in a nationwide and worldwide perspective, have priority:

- Reduction in processes that involve production of emissions as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).
- Trade in greenhouse gas emission permits
- Substitute CO_2 - emitting processes by CO_2 - «free» ones (renewable energy, nuclear energy, fuel cells).
- Avoid CO_2 - emitting processes where possible
- Improve energy efficiency
- Replace CO_2 - intensive processes by less CO_2-emitting ones.

CHAPTER 4

METHODOLOGY

4.1 Characterization of the evaluation model

For this investigation, the guideline that will be employed to quantify Greenhouse Gasses of trucking freight transportation in the province of Quebec is taken from the Recommendations and methodologies for mobile combustion: road vehicles, from the Intergovernmental Panel on Climate Change (IPCC), as unique worldwide organization that provides this kind of information.

To evaluate gas emissions, the Intergovernmental Panel on Climate Change (IPCC) classifies all the sources of Greenhouse gas including the transportation sector. In the transportation sector, the IPCC categorize: civil aviation, road transports, railways, navigation and other transports, therefore, it is possible to calculate greenhouse gas emission for all sources of mobile combustion with the exception of those associated with pipelines and aviation (IPCC, 1997).

The emissions of CO_2 for road transports are best calculated on the basis of the amount and type of fuel combusted and its carbon content. However, CH_4 emissions and N_2O are the most complicated to estimate accurately because emission factors depend on vehicle technology, fuel and operating characteristics.

4.2 Evaluation of emissions from road vehicles

The IPCC Guidelines estimate CO_2 emission from road vehicles, depending on the sources of information available, also provides two kinds of recommendations for this type of evaluations: the first one based on vehicle kilometres travelled and the second one based on fuel consumption, all the emissions in terms of CO_2 – equivalent (CO_2– eq) as a common unit.

4.2.1 Alternatives of evaluation

The first option - Tier 1, or <top down> approach calculates CO_2 emissions by estimating fuel consumption in a common energy unit, multiplying by an emission factor to compute carbon content, computing the carbon stored, correcting for unoxidised carbon and finally converting oxidised carbon to CO_2 emissions (IPCC, 1997). The approach is shown in the next equation:

$$\text{Emissions} = \sum_i \left[(EF \times FC) - CS_j \right] \times FO \times \frac{44}{12}$$

Where:

EF = Emission factor

FC =Fuel consumption

CS =Carbon stores

FO =Fraction oxidized

j = fuel type

The second option - Tier 2, or <bottom-up> approach estimates CO_2 emissions in two steps, the first step is to estimate fuel consumed by vehicle type and fuel type and the second step is to estimate total CO_2 emissions by multiplying fuel consumption by an appropriate emission actor for the fuel type and vehicle type (IPCC, 2000). The approach is shown in the next equation:

$$\text{Emissions} = \sum_{ij} \left(EF_{ij} \times FC_{ij} \right)$$

Where:

i = Vehicle type

j = Fuel type

4.2.2 Choice of method of evaluation

Emission can be estimated from either the fuel consumed (represented by fuel sold) or the distance travelled by the vehicle. The first approach (fuel sold) is recommended for CO_2 and the second (distance travelled by vehicle type and road type) is appropriate for CH_4 and N_2O, also the IPCC recommends the Tier 1 (top down) approach to calculate emissions on the basis of fuel consumption statistics from a National Authority responsible of this information. But considering the objective of this evaluation of GES, to evaluate the Origin – destination Matrix, and the accessibility to information such distances travelled, theoretical fuel consumption, distribution of emissions controls in the fleet and Emission factors for different pollution controls and the intention to avoid the use statistic data, the Tier 2 or "bottom–up" approach will be alternative employed for this quantification of emissions from trucking freight transportation.

4.2.3 Methodological framework

The evaluation of emission for road vehicles proposed by the IPCC depends on the sources of information available. In order to develop this evaluation and considering the data sources available for this quantification, the next methodological framework will be follow:

- **Phase 1**. To make use of the latest trucking freight transportation examination for Quebec's province presented by the Ministère des Transports du Québec (MTQ), which refers to the year 1.999, as our main source of information. This examination contains the Origin - destination matrix for this activity in Quebec's province and depicts the number of trucks traveling between the administrative zones located within Quebec.

- **Phase 2**. To identify and classifying the roads network also to quantify in terms of kilometres, each road used by the Quebec's trucking activity having as reference the 1999 trucking examination. In this phase 2, having as a reference the checking points used during the process of the 1999 trucking survey, the geographical limits will be determinate in a form of administrative areas in order to confines the scenario of evaluation and to know the different cities implicated in this activity.

- **Phase 3**. Considering the information obtained from the previously phase, (distances, trucks classification, type of fuel employed, rates of fuel consumption, and Canadian emission factors), all this data will be evaluated on the Recommendations and methodologies for mobile combustion: road vehicles - Tier 2, or «bottom-up» approach, proposed by the IPCC in order to obtain result of emissions in terms of CO_2 eq.

- **Phase 4**. Having the total trucking freight transportation emission for the year 1999, and considering the necessity to have a forecast of emission for futures years, the concluding pollution number obtained from this quantification in the categories implicated, will be affected by the annuals variations (increasing or decreasing percentages from 1990 - 2004) of Greenhouse gas emission given by Environment Canada, afterwards by means of correlations (lineal, potential, exponential, polynomial and logarithmical) and considering its Coefficient of Determination (R^2), an equation will be deduced to know the emission time series on the future years.

4.3 Definition of the scenario of evaluation and concepts

Considering the necessity to name the scenario of evaluation for this quantification of GHG, it will be referred as scenario « Q 80^+ », that denote the evaluation of emission in Quebec's province (Q) for trucking freight trips of at least 80 km (80^+). This scenario « Q 80 $^+$ » will represent the emission trend for the province considering the following features, parameters and variables.

4.3.1 Description method of evaluation - Tier 2 or 'bottom-up' approach

The analysis of quantification will lead on the Tier 2 or 'bottom-up' approach, guided by the next expression:

$$E_{cat} = EF_{cat} \times FC_{cat}$$

Thus:

E_{cat} =the total emissions in a given vehicle category (CO_2 - eq.)

EF_{cat} = the emission factor for the category (g / L fuel)

Fc_{cat} = the amount of fuel consumed in a given category (L/Km)

Thus Fc_{cat} is defined as:

$$FC_{cat} = VP \times ADT \times FCRs$$

Where:

VP (Vehicle population) = Number of vehicles per category
ADT (Average Distance Traveled (Vkmt's) = Estimates for distances traveled by each class of vehicle (Km)
$FCRs$ (Fuel Consumption Ratio) = liters of fuel per kilometer (L/km)

To calculate final emissions, a specific combination of emission factors for CO_2, CH_4, and N_2O are multiplied by the total fuel in each of the unique consumption categories.

