ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

Well-to-Wheel Life Cycle Analysis of Liquefied Petroleum Gas

AN ANALYTICAL APPROACH

B.Sc. Engineering (Mechanical) Thesis

BY

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Department of Mechanical and Production Engineering
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Candidate's Declaration

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Abstract

Over the past few decades climate has been changed drastically and it has become a crying need to control greenhouse gas emissions for the gas and oil industries. So, it is important to know the impacts on the environment of the gases that we use in our day to day lives while cooking or while using transportation. Life Cycle Assessment (LCA) is an effective method to determine and differentiate the environmental impact of different types of fuels in cooking aspect as well as transportation aspect. In the third world countries and developing countries like Ghana, India, Sri Lanka etc. LPG (Liquified Petroliam Gas) is one of the most dominant fuel in urban area as well as rural areas. Since LPG has an excellent environmental payoff and less GHG emission it has created a lot of emerging possibilities as it has reduced pressures on forests and achieved modest climate benefits. This review paper shows how it is easy to store and transport LPG gas. With this study it brings a lot of possibility for diverse usage for LPG in cooking and transportation as it is believed to be a very attractive fuel option for its outstanding chemical properties that makes it an ideal fuel choice.

Keywords: LCA, LPG, GREET, GHG, Transportation

Chapter 1 Introduction

In the last 25 years, natural problems have long gained more popular transparent and legal analysis. The open have become more aware and curious about the use of products and administrations and their effect on ordinary assets and environmental quality. A 1991 national report by Wall Street the Journal/NBC found that 80% of Americans identify themselves as environmentalists. A rising number of companies have been in the past 12 years shifting their attention from pollutant remediation to preventing pollution. This included practice of “green” nature and the replacement of certain products and materials more environmentally conscious production practices. The levels of industrial waste have been significantly decreased by these measures on behalf of the companies involved. In general, the environmental effect of the use and disposal of goods, or 'MANPRINT', has not been included in the environmental evaluation of the pollution control program. Industry acknowledges the environmental effect of their products. The creation of the item does not begin and end with it the power of the product on the globe begins with the design and finishes after its useful existence at the final disposal of the product. The entire life cycle is influenced by what considerations are made during a product's design process. It is necessary not only to have a means to assess the environmental impact of the production process, but also what impact the product would have on the environment and its recycling capability. Now with the world in dire need of attention we must take steps to reduce pollution as much as possible. World leaders are pushing countries to turn to clean production methods wherever possible. Otherwise, the world cannot sustain and our future generations will be in great danger. They will not know Earth as we know it. The optimum condition for the welfare and growth of this world will be lost.

However, this concern is not new. Held in Stockholm in 1972, the United Nations Conference on the Human Environment was the first international intergovernmental conference to focus on environmental issues. Over the years many environmentalists have raised their voices in order to warn the world leaders of the harmful effect on irresponsible economic development. Humanity is rising at the expense of our own home. Famous environmentalist Wendell Berry once said “We have lived our lives by the assumption that what was good for us would be good for the world. We have been wrong. We must change our lives so that it will be possible to live by the contrary assumption, that what is good for the world will be good for us. And that requires that we make the effort to know the world and learn what is good for it." Although scientist continue to make people aware international politics lead to many countries not adhering to the treaties and protocols set by international organizations. Despite that aware world leaders keep calling countries to set laws and boundaries that will help the earth.

Table 1.1[1]

Convention	**Year**	**Purpose**
Ramsar Convention	1971	for the conservation and sustainable utilization of wetlands
Stockholm Declaration	1972	International protection of the environment
Convention on International Trade in Endangered species of Wild flora and fauna (CITES)	1973	Control or prevent international commercial trade in endangered species or products derived from them.
Convention on Migratory Species (CMS)	1979	Convention on the Conservation of Migratory Species of Wild Animals
Nairobi Declaration	1982	for achieving sustainable developments
Vienna convention	1985	for the protection of the ozone layer
Montreal Protocol	1987	To control Ozone-depleting Substances
Brundtland Report	1987	Sustainable Development
Earth Summit/ United Nations Conference on Environment and Development (UNCED)/ Rio Declaration	1992	Environment conservation & Development
Agenda 21	1992	Sustainable Development

UNFCCC	1992	Reducing greenhouse gas emissions to combat global warming.
Convention on Biological Diversity (CBD)	1992	Three main goals: 1. Conservation of biological diversity (or biodiversity); 2. Sustainable use of its components; 3. Sharing the benefits of genetic resources fairly and equitably
UNCCD	1994	Convention to Combat Desertification
Kyoto Protocol (COP 3)	1997	to fight global warming by reducing greenhouse gas concentrations
Rotterdam Convention	1998	Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade
Cartagena Protocol	2000	Biosafety
Stockholm Convention	2001	Eliminate or restrict the production and use of persistent organic pollutants
REDD & REDD+	2005	Reducing emissions from deforestation and forest degradation in developing countries
Nagoya Protocol	2010	Access to genetic resources and a fair and equitable sharing of benefits arising from their use of the Convention on Biological Diversity
Rio+20	2012	Conference on Sustainable Development
Paris Agreement (COP 21)	2015	Climate Change

Kigali Amendment	2016	Reduce Ozone Layer Depletion

Data source: NASA's Goddard Institute for Space Studies (GISS). Credit: NASA/GISS

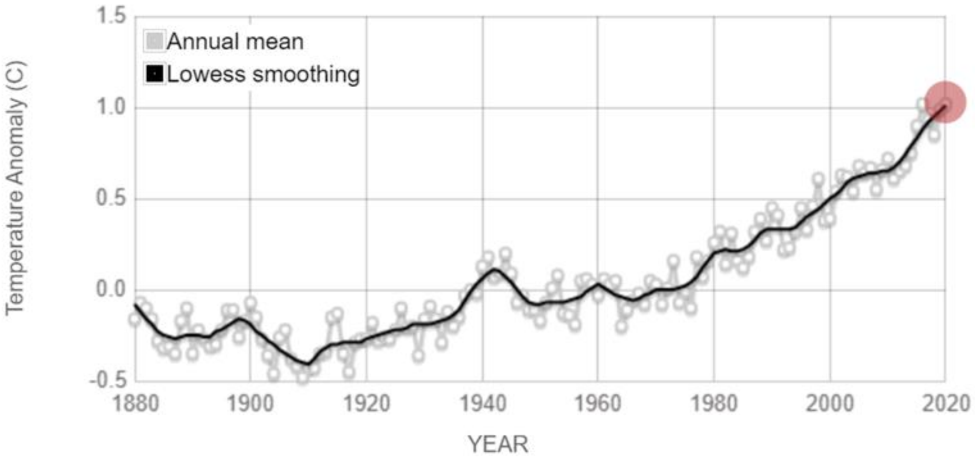


Figure 1.1: - GLOBAL LAND-OCEAN TEMPERATURE INDEX

This graph shows the change in global surface temperature relative to 1951-1980 average temperatures. Since 2000, nineteen of the warmest years have occurred, except for 1998. For the warmest year on record since record-keeping started in 1880, the year 2020 was related to 2016 (source: NASA/GISS). [2]

It is clear that from NASA’s data that the world is heating up and it is rising rapidly. Thus, it is high time we study the effects of our daily economic activities that impact the environment. According to IPCC (2014) Global Greenhouse Gas Emissions by Economic Sector

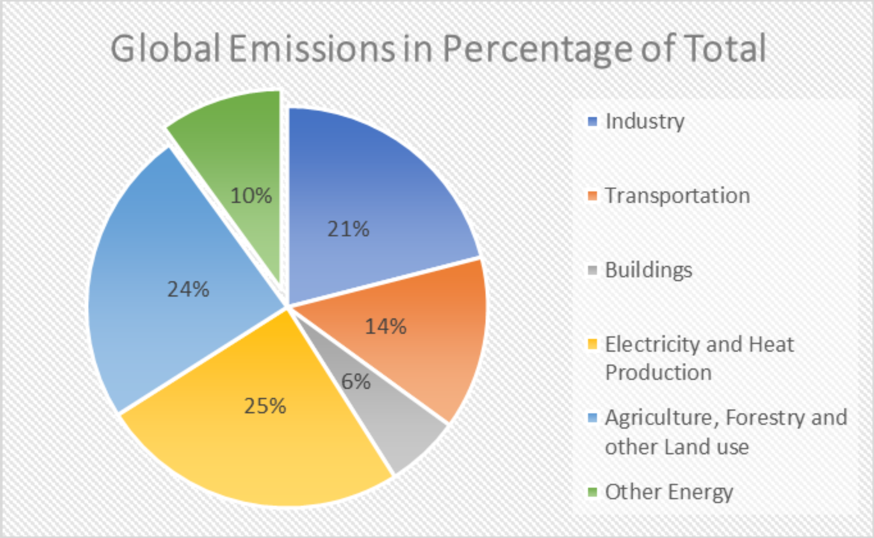


Figure 1.2: Global Emissions in Percentage of Total[2]

1. IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

2. FAO (2014). Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks (PDF). (89 pp, 3.5 MB) Climate, Energy and Tenure Division, FAO.

3. IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Emissions unfortunately cannot be completely eliminated in an instant. It is a slow process and requires a country’s economy and technology to be very powerful. Even the most developed countries are unable to complete rid themselves from emission. But this cannot be an excuse to keep producing harmful gases. At the very least we must reduce the emissions. In this paper we discuss about the emissions produced in transportation. Transportation causes 14 percent of the total GHG emission worldwide and to reduce this we analyze the life cycle of an emerging transportation fuel. [3]

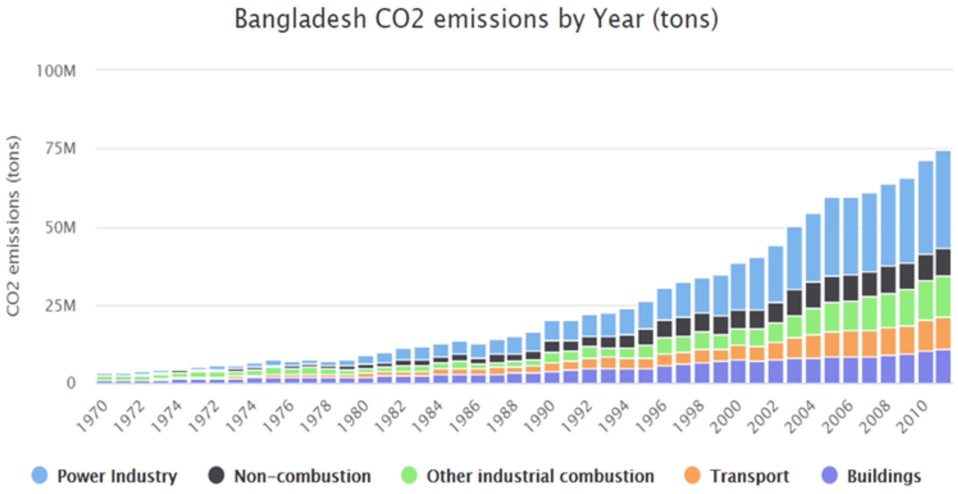


Figure 1.3: Bangladesh CO2 Emission by Year (Tons)[3]

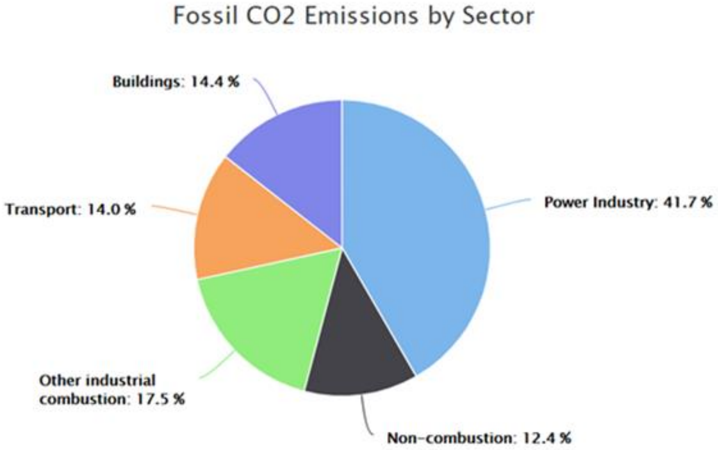


Figure 1.4:Fossil CO2 Emission by Sector[3]

Chapter 2 Literature Review

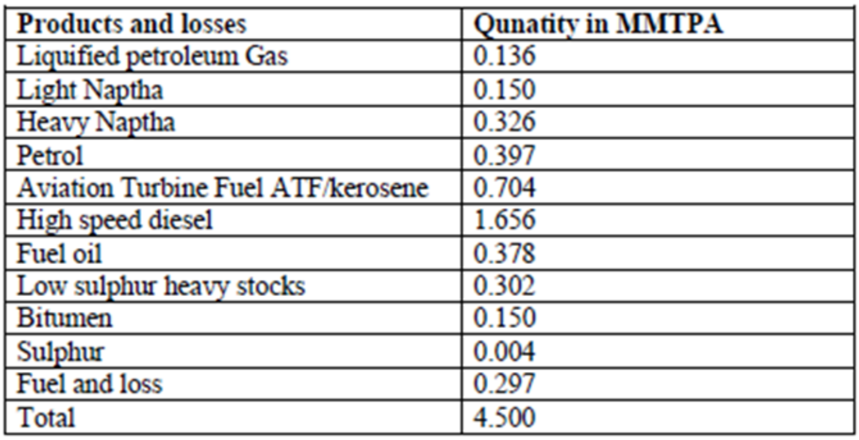
Over the last decade immense research has been conducted on the effects of traditional fuels on the environment. With climate change being a major concern, environmental impact due to fuel has to be studied. For fuels that have heavy impact must be replaced. We must be more responsible towards our planet. Such an alternate for commonly used fuel is LPG. But before we promote its usage, we must keep in check what its effects are on the environment. LPG is largely used as a cooking and transportation fuel. Therefore, we must first evaluate LPG's emission in these cases. The most reliable method of calculating GHG and other emissions are through software's such as GREET. This has been demonstrated on JACOB's consultancy's report for Alberta Energy Research Institute (2009). For different stages different methods are used to present the environmental impacts of LPG. Such as during production stage we use the CML and Eco Indicator 99 Method as demonstrated by Trupti Marmar (2017). She also concludes from her calculation that LPG has the least effect on the environment when compared to other equal amount produced fuels. Sarah Cashman (2016) conducted a study on cookstove fuels life cycle assessment where she concluded that to reduce several impacts such as efficiency loss, eutrophication excreta a solution could be to replace coal, wood excreta with LPG. George Afrane and Augustine Ntiamoah conducted a similar study in Ghana where they also were in agreement with Sarah Cashman's findings. Lav Kumar Kaushik and P Muthukumar (2018) further studied to show that LPG if combined with technologies such as Two Layer Porous Radiant Burners can further improve efficiency and reduce emissions. Ross Ryskamp (2017), Steven Unnasch and Love Goyal (2017), Dr. Ben Lane (2006) all did LCA using different methods on different vehicle fuels. All reached the same conclusion on LPG being the most environmentally friendly fuel in a WTW analysis.

Oil refineries are complex facilities. Several processes, like distillation, vacuum distillation,

or steam reforming are required to supply an outsized sort of oil products like gasoline, light fuel or bitumen. It requires large input of resources, while it also causes several negative environmental effects. Life cycle of a product starts from extraction and refining of raw materials, which are then transported to the manufacturing site to supply a product. The product is then transported to the user and at the top of its useful life is either recycled and returned back to reprocessing or disposed of during a landfill. It is necessary that we analyze the different impact the fuel sources have on the environment as well the energy factors in choosing a good fuel source to invest in.

Below are the different factors comparison that need to be taken into account when assessing different fuels impact at production stage. Their papers supporting our work.

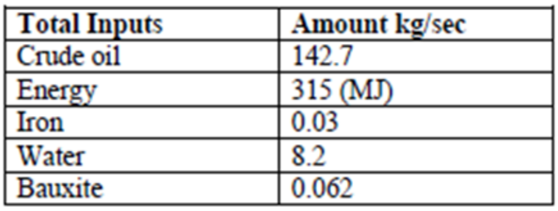
Table 2.1:Below show the material balance for the refinery having capacity of treating 4.5 MMTPA crude oil



Products and losses	Qunatity in MMTPA
Liquified petroleum Gas	0.136
Light Naptha	0.150
Heavy Naptha	0.326
Petrol	0.397
Aviation Turbine Fuel ATF/kerosene	0.704
High speed diesel	1.656
Fuel oil	0.378
Low sulphur heavy stocks	0.302
Bitumen	0.150
Sulphur	0.004
Fuel and loss	0.297
Total	4.500

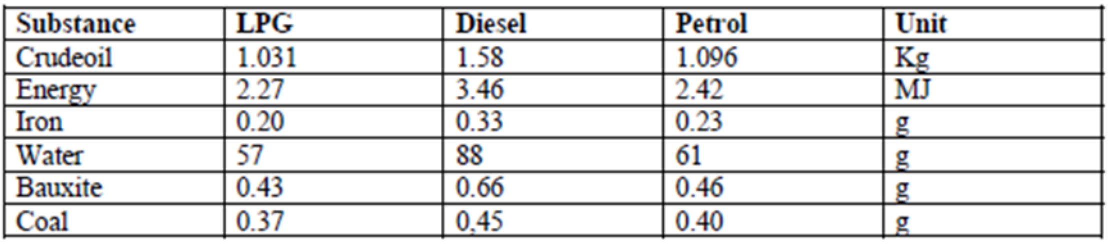
From the mass allocation it's determined that the refinery process yield 3%, 9% and 58% mass fraction of LPG, Petrol and Diesel respectively and remainder of the mass fraction of other co-products. Total LPG produced in Kg/sec is 4.313 and its 12.588kg/sec and 52.54 kg/sec respectively for petrol and diesel.

Table 2.2:Input to Refinery



Total Inputs	Amount kg/sec
Crude oil	142.7
Energy	315 (MJ)
Iron	0.03
Water	8.2
Bauxite	0.062

Table 2.3:Raw Material and Energy Input for 1 kg of Fuel Output

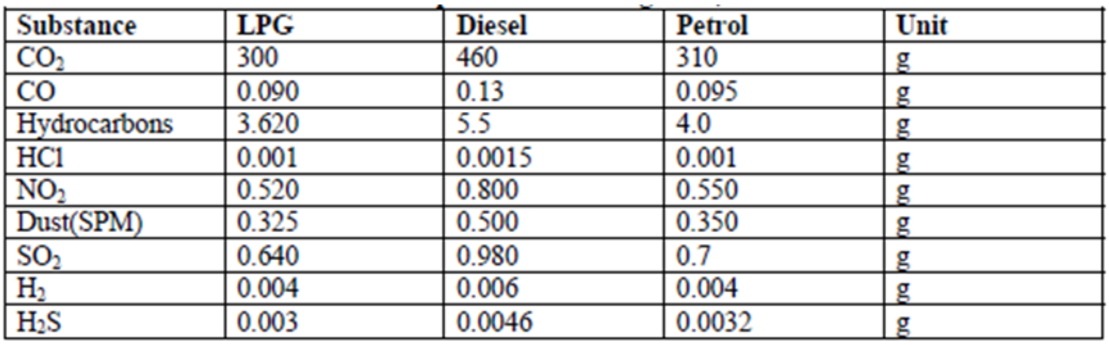


Substance	LPG	Diesel	Petrol	Unit
Crudeoil	1.031	1.58	1.096	Kg
Energy	2.27	3.46	2.42	MJ
Iron	0.20	0.33	0.23	g
Water	57	88	61	g
Bauxite	0.43	0.66	0.46	g
Coal	0.37	0.45	0.40	g

2.1 Output

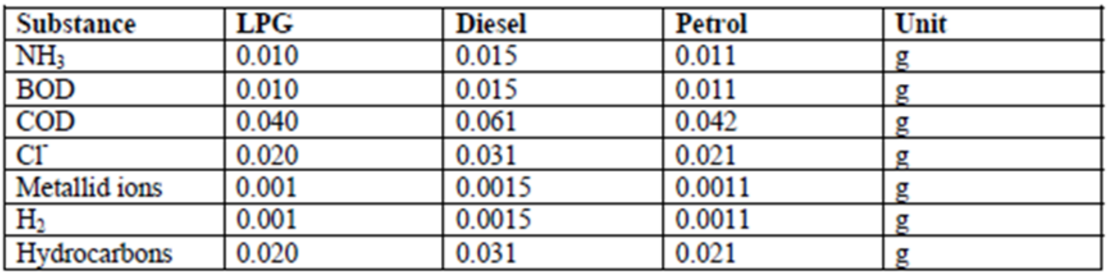
Manufacturing processes are bound to create unwanted waste products. These products are released in the air, water, solid and as non-material emissions. These outputs do affect the environment and should be accounted for. Below a summarized table of the different outputs are shown.

