THE LIFE CYCLE ASSESSMENT – A CASE STUDY OF TRANSPORTING VOLVO CARS

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ABSTRACT

The increase in the number of vehicles in our society is detrimental to the environment because of increased fuel usage and pollutant emissions. This paper analyze the environmental effects of transporting cars from its manufacturer to its end user. The method used is the life cycle assessment (LCA). Life cycle assessment is a method for analyzing and evaluating environmental performance of products, processes or services throughout its entire life cycle. The paper also shows the effect of changing the fuel type used in transporting the vehicles. It can be seen that from the pollutant emissions in the transport chain, carbon dioxide and nitrogen oxides are the leading pollutants, which affect the air quality in the environment. The truck is shown to be a heavy polluter in terms of its emission factors and there is not much difference between a European and an Asian country. With the use of the natural gas as an alternative fuel, emission levels can be reduced to as much as 19 % for CO_2 and 16 % for NOx emissions while costs are higher in the first few years because of conversion costs, it can be said that it is worth the risk. The truck can be an environmentally adapted vehicle if its engine is converted to an alternative fuel engine like the compressed natural gas. The LCA methodology is holistic because it gives a systems analysis of the product.

Keywords: Life cycle assessment, natural gas, transport chain, CO2, NOx, pollutants, environment

INTRODUCTION

Transportation has become important in society because of the mobility it brings. The increase in the number of vehicles in the transport sector is a consequence of population and economic growth. This growth leads to an increase in fossil fuel consumption, which is not sustainable, because oil is a non-renewable resource. The major effect of the increase in fuel usage is on the environment. Pollutants emitted from motor vehicles contribute to the degradation of the environment specifically air quality. With the knowledge that the transport sector is one of the heaviest polluters, it is necessary to measure and study the actual contribution of road transport activities and its products to the environmental impact. An analysis called the Life Cycle Assessment (LCA) is one method to know and assess the total impact of a particular product to the environment.

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OBJECTIVES

The goal of the study is to assess the relevance, effectiveness and accuracy of the Life Cycle Assessment methodology by using a case of transporting 50 Volvo cars from Gothenburg to Japan. The objectives are:

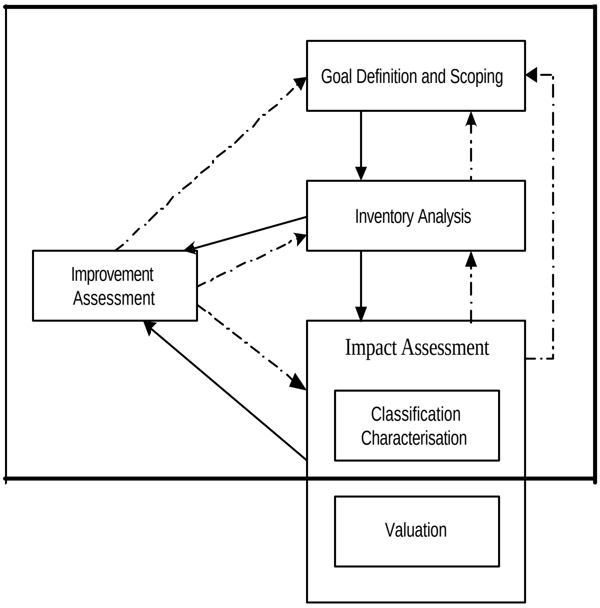
a) To evaluate the transport systems involved in transporting the S80 cars in terms of the emissions of different types of pollutants;
b) To suggest alternative solutions to lessen the environmental impact of transporting the cars;
c) To give the advantages and disadvantages of using the LCA methodology.

SCOPE

Life Cycle Assessment is a long process of assessing the inputs and outputs of a product system from cradle to grave. This study will only focus on the actual transport system of the product from its origin and destination. It will also concentrate on the major transport modes used in the transport chain. It will only evaluate the emissions of six types of pollutants namely CO_2, HC, NO_x, SO_2, PM and CO, from the major transport modes. This study will not deal with the raw material acquisition, car production process or even the use of the car or the waste management.