CH_4 and N_2O are then adjusted according to their specific GWP «Global Warning Potential» to convert their units to CO_2 - eq. (IPCC, 2000), being the final expression:

$$E_{cat(ij)} = \left[EF_{CO2} / EF_{CH4} / EF_{N2O} \times \left[(VP)(DT)(FCR)\right]\right] \times GWP_{(CO2/CH4/N2O)}$$

i = Vehicle type (category)
j = Fuel type

VP =Vehicle Population

DT=Distance traveled

$$\text{Emissions}=\sum_i \sum_j \left(EF_{ij} \times FC_{ij}\right)$$

Where:

$$FC_{ij} = (TP \times DT \times FCR)$$

i = truck

j = fuel type

TP= Truck population

4.3.2 Distance trips

This analysis of quantification of emission for trucking freight transportation only considers long distance trips. Considering the definition of long distance trip given by the document "Le camionnage au Canada" from Statistics Canada, it refers to a trip with a distance of at least 80 Km.

4.3.3 Origin - Destination matrix and Geographical area of analysis

The geographical area of study is defined by the Origin - Destination matrix, which is a kind of information that came directly from soundings on the road network of 17 administrative areas of Quebec, also includes information such of trucks movements to the United States, Ontario and Maritimes. The Origin - Destination matrix for the year 1.999, offers as result 240.000 trucks trip were done during one week on the road network of Quebec (Province). Such trips were intercepted on 51 points of survey all along the roads network of the province.

In order to obtain accuracy and to make possible the calculation of gas emissions, a city of reference is associated to each region administrative, considering the sites of traffic inspection or check-points for the 1999 trucking Survey. This association of a city to each region administrative permits identifies 20 geographical points that permits 400 Origin - Destination alternatives could be evaluated.

Figure 4.1 Geographical area of study and trips number produced by administrative area (MTQ, Enquete sur le camionnage de 1999)

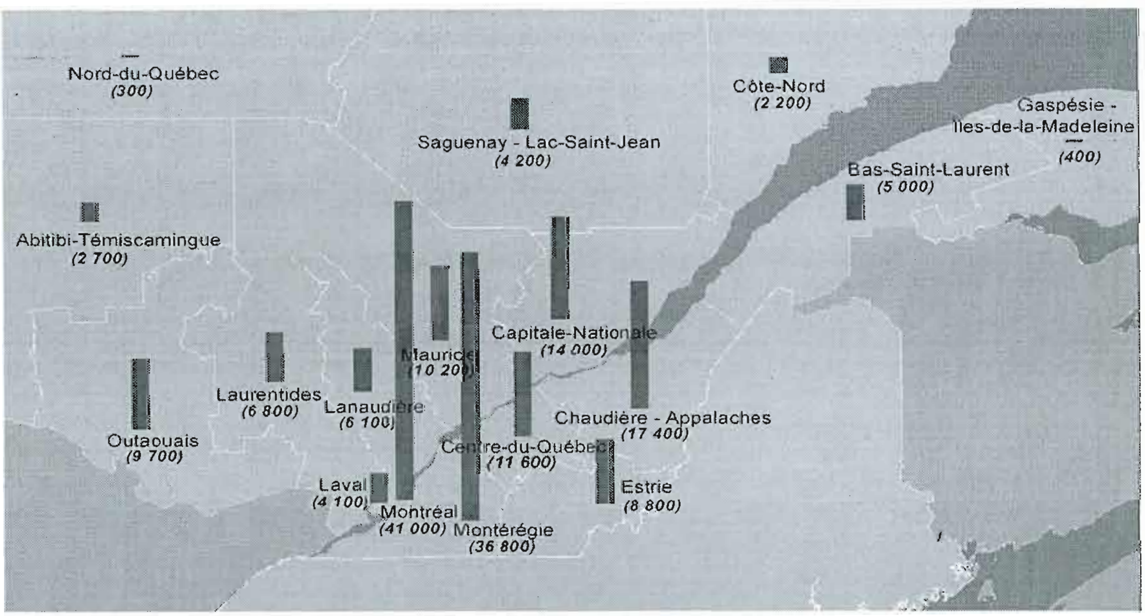


Table 4.1 Administrative areas of evaluation and cities of reference

Administrative area	City of reference
Bas Saint Laurent	Rimouski
Saguenay-lac saint jean	Chicoutimi
Capitale nationale	Quebec
Mauricie	Shawigan
Estrie	Sherbrooke
Montréal	Montréal
Outaouais	Val d`or
Abitibi-Témiscaminque	Rouyn Noranda
Cote nord	Baie Comeau
Nord du Québec	Chibougamau
Gaspésie-iles de la madeleine	Gaspé
Chaudières-Appalaches	St Georges
Laval	Laval
Lanaudière	Joliette
Laurentides	Mont laurier
Montérégie	St Hyacinthe
Centre du Québec	Drummondville
United States (Border)	St Bénard de la Colle (Border)
Ontario	Hull
Maritimes	Degelis

4.3.4 Road corridors

In order to identify the different road corridors implicated in the trucking freight transportation activity in Quebec, these will be designated as follows (Table 4.2):

- Québec freeways (Autoroutes): designated by the letter A and a number.
- Québec highways (Routes): designated by the letter R and a number.
- Canadian highways: designated by the letter H and a number.
- The U.S. Interstate highways system: designated by the letter I and a number.

Table 4.2 Road corridors of study

Administrative area	City of reference	Corridor
Bas Saint Laurent	Rimouski	A-20, R-185, R-132
Saguenay-lac Saint Jean	Chicoutimi	R-167, R-175
Capitale Nationale	Quebec	A-20, A-40, A-73
Mauricie	Shawigan	A-40, A-55, R-155
Estrie	Sherbrooke	A-10, A-55
Montréal	Montréal	A-10, A-15, A-20, A-40
Outaouais	Val d`or	A-5, A-50, R-105
Abitibi-Témiscaminque	Rouyn Noranda	R-117
Cote nord	Baie Comeau	R-138
Nord du Québec	Chibougamau	R-113, R-167
Gaspésie-iles de la Madeleine	Gaspé	R-132
Chaudières-Appalaches	St Georges	A-20, A-73, R-173
Laval	Laval	A-10, A-15, A-20, A-40
Lanaudière	Joliette	A-25, A-40
Laurentides	Mont laurier	A-15, R-117
Montérégie	St hyacinthe	A-10, A-15, A-20, A-40
Centre du Québec	Drummondville	A-20, A-55
United States (Border)	St Bénard de la Colle (Border)	A-15
Ontario	Hull	A-417
Maritimes	Degelis	R-185, R-132

4.3.5 Transportation categories and Vehicle population

This quantification of emission only consider the Heavy duty trucks category, having into account that a heavy duty trucks are any vehicle-truck rated at more than 3900 kg gross vehicle weight (Ministère des Transports du Québec, 1998).