Table 2.4:Emission to Air from production of 1 kg LPG, Diesel and Petrol



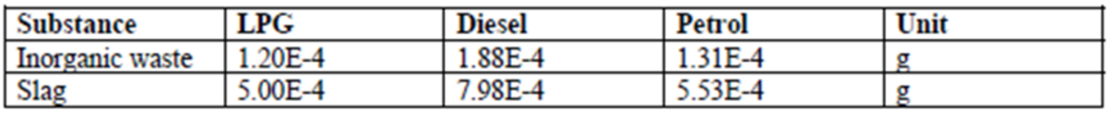
Substance	LPG	Diesel	Petrol	Unit
CO_2	300	460	310	g
CO	0.090	0.13	0.095	g
Hydrocarbons	3.620	5.5	4.0	g
HCl	0.001	0.0015	0.001	g
NO_2	0.520	0.800	0.550	g
Dust(SPM)	0.325	0.500	0.350	g
SO_2	0.640	0.980	0.7	g
H_2	0.004	0.006	0.004	g
H_2S	0.003	0.0046	0.0032	g

Table 2.5:Emission to Water from production of 1 kg LPG, Diesel and Petrol



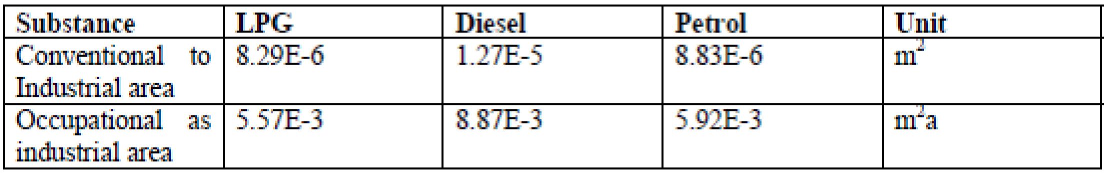
Substance	LPG	Diesel	Petrol	Unit
NH_3	0.010	0.015	0.011	g
BOD	0.010	0.015	0.011	g
COD	0.040	0.061	0.042	g
Cl^-	0.020	0.031	0.021	g
Metallid ions	0.001	0.0015	0.0011	g
H_2	0.001	0.0015	0.0011	g
Hydrocarbons	0.020	0.031	0.021	g

Table 2.6:Solid Emissions from the production of LPG, Diesel and Petrol



Substance	LPG	Diesel	Petrol	Unit
Inorganic waste	1.20E-4	1.88E-4	1.31E-4	g
Slag	5.00E-4	7.98E-4	5.53E-4	g

Table 2.7:Non-Material Emissions from the production of LPG, Diesel and Petrol



Substance	LPG	Diesel	Petrol	Unit
Conventional to Industrial area	8.29E-6	1.27E-5	8.83E-6	m^2
Occupational as industrial area	5.57E-3	8.87E-3	5.92E-3	m^2a

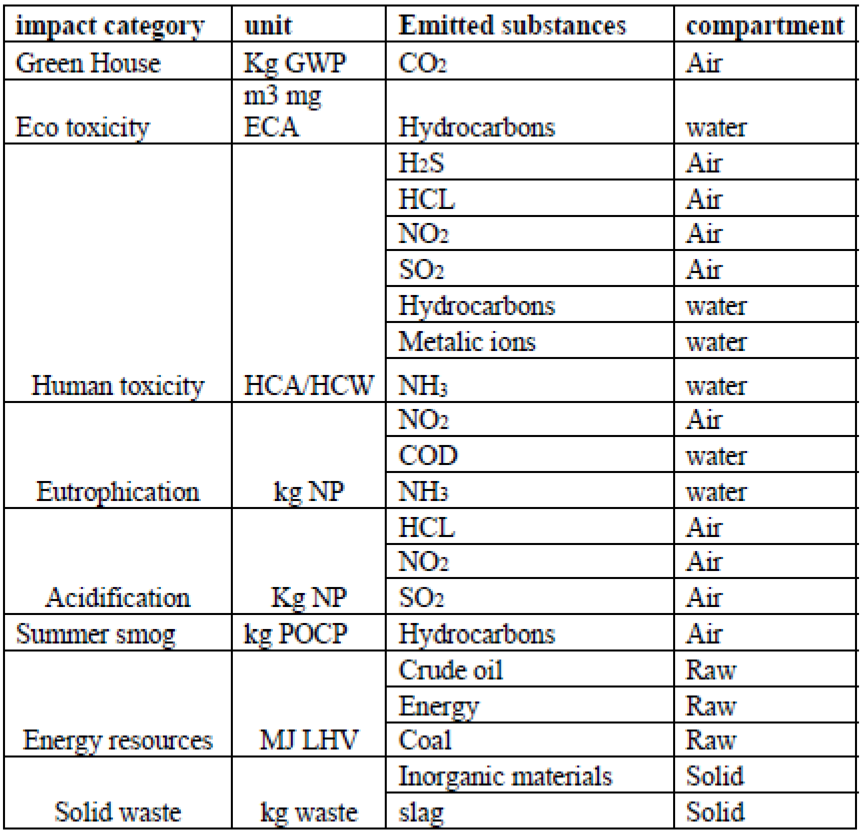
2.2 Life Cycle Impact Assessment (LCIA) at production stage

Life cycle impact assessment may be a technical, quantitative and/or qualitative process to characterize and assess the consequences of the environmental burdens identified within the inventory analysis. The inventory analysis provides an inventory of discharges from the required system and through the appliance of impact assessment it becomes possible to assess the potential effect on the environment resulting from the identified environment burdens. Each discharge listed within the inventory analysis should be systematically studied and evaluated. As shown within the figure the LCIA phase composed of several mandatory elements that converts inventory analysis results to indicators results. In addition there are optional elements, for normalization, grouping or weighting of the indicator results and data quality analysis techniques.In this review we will discuss about two methods

2.3 CML Method

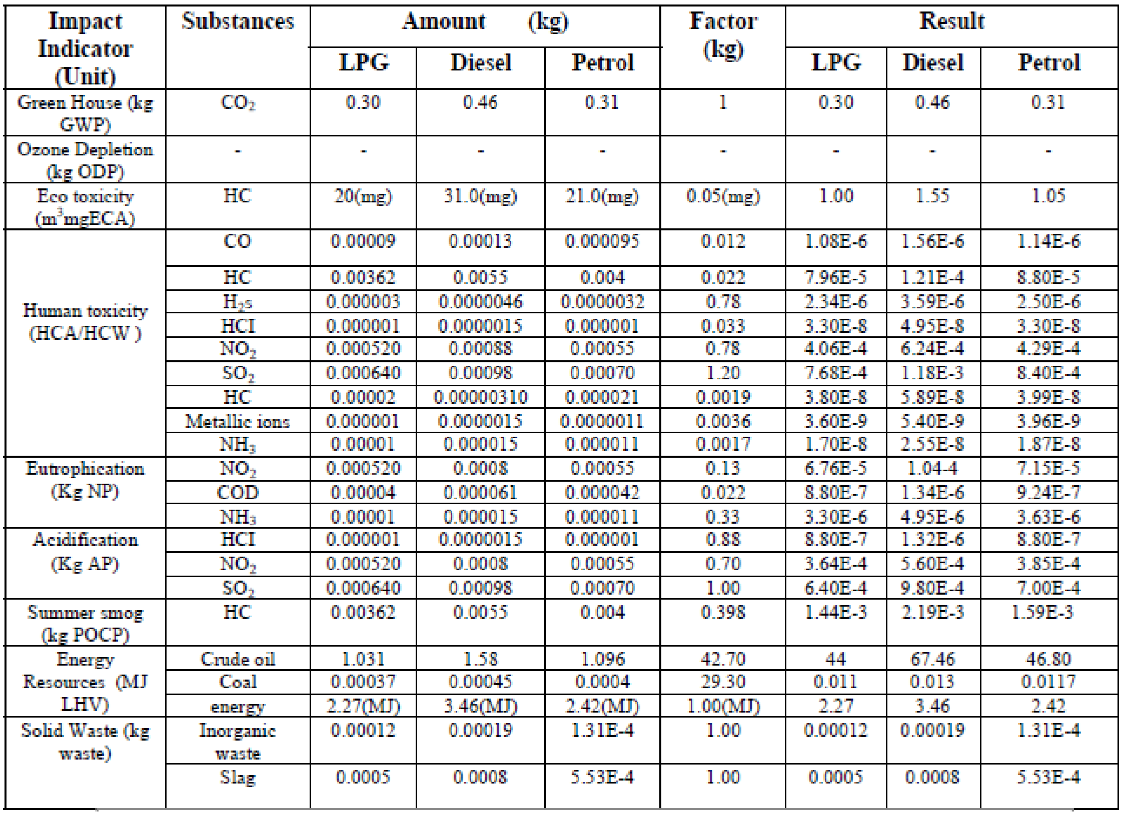
It is one of the first assessment method, developed and used in several countries. The method is named after the Centre of Environmental Management, Leiden University, Netherlands, where it was developed. The CML classification system addresses a number of unidentified, important environmental issues and gives a score for each of their environmental issues.

Table 2.8:Classification of substances to various impact indicators using CML method



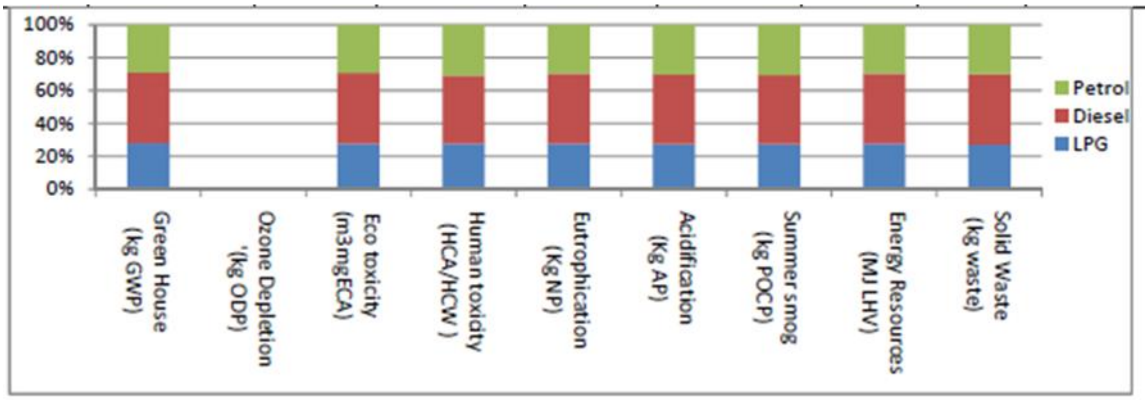
impact category	unit	Emitted substances	compartment
Green House	Kg GWP	CO_2	Air
Eco toxicity	m3 mg ECA	Hydrocarbons	water
Human toxicity	HCA/HCW	H_2S	Air
		HCL	Air
		NO_2	Air
		SO_2	Air
		Hydrocarbons	water
		Metalic ions	water
		NH_3	water
Eutrophication	kg NP	NO_2	Air
		COD	water
		NH_3	water
Acidification	Kg NP	HCL	Air
		NO_2	Air
		SO_2	Air
Summer smog	kg POCP	Hydrocarbons	Air
Energy resources	MJ LHV	Crude oil	Raw
		Energy	Raw
		Coal	Raw
Solid waste	kg waste	Inorganic materials	Solid
		slag	Solid

Table 2.9:Characterization value of impact indicators for production of 1 kg of LPG, Diesel & Petrol



Impact Indicator (Unit)	Substances	Amount (kg)			Factor (kg)	Result		
		LPG	Diesel	Petrol		LPG	Diesel	Petrol
Green House (kg GWP)	CO_2	0.30	0.46	0.31	1	0.30	0.46	0.31
Ozone Depletion (kg ODP)	-	-	-	-	-	-	-	-
Eco toxicity (m^{3}mgECA)	HC	20(mg)	31.0(mg)	21.0(mg)	0.05(mg)	1.00	1.55	1.05
Human toxicity (HCA/HCW)	CO	0.00009	0.00013	0.000095	0.012	1.08E-6	1.56E-6	1.14E-6
	HC	0.00362	0.0055	0.004	0.022	7.96E-5	1.21E-4	8.80E-5
	H_2s	0.000003	0.0000046	0.0000032	0.78	2.34E-6	3.59E-6	2.50E-6
	HCI	0.000001	0.0000015	0.000001	0.033	3.30E-8	4.95E-8	3.30E-8
	NO_2	0.000520	0.00088	0.00055	0.78	4.06E-4	6.24E-4	4.29E-4
	SO_2	0.000640	0.00098	0.00070	1.20	7.68E-4	1.18E-3	8.40E-4
	HC	0.00002	0.00000310	0.000021	0.0019	3.80E-8	5.89E-8	3.99E-8
	Metallic ions	0.000001	0.0000015	0.0000011	0.0036	3.60E-9	5.40E-9	3.96E-9
	NH_3	0.00001	0.000015	0.000011	0.0017	1.70E-8	2.55E-8	1.87E-8
Eutrophication (Kg NP)	NO_2	0.000520	0.0008	0.00055	0.13	6.76E-5	1.04-4	7.15E-5
	COD	0.00004	0.000061	0.000042	0.022	8.80E-7	1.34E-6	9.24E-7
	NH_3	0.00001	0.000015	0.000011	0.33	3.30E-6	4.95E-6	3.63E-6
Acidification (Kg AP)	HCI	0.000001	0.0000015	0.000001	0.88	8.80E-7	1.32E-6	8.80E-7
	NO_2	0.000520	0.0008	0.00055	0.70	3.64E-4	5.60E-4	3.85E-4
	SO_2	0.000640	0.00098	0.00070	1.00	6.40E-4	9.80E-4	7.00E-4
Summer smog (kg POCP)	HC	0.00362	0.0055	0.004	0.398	1.44E-3	2.19E-3	1.59E-3
Energy Resources (MJ LHV)	Crude oil	1.031	1.58	1.096	42.70	44	67.46	46.80
	Coal	0.00037	0.00045	0.0004	29.30	0.011	0.013	0.0117
	energy	2.27(MJ)	3.46(MJ)	2.42(MJ)	1.00(MJ)	2.27	3.46	2.42
Solid Waste (kg waste)	Inorganic waste	0.00012	0.00019	1.31E-4	1.00	0.00012	0.00019	1.31E-4
	Slag	0.0005	0.0008	5.53E-4	1.00	0.0005	0.0008	5.53E-4

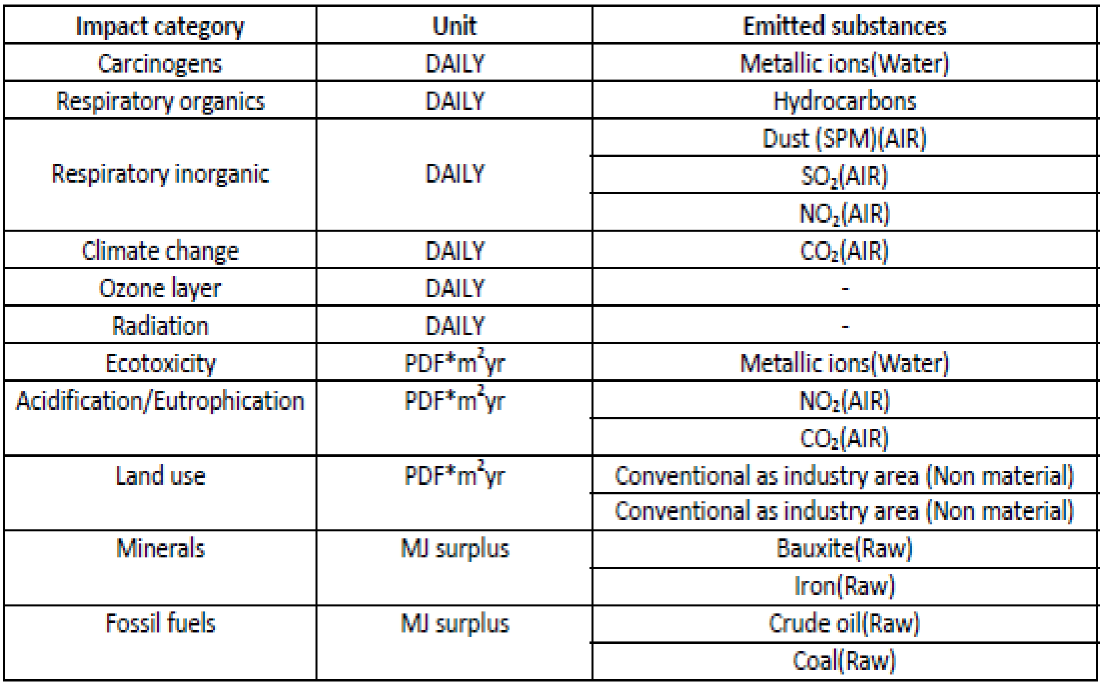
Table 2.10: Comparison of % impact of production of 1 kg LPG, Petrol and Diesel for various impact indicators



2.4 ECO Indicator-99 Method

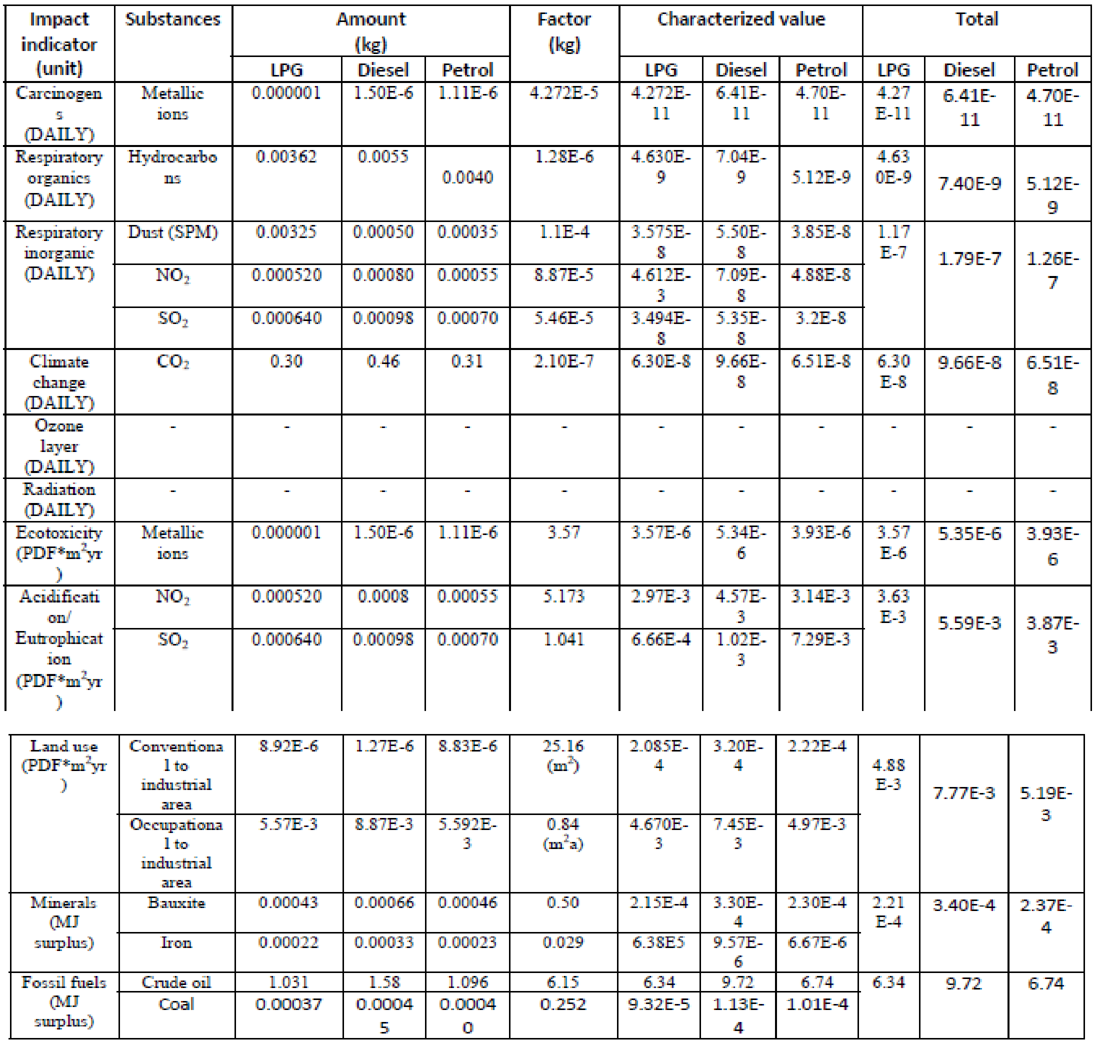
The method was developed under the Dutch NOH program by Pre consultants during a joined project with Philips consumer electronics, Ned Car (Volvo/Mitsubishi), Oce Copier, Schuurink CML Leiden, TU-Delft, IVAM-ER (Amsterdam) and CE delft. During this method normalization and weighting are performed at damage category level (endpoint level in ISO terminology).

Table 2.11: Classification of various substances to various impact categories



Impact category	Unit	Emitted substances
Carcinogens	DAILY	Metallic ions(Water)
Respiratory organics	DAILY	Hydrocarbons
Respiratory inorganic	DAILY	Dust (SPM)(AIR)
		SO_2(AIR)
		NO_2(AIR)
Climate change	DAILY	CO_2(AIR)
Ozone layer	DAILY	-
Radiation	DAILY	-
Ecotoxicity	PDF*m^2yr	Metallic ions(Water)
Acidification/Eutrophication	PDF*m^2yr	NO_2(AIR)
		CO_2(AIR)
Land use	PDF*m^2yr	Conventional as industry area (Non material)
		Conventional as industry area (Non material)
Minerals	MJ surplus	Bauxite(Raw)
		Iron(Raw)
Fossil fuels	MJ surplus	Crude oil(Raw)
		Coal(Raw)

Table 2.12:Value of impact indicators on the production of 1 kg of LPG, Petrol and Diesel



Impact indicator (unit)	Substances	Amount (kg)			Factor (kg)	Characterized value			Total		
		LPG	Diesel	Petrol		LPG	Diesel	Petrol	LPG	Diesel	Petrol
Carcinogens (DAILY)	Metallic ions	0.000001	1.50E-6	1.11E-6	4.272E-5	4.272E-11	6.41E-11	4.70E-11	4.27E-11	6.41E-11	4.70E-11
Respiratory organics (DAILY)	Hydrocarbons	0.00362	0.0055	0.0040	1.28E-6	4.630E-9	7.04E-9	5.12E-9	4.630E-9	7.40E-9	5.12E-9
Respiratory inorganic (DAILY)	Dust (SPM)	0.00325	0.00050	0.00035	1.1E-4	3.575E-8	5.50E-8	3.85E-8	1.17E-7	1.79E-7	1.26E-7
	NO_2	0.000520	0.00080	0.00055	8.87E-5	4.612E-3	7.09E-8	4.88E-8			
	SO_2	0.000640	0.00098	0.00070	5.46E-5	3.494E-8	5.35E-8	3.2E-8			
Climate change (DAILY)	CO_2	0.30	0.46	0.31	2.10E-7	6.30E-8	9.66E-8	6.51E-8	6.30E-8	9.66E-8	6.51E-8
Ozone layer (DAILY)	-	-	-	-	-	-	-	-	-	-	-
Radiation (DAILY)	-	-	-	-	-	-	-	-	-	-	-
Ecotoxicity ($PDF*m^2yr$)	Metallic ions	0.000001	1.50E-6	1.11E-6	3.57	3.57E-6	5.34E-6	3.93E-6	3.57E-6	5.35E-6	3.93E-6
Acidification/ Eutrophication ($PDF*m^2yr$)	NO_2	0.000520	0.0008	0.00055	5.173	2.97E-3	4.57E-3	3.14E-3	3.63E-3	5.59E-3	3.87E-3
	SO_2	0.000640	0.00098	0.00070	1.041	6.66E-4	1.02E-3	7.29E-3			
Land use ($PDF*m^2yr$)	Conventional to industrial area	8.92E-6	1.27E-6	8.83E-6	25.16 (m^2)	2.085E-4	3.20E-4	2.22E-4	4.88E-3	7.77E-3	5.19E-3
	Occupational to industrial area	5.57E-3	8.87E-3	5.592E-3	0.84 (m^2a)	4.670E-3	7.45E-3	4.97E-3			
Minerals (MJ surplus)	Bauxite	0.00043	0.00066	0.00046	0.50	2.15E-4	3.30E-4	2.30E-4	2.21E-4	3.40E-4	2.37E-4
	Iron	0.00022	0.00033	0.00023	0.029	6.38E5	9.57E-6	6.67E-6			
Fossil fuels (MJ surplus)	Crude oil	1.031	1.58	1.096	6.15	6.34	9.72	6.74	6.34	9.72	6.74
	Coal	0.00037	0.00045	0.00040	0.252	9.32E-5	1.13E-4	1.01E-4			

Table 2.13:Percentage Contribution of above data

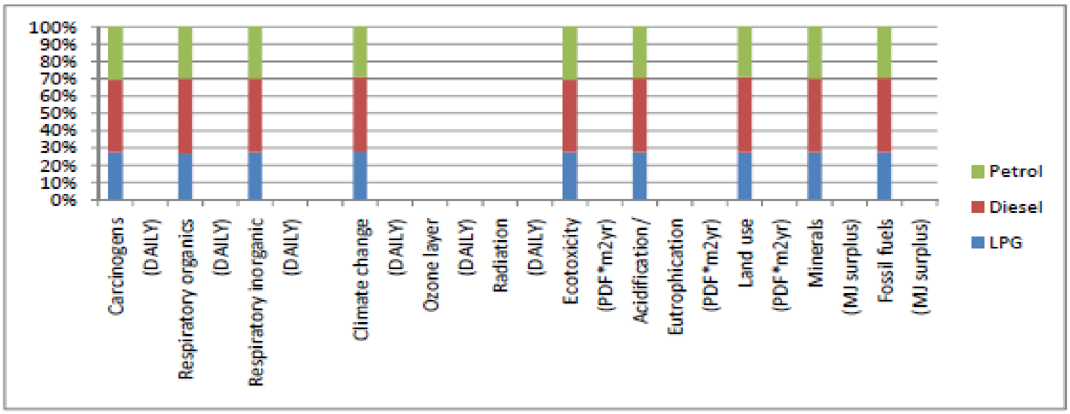
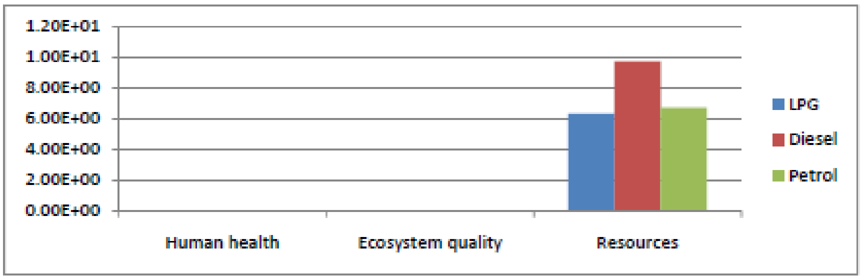


Table 2.14:Damage Assessment of production of 1 kg LPG, Petrol and Diesel

Damage Indicator	Impact category	Substances	Factor	Damage Indicator value			Total		
				LPG	Diesel	Petrol	LPG	Diesel	Petrol
Human health	Climate change	CO_2	1	6.30E-8	9.66E-8	6.51E-8	1.87 E-7	2.83 E-7	1.96E-7
	Respiratory organics	Hydrocarbons	1	4.63E-9	7.04E-9	5.12E-9			
	Respiratory inorganic	Dust (SPM)	1	3.58E-8	5.50E-8	3.85E-8			
		NO_2	1	4.61E-8	7.09E-8	4.88E-8			
		SO_2	1	3.49-E8	5.35E-8	3.82E-8			
	Carcinogens	Metallic ions	1	4.27E-11	6.41E-11	4.70E-11			
	Ozone layer	-	-	-	-	-			
	Radiation	-	-	-	-	-			
Eco-system quality	Acidification/ Eutrophication	NO_2	1	2.97E-3	4.57E-3	3.14E-3	8.52E -3	0.0134	9.07E-3
		SO_2	1	6.66E-4	1.02E-3	7.29E-4			
	Ecotoxicity	Metallic ions	0.1	3.57E-7	5.35E-7	3.93E-7			
	Land use	Conventional to industrial area	1	2.08E-4	3.20E-4	2.22E-4			

		Occupational to industrial area	1	4.68E-3	7.45E-3	4.97E-3			
Resources	Minerals	Bauxite	1	2.15E-4	3.30E-4	2.30E-4	6.34	9.72	6.74
		Iron	1	6.38E-6	9.57E-6	6.67E-6			
	Fossil fuels	Crude oil	1	6.34	9.72	6.74			
		Coal	1	9.32E-5	1.13E-4	1.01E-4			



From the data above it is safe to assume that the environmental impacts upon production is highest by Diesel followed by Petrol and then LPG. Although a cleaner choice LPG is but the by-product of the crude oil refining. Till now it is not possible to solely produce LPG. But this analysis shows that using LPG is better for the environment based upon the production emission and input requirements.