METHODOLOGY

The framework of the LCA methodology can be characterized into 4 significant steps namely: the goal definition and scoping, the inventory analysis, impact assessment and improvement assessment. The goal definition and scoping defines and limits the objectives of the study. Inventory analysis is the detailed description of the product systems and the inputs and outputs of that system. Within the impact assessment, there is a need to characterize the pollutants in terms of the impact they give to the environment then an indexing or valuation is done to combine the results together into one value [1]. For this case study, the LCA methodology will only be until the classification characterization as bounded by the thick black lines in the LCA framework shown in Figure 1.



Note: 1. The unbroken arrows show the main route of the assessment
2. The dotted lines illustrate the iterations that may be necessary.

Figure 1. The methodological framework of the LCA.. [2]

Data for the inventory analysis was collected mainly by a questionnaire e-mailed to the company, a telephone interview and secondary data collection through the Internet. The company responsible for the export of Volvo cars to the Japanese market is the Hyundai Sweden Shipping Agency AB. The group had made a questionnaire for the agency to answer. The person responsible for the export was not able to answer all the questions so some questions were refered to Hyundai Merchant Marine Europe located in London, which is the headquarters of Hyundai Shipping in Europe. A telephone interview to Volvo Cars was also conducted to get necessary data such as cost required for the inventory analysis.

THE LIFE CYCLE ASSESSMENT ANALYSIS

The Product

The new Volvo cars S80 (see figure 2) are in demand throughout the world today, because of its safety features. Volvo cars export 50 cars per shipment and that will be 100 cars per month.

Figure 2. Volvo S80

The Transport Chain

The transport of the Volvo S80 cars begins from the factory at Torslanda, Hisingen. It is transported by a Volvo F16 truck for 12 kilometers from the factory to the Port of Gothenburg. A Roll-on Roll-Off (RoRo) ship is then used to transport the cars to Nagoya, Japan, where trucks are again used to move the cars to the Volvo dealer in Tokyo. The ship, from the Gothenburg Port, will go to Antwerp, Belgium and then to Southampton in England. From Southampton it proceeds to Jeddah, Saudi Arabia and calls to port in Singapore until it will reach Nagoya, Japan. The route is shown in Figure 3. The RoRo ship carries 6,000 units of cars, 3,100 units of mini-vans, 540 units of trucks and 415 units of bus. It usually takes 34 days to travel from Gothenburg to the dealer in Tokyo.

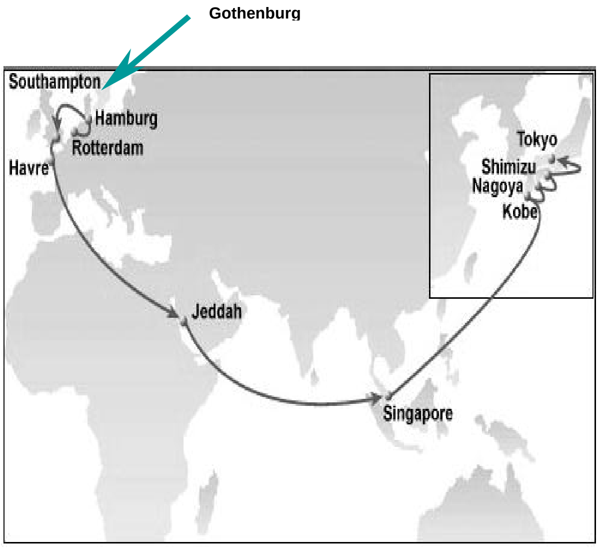


Figure 3. Route of Ship from Gothenburg to Japan

The total distance traveled by the RoRo ship from Gothenburg port to Nagoya, Japan is 28,000 kilometers. When the ship arrives at Nagoya port, the cars are usually transported to the dealer in Tokyo using a car carrier. The distance traveled by the truck to Tokyo is 260 kilometers. The cost of transporting an S80 Volvo car to Japan is approximately SEK 2,500 (1US$ = SEK 8.35). The total cost is divided by the total distance traveled in the transport chain, which is 28,272 kilometers to get the cost per kilometer, which is SEK 0.0884 (US$0.01).