To improve the exactness on this evaluation of GHG, also the 1.999 trucking survey shows the truck category is composed by next three sub-categories.

Table 4.3 Trucks composition

Subcategory of truck	Percentage (%)
Truck (T1)	71
Tractor with semi-trailer (T2)	24
Truck with trailer (T3)	5

Source: Ministère des Transports du Québec, 2003

The following three graphics provide an image of the truck subcategories considered into the evaluation:

Figure 4.2 Truck (T1)

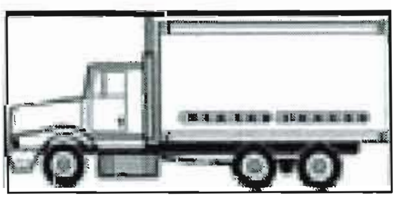


Figure 4.3 Tractor with semi-trailer (T2)

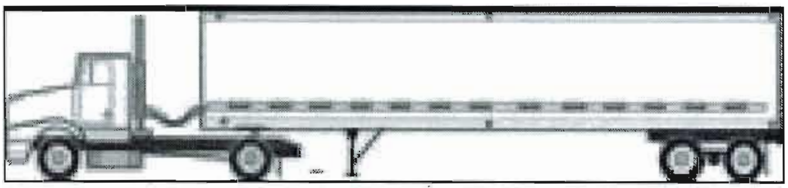
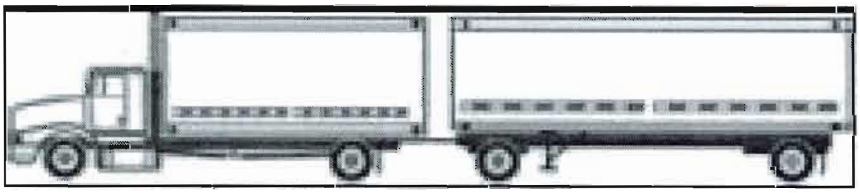


Figure 4.4 Truck with trailer (T3)



Figures 3-4-5 / Source: MTQ, 1998. Guide des normes de charges et de dimensions des véhicules.

4.3.6 Fuel and consumption ratios

In the truck freight transportation activity is possible to consider both diesel and gasoline engines. Diesel engines are more efficient than gasoline (petrol) engines of the same power (Environment Canada, 2001). But having into account the characteristics of this evaluation, regarding to quantify emissions for long distances trips, *in this evaluation only diesel engines are considered*.

As principal features to name about diesel fuel, this combustible is denser, most efficient and contains about 15% more energy: a given amount of diesel fuel can make more power than the same amount of gasoline. Also, nowadays, there's a powerful impetus for the government to encourage diesel-powered vehicles.

The fuel consumption ratios (FCR) it is a parameter given in liters of fuel per kilometer. FCR is a factor that is determined by standard vehicle laboratory tests. However, recent research has shown that real-world fuel use is consistently higher than laboratory- generated data. Based on studies performed in the United States and Canada on on-road vehicle fuel consumption, Environment Canada proposes a 25% increase above the laboratory Fuel Consumption Radios ratings (FCR). Average FCR for all operating vehicles within each truck subcategory are calculated by apportioning the model-year consumption data according to the vehicle age and control technology distribution (Environment Canada, 2006).

In this evaluation, the following fuel consumption ratios will be employed:

Table 4.4 Fuel Consumption Ratios (FCR)

Truck sub-categories	FCR
Truck (T1)	0.393 Lt / Km
Tractor with semi-trailer (T2)	0.54 Lt / Km
Truck with trailer (T3)	0.54 Lt / Km

Source: "Fuel Consumption Guide Ratings for new cars, pickup trucks and vans 2003", "Santini et al, 2001" and Energy Information Administration (EIA), 2007.

4.3.7 Emission control and technology penetration rates description

This is a simple division of fuel consumption by vehicle type that enables the allocation of emissions of carbon to different vehicle categories. It does not consider the effect that different pollution control devices have on emission rates (SGA, 2000).

To procure accuracy on the input data is important to consider the next information to select the appropriate emission factor (SGA, 2000):

Trucks without emission controls were the norm in Canada in the 1960s. Non-catalyst-controlled vehicles were brought into the market in the late 1960s. Emission control technology on these included modifications to ignition timing and air-fuel ratios, exhaust gas recirculation, and air injection into the exhaust manifold. Oxidation (two-way) catalytic converters were first used on Canadian vehicles introduced in 1975, and their use continued on production vehicles until the 1987 model year. These so-called two-way converters oxidized hydrocarbons.

The three-way (oxidation-reduction) catalytic emission control technology was introduced in Canada in 1980. Typical ancillary equipment included carburetors with simple electronic ignition. Later, for the 1984 model year, a portion of the fleet was equipped with electronic computer-controlled fuel injection, which became an integral part of the emission control system. By 1990, such computer systems were standard equipment on all gasoline vehicles.

The broad category of control technologies produced from the time three-way catalytic converters were introduced up until 1993 has become known in North America as Tier 0 emission control. Tier 0 catalytic converter technology is further subdivided into "new" and "aged" types. The "new" subcategory representing units less than a year old. Tier 1, (a more advanced emission control technology), was introduced to North American Light Duty Gasoline Vehicles in 1994. It consists of an improved three-way catalytic converter under more sophisticated computer control vehicle. (Environment Canada, 2006).

4.3.8 Global warming potential (GWP)

A GWP is defined as an index, comparing the climate impact of an emission of a greenhouse gas relative to that of emitting the same amount of carbon dioxide (IPCC/TEAP. Special report). Also is defined as the measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. A GWP is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless (IPCC, 1995).

In order to procure this quantification, the evaluation of emissions will be led using the GWP published in 1996 in the IPCC's Second Assessment Report.

Table 4.5 Global warming potential

GAS	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310

Source: Intergovernmental Panel on Climate Change, Climate Change 1995: The Science of Climate Change.

4.3.9 Emission factor (EF)

The IPCC refers to an EF as the average emission rate of a given pollutant for a given source, relative to units of activity, also could be defined as the representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant.

The EF can be used to derive estimates of gas emissions based on the amount of fuel. The level of precision of the resulting estimates depends significantly on the activity in question.