2.5 Assessment of LPG as a Cooking Fuel

2.5.1 Methodology and Review from study in Ghana

The examination is done by the standard life cycle appraisal (LCA) rules created by the International Organization for Standardization (ISO) in its ISO 14040–14043 arrangement. LCA is a rising hypothetical instrument for the appraisal of ecological effects of item frameworks from support to grave. Information for LCA examines are taken from the extraction of crude materials and vitality assets from nature. The transformation of these assets into the ideal item; the use of the item by the purchaser; and, at long last, the removal, reuse, or reusing of the item after its administration life. The examination is a successful method to present ecological contemplations in cycle and item structure or choice.

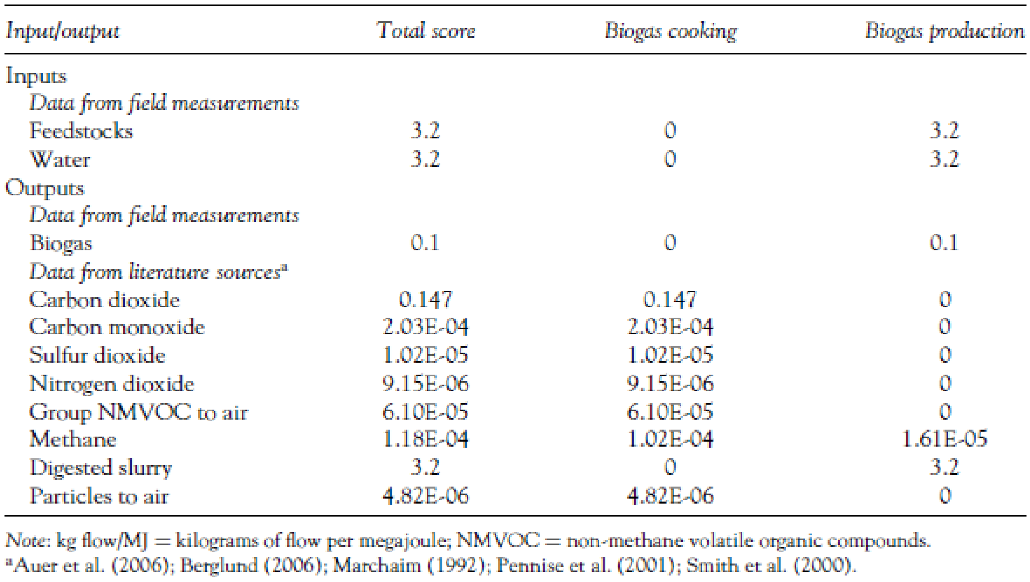
D Singh , S Pachauri and H Zerriffi used three key method to determine the environmental payoffs of LPG as cooking fuel in India although they did not conduct

LCA. Still we can get idea how much gas emission occurs from LPG which can help to understand the LCA method better.

2.5.2 LCIA and comparison to other options

Different methods were used to collect inventory data of LPG, Bio-Gas and Charcoal. Then LCIA was conducted and results were obtained. The potential human health and environmental impacts associated with the inventory data were determined and analyzed. The following impact assessment categories were considered because of their relevance to the systems studied: acidification, eutrophication, freshwater aquatic Eco toxicity, global warming, human toxicity, photochemical ozone creation (smog), and terrestrial Eco toxicity potentials. The impact assessment method chosen to quantify these impact categories was the CML 2001 method.

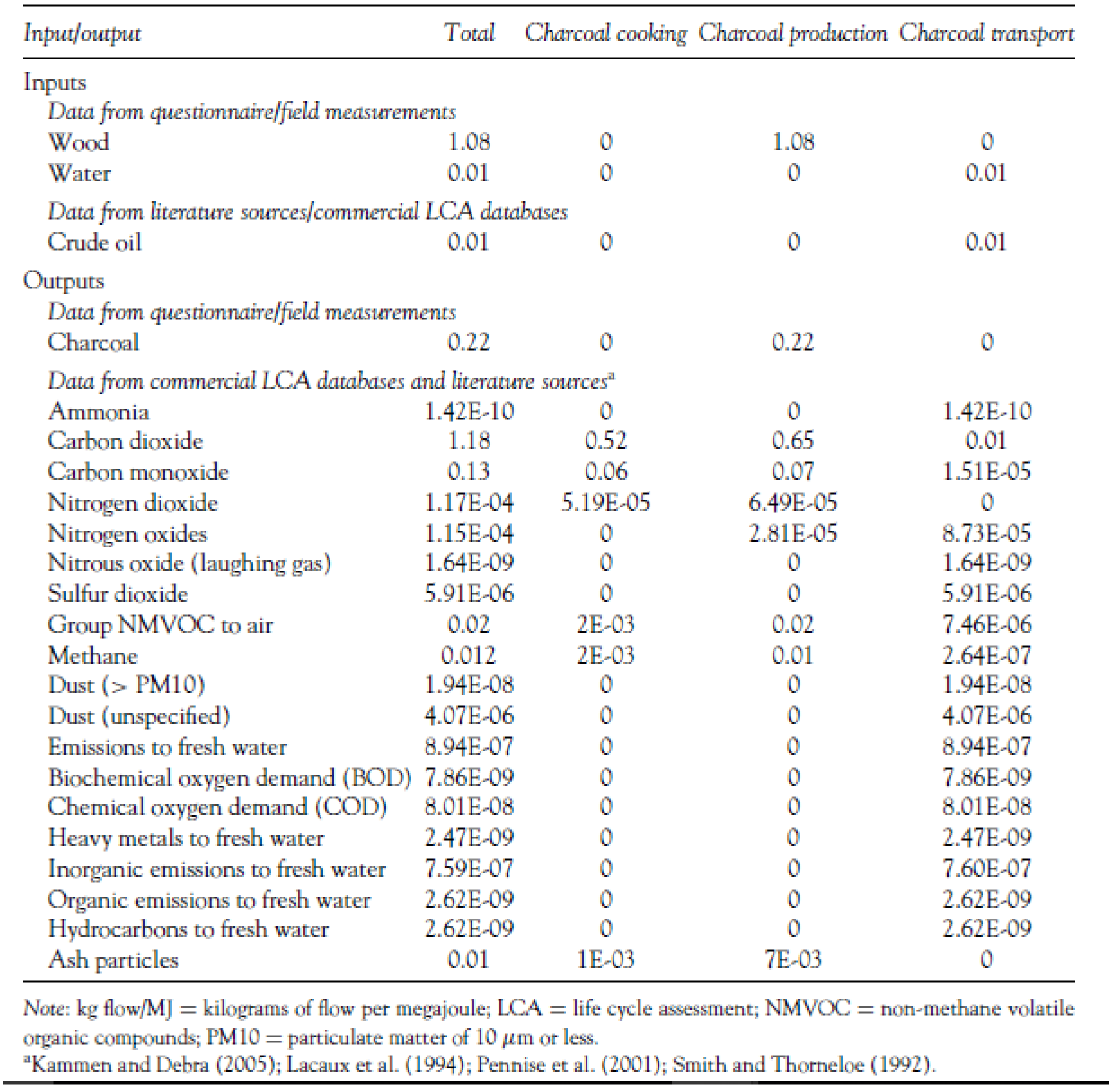
Table 2.15:Inventory Data for Charcoal



Input/output	*Total score*	*Biogas cooking*	*Biogas production*
Inputs			
Data from field measurements			
Feedstocks	3.2	0	3.2
Water	3.2	0	3.2
Outputs			
Data from field measurements			
Biogas	0.1	0	0.1
Data from literature sources[a]			
Carbon dioxide	0.147	0.147	0
Carbon monoxide	2.03E-04	2.03E-04	0
Sulfur dioxide	1.02E-05	1.02E-05	0
Nitrogen dioxide	9.15E-06	9.15E-06	0
Group NMVOC to air	6.10E-05	6.10E-05	0
Methane	1.18E-04	1.02E-04	1.61E-05
Digested slurry	3.2	0	3.2
Particles to air	4.82E-06	4.82E-06	0

Note: kg flow/MJ = kilograms of flow per megajoule; NMVOC = non-methane volatile organic compounds.
[a] Auer et al. (2006); Berglund (2006); Marchaim (1992); Pennise et al. (2001); Smith et al. (2000).

Table 2.16: Inventory Data for Biogas

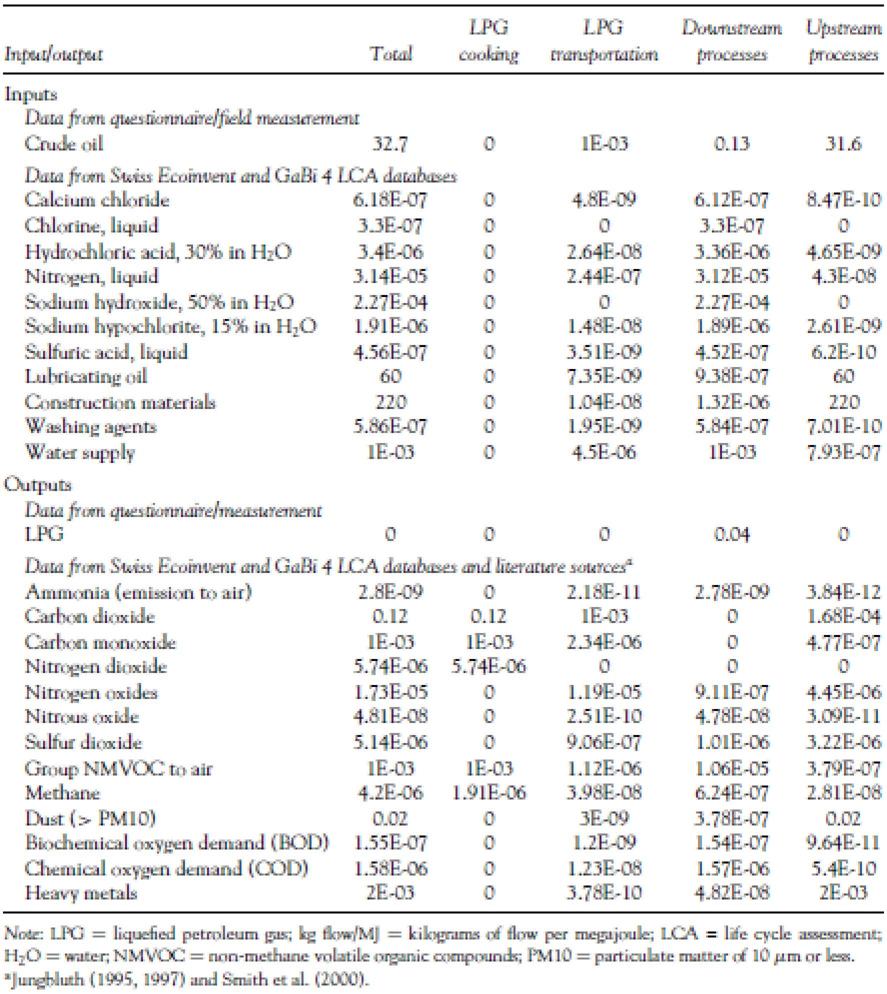


Input/output	*Total*	*Charcoal cooking*	*Charcoal production*	*Charcoal transport*
Inputs				
Data from questionnaire/field measurements				
Wood	1.08	0	1.08	0
Water	0.01	0	0	0.01
Data from literature sources/commercial LCA databases				
Crude oil	0.01	0	0	0.01
Outputs				
Data from questionnaire/field measurements				
Charcoal	0.22	0	0.22	0
Data from commercial LCA databases and literature sources[a]				
Ammonia	1.42E-10	0	0	1.42E-10
Carbon dioxide	1.18	0.52	0.65	0.01
Carbon monoxide	0.13	0.06	0.07	1.51E-05
Nitrogen dioxide	1.17E-04	5.19E-05	6.49E-05	0
Nitrogen oxides	1.15E-04	0	2.81E-05	8.73E-05
Nitrous oxide (laughing gas)	1.64E-09	0	0	1.64E-09
Sulfur dioxide	5.91E-06	0	0	5.91E-06
Group NMVOC to air	0.02	2E-03	0.02	7.46E-06
Methane	0.012	2E-03	0.01	2.64E-07
Dust (> PM10)	1.94E-08	0	0	1.94E-08
Dust (unspecified)	4.07E-06	0	0	4.07E-06
Emissions to fresh water	8.94E-07	0	0	8.94E-07
Biochemical oxygen demand (BOD)	7.86E-09	0	0	7.86E-09
Chemical oxygen demand (COD)	8.01E-08	0	0	8.01E-08
Heavy metals to fresh water	2.47E-09	0	0	2.47E-09
Inorganic emissions to fresh water	7.59E-07	0	0	7.60E-07
Organic emissions to fresh water	2.62E-09	0	0	2.62E-09
Hydrocarbons to fresh water	2.62E-09	0	0	2.62E-09
Ash particles	0.01	1E-03	7E-03	0

Note: kg flow/MJ = kilograms of flow per megajoule; LCA = life cycle assessment; NMVOC = non-methane volatile organic compounds; PM10 = particulate matter of 10 μm or less.

[a] Kammen and Debra (2005); Lacaux et al. (1994); Pennise et al. (2001); Smith and Thorneloe (1992).

Table 2.17:Quantified environmental profile of biogas, LPG, and charcoal (characterization results) on the basis of the CML 2001 environmental impact assessment

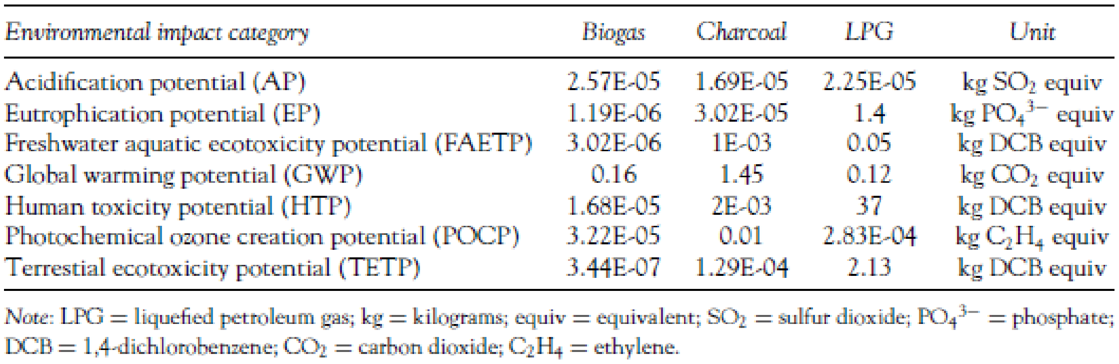


Input/output	*Total*	*LPG cooking*	*LPG transportation*	*Downstream processes*	*Upstream processes*
Inputs					
Data from questionnaire/field measurement					
Crude oil	32.7	0	1E-03	0.13	31.6
Data from Swiss Ecoinvent and GaBi 4 LCA databases					
Calcium chloride	6.18E-07	0	4.8E-09	6.12E-07	8.47E-10
Chlorine, liquid	3.3E-07	0	0	3.3E-07	0
Hydrochloric acid, 30% in H_2O	3.4E-06	0	2.64E-08	3.36E-06	4.65E-09
Nitrogen, liquid	3.14E-05	0	2.44E-07	3.12E-05	4.3E-08
Sodium hydroxide, 50% in H_2O	2.27E-04	0	0	2.27E-04	0
Sodium hypochlorite, 15% in H_2O	1.91E-06	0	1.48E-08	1.89E-06	2.61E-09
Sulfuric acid, liquid	4.56E-07	0	3.51E-09	4.52E-07	6.2E-10
Lubricating oil	60	0	7.35E-09	9.38E-07	60
Construction materials	220	0	1.04E-08	1.32E-06	220
Washing agents	5.86E-07	0	1.95E-09	5.84E-07	7.01E-10
Water supply	1E-03	0	4.5E-06	1E-03	7.93E-07
Outputs					
Data from questionnaire/measurement					
LPG	0	0	0	0.04	0
Data from Swiss Ecoinvent and GaBi 4 LCA databases and literature sources[a]					
Ammonia (emission to air)	2.8E-09	0	2.18E-11	2.78E-09	3.84E-12
Carbon dioxide	0.12	0.12	1E-03	0	1.68E-04
Carbon monoxide	1E-03	1E-03	2.34E-06	0	4.77E-07
Nitrogen dioxide	5.74E-06	5.74E-06	0	0	0
Nitrogen oxides	1.73E-05	0	1.19E-05	9.11E-07	4.45E-06
Nitrous oxide	4.81E-08	0	2.51E-10	4.78E-08	3.09E-11
Sulfur dioxide	5.14E-06	0	9.06E-07	1.01E-06	3.22E-06
Group NMVOC to air	1E-03	1E-03	1.12E-06	1.06E-05	3.79E-07
Methane	4.2E-06	1.91E-06	3.98E-08	6.24E-07	2.81E-08
Dust (> PM10)	0.02	0	3E-09	3.78E-07	0.02
Biochemical oxygen demand (BOD)	1.55E-07	0	1.2E-09	1.54E-07	9.64E-11
Chemical oxygen demand (COD)	1.58E-06	0	1.23E-08	1.57E-06	5.4E-10
Heavy metals	2E-03	0	3.78E-10	4.82E-08	2E-03

Note: LPG = liquefied petroleum gas; kg flow/MJ = kilograms of flow per megajoule; LCA = life cycle assessment; H_2O = water; NMVOC = non-methane volatile organic compounds; PM10 = particulate matter of 10 μm or less.

[a] Jungbluth (1995, 1997) and Smith et al. (2000).

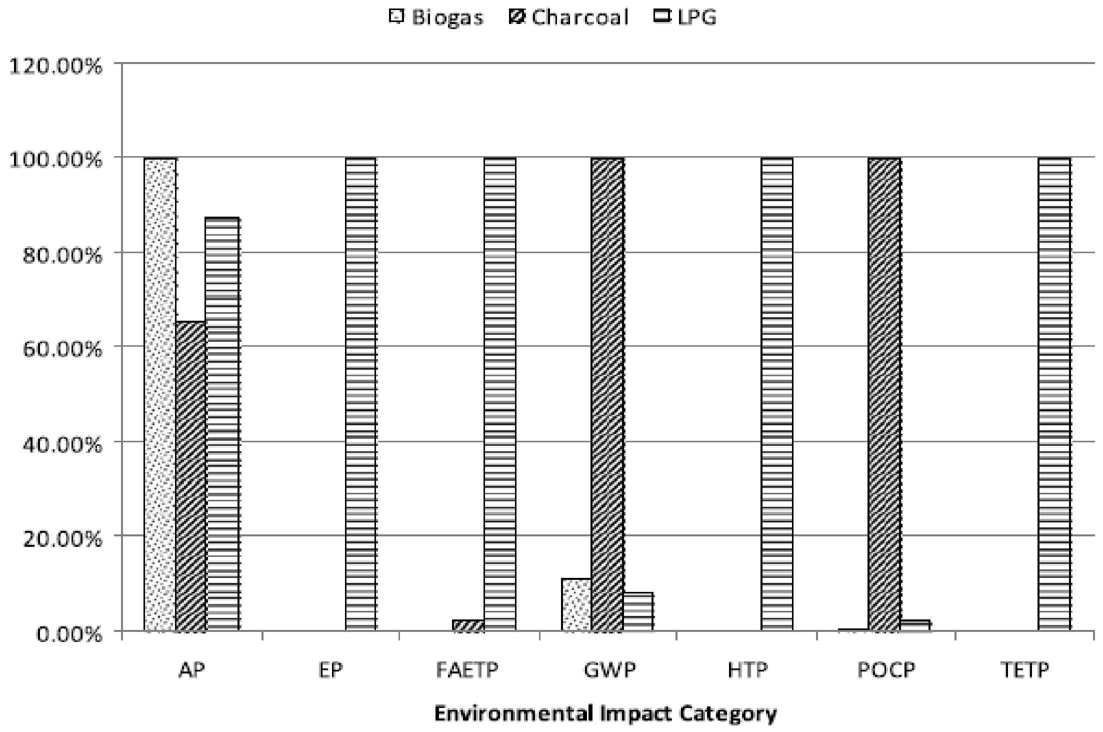
Table 2.18:Relative environmental impacts from producing 1 mega joule (MJ) of useful energy from biogas, charcoal, or liquefied petroleum gas. AP = acidification potential; EP = eutrophication potential; FAETP = freshwater aquatic Eco toxicity potential; GWP = global warming potential; HTP = human toxicity potential; POCP = photochemical ozone creation potential; TETP = terrestrial Eco toxicity potential.

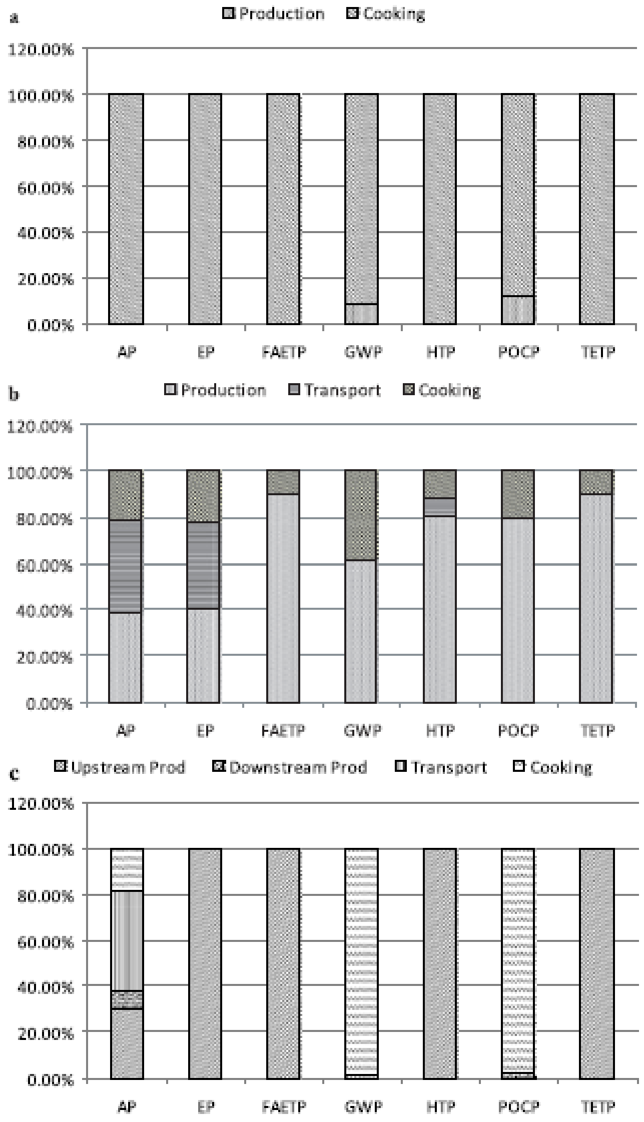


Environmental impact category	*Biogas*	*Charcoal*	*LPG*	*Unit*
Acidification potential (AP)	2.57E-05	1.69E-05	2.25E-05	kg SO_2 equiv
Eutrophication potential (EP)	1.19E-06	3.02E-05	1.4	kg PO_4^{3-} equiv
Freshwater aquatic ecotoxicity potential (FAETP)	3.02E-06	1E-03	0.05	kg DCB equiv
Global warming potential (GWP)	0.16	1.45	0.12	kg CO_2 equiv
Human toxicity potential (HTP)	1.68E-05	2E-03	37	kg DCB equiv
Photochemical ozone creation potential (POCP)	3.22E-05	0.01	2.83E-04	kg C_2H_4 equiv
Terrestial ecotoxicity potential (TETP)	3.44E-07	1.29E-04	2.13	kg DCB equiv

Note: LPG = liquefied petroleum gas; kg = kilograms; equiv = equivalent; SO_2 = sulfur dioxide; PO_4^{3-} = phosphate; DCB = 1,4-dichlorobenzene; CO_2 = carbon dioxide; C_2H_4 = ethylene.