Inventory Analyses

To evaluate the transport system and to show the impact of this system on the environment, the analyses are divided into two cases, the present situation and the ecoplan case.

Case 1: The present situation is analyzed into three parts. The first part is a calculation of emissions for the truck transport in Gothenburg. The second part is the analysis for the ship transport and the third part is the truck transport in Japan. It is reiterated that only the transport process is analyzed in this report.

Case 2: The ecoplan case will use compressed natural gas as an alternative fuel for the truck in Gothenburg while the speed of the ship will be lowered by 3 knots and the electric train will be used to transport the vehicles in Japan.

Life-Cycle Model

Figure 4 shows the life cycle model of a product. The life cycle of a product starts from the acquisition of raw materials to the transport of these materials to the manufacturing plant for production. From manufacturing, it is transported to the end user. The final destiny of the product is as waste.

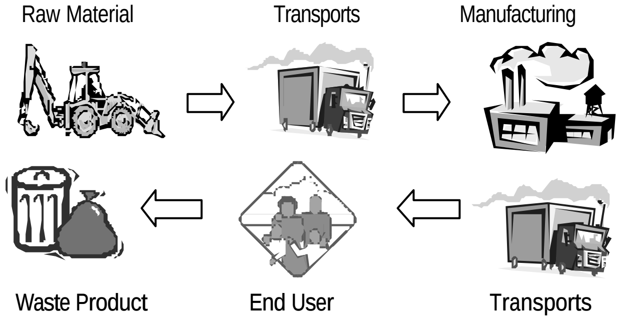


Figure 4. The life cycle model of a product

The case study will only deal with the transport of the product from the manufacturer to the end user or the intermediate user as the dealer. Figure 5 shows the model of transporting the product from the factory to the dealer.

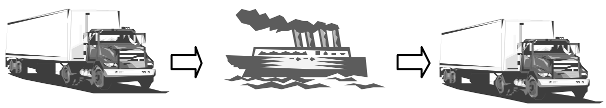


Figure 5. Transport chain model for the LCA analysis

PRESENT SITUATION

The emission calculation for truck transportation in Gothenburg

The truck, which transports the S80 cars to the port of Gothenburg, is an F16 truck, which has an engine, built in 1989. It has a diesel engine that is assumed to run on the Swedish MK-1 diesel. This Swedish diesel has energy content of 9.77 kWh/liter, sulfur content of 0.001 % weight [3]. Since this engine was from 1989 it is under the EURO 0 class. Cargo capacity was assumed to be the number of cars it can carry instead of the maximum weight in tons. The truck can carry a total of ten (10) cars therefore five (5) car carriers are needed to move fifty (50) S80 cars. Table 1 shows the calculation for emission factors for each type pollutant.

Using the assumed fuel consumption for the truck to be 0.4 liters/km, the total emissions are calculated in Table 2. The functional unit used for the emissions is in grams/ car-km. This means that each gram of pollutant emitted is attributed to the product transported over a certain distance.

Table 1. The emission factor for diesel truck transport in Gothenburg [4]

Emission element	CO_2	NOx	SO_2	HC	PM	CO
Energy of engine: (g/kWh)	665.50	12.00	207.00	0.50	0.27	1.20
Efficiency of engine: (%)	40.00	40.00	40.00	40.00	40.00	40.00
Conversion to fuel: (g/kWh(fuel))	266.20	4.80	82.80	0.20	0.108	0.48
Energy Content of Fuel: (kWh/litre)	9.77	9.77	9.77	9.77	9.77	9.77
Emission factors: (g/litre)*	2600.77	46.89	808.95	1.95	1.05	4.68

* Emission factor = Conversion to Fuel * Energy Content of Fuel

Table 2. Emissions calculated for diesel truck transport in Gothenburg

Emission elements	CO_2	NOx	SO_2	HC	PM	CO
Fuel Consumption: (litre/km)	0.40	0.40	0.40	0.40	0.40	0.40
Emission Factor: (g/litre)*	2600.77	46.89	808.95	1.95	1.05	4.69
Cargo Capacity: (cars)	10	10	10	10	10	10
Cargo Utilisation: (%)	100.00	100.00	100.00	100.00	100.00	100.00
Total Emissions: (g)**	62,418	1,125	19,416	48	24	114