CO_2 emissions from the combustion of fuel can be estimated with a high degree of certainty regardless of how the fuel is used, as these emissions depend almost exclusively on the carbon content of the fuel, which is generally known with a high degree of certainty. In contrast, the levels of non-CO_2 emissions from combustion depend on the precise nature of the activity in which the fuel is being combusted. For instance, methane emissions from transport depend on a vehicle's type, whether the vehicle has been fitted with emissions controls and so on. Therefore, because of the uncertainties involved, the estimates of non-CO_2 emissions from transport using emission factors are much less precise than estimates of CO_2 emissions (SGA, 2000).

The EF`s are fuel dependent, whereas CH_4 and N_2O emission factors are highly dependent upon the specific pollution control devices on each vehicle. EF associated with these gases varies with vehicle type. Also, fuel combustion CO_2 emissions depend upon the amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel oxidized. The EF employed to estimate GHG emissions are subdivided by the type of fuel used and technology employed. The methods used to derive the factors are based on the carbon contents of the fuels and the typical fraction of carbon oxidized. Both the hydrocarbons and particulate formed during combustion are accounted for to some extent, but emissions of CO are included in the estimates of CO_2 emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO_2 shortly after combustion (within 5-20 weeks of its release). (EPA, 1996).

In order to procure the evaluation, the following Emission factors will be used, considering the truck category and the fuel employed:

Table 4.6 Canadian Emission Factors for Energy Mobile Combustion Source

On-Road Transport	Emission Factors		
	CO_2 g/L fuel	CH_4 g/L fuel	N_2O g/L fuel
Gasoline Vehicles			
Light-Duty Gasoline Vehicles (LDGVs)			
- Tier 1, Three-Way Catalyst	2360	0.12	0.26
- Tier 0, New Three-Way Catalyst	2360	0.32	0.25
- Tier 0, Aged Three-Way Catalyst	2360	0.32	0.58
- Oxidation Catalyst	2360	0.42	0.2
- Non-Catalyst	2360	0.52	0.028
Light-Duty Gasoline Trucks (LDGTs)			
- Tier 1, Three-Way Catalyst	2360	0.22	0.41
- Tier 0, New Three-Way Catalyst	2360	0.41	0.45
- Tier 0, Aged Three-Way Catalyst	2360	0.41	1
- Oxidation Catalyst	2360	0.44	0.2
- Non-Catalyst	2360	0.56	0.028
Heavy-Duty Gasoline Vehicles (HDGVs)			
- Three-Way Catalyst	2360	0.17	1
- Non-Catalyst	2360	0.29	0.046
- Uncontrolled	2360	0.49	0.08
Diesel Vehicles			
Light-Duty Diesel Vehicles (LDDVs)			
- Advance Control	2730	0.05	0.2
- Moderate Control	2730	0.07	0.2
- Uncontrolled	2730	0.1	0.2
Light-Duty Diesel Trucks (LDDTs)			
- Advance Control	2730	0.07	0.2
- Moderate Control	2730	0.07	0.2
- Uncontrolled	2730	0.08	0.2
Heavy-Duty Diesel Vehicles (HDDVs)			
- Advance Control	2730	0.12	0.08
- Moderate Control	2730	0.13	0.08
- Uncontrolled	2730	0.15	0.08

Source: Environment Canada Canada's Greenhouse Gas Inventory, 1990 - 2003.

4.3.10 Time series

Having into account, the Phase 4 proposed in the Methodological framework, and in order to obtain an emissions forecast trend for the Heavy Duty Diesel Vehicles category, the next data will be employed to deduct an equation that describes the emissions tendency from 1991 to 2004.

Table 4.7 Times series data

YEAR	Quebec's province HDDV emission (Kt CO_2 eq)	Annual Increase (%)
1990	5900	-
1991	5980	1,01356
1992	6060	1,01338
1993	6110	1,00825
1994	6560	1,07365
1995	7090	1,08079
1996	7270	1,02539
1997	8000	1,10041
1998	8100	1,01250
1999	8350	1,03086
2000	7970	0,95449
2001	7780	0,97616
2002	8210	1,05527
2003	8490	1,03410
2004	8960	1,05536

Source: Environment Canada, 2006. Canada's Greenhouse Gas Inventory 1990 - 2004.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Results for the Scenario «Q-80+» (Year 1999)

As result of this evaluation made in order to quantify Greenhouse Gas emission products of the Truck freight transportation activity in Quebec's province and considering the methodological framework (section 4.2.3), the parameters and variables taking into account for the scenario of evaluation «Q-80+» (section 4.3), the final result of gas emission obtained for the year 1.999 is 4790, 72 Ktn CO_2 - eq.

In order to understand the results obtained from this evaluation, the following tables depict the result of Greenhouse emissions for the scenario «Q-80+» and the comparisons against the information given by Environment Canada for the province of Quebec and Canada.

Table 5.1 Scenario « Q 80+ » Total GHG Emissions year 1999. Detailed result for each sub category of truck analyzed

Vehicle	Gas	GWP	(1) Emission (Ktn - CO_2 eq)
Truck	CO_2	1	886.33
Tractor with semi-trailer	CO_2	1	3602.85
Truck with trailer	CO_2	1	253.71
Truck	CH_4	21	0.89
Tractor with semi-trailer	CH_4	21	3,60
Truck with trailer	CH_4	21	0,25
Truck	N_2O	310	8.05
Tractor with semi-trailer	N_2O	310	32.73
Truck with trailer	N_2O	310	2,30
Total emission year 1999			4790.72

Source: (1) - Calculated considering the Methodological framework (section 4.2.3) - phase 4

Table 5.1: It presents the information of emissions in terms of CO_2 – eq for the year 1999, considering the three types of trucks proposed (section 4.3.5). Also this table shows the partial result of emissions for the three gases evaluated (CO_2, CH_4, and N_2O) in each truck category evaluated, having into account their Global warming Potential (section 4.3.8) as was proposed in the objectives of this research (section 1.3).

5.2 Quantification of emissions for the Scenario «Q-80+» from 1999 to 2004

Considering the Phase 4 proposed in the methodological framework (section 4.2.3), the result of GHG emission for the year 1999 (Table 5.1) for the scenario «Q-80+» is affected by the annual percentages of variation (increases and decreases) calculated from the evaluation made by Environment Canada between 1.990 to 2.004 (Table 4.7) for the Heavy Duty Diesel Vehicles (HDDV) category for the Quebec's province. This procedure is made in order to obtain a graphic on annual basis of emission that represents of our scenario of evaluation «Q-80+».