Table 2.19:Contributions to environmental impacts by different life cycle stages for (A) biogas, (B) charcoal, and (C) liquefied petroleum gas. AP = acidification potential; EP = eutrophication potential; FAETP = freshwater aquatic Eco toxicity potential; GWP = global warming potential; HTP = human toxicity potential; POCP = photochemical ozone creation potential; TETP = terrestrial Eco toxicity potential.





This study, the environmental impacts of three cooking fuels in Ghana—namely, bio gas, charcoal, and LPG—have been assessed with the LCA tool. Airborne emission factors resulting from production facilities and cook stove usage were taken from studies conducted in Kenya and India, which are developing countries like Ghana. It had been assumed that the technologies utilized in these countries and other conditions are similar to those prevailing in Ghana. This particular LCA study shows that bio gas production and utilization as cooking fuel may cause many environmental improvements. The study also shows that the cooking stage makes the foremost significant contributions to all or any of its impacts. Therefore, if bio gas cook stoves are designed to be more efficient and managed properly, substantial environmental gain could result. Although LPG features a slight advantage over the opposite fuels in terms of its overall heating emissions, most of its heating potential impact occurs during the cooking stage. Any plan to reduce the worldwide warming potential therefore has got to be directed at this stage. This might be done by improving on stove efficiencies and consciously adopting energy-saving practices, like putting a lid on the pot during cooking, warming food only enough to eat, and switching off the heating when not needed. Also, the human toxicity potential, which is highest with LPG, is restricted to the upstream stage. This is often comforting, because, unlike the opposite fuels, LPG is especially used indoors, and therefore the government features a program in place that's meant to market its use. Charcoal is far and away the foremost dominant cooking fuel in urban Ghana, and thanks to the expected increase in demand with urbanization, improvements are needed in its production methods. Consumers of charcoal must even be encouraged to modify to high-efficiency charcoal cook stoves to scale back the cooking-phase emissions.

2.6 Assessment of Transportation Fuel

2.6.1 Methodology and LCA review

GHGs typically include CO2, CH4, and nitrous oxide (N2O). The low GHG emissions profile of LPG vehicles over gasoline and diesel alternatives is well known. GHG impacts are compared through the global warming potential (GWP) weighted emissions for the primary GHG emissions associated with fuel combustion – CO2, CH4, and N2O. Emissions of these gases are weighted by factors of 1, 25, and 298 respectively (Assessment Report 2007). These values are used in the CA_GREET2.0 and 3.0 models used for the LCFS. In GREET1_2014, the Global Warming Potential (GWP) values are revised to 1, 30, and 265 for these gases on the IPCC Fifth Assessment Report (2013). The GWP value of 25 for methane does not include the fully oxidized CO2 from methane combustion.

The GREET model calculates emissions in WTT and TTW steps. These emissions are presented per million Btu (mmBtu) of fuel in the model. The TTW emissions include fully oxidized carbon as CO2, as well as CH4 and N2O emissions from vehicle fuel combustion.

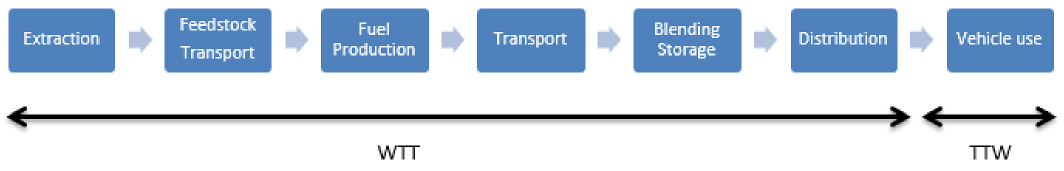


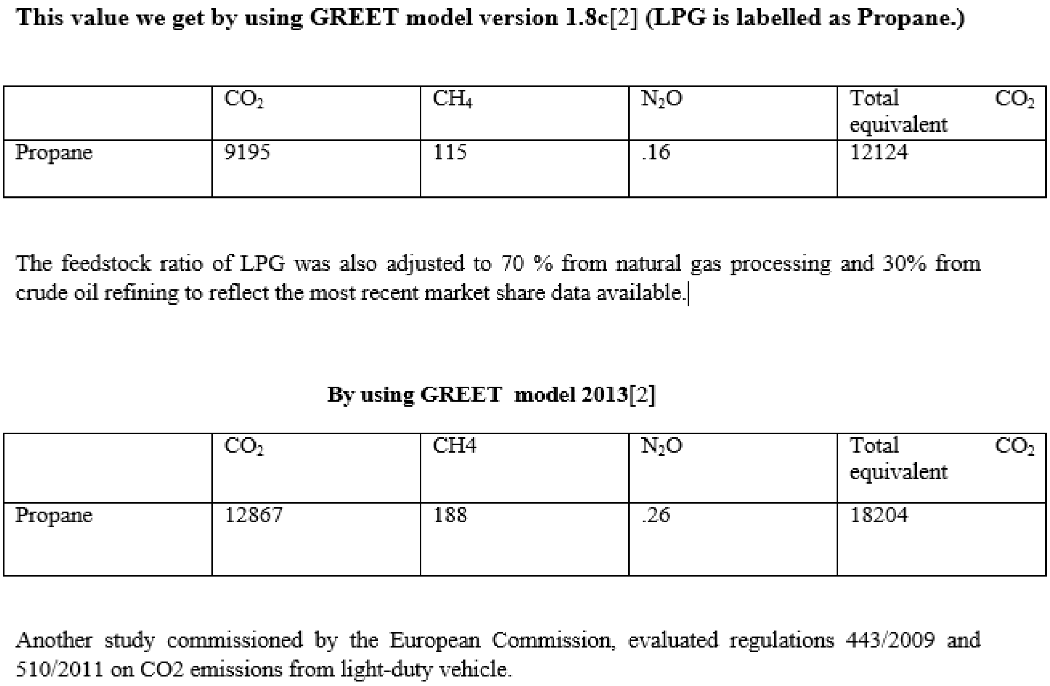
Fig: Life Cycle Schematic

Figure 2.1: Life Cycle Schematic[4]

WTW LCA= WTT+TTW

As shown in Figure, nearly 80% of the GHG emissions come from consumption of the fuel in the vehicle. Only 20% of the emissions result from crude production, refining, transportation and distribution.
WTT: the authors demonstrated that propane (i.e. LPG) produced the lowest WTT GHG emissions of all transportation fuels on a CO_2 basis. Here Ratio of natural gas and crude oil is respectively 60% and 40%.

Table 2.20:Greet Values



This value we get by using GREET model version 1.8c[2] **(LPG is labelled as Propane.)**

	CO_2	CH_4	N_2O	Total CO_2 equivalent
Propane	9195	115	.16	12124

The feedstock ratio of LPG was also adjusted to 70 % from natural gas processing and 30% from crude oil refining to reflect the most recent market share data available.|

By using GREET model 2013[2]

	CO_2	CH4	N_2O	Total CO_2 equivalent
Propane	12867	188	.26	18204

Another study commissioned by the European Commission, evaluated regulations 443/2009 and 510/2011 on CO2 emissions from light-duty vehicle.

Table 2.21:WWT Emission Factors

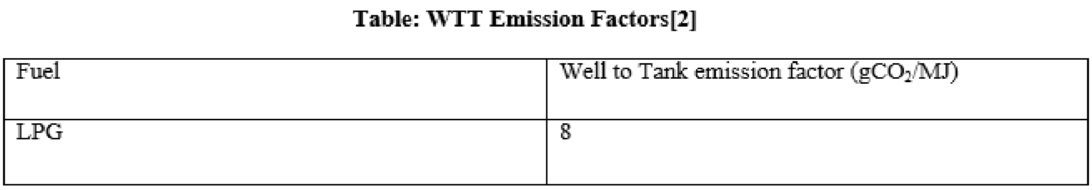


Table: WTT Emission Factors[2]

Fuel	Well to Tank emission factor (gCO_2/MJ)
LPG	8

Quantifying these emissions is not a trivial task and thus computer generated models are used to characterize them. These models generally rely on a combination of real world data, assumptions, and theory to provide estimates for a variety of situations.
Empirical data on the TTW or tailpipe CO2 emissions was collected from sources that were surveyed for regulated pollutants. Considering all the fuels surveyed, LPG produces slightly less tailpipe CO2 emissions on average.

The effect of vehicle efficiency on TTW emissions is also adjusted with an energy economy ratio (EER). EER compares the fuel economy values of different alternative fuel vehicles against comparable gasoline and diesel vehicles. This ratio is based on the lower heating value of the fuel. The EER is defined as the fuel economy of the alternative fuel vehicle in miles per gallon equivalent (mpg) of the alternative fuel, divided by the fuel economy of a reference fuel, such as gasoline or diesel. . ARB uses the EER values to adjust LCFS credits by taking the differences in fuel economy into account, where necessary, by multiplying the EER by the number of MJ in the alternative fuel.

Information regarding WTW emissions has been predominantly sourced from studies that utilized GHG WTW modelling tools such as GREET. As noted previously, these tools use models, assumptions and empirical data to provide GHG life cycle analysis for various energy sources and technologies. WTW studies originating from North America that were surveyed present data only on select on-road vehicle segments, including light-duty trucks and vans, school buses, and bob-tail LPG delivery vehicles.

In many regions of the world regulations exist limiting the GHG emissions of engines and vehicles. These GHGs typically include CO2, CH4, and nitrous oxide (N2O). For analysis, GHGs are typically examined on a WTT, TTW, and WTW basis. Additionally, results are commonly presented on a CO2 equivalent basis (CO2e) that includes CH4 and N2O with their respective GWPs.

Using LCA different results were obtained for different fuels. The results are shown below

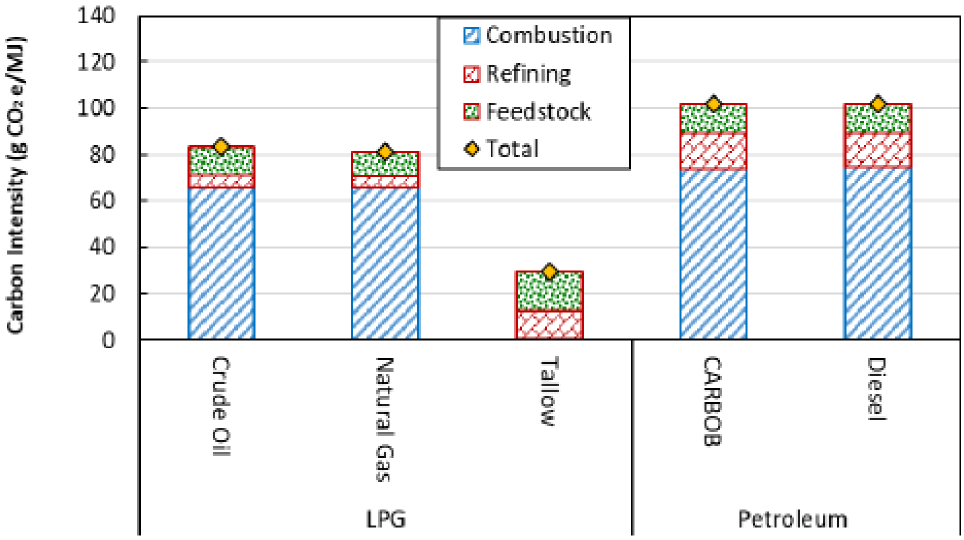
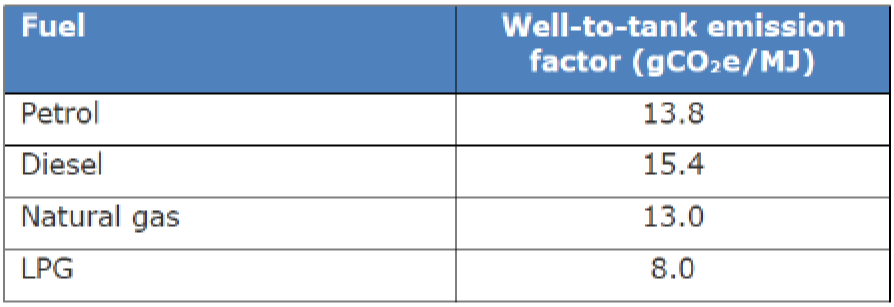


Figure S.1. Comparison of WTW Emissions from LPG analyzed using CA_GREET3.0.

Figure 2.2: Comparison of WTW Emission From LPG Aalyzed using CA_Greet3.0

Table 2.22:Well to Tank Emission



Fuel	Well-to-tank emission factor (gCO_2e/MJ)
Petrol	13.8
Diesel	15.4
Natural gas	13.0
LPG	8.0

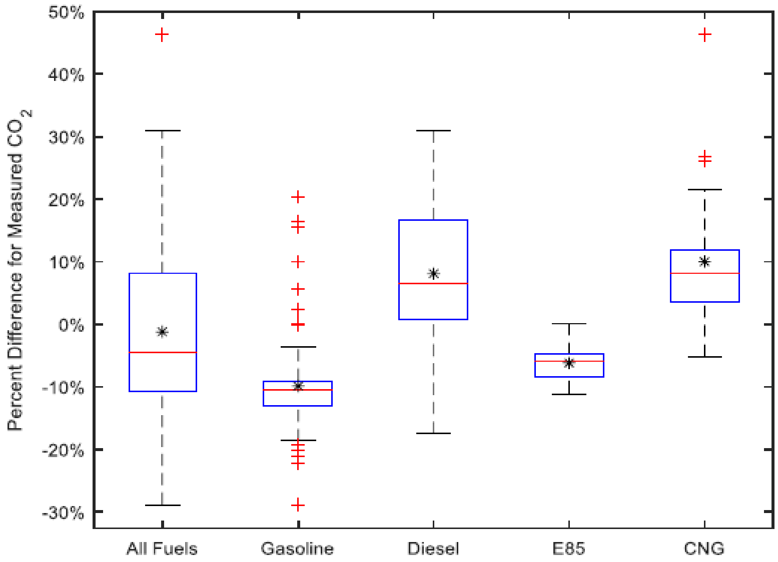


Figure 12: TTW Percent Difference of CO_2 Emissions for LPG Versus Other Fuels from Empiracle Data

Figure 2.3: TTW Percent Difference of CO2 Emission for LPG Versus Other Fuel From Empirical Data

Considering all the fuels surveyed, LPG produces slightly less tailpipe CO2 emissions on average. Compared to gasoline, LPG produces lower on average CO2 emissions. This is expected given that both fuels use spark ignition and LPG has a higher H:C ratio compared to gasoline. The range of the box and whisker plot and standard deviation provide further confidence in this assessment, noting that only data points deemed outliers (marked by crosses) demonstrated higher CO2 for LPG compared to gasoline. E85 shares a similar percent difference trend. Diesel on the other hand displays a bias towards lower CO2 emissions compared to gasoline. Although diesel has a similar H:C ratio as gasoline, CI engines are inherently more fuel efficient which equates to lower CO2 production. As noted previously CNG and LPG fueling systems share many similarities and both require spark ignition, but the H:C ratio of CNG is higher than that of LPG providing it with an additional reduction in CO2 emissions. However, it is important to reference Figure 7, where CH4 tailpipe emissions for CNG are displayed to be significantly higher than LPG noting that CH4 is a potent GHG.

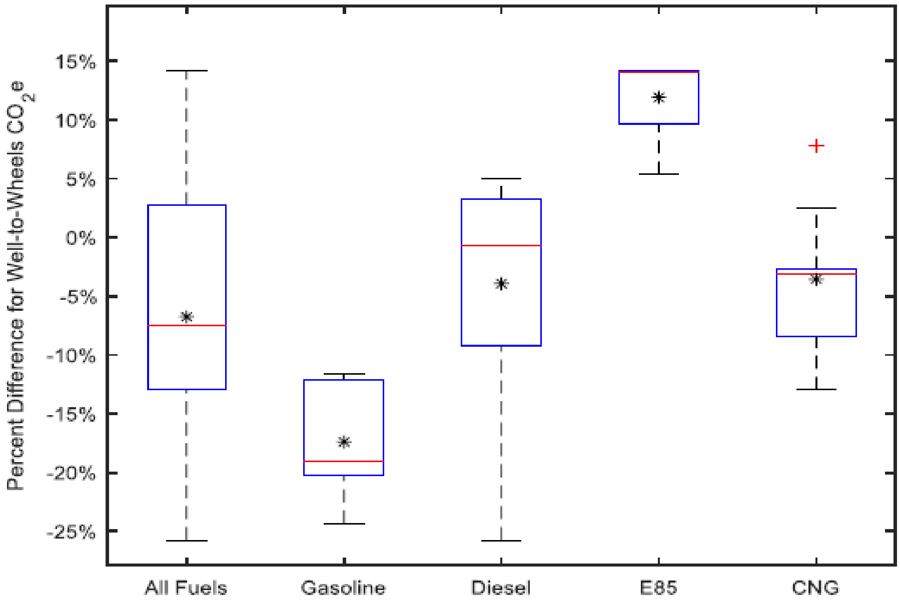


Figure 13: WTW Percent Difference of GHG CO_2e Emissions for LPG Versus Other Fuels

Figure 2.4: WTW Percent Difference of GHG CO2 Emission for LPG Versus Other Fuel

The WTW CO2e emissions percent difference of LPG compared to all the other fuels considered in Figure 13 demonstrates that LPG is amongst the lower GHG producing fuels. As mentioned previously LPG unanimously produces less CO2e emissions than gasoline over its life cycle from production to end use. In fact, E85 is the only fuel presented that resulted in an average CO2e emissions that was less than LPG. This is directly related to the growth of crops and photosynthesis during the production of ethanol as noted previously. Although it is outside of the context of this study, there are current technologies that produce Bio LPG as byproduct such as the process to hydrogenated vegetable oil diesel fuel from renewable feedstock. As these technologies progress and more data is available, it is almost certain that the WTW footprint of Bio LPG would certainly be on the order of E85.

Table 2.23: Average Life Cycle (WTW) GHG Intensity Various Transportation Fuels in the EU

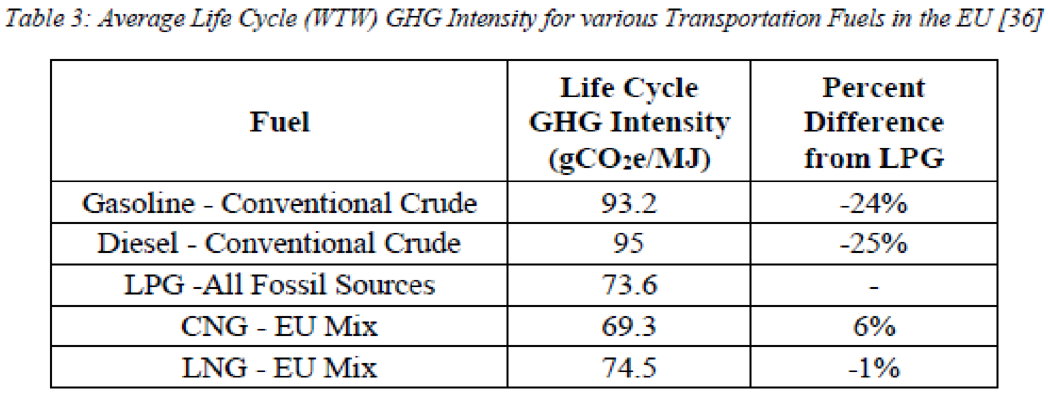


Table 3: Average Life Cycle (WTW) GHG Intensity for various Transportation Fuels in the EU [36]

Fuel	Life Cycle GHG Intensity (gCO_2e/MJ)	Percent Difference from LPG
Gasoline - Conventional Crude	93.2	-24%
Diesel - Conventional Crude	95	-25%
LPG -All Fossil Sources	73.6	-
CNG - EU Mix	69.3	6%
LNG - EU Mix	74.5	-1%

Table 2.24:Average WTW CO2 Emission for Various Transportation Fuel and Application in the EU

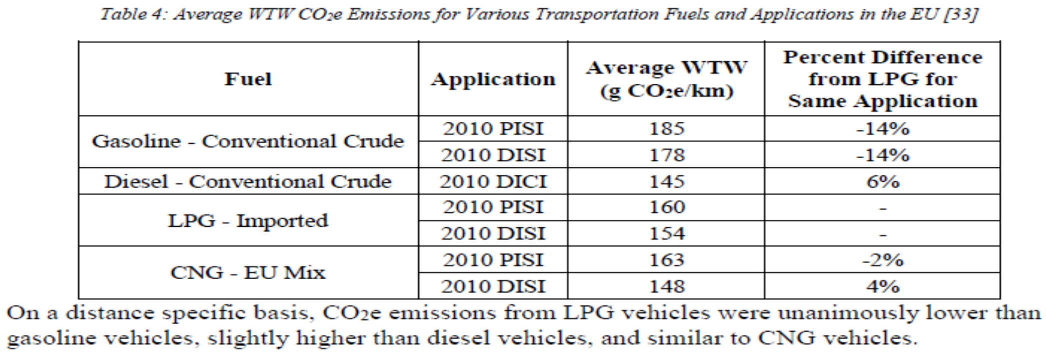


Table 4: Average WTW CO_2e Emissions for Various Transportation Fuels and Applications in the EU [33]

Fuel	Application	Average WTW ($g\ CO_2e/km$)	Percent Difference from LPG for Same Application
Gasoline - Conventional Crude	2010 PISI	185	-14%
	2010 DISI	178	-14%
Diesel - Conventional Crude	2010 DICI	145	6%
LPG - Imported	2010 PISI	160	-
	2010 DISI	154	-
CNG - EU Mix	2010 PISI	163	-2%
	2010 DISI	148	4%

On a distance specific basis, CO_2e emissions from LPG vehicles were unanimously lower than gasoline vehicles, slightly higher than diesel vehicles, and similar to CNG vehicles.