* From table 1

** Total Emission = (Fuel Consumption* Emission factor)*(1/ Cargo Capacity) *(1/ Cargo utilization)

The emission calculation for the ship transportation

The ship used in transporting the cars from the port of Gothenburg to the port of Nagoya is a Roll-On Roll-Off ship with a service speed of 19.5 knots or 36 kilometers per hour. The group used the middle speed (medelvarv) from the table in the WebPage because the speed of the RoRo ship has a high value compared to other ships. The ship was built in 1988 with a shaft horsepower of 11,950 brake horsepower. The distance traveled by the ship from Gothenburg to Japan is approximately 28,000 kilometers.

Table 3. The Emission calculated for ship transportation

Pollutant	CO_2	NOx	HC	PM	CO
Energy of engine: (g/kWh)	620.00	14.00	0,20	0,40	1.00
Engine power: (kW)	8,914.70	8,914.70	8,914.70	8,914.70	8,914.70
Speed: (kph)	36.00	36.00	36.00	36.00	36.00
Cargo Capacity: (vehicle)	10,055.00	10,055.00	10,055.00	10,055.00	10,055.00
Cargo Utilisation: (%)	80.00	80.00	80.00	80.00	80.00
Emission Factor Calculated: (g/car-km)	18.571	0.419	0.006	0.012	0.030
Distance from Gothenburg to Japan: (km)	28,000.00	28,000.00	28,000.00	28,000.00	28,000.00
Number of vehicle: (car)	50	50	50	50	50
Total emission by Ship: (kg)	25,998.76	587.07	8.39	16.77	41.93

*Total Emission = (Fuel conversion*Engine Power/Speed) *(1/Cargo Capacity) *(1/Cargo Utilization)

The emission factor calculated is dependent on the number of vehicles in the RoRo ship. It was assumed that each vehicle is equal in terms of the contribution to the emissions. This distance together with the number of cars transported is multiplied to the emissions calculated to get the total emissions in kilograms.

The emission calculation for the truck transport in Japan

The US 1996 emission standards were assumed to represent the emissions for the Japanese truck. US emissions were assumed because both countries are part of the OECD wherein their economies are relatively similar therefore transport characteristics especially for freight vehicles may be similar. The climate in both countries are alike, each have four (4) seasons, which will have the same air pollution problems caused by the pollutants. Although, US is bigger geographically, it can be assumed that Japan is a microcosm of the US. Another reason is that both countries have relatively the same awareness regarding the protection of the environment therefore their vehicles have similar technologies in terms of catalytic converters and even environmental standards. The total distance from Nagoya to Tokyo is 260 kilometers, this value is used to get the total pollutant emissions in grams. The diesel engine for this case uses low-sulfur diesel, similar to that used in Gothenburg. The fuel consumption is 2.8 km/liter.

Table 4. The emission for diesel truck transportation in Japan

Pollutants	CO_2	NOx	SO_2	HC	PM	CO
Emission Factor (g/kWh) [5]	628	6.702	-	1.742	0.3351	2.08
Emission calculated: (g/car-km)	98.17	1.05	-	0.27	0.0523	0.3248
Distance from Japan port:(km)	260	260	260	260	260	260
Number of Vehicle. (car)	50	50	50	50	50	50
Total emissions by truck in Japan: (kg)	1,276.21	13.5	-	3.51	0.68	4.22

\- No data available

ECO PLAN

The alternative solution proposed for this case is the use of compressed natural gas for the truck transport in Gothenburg and a speed reduction of 3 knots for the ship transport. Electric train usage for freight haulage in Japan is also proposed.