Table 5.2 Scenario « Q 80+ » Times series data

YEAR	(1) Québec's province HDDV Category Emission (Environment Canada) (Ktn CO_2 - eq)	(2) Annual Variation (%)	(3) Scenario « Q-80+ » HDDV Category Emission (Ktn CO_2 - eq)
1990	5900	-	3385
1991	5980	1,01356	3431
1992	6060	1,01338	3477
1993	6110	1,00825	3506
1994	6560	1,07365	3764
1995	7090	1,08079	4068
1996	7270	1,02539	4171
1997	8000	1,10041	4590
1998	8100	1,01250	4647
1999	**8350**	**1,03086**	**4791**
2000	7970	0,95449	4573
2001	7780	0,97616	4464
2002	8210	1,05527	4710
2003	8490	1,03410	4871
2004	8960	1,05536	5141
Total	**110830**	**14,43418**	**63587**

Source: (1) - Canada's Greenhouse Gas Inventory 1990 - 2004.
(2) - Methodological framework (section 4.2.3) - phase 4 / Table 4.7
(3) - Calculated considering the Methodological framework (section 4.2.3) - phase 4

Table 5.2: this table, in the column (3) shows the annual basis of emissions in terms of "CO_2 - eq" for the scenario « Q-80+ » from 1990 to 2004, approximately 63587 Ktn CO_2 - eq has been released to the environment as a product of the trucking freight activity in Quebec's province.

Also, this table in the column (2) shows the annual variation in terms of percentage (%) having an accumulative annual variation in the same horizon (1990 to 2004) of 14, 43% (approximately 1% per year).

5.3 Graphic representation Scenario «Q-80+»

Taking into account the annual emissions results deducted for the scenario «Q-80+» from 1.990 to 2.004, and considering the phase 4 of the methodological framework (section 4.2.3) and looking for an equation that not only represents the emission tendency but also it will depict future emission, five types of correlations were evaluated (Lineal, Potential, Logarithmical, Polynomial and Exponential). These equations were analyzed considering its coefficient of determination (R^2) in order to select the equation that represents with more accuracy the emission tendency.

The Coefficients of Determination (R^2) in a regression analysis indicate a measure of correlation between the dependent and independent variables (year / emissions). A higher value for this coefficient (whose range is between 0 – 1), means the information analyzed into a specific correlation got a better fit.

Table 5.3 Coefficient of determination (R2)

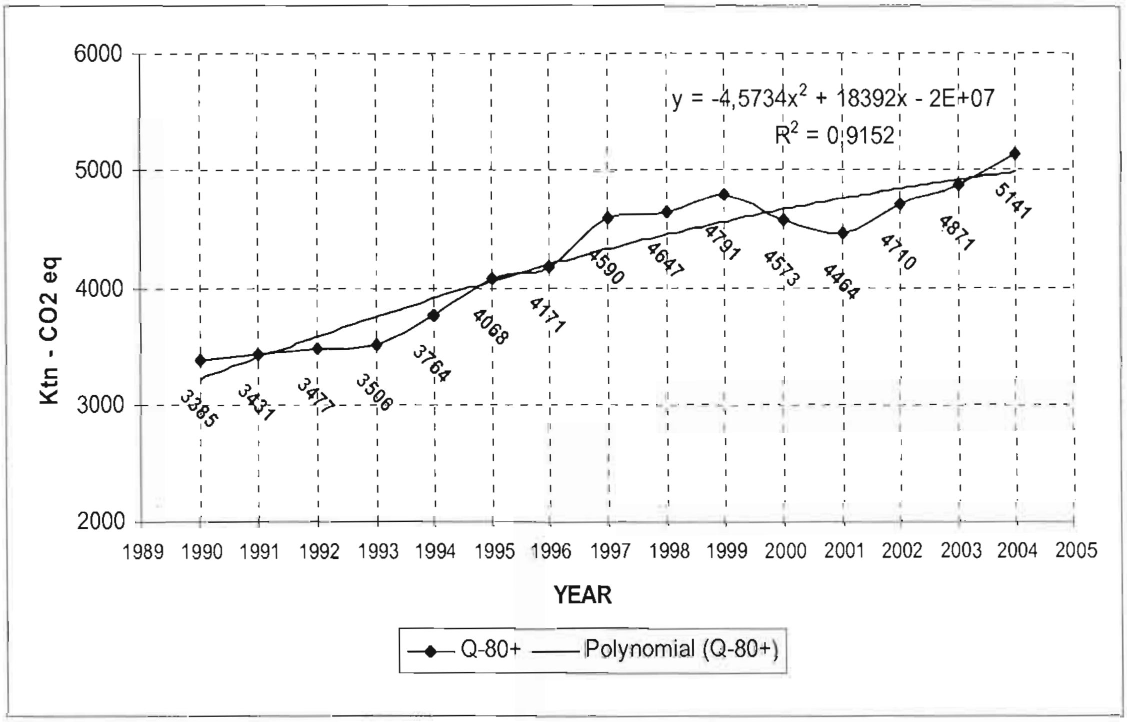
Type of correlation	Coefficient of Determination (R^2)
Lineal	0.8977
Potential	0.8929
Logarithmical	0.898
Polynomial	0.9152
Exponential	0.8926

Considering the Coefficient of Determination (R^2) as result of each correlation analyzed, the emissions tendency for the Scenario « Q-80+ » is well adapted by the next Polynomial correlation equation:

$$Y = - 4.5734X^2 + 18392X - 2E(+07)$$

$$R^2: 0.9152$$

Table 5.4 Graphic representation Scenario « Q-80+ »



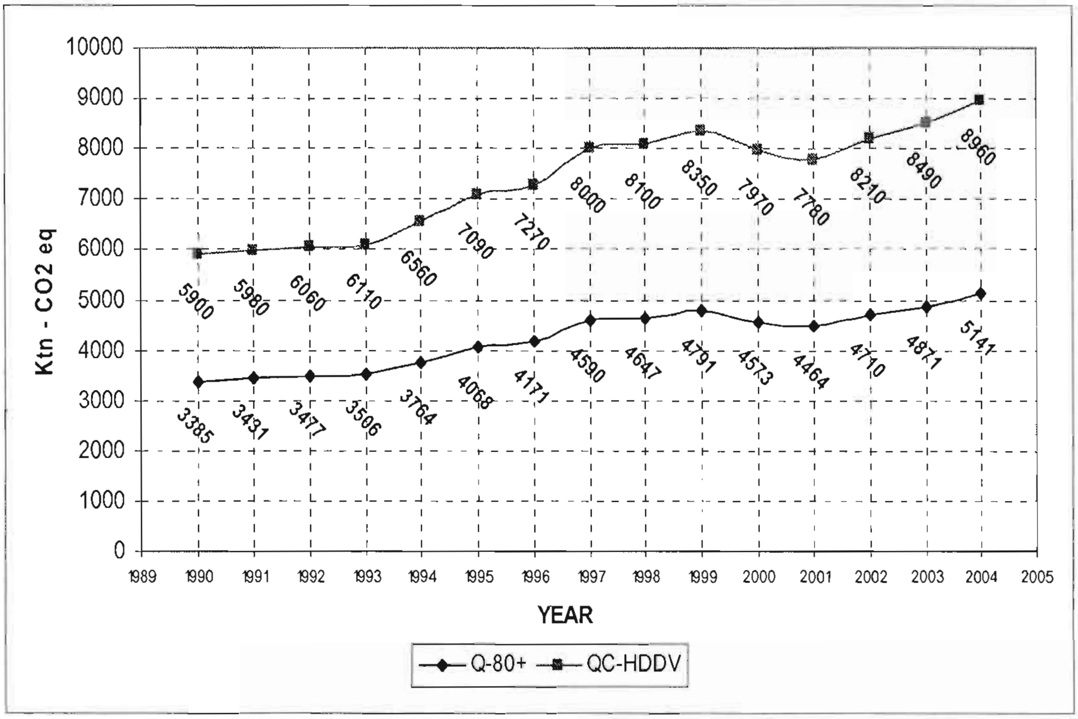
The graphic represented by (--■--) depicts the annual results of emission for the category Heavy Duty Diesel Vehicles (HDDV) evaluated in the scenario « Q-80+ », between 1.990 to 2.004, taking into consideration the framework proposed.