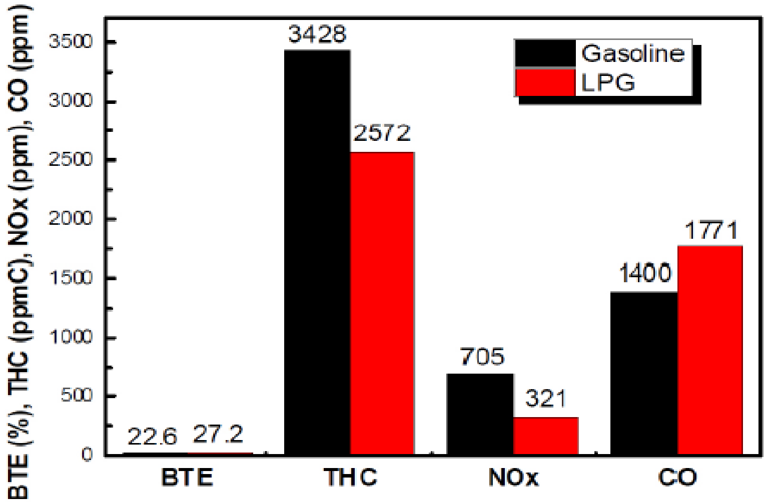


Figure 14: Comparison of performance and emission results for GDI and LPG DI at Lean Conditions [26]

Figure 2.5: Comparison of Performance Emission Results for GDI and LPG at Lean Conditions

The results presented during this document highlight the advantages of LPG compared to standard and other alternative transportation fuels. The emissions benefits of LPG advocate for its utilization and its advantageous application to modern technologies like DI further that case. Compared to gasoline powered vehicles, LPG has demonstrated a capability to supply similar NOX, CO, and THC emissions with lower levels of PM, PN, and CO2 emissions. With reference to GHGs, the use of LPG compared to gasoline produces significantly lower CO2e emissions on a WTW basis. Evidence also suggests that the appliance of LPG to modern DI technology can improve the shortcomings of GDI like increased PM and PN while delivering improved BTE.Comparisons of LPG made to diesel powered vehicles demonstrated the potential to supply lower NOX and PM emissions even when costlier and far more complex after treatment systems were applied to diesel vehicles. Although the use of diesel provided a lower TTW GHG footprint, on a WTW basis the utilization of LPG releases similar or less GHG emissions on the average than diesel counting on the literature source. Compared to other alternative fuels, the argument for LPG is robust. On the average tailpipe emissions of NOX from CNG powered vehicles were lower while THC and CO emissions were higher compared LPG powered vehicles. Emissions of CH4, a strong GHG and first components of CNG, were significantly higher for CNG compared to LPG powered engines and vehicles. The negative effect of CH4 emissions for CNG was also observed on a WTW GHG emissions basis, where it's been demonstrated that the utilization of LPG offers very similar or maybe lower GHG emissions on a CO2e basis compared to CNG counting on the literature source. Additionally, the properties of LPG versus CNG leave significantly less expensive storage tanks. Compared to E85, the typical emissions from LPG powered vehicles and engines were showed be higher in NOX emissions, lower in HC emissions, and similar in CO emissions. However, when comparing ethanol and LPG it's important to think about all aspects on production, noting that LPG doesn't share a food source for feedstock as ethanol commonly does, also as significant requirements of land to grow the crops required to supply ethanol. Furthermore, recent BioLPG opportunities, like those from renewable diesel oil, may provide a WTW GHG footprint almost like ethanol blends.

We have analyzed deeply using GREET and other LCA methods to understand the emissions and evaluate the life cycle of LPG and other fuel options. We have discussed the emissions in 3 different phases. In production, as cooking fuel and as transportation fuel. All the analysis has led us to believe that in terms of emission LPG is the best option. The details of each stage were already discussed previously. From lower emission from production to WTT, WTW and in cooking LPG can be a great substitute for existing fuel options. LPG is also cheaper and easy to store. The purpose of this review was to put forth data to back up the claim of LPG being the cleanest source of energy.

Chapter 3 Life Cycle Analysis (LCA)

Environmental Management ISBN 978-0-12-811989-1 [5]

The idea of carrying out a thorough analysis of the life cycle. A product or a system is a relatively recent one that has arisen from the general public, industry, and governments in reaction to increased environmental awareness. A number of various terms are coined to describe the processes. Life cycle assessment (also referred to as life cycle analysis, Eco balance, and cradle-to-grave analysis) could be a technique to assess environmental impacts related to all the stages of a product's life from cradle-to-grave (i.e., from material extraction through materials process, manufacture, distribution, and use). These higher mirrors the various stages of the method. The life cycle assessment (LCA) methodology features a mounted structure and is practiced consistent with international standards (ISO) 14040.

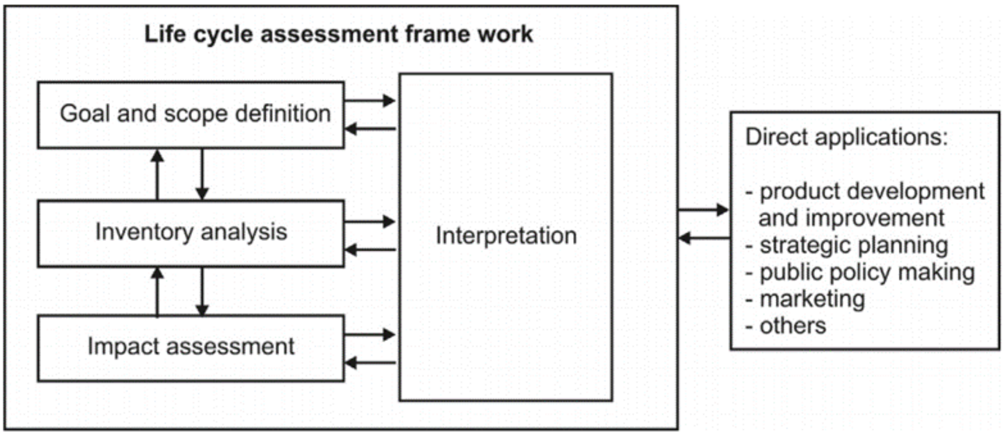


Figure 3.1: stages of LCA according to EN ISO 14040 [5]

Life cycle assessment could be a technique for assessing the environmental aspects related to a product over its life cycle. The foremost necessary applications area unit these:

- Analysis of the contribution of the life cycle stages to the general environmental load, sometimes with the aim to place enhancements on products or processes.
- Comparison between merchandise for internal use

An LCA study consists of 4 stages:

Stage 1: Goal and scope aims to outline however massive a region of product life cycle is going to be taken in assessment and to what finish can assessment be serving. the standards serving to system comparison and specific times area unit described during this step.

Stage 2: During this step, inventory analysis provides an outline of fabric and energy flows inside the merchandise system and particularly its interaction with atmosphere, consumed raw materials, and emissions to the environment. All necessary processes and subsidiary energy and material flows area unit delineate later.

Stage 3: Details from inventory analysis serve for impact assessment. The indicator results of all impact classes area unit elaborated during this step; the importance of each impact class is assessed by social control and eventually by coefficient.

Stage 4: Interpretation of a life cycle involves review article, determination of information sensitivity, and result presentation.

Figure provides the four stages underneath the ISO 14040 tips. When enterprise a life cycle assessment study the subsequent problems need to be addressed:

The burdens obligatory on the atmosphere by human activities could also be ascertained by accounting for the resources and energy (inputs) consumed at every stage within the life cycle of a product and therefore the ensuing pollutants and wastes (outputs) emitted. The inputs and outputs area unit then assessed for his or her adverse impacts on long-run property of renewable and unrenewable resources, human health, and diverseness, amongst others. Once these area unit known, measures could also be taken to mitigate the impact of the outputs (or inventories) on the atmosphere.

The utilization of LCA methodology will facilitate within the following:

- Looking out the foremost life cycles, e.g., those with least negative impact on atmosphere,
- Presumptuous the selections in trade, public organizations, or NGOs, which confirm direction and priorities in strategic designing, design or style product, or method amendment,
- Select necessary indicators of environmental behavior of organization including measure and assessing techniques, chiefly in association with the assessment of the state of its atmosphere,
- Selling with the link on formulation of environmental declaration or eco-labeling

3.1 Life Cycle Assessment Type

Cradle-to-Grave

Cradle-to-grave is that the full life cycle assessment from manufacture (cradle) through the utilization section to the disposal section (grave). All inputs and outputs are thought of for all the phases of the life cycle.

Cradle-to-Gate

Cradle-to-gate is an assessment of a partial product life cycle from manufacture (cradle) to the plant gate, i.e., before it's transported to the consumer. the utilization section and disposal section of the merchandise square measure sometimes omitted. Cradle-to-gate assessments square measure typically the idea for Environmental Product Declarations. the utilization of biofuel, rather than fuel throughout transportation, might have a sway on the ultimate analysis of LCA.

Cradle-to-Cradle

Cradle-to-cradle is a specific kind of cradle-to-grave assessment, where the end-of-life disposal step for the product is a recycling process. From the recycling process originates new, identical products (e.g., aluminum beverage cans from recycled cans), or different products (e.g., glass wool insulation from collected glass bottles).

3.2 Life Cycle Analysis Usage

A technical report by Sonia Valdivia on 2016 gives us a very good insight of the worldwide condition of LCA usage. Her report gives extensive information from the United Nations Environment Program (UNEP). The data collected are commissioned by UNEP/SETAC Life Cycle Initiative on an effort to contribute to the global dialogue on how to efficiently and effectively operationalize sustainability efforts. Life Cycle Assessment (LCA) is a quantitative modeling exercise in which a wide variety of impacts of a product or service are measured during its life cycle (i.e., from the extraction of raw material to the end of use and re-use of the finished product).

The LCA definition dates back to the 1980s, when it originated as a method to better understand the threats, benefits and trade-offs of product processes, as well as the nature of environmental impacts. In 1993, a small group of LCA experts grouped within the Society of Environmental Toxicology and Chemistry (SETAC) were tasked by the International Organization for Standardization (ISO) to establish a a recommendation regarding the need to standardize LCA.

Subsequent to this recommendation, ISO 14040:1997, up to 1997 norm for measurement of the life cycle. Principles and the framework was finished.

The LCA standardization process was a real system of challenge from 1997 to 2000 in the early days, because of a complete lack of consensus on many topics such as methodological problems. Despite some significant references serving as seed documents, in particular the so-called 'Code of Practice' (SETAC 1993) and other SETAC documents, parallel to the on-going scientific progress, the methodologies of impact evaluation and analysis in particular had to be standardized. As such, the development of international LCA standards (ISO 14040 series) was of vital importance for the worldwide widespread acceptance of LCA. The updated version of the ISO Standards of LCA (ISO 14040 and ISO 14044) is, until today, the only and only applicable international standard documents relating to LCA that are commonly cited by users and other standardization documents.

An overview of life cycle networks worldwide has been developed by the UNEP/SETAC Life Cycle Initiative, with a list of regional networks and national networks differentiated across various regions of the world: Europe and Central Asia, North America, Asia/Pacific, Latin America and the Caribbean, plus Africa. This is not to be confused with the Life Cycle Inventory Register of UNEP/SETAC.

Regional networks are autonomous, but the Life Cycle Project is sponsored by them. On the website of the Life Cycle Initiative, the following networks are listed (UNEP/SETAC, 2014a):

Europe and Central Asia

• European Platform on Life Cycle Assessment • Nordic Life Cycle Association (NorLCA) • Central and Southeast Europe LCA network (CASE-LCA)

Asia/ Pacific

• LCA Agrifood Asia Network • Latin America and the Caribbean • Iberoamerican

LCA Network Africa

• African Life Cycle Assessment Network (ALCANET)

With regard to the national networks the following list is provided (UNEP/SETAC, 2014b).

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• avniR (Life Cycle Assessment Platform) (France) • Catalan LCA network (Spain)Estonian LCA Network • FINLCA (Life Cycle Assessment Framework and Tools for Finnish Companies) • German Network on Life Cycle Inventory Data • LCA Center Association (Association of Hungarian LCA users) • LCA Center (Denmark) • Polish Center for Life Cycle Assessment (PCLCA) • Rete Italiana LCA (Italian LCA network) • L'Association SCORE LCA (France) • Spanish LCA society • Swiss Discussion Forum on Life Cycle Assessment • Swedish Life Cycle Center (CPM) • Linkedin Group: LCA Turkey Network North America • The American Center for LCA Asia/ Pacific

• Carbon Footprint Japan forum • China Lifecycle Initiative (CNLCI) • Indian Society for LCA • India LCA Alliance • Indonesian Life Cycle Assessment Network (ILCAN) • Korea Society for Industrial Ecology (KSIE) • Korean Society of LCA (KSLCA) • LCA Malaysia • LCA Society of Japan • The Institute of LCA, Japan • Life Cycle

Assessment Research Center (LCARC) (South Korea) • Life Cycle Assessment & Design for Sustainability Network (Sri Lanka) • Thai LCA network • Australian LCA Society (ALCAS) • Life Cycle Association New Zealand (LCANZ) .

• Argentinian LCA network • Association for Life Cycle Assessment in Latin America (ALCALA) (Costa Rica) • Brazilian Association for Life Cycle Assessment (ABCV) • Colombian LCA network • Ecuadorian LCA network • Peruvian LCA network • Chilean LCA network • Mexican LCA network

Other Networks In addition, the UNEP/SETAC Life Cycle Initiative lists some other networks that are not the actual focus of this report. Here are some other networks you can contact: • The Sustainability Consortium • Global Footprint Network • International Society for Industrial Ecology (ISIE) • LCE engineering • GaBi User Forum • PRé LCA Discussion List • LCA links! • Cluster Research, Excellence in Eco design & Recycling (CREER) • Water Footprint Network • Water Use in Life Cycle Network • open LCA user forum • Umberto Users Forum

Figure Geographical distribution of LCA networks. The country score indicates the sum of local LCA networks (country level or below) and participations in regional LCA networks (above country level) per country. Global networks are excluded to make the figure more legible. East Timor and Tibet are listed as members of the South and South East Asia (SEASIA) Network on Life Cycle Initiative of UNEP, but are not indicated in the map. For regional LCA networks covering Europe, all EU-27 member states were assumed to participate. Adapted from Bjørn et al. (2012)

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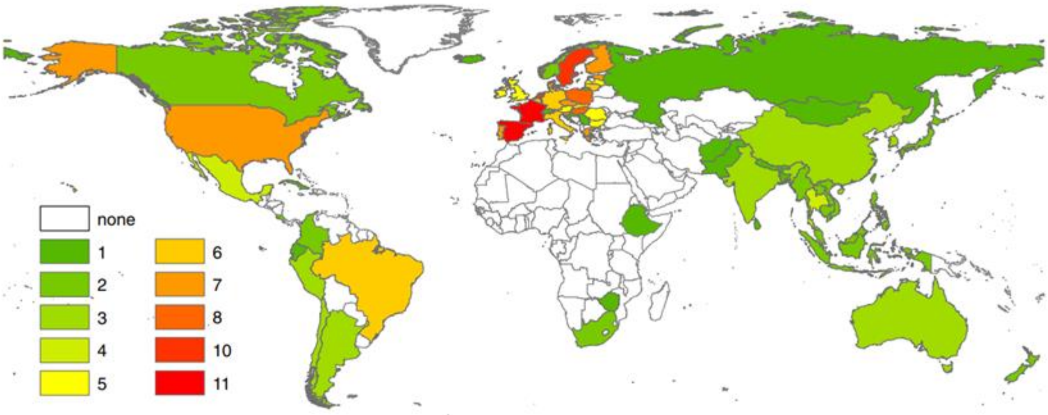


Figure 3.2 : For regional LCA networks covering Europe

Time series for (1) aggregated number of established networks globally (it was only possible to identify the year of formation for 76 of the 100 identified networks. For 2012, the graph only covers until the end of February) and (2) aggregated number of LCA publications globally as indexed in the Web of Science database (de Souza and Barbastefano 2011). Articles published prior to 1993 have not been included in the figure due to lack of data.

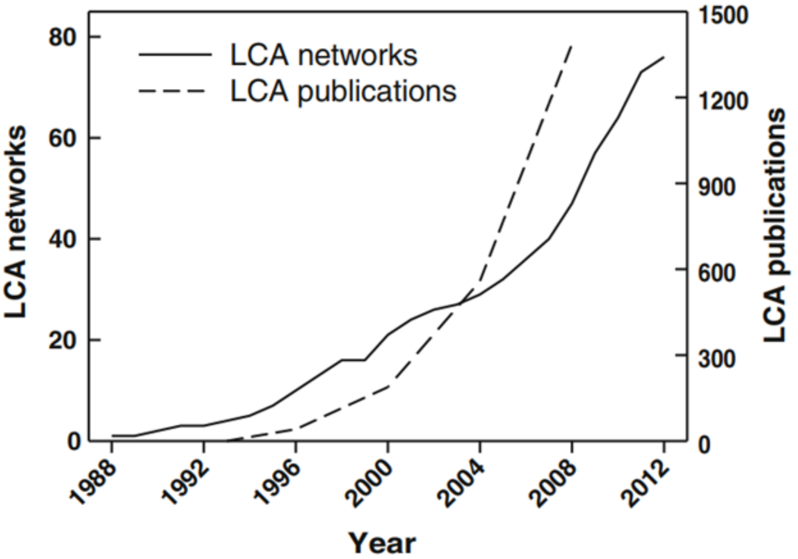


Figure 3.3 : LCA Analysis

LCA networks may appear to be predating LCA publications, but a closer analysis shows that networks devoted exclusively to LCA (i.e., 'LCA' being part of their name) were not established until 1995. Sometime after their creation, older networks dealing more generally with environmental and sustainability concerns are likely to have embraced LCA practices. After the year 2000, publishing growth surpassed that of the network. Formations, implying that, in the form of publications, LCA networks may have a catalytic impact on scientific production. A possible explanation is that networks promote communication between researchers from various institutions and representatives of industry who may provide LCA methodology testing cases as well as provide academia with input on the operationalization of the latest methodological growth.

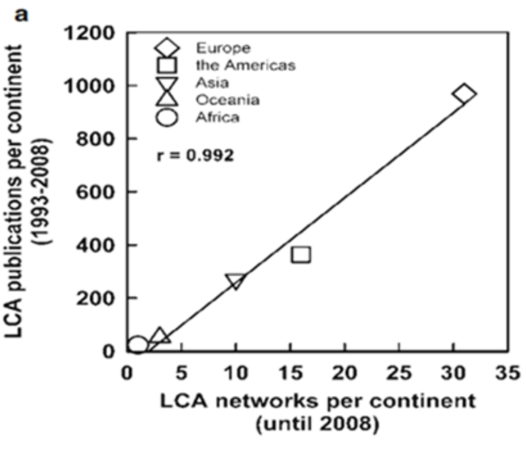


Figure 3.4 : LCA Networks Per Continent (Unit 2008)

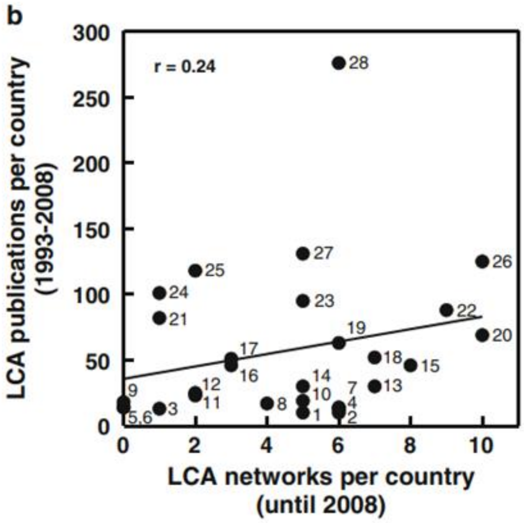


Figure 3.5 : LCA Network Per Country

Fig. 7 a Relation between number of LCA networks per continent (local or regional) and number of LCA publications in each continent as indexed in the Web of Science database (data from de Souza and Barbastefano 2011). Publications may be double counted if authors represent more than one continent. Networks with no information on formation year were assumed to have been formed before 2009. Solid line shows a linear regression fit to the data. r0Pearson correlation coefficient; From several surveys conducted by many we get the following visual representations of the condition of LCA around the globe. Level of education activities in the countries around the world covered by the survey

Figure 3.6:Level of LCA seminars and training in APEC countries in 2004 (Sagisaka, 2004)

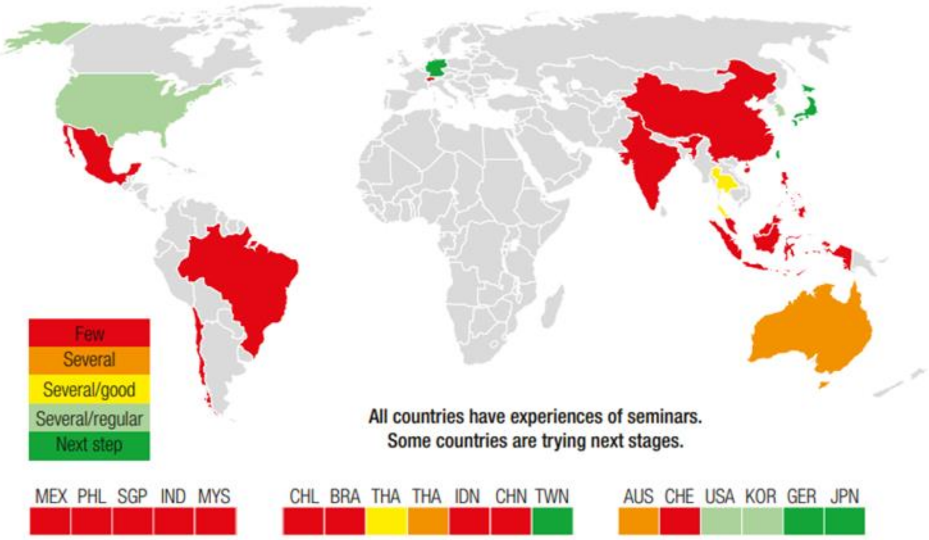


Figure 3.7: Maturity of the market for consultancy services around the world in line with survey

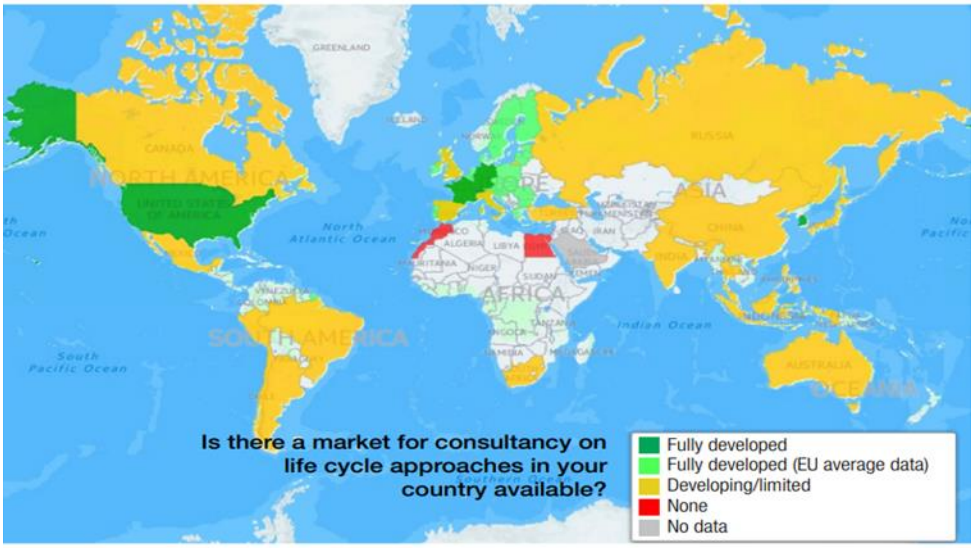


Figure 3.8: Level of LCA consultants in APEC countries in 2004 (Sagisaka, 2004)

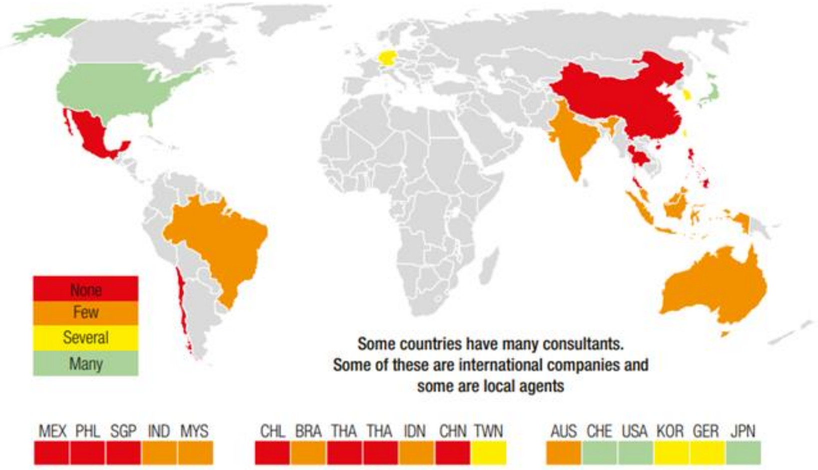


Figure 3.9: Level of research activities in the countries around the world covered by the survey