The alternative transportation model

Compressed natural gas as an alternative fuel is used because the technology is already available and it is ready to be put in operational use. Another reason for the choice is that [6] "the same diesel engine can be used but only converted to take in natural gas. The converted engine will have equivalent - or better- power and torque characteristics than the original engine". The emission factors for a CNG engine is shown in table 5 [7]. Table 5 also presents the emissions calculated.

Table 5. The alternative result for use of natural gas engine in Gothenburg

Pollutant	CO_2	NOx	HC	PM	CO
Emission factor (g/kWh) [7]	0.98	2.0	0.2	0.05	0.30
Emissions Calculated: (g/car-km)	0.153	0.313	0.0313	0.008	0.047
Total Emissions: (g)	91.8	187.8	18.78	4.8	28.2

The ship transport emits the most pollutants in the air but it is because of the distance traveled by the ship, which makes it a heavy polluter. A natural gas engine could be proposed for the ship but the use of this type of engine has a limited trip range, which might not be applicable at this time. Therefore, the solution proposed is the change in speed of the ship from 20 knots to 17 knots. This reduction in speed will incur a delay of three (3) days so that the total travel time from Gothenburg to Tokyo will be 37 days. The results are shown in Table 6.

Table 6. The alternative result for lower speed

Pollutant	CO_2	NOx	HC	PM	CO
Speed (kph)	31.45	31.45	31.45	31.45	31.45
Emissions Calculated: (g/veh-km)	15.784	0.356	0.005	0.010	0.025
Total Emissions: (g)	2.2E7	498,400	7,000	14,000	35,000

Japan has an extensive use of electric trains for passenger as well as freight transport. It is proposed to shift from use of truck transport to the train and then use of trucks from the train terminal to the dealer which is about 5 kilometers. This type of transport is sometimes referred to as "piggy back" transport wherein the trucks are allowed to ride on the long haul journey. The truck transport will use a natural gas engine, similar to that in the Gothenburg side. Usage of the electric train will give no emissions to the environment only considering the transport system and not the production process. The 5-kilometer use of the truck will, of course, have emissions as presented in Table 7.

Table 7. The alternative result for use of electric train and natural gas engine in Japan

Pollutant	CO_2	NOx	HC	PM	CO
Emission factor (g/kWh)	0.98	2.0	0.2	0.05	0.30
Emissions Calculated: (g/veh-km)	0.153	0.313	0.0313	0.008	0.047
Total Emissions: (g)	38.25	78.25	7.825	2.0	11.75

Table 8 shows the comparison of total emissions for the present situation and the ecoplan. It can be seen in the present situation column that carbon dioxide is the biggest problem in terms of pollutants for the present situation. It contributes almost 98% to the total emissions in the whole transport chain. The ship is the biggest contributor to the emissions not because of the poor quality of fuel or the efficiency of the engine but merely because of the distance traveled by this mode. It is said that a ship diesel engine is already the most efficient engine because it has the lowest emission factor for each pollutant if compared to the trucks. Another pollutant in the analysis, which is a problem, is the nitrogen oxide. Nitrogen oxide affects the respiratory system and increases susceptibility to infection [8]. Control of this gas is also needed. The solution that the group proposes is a combination of natural gas use, piggyback transport and reduction of speed for the ship. The solution caused a time delay of three (3) days, which can be recovered by efficient handling in the ports. It is seen in the ecoplan column that emissions for all types of pollutants reduced to as much as 41% for hydrocarbons while carbon dioxide has a reduction of 19%.

Table 8. Comparison of total emissions in kg

Emissions to air	Present Situation	EcoPlan	% Reduction
CO_2 (kg)	27,337.39	22,099.08	19
No_x (kg)	593.21	498.67	16
SO_2 (kg)	-	-	-
HC (kg)	11.95	7.03	41
PM (kg)	17.48	14.01	20
CO (kg)	46.20	35.04	24

Figure 6 shows the araphical comparison between the present situation and the EcoPlan log scale is used for the emissions.