The graphic represented by (-----) and led by the equation Y = - 4.5734 + 18392X - 2E (+07), shows the tendency of gas emissions. Alternatively, this equation represents the pollution forecast for the scenario « Q-80+.

Both tendencies presented in figure 5.1 (--■-- and -----) shows that the production of Greenhouse gases are increasing annually and there is not an indicator into the graphic that illustrates the opposite situation in futures years.

5.4 Comparison and contribution Scenario «Q-80+» against total Quebec's province emissions for Heavy Duty Diesel Vehicles

Table 5.5 Comparison Scenario « Q 80+ » and Total Québec emission for HDDV



The table 5.5 illustrates the comparison between the GHG emission for the scenario «Q-80+» and the scenario "total emission for the category Heavy Duty Diesel Vehicles in Quebec province" (table 5.2 – column (1)).

It is important to make a note that in the table 5.5, either the scenario «Q-80+» and the scenario "total emission for the category Heavy Duty Diesel Vehicles in Quebec province" are increasing their release of GHG each year.

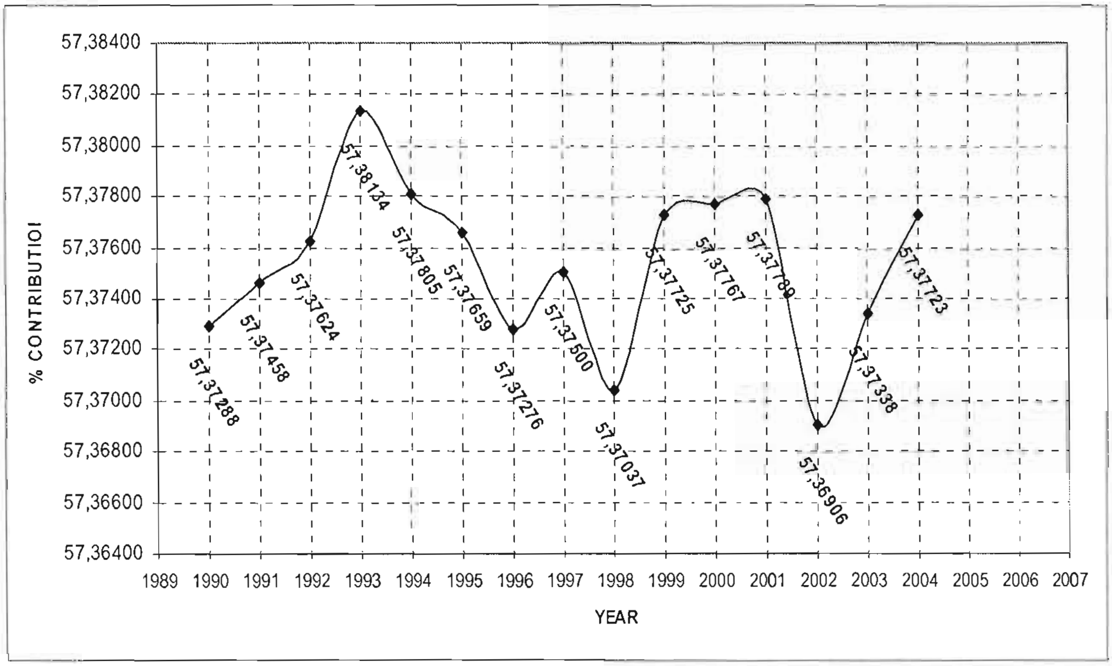
Table 5.6 Contribution of emissions Scenario « Q 80+ » to Total Heavy Duty Diesel Vehicles (HDDV) emission in Québec

YEAR	(1) Québec's province HDDV Category Emission (Ktn CO_2 eq) (Environment Canada)	(2) Scenario « Q-80⁺ » HDDV Category Emission (Ktn CO_2 eq)	Variation (Ktn CO_2 eq)	Contribution % Q-80⁺
1990	5900	3385	2515	57.37288%
1991	5980	3431	2549	57.37458%
1992	6060	3477	2583	57.37624%
1993	6110	3506	2604	57.38134%
1994	6560	3764	2796	57.37805%
1995	7090	4068	3022	57.37659%
1996	7270	4171	3099	57.37276%
1997	8000	4590	3410	57.37500%
1998	8100	4647	3453	57.37037%
1999	8350	4791	3559	57.37725%
2000	7970	4573	3397	57.37767%
2001	7780	4464	3316	57.37789%
2002	8210	4710	3500	57.36906%
2003	8490	4871	3619	57.37338%
2004	8960	5141	3819	57.37723%

Source: (1) - Canada's Greenhouse Gas Inventory 1990 - 2004.
(2) - Methodological framework (section 4.2.3) - phase 4 / Table 4.7

This table 5.6 illustrates the contribution of emissions of the scenario «Q-80⁺» to the scenario "total emission for the category Heavy Duty Diesel Vehicles in Quebec province". Also it is possible to look that the scenario «Q-80⁺» has been contributing constantly in annual basis from 1990 to 2004 with a 57.37% of emission.