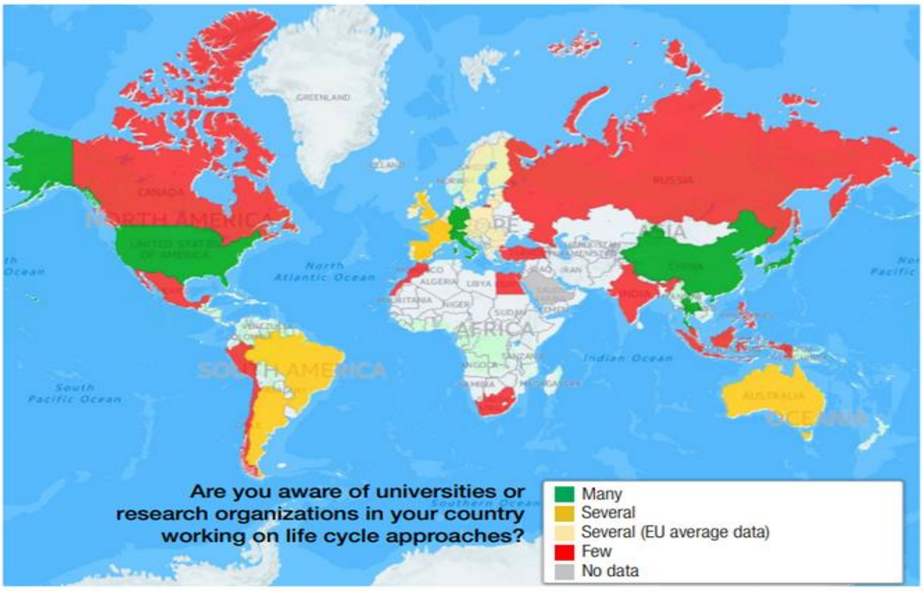


Figure 3.10: Level of the preparation of LCA studies around the world in line with the survey

Figure 3.11: Level of LCIA activities in the countries around the world covered by the survey

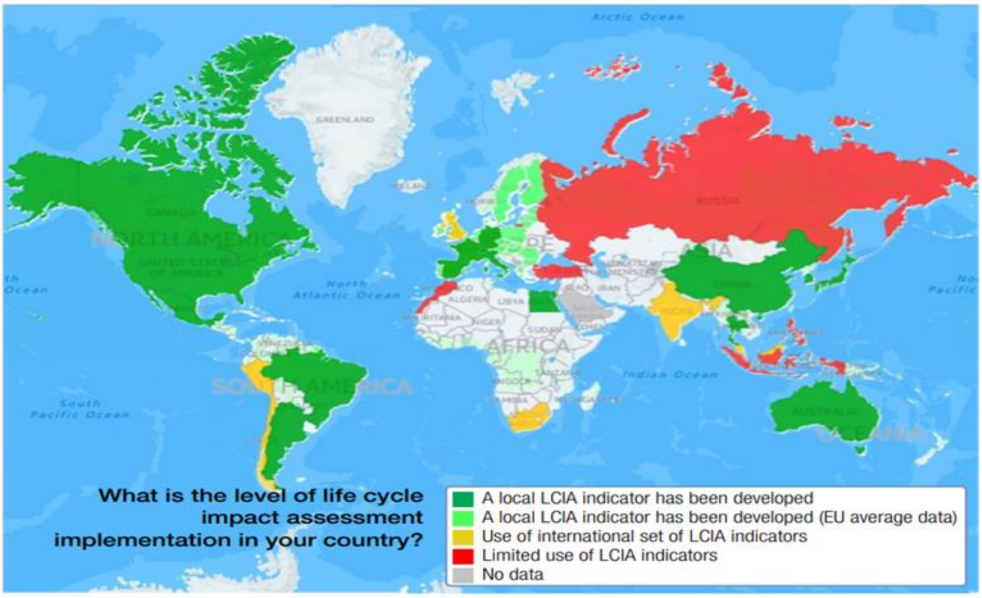


Figure 3.12: Level of LCIA implementation in APEC countries in 2004 (Sagisaka, 2004)

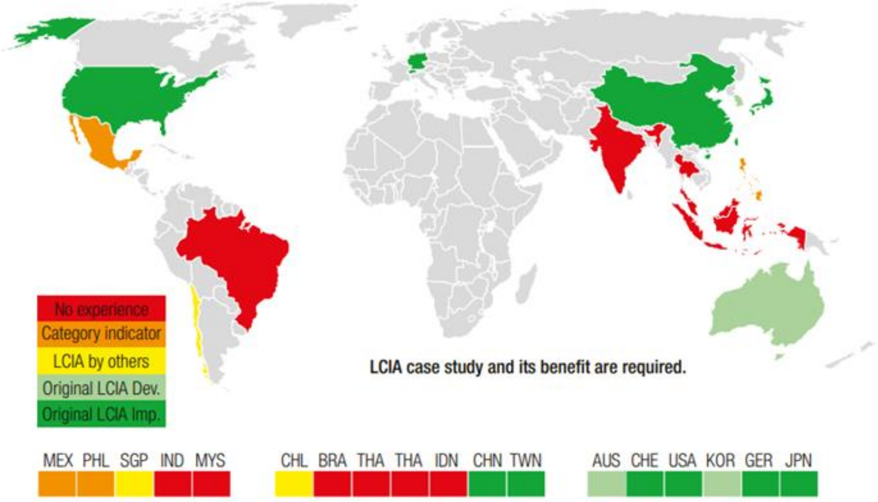


Figure 3.13: Software update in countries around the world according to survey and international software sales information

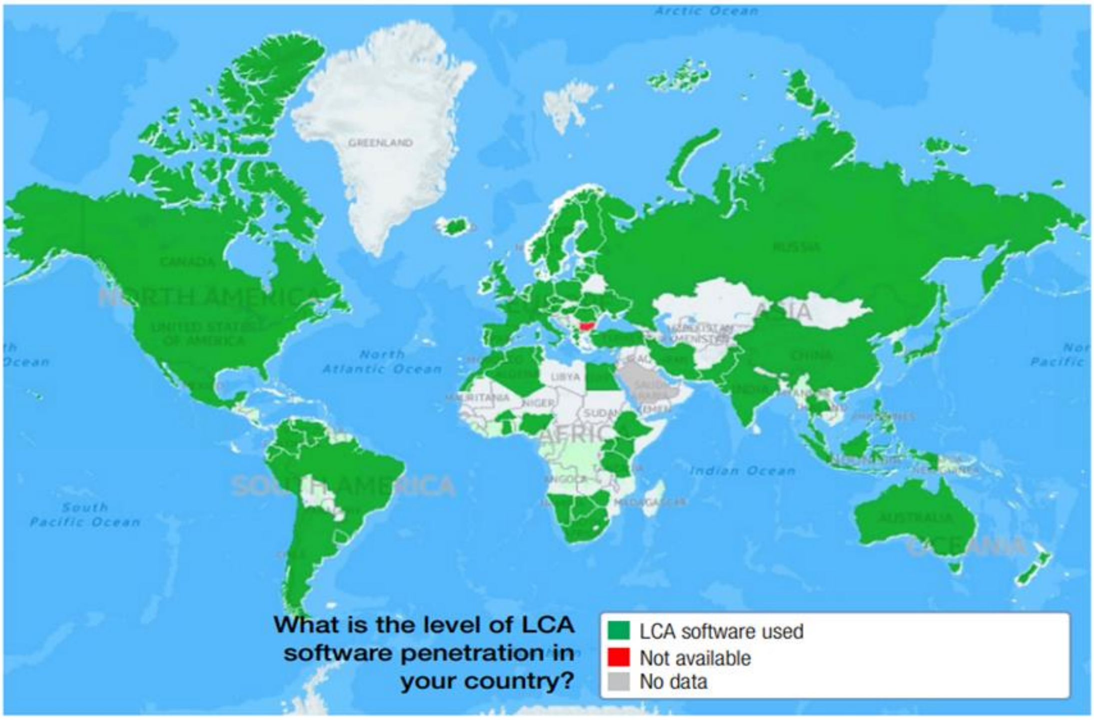


Figure 3.14: Availability of national life cycle networks around the world

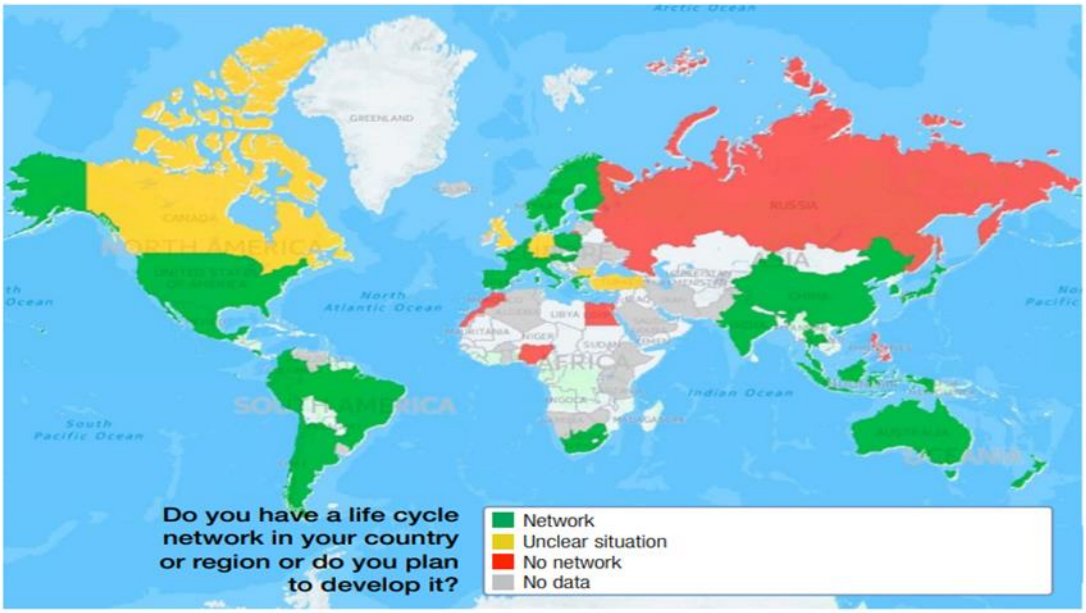


Figure 3.15: LCA Forum or Society in APEC countries in 2004 (Sagisaka, 2004)

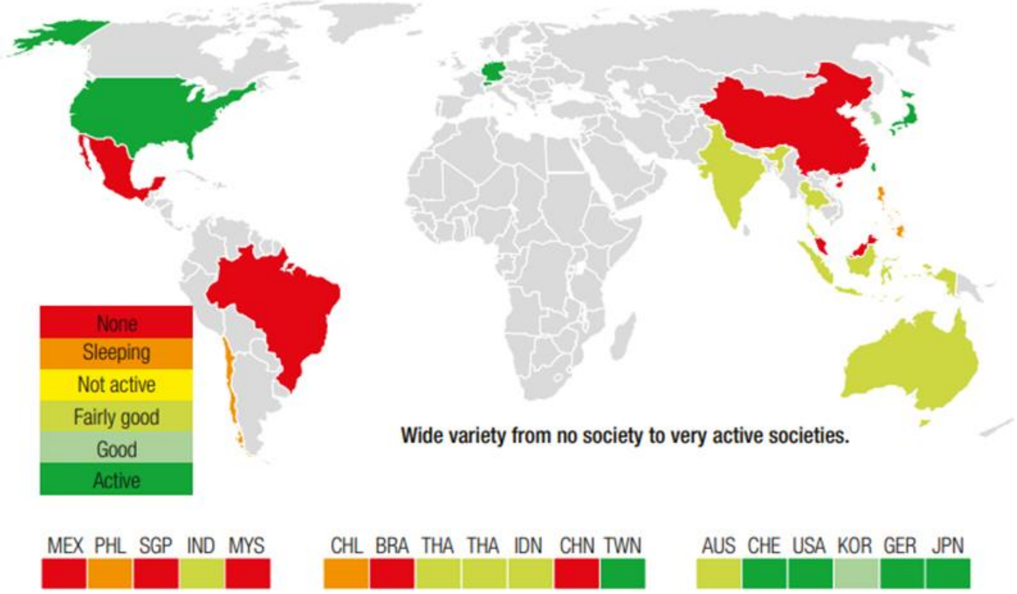


Figure 3.16: Activity level of national life cycle networks around the world according to survey

Figure 3.17: Databases availability in the countries around the world according to the survey

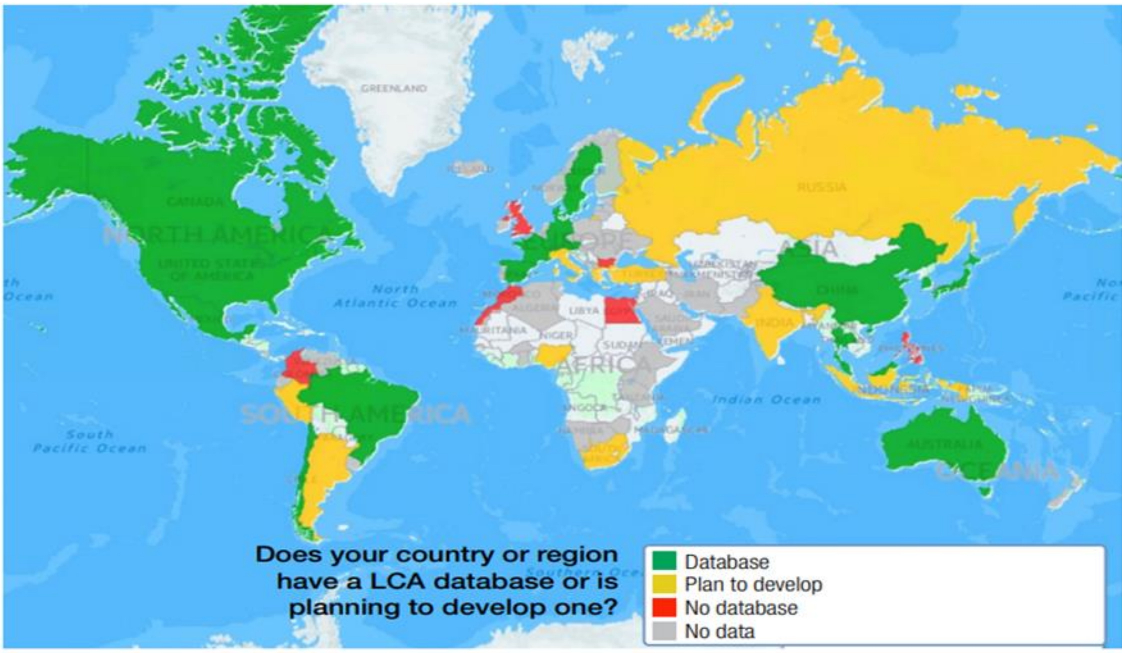


Figure 3.18: Public Life Cycle Inventory Databases in APEC countries (Sagisaka,)

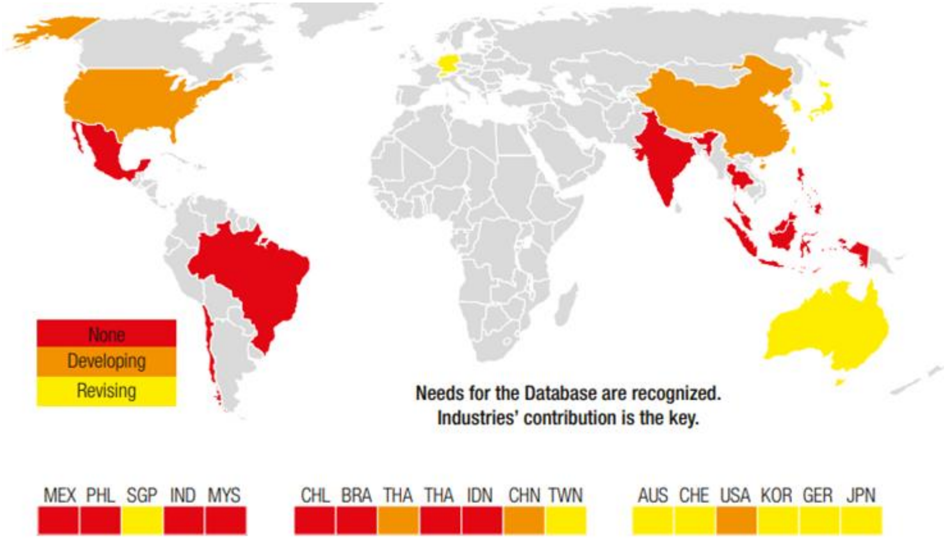


Figure 3.19 : Industry Contribution

From the surveys we observe that there is little to no data of LCA analysis in Bangladesh. Which means there is a huge scope of study in the country. Databases and Life Cycle Inventories are yet to be produced.

Chapter 4 Over View of Transportation Fuel

Different types of fuels that are used for transportation in Bangladesh. The major types of fuels used for transportation are Diesel, Petrol, LPG,CNG, Biofuel, Hydrogen.

4.1 Diesel and Gasoline

4.1.1 Chemical Properties of Gasoline

Commercial gasoline is made up of a diverse range of hydrocarbons. Gasoline can be made in a variety of formulations to satisfy a variety of engine performance requirements. As a result, the chemical composition of fuel is unknown. The performance specification also varies with season, with more volatile blends due to added butane during winter, so as to be ready to start a chilly engine. At the refinery, the composition varies consistent with the crude oils from which it's produced, the sort of processing units present at the refinery, how those units are operated and which hydrocarbon streams blend stocks the refinery opts to use when blending the ultimate product.

Paraffins, such as hexane (C6H14), and octane (C8H18)

Olefins, such as hexene (C6H12)

4.1.2 Physical Properties of Gasoline

Gasoline has a basic gravity ranging from 0.71 to 0.77 (wiki), with higher densities containing more aromatics. In Europe, finished marketable gasoline is traded with a normal comparison density of 0.755 kg/L (6.30 lb/US gal), and its price is elevated or de-escalated depending on its real density.[6] Since fuel floats on water due to its low density, it cannot be used in most cases. Since gasoline floats on water due to its low density, it can only be used to extinguish a gasoline fire if applied in a fine mist. If treated properly, decent gasoline can last six months, but because gasoline is a mixture rather than a pure compound, it can eventually decay with time as the components split. The consequences of long-term storage will become more apparent with each passing month until a period comes when the gasoline can be diluted with ever-increasing quantities of freshly made petrol so that the older gasoline can be used up. If excessive procedure is not diluted, it will result in death. If left undiluted, unsafe operation will result, including engine damage from misfiring or a lack of proper fuel intervention inside a fuel injection system, as well as compensation from an onboard computer. Gasoline should be contained in an airtight container that can handle the vapor pressure of the gasoline (to resist combustion or water vapor mixing in with the gas).

4.1.3 Chemical Properties of Diesel

Around 75% of petroleum-derived diesel is saturated hydrocarbons (primarily paraffins such as n, iso, and cycloparaffins) and 25% is aromatic hydrocarbons (including naphthalines and alkylbenzenes). The chemical formula for typical diesel fuel is C12H23, with chemical formulas ranging from C10H20 to C15H28.s

“Most diesel fuels freeze at common winter temperatures, while the temperatures greatly vary. Petro diesel typically freezes around temperatures of −8.1 °C (17.5 °F), whereas biodiesel freezes between temperatures of 2° to 15 °C (35° to 60 °F). The viscosity of diesel noticeably increases as the temperature decreases, changing it into a gel at temperatures of −19 °C (−2.2 °F) to −15 °C (5 °F), that cannot flow in fuel systems. Conventional diesel fuels vaporize at temperatures between 149 °C and 371 °C.”

Conventional diesel flash points range from 52 to 96 degrees Celsius, making it cleaner than gasoline but incompatible with spark-ignition engines. Unlike gasoline, the flash point of diesel fuel has no bearing on the engine output or auto ignition properties.

4.1.4 Production

The two most widely used automotive fuels in the world are diesel and gasoline. These fuels are made from crude oil mined from the earth, which is derived from fossil fuels. The emissions from crude oil refining and transportation to the refinery, like those from other energy sources like natural gas, LPG, and coal, can differ greatly depending on the area and equipment used. For example, certain parts of the world source all of their oil from other parts of the world, so pollutants from maritime tankers, pipelines, railways, and trucking must be taken into account for an effective well-to-wheels (WTW) measurement. The method of refining diesel and gasoline is also a significant cause of WTW energy demand and pollution.

4.1.5 Demand as Transportation Fuel

Diesel: The majority of the goods we use are shipped by diesel-powered trucks and trains, and the majority of manufacturing, agricultural, and military vehicles and equipment are also powered by diesel engines. Diesel fuel has a wide variety of performance, power, and safety characteristics as a transportation fuel. Diesel fuel has a higher energy density than other liquid fuels, resulting in more usable energy per unit. Diesel fuel has a higher energy density than other liquid fuels, resulting in more usable energy per unit of volume.

The automotive industry in the United States consumed approximately 47.2 billion gallons of distillate fuel (essentially diesel fuel) in 2019. (1.1 billion barrels). This figure accounted for 15% of total petroleum consumption in the United States and approximately 23% of total oil content. [7]

Gasoline : Most vehicles today operate on petrol because it is a relatively inexpensive, easy, and durable fuel that provides good vehicle efficiency and range. It's also easy to store and treat.

4.2 Natural gas (LNG and CNG)

4.2.1 Chemical Properties

Natural gas is a gas mixture that occurs naturally that is mostly composed of methane. Enbridge Gas gets its gas from suppliers in western Canada, the United States, and Ontario. Although the gas from these sources has a similar composition, it is not equivalent. The elements Carbon and Hydrogen make up the heat-producing hydrocarbons. The largest portion is always methane (CH_4). Ethane, propane (C_3H_8), and butane are darker, "hotter" hydrocarbons that are derived from natural gas fields and are available in small amounts. The main components of air (99.9%) are nitrogen, oxygen, and carbon dioxide, although they are pollutants of natural gas.

In the Enbridge Gas system, the typical sulphur content is from 3 to 6 mg/m3. This includes from 3 to 5 mg/m3 of sulphur in the odorant (mercaptan) added to gas for safety reasons. [8]

4.2.2 Production

Natural gas production and use have risen significantly in the last decade, owing in part to unconventional recovery methods such as horizontal drilling and fracking. The amount of pollution generated by these activities varies depending on the breadth and nature of their application. Emissions from natural gas transmission and transportation, including those from other energy sources, differ considerably depending on the country and the technologies used. Furthermore, methane (CH_4), the primary ingredient of natural gas, is a dominant greenhouse gas. “Ch_4 emissions from natural gas production, refining, and distribution must also be addressed for WTT and WTW GHG assessments of natural gas emissions because they have a global warming capacity (GWP) of 28 to 36 on a 100-year basis (CO_2 has a GWP of 1)”.[9]

When it comes to WTW pollution in the transportation industry, and more precisely end-use or tank-to-wheels (TTW) emissions, the form of storage and related energy needs must be taken into account. “ Natural gas must be compressed to high pressures (CNG: approximately 200 to 250 bar) or cryogenically frozen to liquid form (LNG: approximately 200 to 250 bar) in order to obtain adequate energy density for transportation use.

4.2.3 Demand of CNG

CNG is actually used in around half a million cars, mainly in Italy, New Zealand, and Canada. Many converted vehicles, on the other hand, keep their petrol tanks and are dual-fuelled. Since the compression ratio and engine performance of dual-fuel vehicles cannot be improved to take advantage of CNG's high octane number, the advantages of CNG are significantly reduced. CNG storage is also a problem. CNG storage is also a problem. Natural gas must be contained in high-pressure tanks due to its low boiling point. These are wide and bulky, restricting payload and space in smaller vehicles. A CNG-fueled vehicle with a 75-liter tank weighs around 150kg more than a petrol-powered car of similar dimensions. Big vehicles, such as buses, do not have this issue. Since natural gas is lighter than air, it can dissipate easily. Natural gas is thinner than air, but if there is a spill, it will dissipate into the atmosphere. It is normally scented to make it detectable, similar to LPG. It is non-reactive and non-toxic. The key concerns with CNG are that it is uneconomical due to the high cost of converting cars and the uncomfortable short range between refuelings.