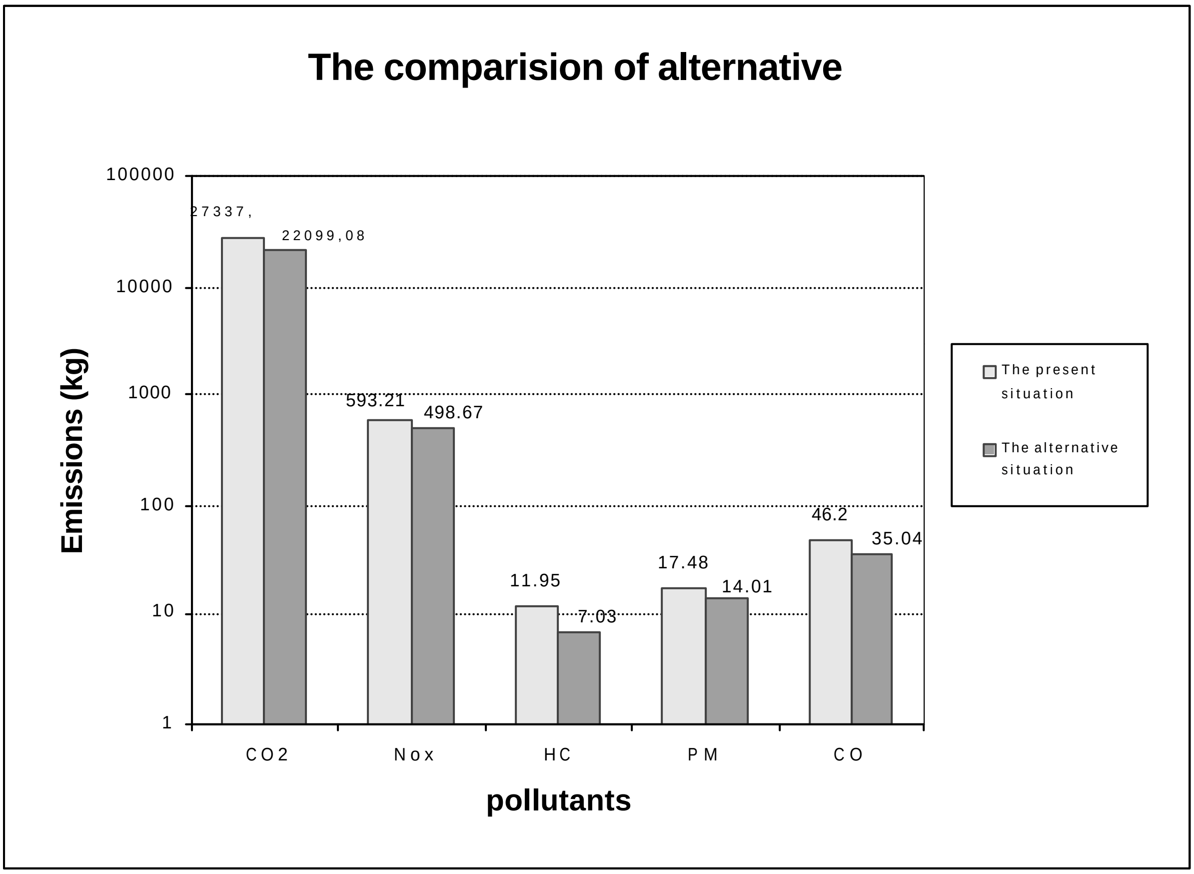


Figure 6. Comparison of the pollutant emissions for the present situation and the EcoPlan.

IMPACT ASSESSMENT

This section will discuss the impacts of the emissions presented in the previous section. The impacts presented will be based on the emission levels and costs.

Figure 7 shows the impact of the pollutants to the environment. Each type of pollutant can be grouped together to see the effects they have on the environment. Carbon dioxide, CO_2 is a greenhouse gas, which can cause global climate warming that may have disastrous effects. Methane, CH_4 that is the natural gas it self but it is efficiently burned for use therefore the effect is negligible. Sulfur dioxide, SO2 and nitrogen oxides are two of the pollutants, which cause acidification when mixed with water in the air. Acid rain is one effect of acidification, which causes plants to wither and buildings to be corroded. NOx also causes eutrophication, which causes the nutrients of the soil to be depleted, thereby decreasing agricultural productivity. The pollutants in the study cause detrimental health effects as shown in the figure. NOx when inhaled affects the respiratory system and it increases susceptibility to infections among others, SOx, likewise affects the lungs. Carbon monoxide, an odorless gas affects the nerve, heart and vascular systems and even causes death when inhaled indoors in large amounts. Hydrocarbons (HC) and particulate matter (PM) are both cancer inducing and irritates the throat and eyes as well.