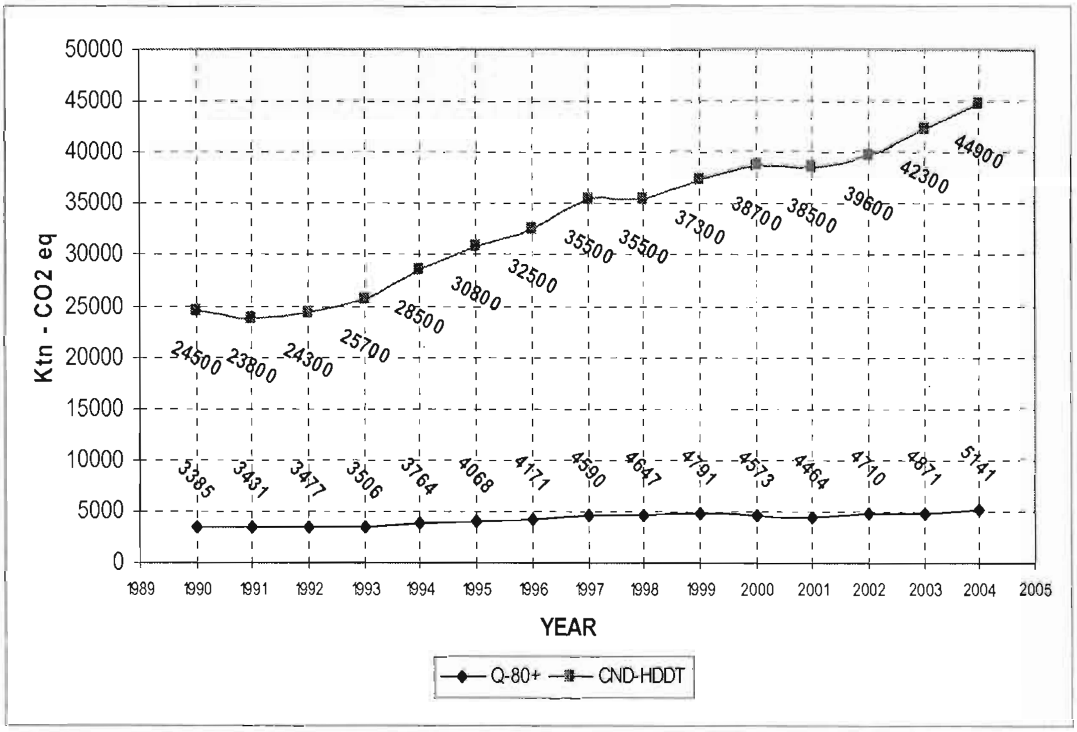
Table 5.7 Contribution of emissions Scenario « Q 80+ » to Total Québec emission for HDDV (Heavy Duty Diesel Vehicles)



5.5 Comparison and contribution Scenario «Q-80+» against total Canada's emissions for Heavy Duty Diesel Vehicles

The next Table 5.8 illustrates the comparison of GHG emission as product of the trucking freight transportation activity from 1999 to 2004 between the scenario of evaluation «Q-80+» and the scenario "total emission for the category Heavy Duty Diesel Vehicles in Canada".

Table 5.8 Comparison Scenario « Q 80+ » and Total Canada emission for HDDV (Heavy Duty Diesel Vehicles)



Source: Canada HDDV Category Emission. Canada's Greenhouse Gas Inventory 1990 - 2004.

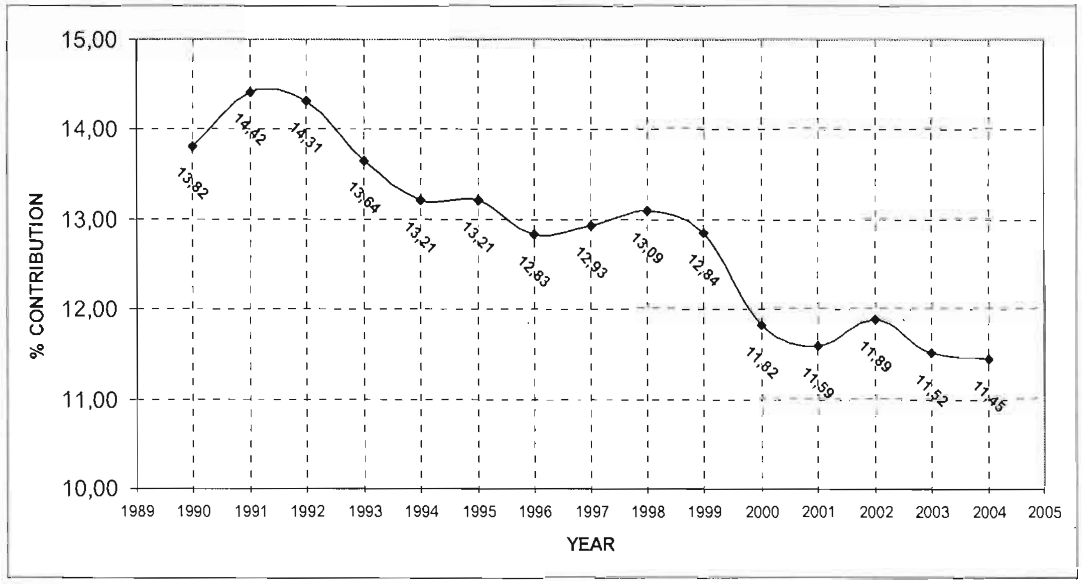
The tendencies of gas release presented in the table 5.8 for both the scenarios «Q-80+» and the scenario "total emission for the category Heavy Duty Diesel Vehicles in Canada", it shows that every year the release of GHG emissions are increasing.

Table 5.9 Contribution of emissions Scenario « Q 80+ » to Total Heavy Duty Diesel Vehicles (HDDV) emission in Canada

YEAR	(1) Canada HDDV category emission (Environment Canada) (Ktn CO_2 eq)	(2) Scenario « Q-80+ » HDDV category emission (Ktn CO_2 eq)	Variation (Ktn CO_2 eq)	Contribution % Q-80+
1990	24500	3385	21115	13.82
1991	23800	3431	20369	14.42
1992	24300	3477	20823	14.31
1993	25700	3506	22194	13.64
1994	28500	3764	24736	13.21
1995	30800	4068	26732	13.21
1996	32500	4171	28329	12.83
1997	35500	4590	30910	12.93
1998	35500	4647	30853	13.09
1999	37300	4791	32509	12.84
2000	38700	4573	34127	11.82
2001	38500	4464	34036	11.59
2002	39600	4710	34890	11.89
2003	42300	4871	37429	11.52
2004	44900	5141	39759	11.45

Source: (1) - Canada's Greenhouse Gas Inventory 1990 - 2004.
(2) - Methodological framework (section 4.2.3) - phase 4 / Table 4.7

Table 5.10 Contribution of emissions Scenario « Q 80+ » to Total Canada emission for HDDV (Heavy Duty Diesel Vehicles)



Considering the horizon of evaluation presented in the Table 5.8 from 1990 to 2004, this quantification shows that each year both scenarios, the «Q-80+» and the scenario "total emission for the category Heavy Duty Diesel Vehicles in Canada" are increasing their discharges of Greenhouse emissions.