CNG buses are still more costly than diesel buses, although this price gap is projected to narrow with time. The new excise loophole provides a financial incentive for bus operators to use them where they can be refueled centrally.

4.3 Hydrogen

4.3.1 Chemical Properties

The lightest atom in the world is hydrogen. It is a colorless, odorless, and tasteless gas in normal conditions. Full hydrogen combustion is very clean if the peak temperature is kept down.

$2H2 +O2-> 2H2O$

When hydrocarbons react with steam, hydrogen is formed. While this is a very simple operation, it is dependent on the earth's limited hydrocarbon supplies, making hydrogen not a true non-fossil substitute in this situation. When vegetable oils/plants are used as a source of hydrocarbons, however, hydrogen becomes a renewable, though costly, option.

4.3.2 Production

Water and hydrocarbons like methane are the most common feedstocks for hydrogen production. Hydrolysis uses energy to produce hydrogen from water. The main advantages of hydrogen are that it has an almost infinite abundance of liquids (assuming there is an infinite supply of electricity) and that it is non-toxic. When hydrocarbons react with steam, hydrogen is formed.

Hydrogen is the lightest molecule in the world in terms of chemical properties. It is a colorless, odor less, and tasteless gas in normal conditions. Full hydrogen combustion is very clean if the peak temperature is kept low:

$2H2 + O2 -> 2H2O$

Nitrogen in the air is heated as it fires at elevated temperatures, resulting in nitrogen oxides. However, by adding water to the hydrogen/air mixture, the temperature can be regulated while also achieving strong combustion. Excess air can also be used to cool the combustion and hydrogen burns even in dilute mixtures.

4.3.3 Demand

Hydrogen is now only used as a fuel in space rockets. However, several automakers are focusing on hydrogen-powered engines, which could be tested as prototypes in three years. Ford has been collaborating with the University of Melbourne on the construction of a hydrogen-powered car in Australia. The first car used was a Ford Cortina, and the effects were later modified to the Ford Mustang. Initially, a Ford Cortina was used, and the effects were later translated to the Capri. The most important technological problem for hydrogen is storage. It necessitates a large and costly tank in compressed or liquid form. Another option is to use metal hydrides' ability to absorb hydrogen and desorb it when desired, as Mazda's prototype does.

4.4 LPG

4.4.1 Chemical Properties

Liquefied petroleum gas, or LPG for short, is a form of hydrocarbon. Propane (C3H8), butane (C3H6), propylene (C3H6), and butylene (C3H6) are all present (C4H10). It must be stored with caution since it is an inflammable blend of all of these gases.

Propane and Butane make up the rest of this blend of gases. In chemical terminology, it has a straightforward composition. It is one of the cleanest alternative fuels available. It is a liquid under normal pressure, but it is found to be gaseous at atmospheric pressure. LPG is two times thicker than air when vaporized.

4.4.2 Physical Properties

LPG has a boiling point that varies between -42 and 0 degrees Fahrenheit. The boiling point of a mixture is determined by the proportions of Butane and Propane present. LPG is almost colorless and must be processed under pressure as a vapor. It weighs about half as much as the same amount of water. Another chemical used to track LPG leakage is ethyl Mercaptan. It acts as an odorant and aids in the detection of LPG leaks. -76 degrees Fahrenheit is the flash point of LPG. While LPG is a non-toxic material, it can be hazardous if not treated properly.

4.4.3 Production

LPG is derived mainly from two sources: crude oil refining (about 40% worldwide) and natural gas extraction and processing (about 60% worldwide) [9]. Both methods of processing have different standards for greenhouse gas (GHG) emission and pollutant quantities, which can be very different. The proportion of LPG derived from each source differs across the world, even also within a single nation or continent. LPG is derived from natural gas extraction and processing in the Marcellus Shale area of the United States, while crude oil refinery activities in the Gulf of Mexico generate large volumes of LPG. The emissions from these operations will also differ depending on the original feedstock and the machinery used to extract and refine natural gas or crude oil. In terms of the total pollution from the use of LPG as a transportation product, emissions from these operations are considered a part of the "upstream emissions." Quantifying WTT pollution is difficult due to differences in processing processes, transportation methods, and size. However, models have been built that use industry data and projections to measure these pollutants for both upstream and downstream operations in the transportation sector; the Greenhouse Gases, Controlled Emissions, and Transportation Sector Emissions models. Energy use in Transportation (GREET) model is one such tool that has been utilized by studies referenced in this document .

4.4.4 Demand

The study also looks at the competitive landscape of LPG in the area. In addition, the region's refining industry is analyzed in depth, including refining facilities, businesses, capacity, and proposed projects. The report also looks at the competitive environment for LPG in the area. In addition, the region's refining industry is examined in depth, including facilities, businesses, capacity, and proposed projects.

The study also includes information on the top North American refiners, as well as detailed market profiles of three leading North American LPG firms, including company descriptions, SWOT analyses, and financial analyses. The research work also covers the most recent industry trends in North America and their effect on businesses and industries. Because of its very safe combustion, cost effectiveness, and ease of transportation, LPG demand is skyrocketing. Bangladesh's current LPG demand is about 100,000 mt per year. LPG plants in Kailashtila, Sylhet, and Chittagong supply about 15-20% of current demand, while private players import the remaining 80%.. In the foreign market, the price of LPG has fallen by more than 50%, though the price in Bangladesh has not yet caught up with the global market. In the other hand, the price of natural gas in the world has risen by an average of 26.29 percent, with a 50 percent surge for domestic consumers.

4.5 Overall Demand

Reduced industrial development and stay-at-home directives aimed at halting the spread of the 2019 novel coronavirus disease have resulted in a fall in transportation fuel demand since early March 2020. (COVID-19). Refineries in the United States have decreased the volume of crude oil and other inputs they handle (also known as refinery runs). Refinery runs in the United States dropped for four weeks in a row, hitting 12.8 million barrels per day (b/d) in the week ending April 17 and marginally rising to 13.2 million b/d in the week ending April 24, but roughly 21% lower than the previous five-year average for this time of year.

“Worldwide, petroleum and other liquid fuels326 are the dominant source of transportation energy, although their share of total transportation energy declines over the IEO2016 projection period, from 96% in 2012 to 88% in 2040. World transportation sector liquid fuels consumption grows by 36 quadrillion Btu in the Reference case projection, with diesel (including biodiesel) showing the largest gain (13 quadrillion Btu), jet fuel consumption increasing by 10 quadrillion Btu, and motor gasoline (including ethanol blends) increasing by 9 quadrillion Btu .” While gasoline remains the most common mode of transportation, its share of overall transportation energy consumption falls from 39% in 2012 to 33% in 2040. Between 2012 and 2040, the overall transportation market share of diesel fuel (including biodiesel), the second-largest transportation fuel, falls from 36 percent to 33 percent, while the market share of jet fuel rises from 12 percent to 14 percent. Pipelines accounted for 66% of natural gas use in the energy industry in 2012, followed by light-duty trucks (28%), and buses (4%). Because of attractive fuel economics, natural gas is increasingly being used for modes of transportation other than pipelines. In the Comparison scenario, the natural gas share of overall energy consumption by big trucks is predicted to grow sharply from 1% in 2012 to 15% in 2040, as well as 17% of freight rail, 7% of light-duty vehicles, and 6% of domestic marine vessels. [10]

The world transportation industry absorbed approximately 2,200 million tons of oil equivalent in 2010, accounting for about 19 percent of global energy supplies. As seen in the graph, oil accounted for roughly 96% of the total, with the remainder coming from natural gas, biofuels, and electricity. The shipping industry consumes more than 60% of all oil consumed globally (around 51 million barrels per day).

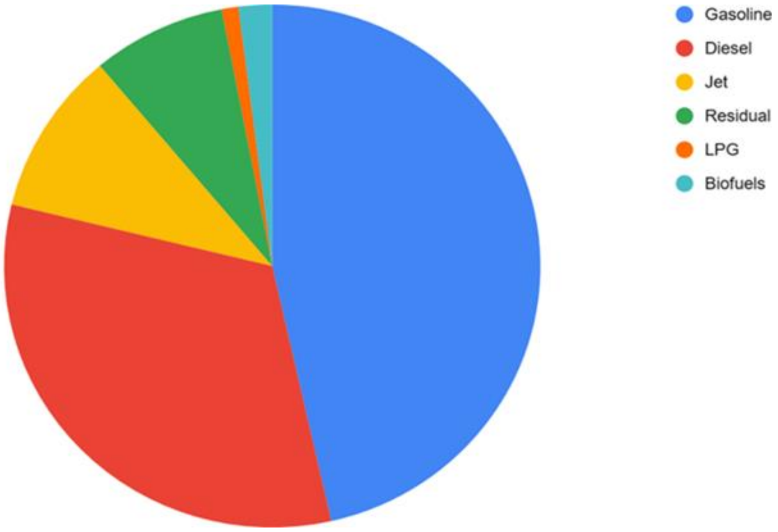


Figure 4.1: Overall Demands of Fuels , 2010 .[11]

The global market for LPG is growing every day. Bangladesh's overall LPG demand is 100000 mt per year. In 2015, India's demand was 19.2 million tons, while China imported 7.1 million tons of LPG. Here is a contrast of importer and exporter nations. Aside from that, the United States exported nearly 14 million tons of LPG in 2014.The largest LPG exporters are found in the Middle East, West Africa and Norway, the largest importers include Japan, China and South Korea, the USA and the EU.

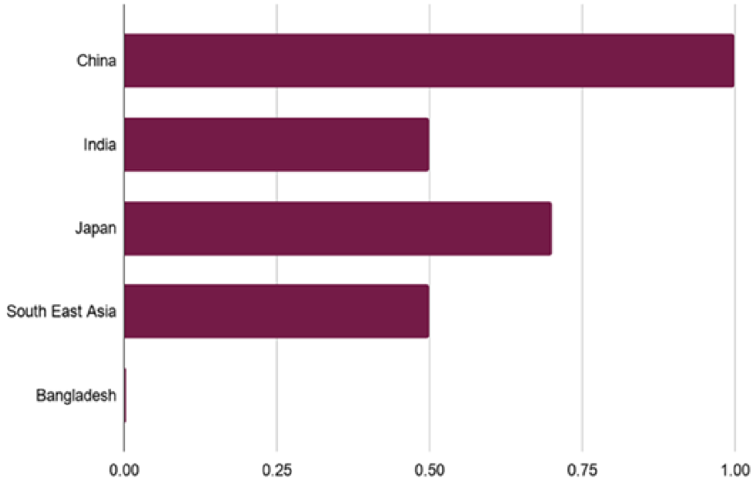


Figure 4.2: Comparison among LPG demands of Bangladesh with other country(Thousand barrel per day) [12]

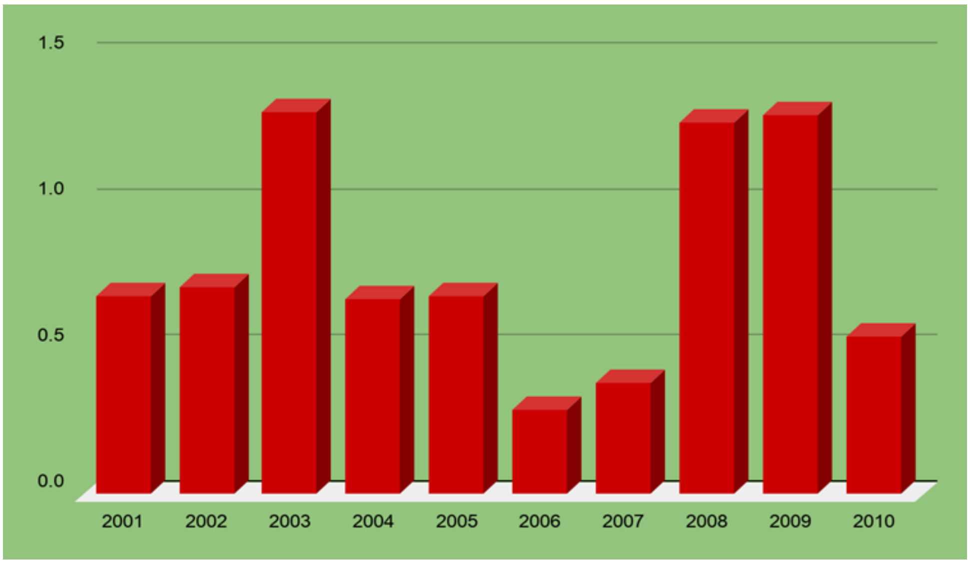


Figure 4.3: Bangladesh LPG Consumption.[12]

We can see from the graph that LPG demand is much smaller than in other countries, but we can increase it because it is more viable than other fuels. Because of its very safe burning, cost effectiveness, and ease of transportation, LPG demand is growing rapidly, as seen in the graph below. Bangladesh's current LPG demand is about 100,000 mt per year. LPG plants in Kailashtila, Sylhet, and Chittagong supply about 15-20% of current demand, while private players import the remaining 80%. In the foreign market, the price of LPG has fallen by more than 50%, though the price in Bangladesh has not yet caught up with the global market. On the other hand, the price of natural gas has risen by 26.29 percent in the region.[11]

Chapter 5 Overview of existing cooking fuels

5.1 Coal

Coal is a fossil fuel that is formed over millions of years from decaying plant and animal under high temperature and pressure below the Earth's crust over a long period of time[13]. It is a nonrenewable energy source. Coal is used in both heating and cooking purpose in stoves and it is predominant in many countries. China is one of them. Twenty-nine percent of Chinese cooking is currently done with stoves using various coal products whereas se of coal is much more limited in India than China. In this case the percentage is 1.9 percent [14].

5.2 Charcoal

Charcoal is produced by heating wood (or any other biomass) in a kiln (earth mound kilns are commonly used in India) with limited access to air through a process called "carbonization." With carbonization higher quality of fuel than firewood is produced. The charcoal yield from the kiln is approximated to be 30%[15]. Charcoal production in Ghana is concentrated in the transition belt between the tropical forests of the south and the savanna woodlands of the north, where fresh wood is harvested for processing. Charcoal is also extracted from logging and sawmills operation. In Ghana, cultivated forests are available for wood harvesting which provides less than 2% of the total charcoal industry's output. Traditional earth mound kilns have yield about 14% which is the least efficient method used in Ghana. The process constraints for charcoal consist of the oxidation of the wood, the transport and cooking of the resulting product to consumers. Wood cultivation and harvesting were omitted from the analysis because the wood was manually extracted from natural forests and land clearing operations without the use of agricultural machinery [14].

5.3 Biomass and Biogas

Biomass is one of the largest energy sources as cooking fuel in both China (26.7%) and India (57.9%). Biomass fuels like unprocessed crop residues and firewood are used in many countries like China, India, Ghana etc. Also a densified form of traditional biomass which is known as non-carbonized processed fuels are being used in a wide range in developing countries[16]. On the other hand, biogas is also a popular fuel for cooking purpose worldwide. It is a mixture of methane and carbon dioxide and can be produced from anaerobic digestion of organic wastes such as cow dung. It is also to be noted that cow dung as a nonrenewable source of energy, is a cheap cooking fuel. Hence it is quite popular in rural areas. But burning of biogas leads to emissions of harmful air and high levels of volatile organic compounds (VOCs)[14].

5.4 Kerosene

Kerosene is a liquid product which is obtained from crude oil. Kerosene is predominantly used for cooking in urban households. But it has high flammability as a result of which a high number of accidents each year. Kerosene is used more widely in India, where it constitutes 3.2% of the current fuel mix, compared to China, where it is only 0.3% of all cooking fuel [16]. Kerosene oil cooking is boundless in many agricultural nations, particularly in metropolitan family units, where biomass should be bought, and power and LPG are costly or unreliable. It is typically shipped in mass, with country zones buying kerosene oil by liter or container[17]

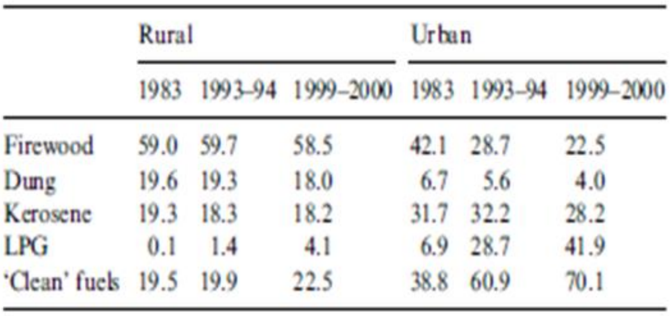
5.5 Liquid Natural Gas(LNG)

LNG mainly comprises of methane and it has a boiling point of-164^{0}C and contains cryogenic insulated tanks at about atmospheric pressure for liquefaction. Recent practice has been to liquefy the gas which would also be commonly flared in remote areas in oil fields, but when processed, it can also be made from landfill gas. At constant temperature and pressure, LNG is somewhere around 1/614th of the volume of natural gas, makes transportation over long distances much more cost-effective, especially where pipelines do not exist. This portability, similar to LPG, is a major advantage. LNG is used as a chemical feedstock in transport and in heating and cooking, as well as in industry.

The KOGAS Environmental Load project, initiated by the Government of Korea in 2002 to collect environmental load data on a variety of industrial chemicals, is an important example of exploring the environmental impact of LNG. KOGAS, the Korean Power Production firm, in order to comply with the government initiative and to maintain ISO 14001 certification standards, a lifecycle analysis was also carried out on the fuel cycle for LNG produced or imported compared to coal and oil for the production of 1GWh of electricity. The findings apply to the fuel cycle and give an indication of where there may be problems. These results show that, as predicted from the low carbon/hydrogen ratio of the fuel, LNG generates less CO2. Also, CFC production is much lower than for other fuels. Similarly, for LNG, sulphur dioxide acidification and NOx eutrophication are the lowest[18]

5.6 Liquefied Petroleum Gas(LPG)

A mixture of propane and butane, which are gases that become liquid under pressure and can then be stored in pressurized containers, is liquefied petroleum gas (LPG). Depending on the source and climate, the proportion of each gas varies. It is preferred to use propane where the climate is cold and butane where it is warm. LPG has a high volume of energy per unit and it is convenient to use. During refining, LPG is manufactured from crude oil (40 percent) or natural gas during extraction (60 percent)[18]. LPG is either imported into Ghana, or manufactured by the sole refinery in the world, the refinery Tema Crude. The raw material, crude oil, it is imported from Nigeria for LPG production [14]. Large amounts of LPG are currently used by both India and China, with the fuel comprising 25% and 31% of the current cooking fuel mix of each region, respectively. Urban customers have slightly greater access to LPG than their counterparts in rural areas [16].



	Rural			Urban		
	1983	1993–94	1999–2000	1983	1993–94	1999–2000
Firewood	59.0	59.7	58.5	42.1	28.7	22.5
Dung	19.6	19.3	18.0	6.7	5.6	4.0
Kerosene	19.3	18.3	18.2	31.7	32.2	28.2
LPG	0.1	1.4	4.1	6.9	28.7	41.9
‘Clean’ fuels	19.5	19.9	22.5	38.8	60.9	70.1

Figure 5.1: Uses of Cooking Fuels

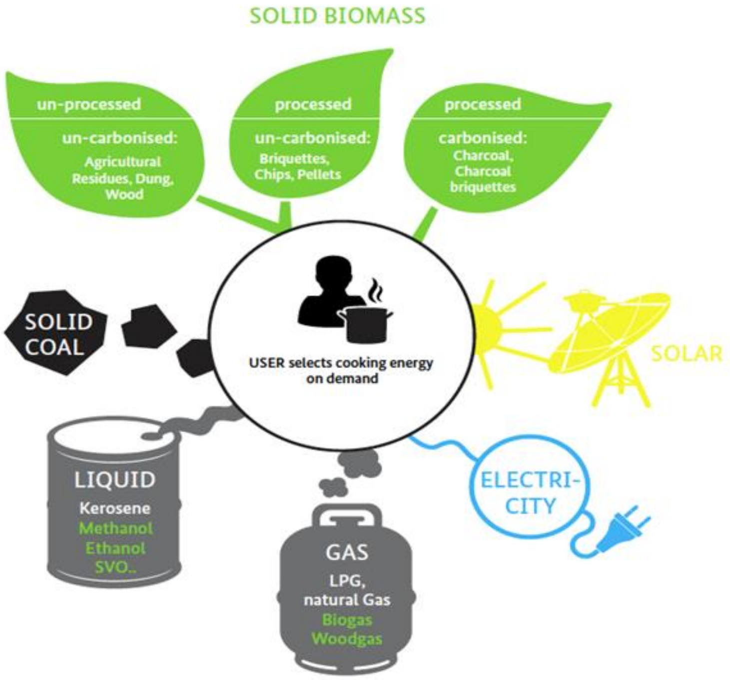
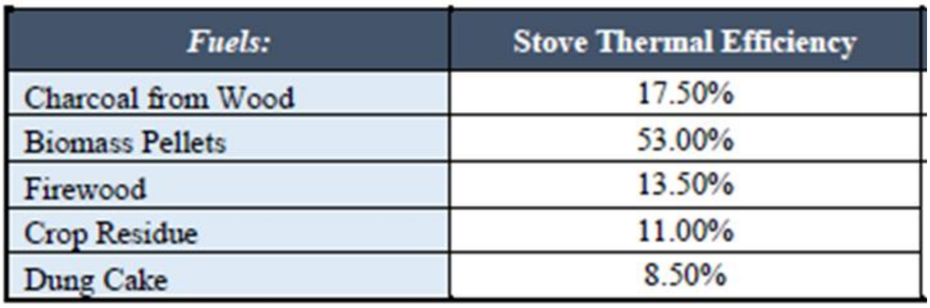


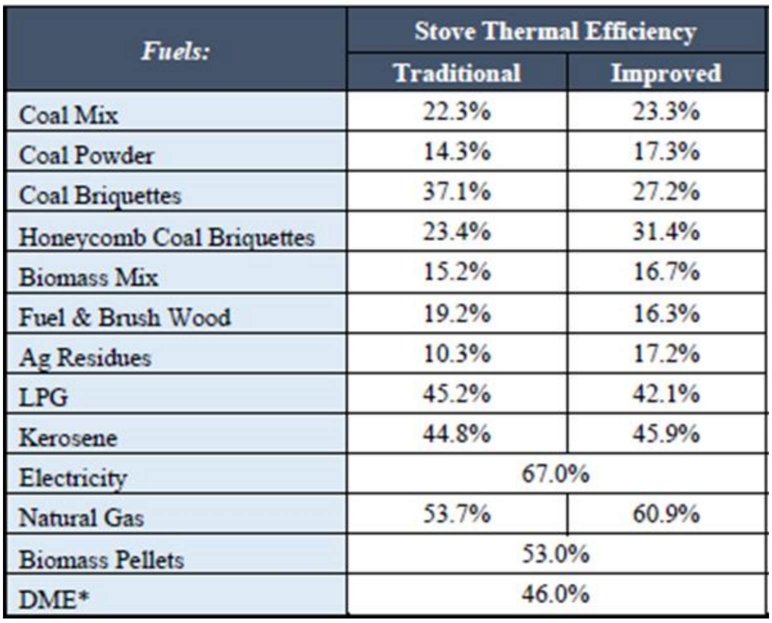
Figure 5.2: different options for users for using different fuels for cooking purpose.

Different cooking fuels have different thermal cook stove efficiencies. Two tables are added below in terms of India and China respectively to understand the concept better.