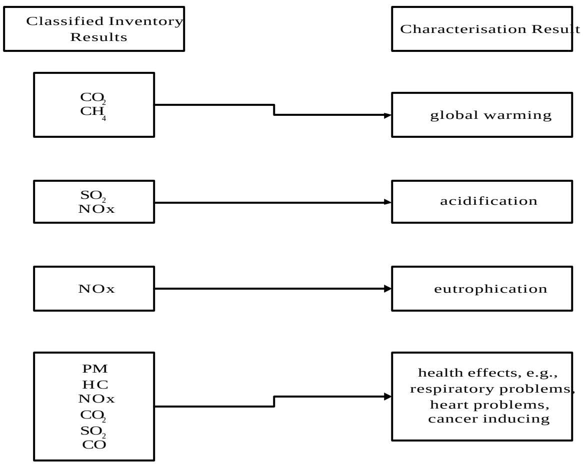


Figure 7. Impact of the pollutants to the environment.

CONCLUSION

Life Cycle Assessment as a methodology is holistic because it gives a systems analysis of the product. It analyzes and studies the environmental aspects and potential impacts throughout the product's life. It can be seen that from the pollutant emissions in the transport chain, carbon dioxide and nitrogen oxides are the leading pollutants, which affect the environment specifically the air quality. The truck is shown to be a heavy polluter in terms of its emission factors and it does not differ much between a European and an Asian country. With the use of the natural gas as an alternative fuel, emission levels can be reduced to as much as 19 % for CO_2 and NOx emissions while costs are higher in the first few years because of conversion costs, it can be said that it is worth the risk. The truck can be an environmentally adapted vehicle if its engine is converted to an alternative fuel engine like the compressed natural gas. The costs can be high but tradeoffs should be made to be able to have sustainable development and improved environmental quality.

The methodology still has disadvantages, it takes a lot of time to collect and compile detailed data for inventory. Another uncertainty is the accuracy and veracity of data collected. Some emission factors have different methodologies in getting its values therefor can not be directly compared with each other. System boundaries should really be defined. Functional units also should be defined well so that comparisons can be done. Since LCA is multidisciplinary systems analysis, uncertainties arise in the relationships among the social, technical and natural systems. The best advantage of the LCA is its quantitative approach and sensitivity analyses can be done because of that nature. As a whole, the LCA is a methodology, which can be used to evaluate the environmental attractiveness of a certain product.

RECOMMENDATIONS

It is recommended that a further study on this subject especially the use of natural gas in propelling the ship. This type of fuel can easily reduce the CO_2 and NOx emissions by half for the ship alone. However, studies have shown that the capacity of the ship might be reduced if the natural gas is used.

REFERENCES

1. Backstrom, Sebastian, *Lecture Notes on Emission caused by different kinds of transport modes and transport chains*, 1999.
2. Baumann, H. and Tillman, A., *LCA in a Nutshell*, Technical Environmental Planning Report, pp. 1- 14.
3. Blinge, Magnus. *ELM: Environmental Assessment of Fuel Supply Systems for Vehicle Fleets*, Rapport 35, Department of Transportation and Logistics, Chalmers University of Technology, 1998, p.27-33.
4. Compendium. *Lecture Notes on Alternative Fuels-Natural Gas and other Propulsion*, 1999.
5. http://www.ntm.a.se, viewed January, 1999.
6. http://www.afdc.gov, viewed January, 1999.
7. http://www.natgas.com, viewed January, 1999.
8. Saigo, Barbara, *Environmental Science: A Global Concern*, McGraw-Hill, 1998.