On the other hand, the contribution of emissions from the scenario «Q-80+» to the scenario "total emission for the category Heavy Duty Diesel Vehicles in Canada" (Table 5.10) is diminishing annually, despite of both sceneries are increasing their release of emissions. It possible means that the contributions done for the other province are higher than the contributions made for the Quebec province.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The main conclusions from this evaluation are summarized as follow:

1. The use of the «Origin - destination Matrix surveys» from the Ministère des transports du Québec (MTQ), it is an excellent option to evaluate gas emission as product of trucking freight transportation activity. Consequently with this evaluation is possible to know the total volume of emissions produced by a specific vehicle category and activity of vehicles, and the emissions linked to the road network (see annexes).

2. This quantification and evaluation of emissions for the trucking freight activity in the Quebec's province shows that this task is very complex and its accuracy depends on the type of data employed, also the interpretation of results and its explanation are very relative.

   In this case, the comparison between the GHG emission for the scenario «Q-80+ », Quebec and Canada show that every year the release is increasing. On the other hand, the situation of the scenario « Q-80+ » respect to the Quebec's province emission shows that this trend has been stable on the analyzed horizon (Table 5.6). Furthermore if we make the comparison against the Canadian emission situation of trucking freight transportation activity, it shows the emission release of the scenario « Q-80+ » is diminishing from 1999 to 2004 (Table 5.9 and Table 5.10).

3. In Quebec from 1990 until 2007, the Ministère des transports du Québec (MTQ) has produced three Origin - Destination survey during the years 1991, 1995 and 1999. However the information of 1991 and 1995 surveys was not enough to have into account for this evaluation, considering the proposed methodological framework. In 2007 the Ministry is carrying out a new survey, but its result will be ready in approximately 3 years. For this reason, and considering the necessity of annual measurements of GHG`s and also in order to produce futures quantifications, the proposed methodological frame work could be can have improvements and up dates, considering the sources of information and the availability of data to use. As previously mentioned, this kind of quantitative evaluation depends on the information provided by the institution or authority uncharged of the transportation in the province.

4. This evaluation has considered just one border point (De Lacolle) in the quantification of emissions, but for futures estimations, it is important to consider that Quebec's province share 28 border points with the Unites Sates, also share other few ones with the provinces that surround it. In order to procure accurateness on this kind of evaluation, it is essential to take into account all the incoming and outgoing displacements implicated in each of those points.

5. With the intention to compare this kind of analysis and its result of gas emission as product of truck freight transportation, it is important to consider every geographic area of study, involving its own characteristics (weather, topography, geographic conditions, type of roads, speed of operation, roads capacity, fuels, etc.). Consequently, the fact to comparing two or more

balances of gas emission must involve an previously analysis of which parameters and variables are employed in order to standardize the results and their interpretation

6. The Trucking freight transportation activity is mostly concentrated on the south area of Quebec – Province. Therefore for future evaluation of Greenhouse emissions will be important to improve the data regarding the administrative areas located on the north.

7. All the results aimed to truck freight transportation emission are increasing every year, but considering the type of unit employed to refer its emissions (Ktn CO_2 - eq) will be important to improve the accuracy on the methodology, considering what a « Ktn CO2 – eq » represents.

8. This quantification of emission makes possible to evaluate 400 trajectories in the province of Québec in approximately 95.000 Km of roads. For future evaluations, will be important to connect the Montreal port, as an important point of departure and arrives for the roads network in Quebec with the purpose to improve the Provincial Gas Inventory of emission.

9. This evaluation guided by the Tier 2, or <bottom-up> approach to estimates CO_2 emissions only has concerns to emission of "running" type. But on the other hand and in order to improve the exactness on this type of quantification, they are other emissions associated to the combustion of fuel in the trucking freight activity as:

   - Start: emission when the motor is started
   - Hot soak: emission (by evaporation) when the truck is parked after finishing a trip. The engine is still hot.

- Diurnal: emission (by evaporation) when the vehicle is inactive due to the heat increase during the day.
- Resting: emission (by evaporation) by loss, at rest (escape and infiltration).
- Run loss: emission (by evaporation) by loss when the vehicle runs.
- Crankcase: emission (by evaporation) due to the heating at the level of the carter.
- Refueling: emission (by evaporation) during the filling of the fuel tank.

10. Regarding the data consumption of fuel, all the documentation used in this evaluation recommends the American consumption ratios to produce the evaluation of Canadian emission. However, in order to improve this kind of evaluation is essential to develop the Canadian consumption ratios according to the next parameter:

    - Fleet trucks characteristics
    - The activities associated to this kind of vehicles
    - Local fuel features
    - Temperatures
    - Humidity
    - Season of calendar to evaluate

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Annexes

This Annex includes, for each of the twenty geographical areas examined, two sections (1) and (2), not only the parameters of evaluation used but also the results of the quantification.

The section (1) refers to the next parameters:

- Administrative area of destination
- City of reference in the administrative area of destination
- Distance between city of reference administrative area of origin and the city of reference administrative area of destination
- Total number of trucks (category of study)
- Total number of Truck - Sub category T(1)
- Total number of Tractor with semitrailer - Sub category T(2)
- Total number of Truck with trailer - Sub category T(3)
- Consumption (Lt/Km) Sub category T(1)
- Consumption (Lt/Km) Sub category T(2)
- Consumption (Lt/Km) Sub category T(3)
- Emission factor for CO_2 (g/Lt Diesel)
- Emission factor for CH_4 (g/Lt Diesel)
- Emission factor for N_2O (g/Lt Diesel)

The section (2) includes the results of the evaluation for:

- Emission in terms of CO_2 – eq for: CO_2 emission - Sub category T(1)
- Emission in terms of CO_2 – eq for: CO_2 emission - Sub category T(2)
- Emission in terms of CO_2 – eq for: CO_2 emission - Sub category T(3)
- Emission in terms of CO_2 – eq for: CH_4 emission - Sub category T(1)
- Emission in terms of CO_2 – eq for: CH_4 emission - Sub category T(2)

- Emission in terms of CO_2 – eq for: CH_4 emission - Sub category T(3)
- Emission in terms of CO_2 – eq for: N_2O emission - Sub category T(1)
- Emission in terms of CO_2 – eq for: N_2O emission - Sub category T(2)
- Emission in terms of CO_2 – eq for: N_2O emission - Sub category T(3)
- Total emission year 1.999 in terms of CO_2 – eq ($\sum$ (CO_2 + CH_4 + N_2O)) between city of reference (administrative area of origin) and the city of reference (administrative area of destination)