Fuels:	Stove Thermal Efficiency
Charcoal from Wood	17.50%
Biomass Pellets	53.00%
Firewood	13.50%
Crop Residue	11.00%
Dung Cake	8.50%

Figure 5.3: Stove thermal efficiencies modeled for Indian Cook stove [16]



Fuels:	Stove Thermal Efficiency	
	Traditional	Improved
Coal Mix	22.3%	23.3%
Coal Powder	14.3%	17.3%
Coal Briquettes	37.1%	27.2%
Honeycomb Coal Briquettes	23.4%	31.4%
Biomass Mix	15.2%	16.7%
Fuel & Brush Wood	19.2%	16.3%
Ag Residues	10.3%	17.2%
LPG	45.2%	42.1%
Kerosene	44.8%	45.9%
Electricity	67.0%	
Natural Gas	53.7%	60.9%
Biomass Pellets	53.0%	
DME*	46.0%	

Figure 5.4: Stove thermal efficiencies modeled for Chinese cook stove [16]

A diagram for yearly energy consumptions for cooking fuels in three rural areas of Bangladesh that shows how much energy is used for cooking purpose in Bangladesh is given below:[19]

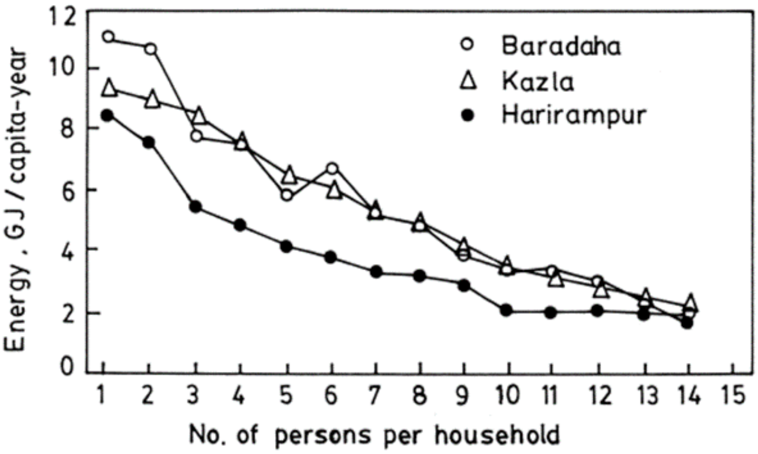


Figure 5.5: Yearly per capita energy consumption for cooking in Baradaha, Kazla, and Harirampur

Chapter 6 Data Collection

We collected several data from different papers and Bangladesh Gas Field Company Limited. These data were then used in the GREET software to calculate the well to pump emissions.

Table 6.1:

	Lower Heating Value	Higher Heating Value	Density	Carbon Ratio	Sulfur Ratio (year 2010)
Conventional Diesel	0.13 mmBtu/gal	0.14 mmBtu/gal			
Residual Oil	39119 MJ/m^3	0.15 mmBtu/gal			
Ethanol	76330.02 Btu/gal	84530.02 Btu/gal	22.35 kg/ft^3	52.20 %	5.7e-5%
Pure Methane	128.63 Btu/gal	142.77 Btu/gal	20.30 g/ft^3	75%	
Denatured ethanol	21496 MJ/m^3	23782 MJ/m^3	788.45 kg/m^3	0.53	7.48e-7
E85	23125 MJ/m^3	25413 MJ/m^3	781.89 kg/m^3	0.58	2.07e-6
High Octane Fuel (E25)	29641 MJ/m^3	31937 MJ/m^3	755.64 kg/m^3	0.78	7.59e-6
High Octane Fuel (E40)	28012 MJ/m^3	30306 MJ/m^3	770.95 kg/m^3	0.72	6.1e-6

LPG extraction was done in two process. From crude oil and from natural gas. Now these models are as follows:

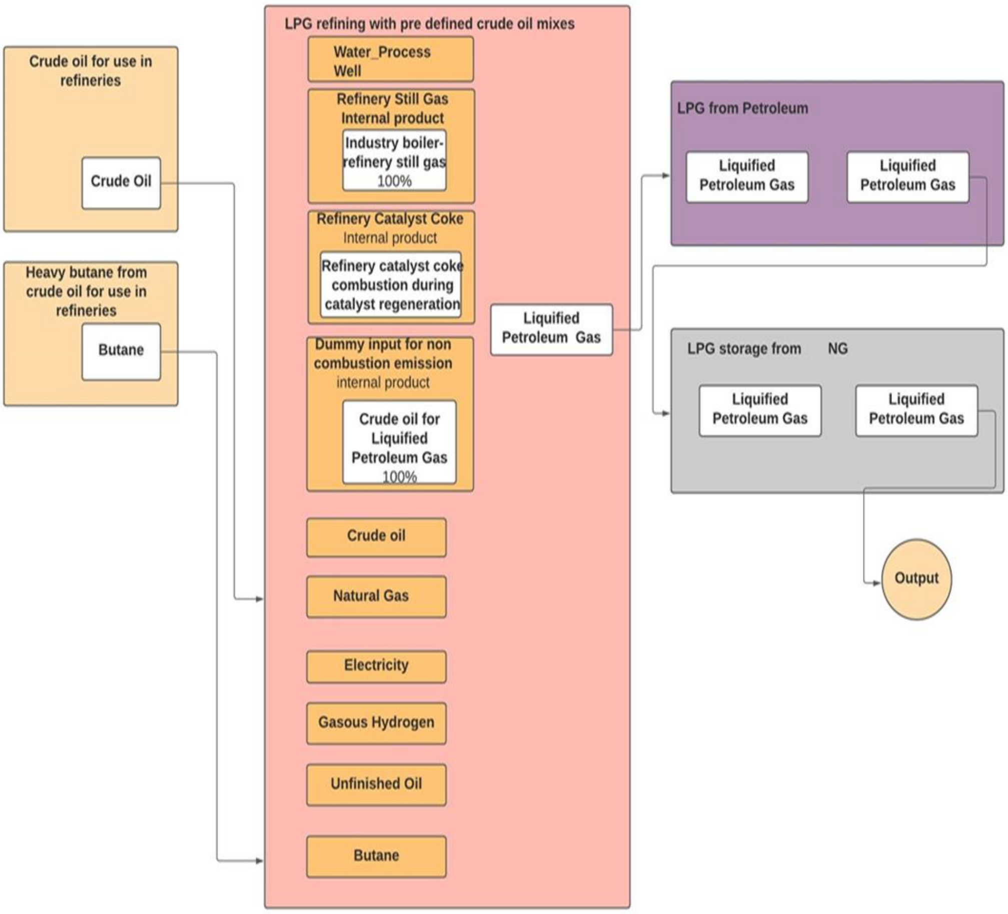


Figure 6.1: Flow process of LPG extraction from Crude oil

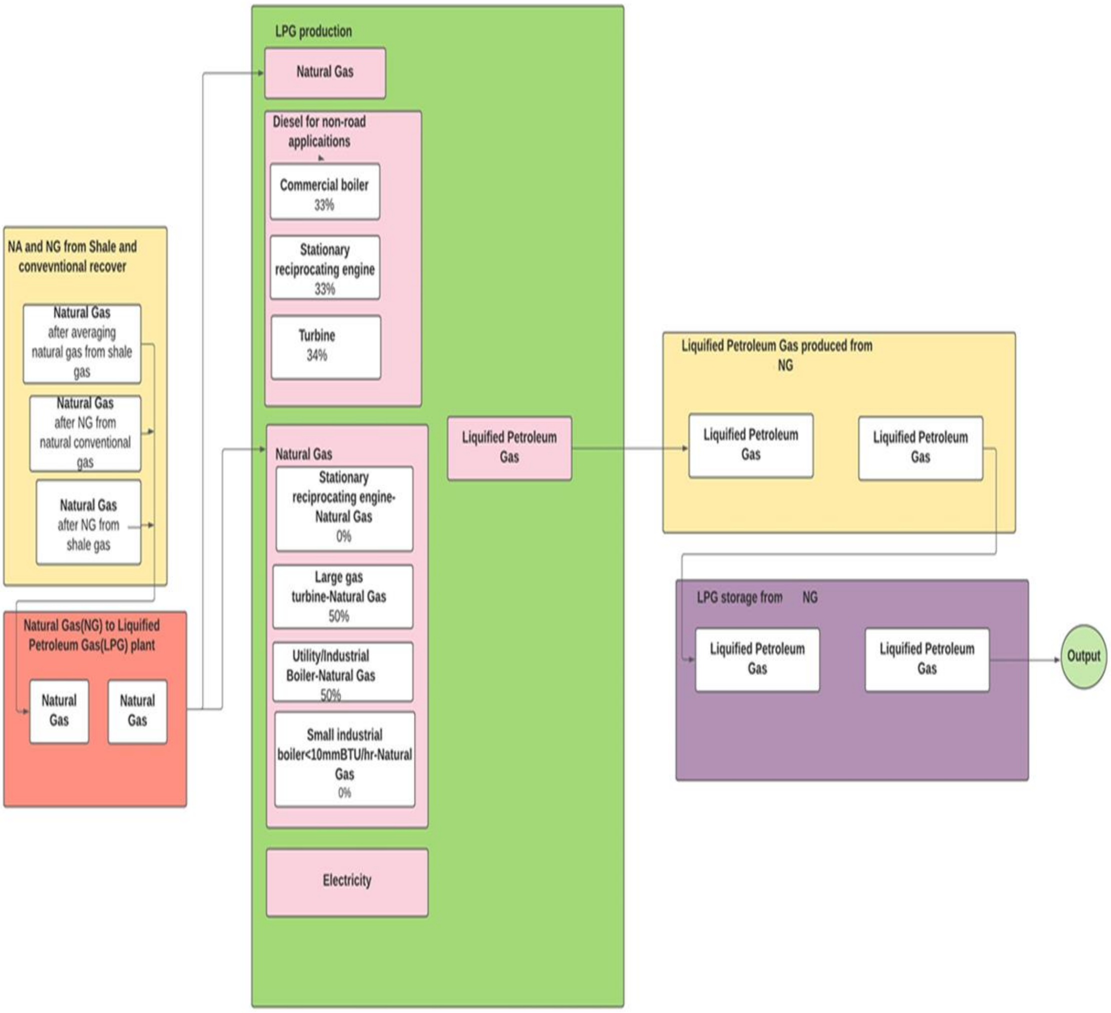


Figure 6.2: Flow process of LPG extraction from Natural Gas

Chapter 7 Calculation and Formulas

There are hundreds of equations used in our GREET model. The most significant equations are discussed below.

7.1 Calculation of Energy Use for an Upstream Stage

For a given upstream stage, energy input per unit of energy product output is calculated by using the energy efficiency of the stage. Energy efficiency is the energy output divided by the energy input (including energy in both process fuels and energy feedstock). Thus, total energy input is:

Energy in = 1/efficiency

Here,

Energy in = Energy input of a given stage (say, in Btu per Btu of energy product output from the stage), and 20 Efficiency = Energy efficiency for the given stage (defined as [energy output]/[energy input] for the stage).

Of the total energy feedstock input, a unit of energy in fuel product output requires a unit of energy in feedstock input. The difference between the energy in the feedstock input and the energy in the energy product is the amount of feed used as the process fuel. Examples include CNG and LNG production. For this case, the following equation is used to estimate the amount of process fuel required:

Process Fuels = 1/efficiency – 1,

where Process fuels = The amount of process fuels required during a given stage to generate one unit of energy for production (say, in Btu per Btu of energy output from the stage), and Efficiency = Energy efficiency for a given stage (defined as [energy output]/[energy input] for the stage).

7.2 Calculation of Emissions for an Upstream Stage

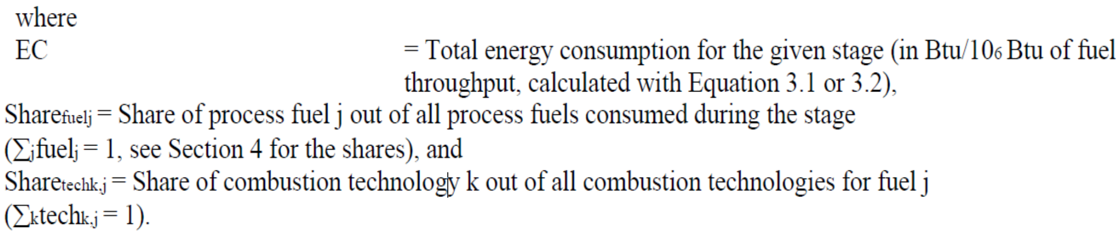
Emissions from combustion of process fuels for a particular stage are calculated by using the following formula:

$$EM_{cm,i} = (\sum_{j} \sum_{k} EF_{i,j,k} \times EC_{j,k}) \div 1{,}000{,}000\,,$$

Figure 7.1:

where EM cm,i = Combustion emissions of pollutant i in g/106 Btu of fuel throughput, EFi,j,k = Emission factor of pollutant i for process fuel j with combustion technology k (g/106 Btu of fuel burned), and ECj,k = Consumption of process fuel j with combustion technology k (Btu/106 Btu of fuel throughput). 22 ECj,k for a given stage is, in turn, calculated by using the following formula:

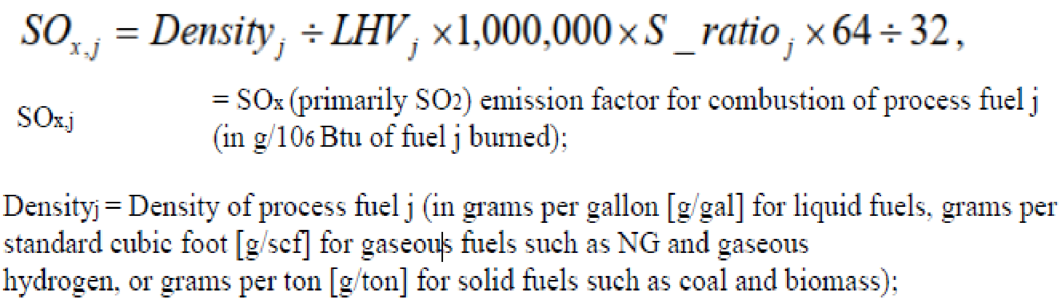
$EC j ,k = EC * Sharefuelj *Sharetechk, j ,$



where
EC = Total energy consumption for the given stage (in Btu/10^6 Btu of fuel throughput, calculated with Equation 3.1 or 3.2),
Share$_{fuelj}$ = Share of process fuel j out of all process fuels consumed during the stage ($\sum_j$fuel$_j$ = 1, see Section 4 for the shares), and
Share$_{techk,j}$ = Share of combustion technology k out of all combustion technologies for fuel j ($\sum_k$tech$_{k,j}$ = 1).

Figure 7.2: Formula for EC

In the GREET model, SOx emission factors for combustion technologies fueled with all fuels except coal, crude oil, and residual oil are calculated by assuming that all sulfur contained in these process fuels is converted into sulfur dioxide (SO2). The following formula is used to calculate the SOx emissions of combustion technologies:

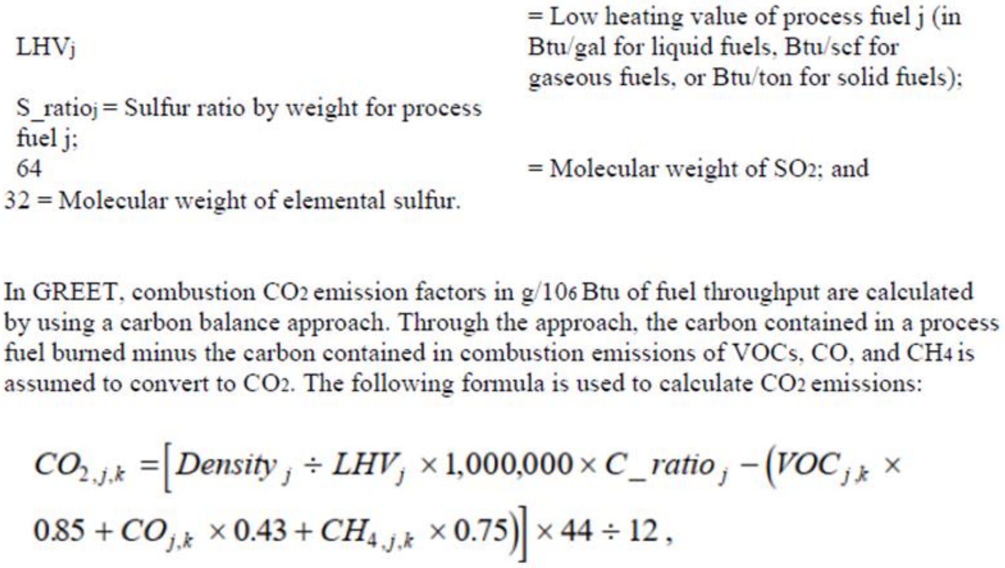


$$SO_{x,j} = Density_j \div LHV_j \times 1{,}000{,}000 \times S\_ratio_j \times 64 \div 32,$$

$SO_{x,j}$ = SO_x (primarily SO_2) emission factor for combustion of process fuel j (in g/10^6 Btu of fuel j burned);

$Density_j$ = Density of process fuel j (in grams per gallon [g/gal] for liquid fuels, grams per standard cubic foot [g/scf] for gaseous fuels such as NG and gaseous hydrogen, or grams per ton [g/ton] for solid fuels such as coal and biomass);

Figure 7.3: Formula to find out Sox



LHV_j = Low heating value of process fuel j (in Btu/gal for liquid fuels, Btu/scf for gaseous fuels, or Btu/ton for solid fuels);

S_ratio_j = Sulfur ratio by weight for process fuel j;

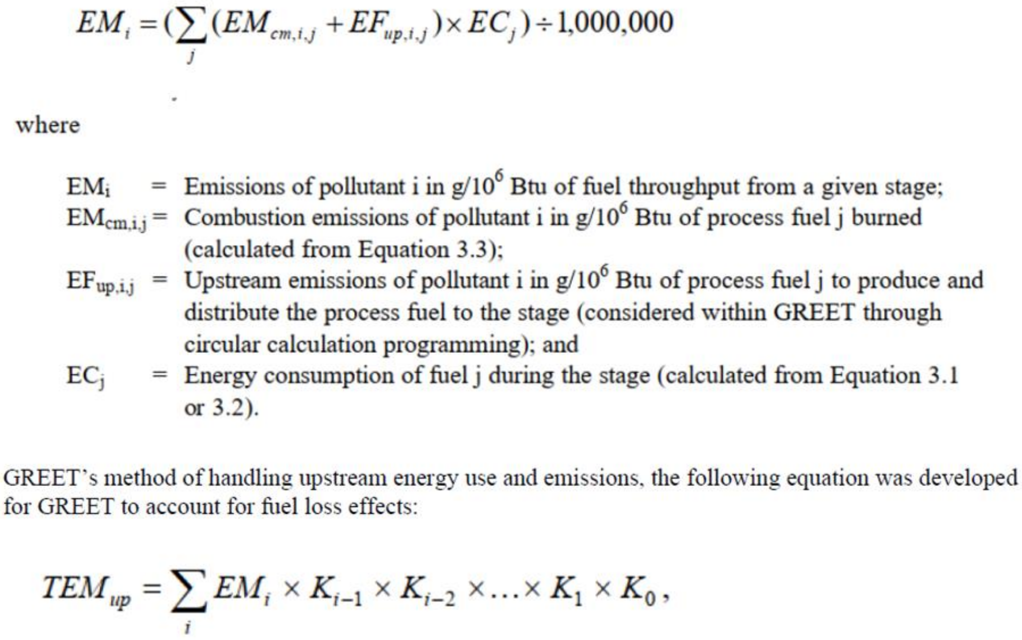
64 = Molecular weight of SO_2; and

32 = Molecular weight of elemental sulfur.

In GREET, combustion CO_2 emission factors in g/10^6 Btu of fuel throughput are calculated by using a carbon balance approach. Through the approach, the carbon contained in a process fuel burned minus the carbon contained in combustion emissions of VOCs, CO, and CH_4 is assumed to convert to CO_2. The following formula is used to calculate CO_2 emissions:

$$CO_{2,j,k} = \left[Density_j \div LHV_j \times 1{,}000{,}000 \times C\_ratio_j - \left(VOC_{j,k} \times 0.85 + CO_{j,k} \times 0.43 + CH_{4,j,k} \times 0.75\right)\right] \times 44 \div 12,$$

Figure 7.4: Formulas to find out CO2



$$EM_i = (\sum_j (EM_{cm,i,j} + EF_{up,i,j}) \times EC_j) \div 1{,}000{,}000$$

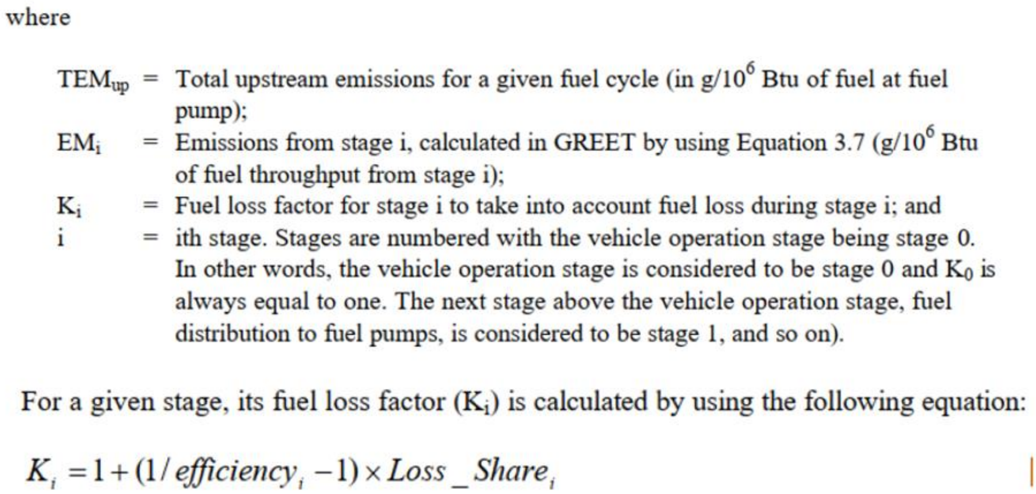
where

EM_i = Emissions of pollutant i in g/10^6 Btu of fuel throughput from a given stage;
$EM_{cm,i,j}$ = Combustion emissions of pollutant i in g/10^6 Btu of process fuel j burned (calculated from Equation 3.3);
$EF_{up,i,j}$ = Upstream emissions of pollutant i in g/10^6 Btu of process fuel j to produce and distribute the process fuel to the stage (considered within GREET through circular calculation programming); and
EC_j = Energy consumption of fuel j during the stage (calculated from Equation 3.1 or 3.2).

GREET's method of handling upstream energy use and emissions, the following equation was developed for GREET to account for fuel loss effects:

$$TEM_{up} = \sum_i EM_i \times K_{i-1} \times K_{i-2} \times \ldots \times K_1 \times K_0 \,,$$

Figure 7.5: Overall Emission Formula



where

TEM_{up} = Total upstream emissions for a given fuel cycle (in g/10^6 Btu of fuel at fuel pump);

EM_i = Emissions from stage i, calculated in GREET by using Equation 3.7 (g/10^6 Btu of fuel throughput from stage i);

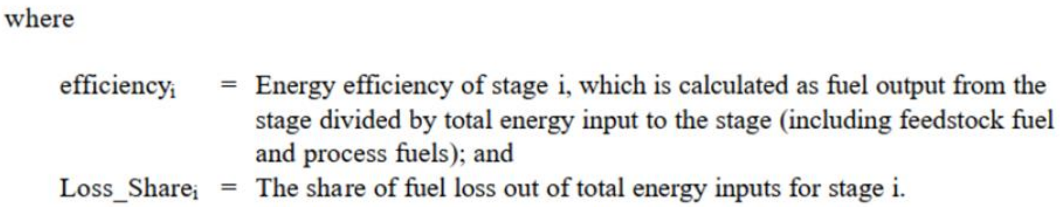
K_i = Fuel loss factor for stage i to take into account fuel loss during stage i; and

i = ith stage. Stages are numbered with the vehicle operation stage being stage 0. In other words, the vehicle operation stage is considered to be stage 0 and K_0 is always equal to one. The next stage above the vehicle operation stage, fuel distribution to fuel pumps, is considered to be stage 1, and so on).

For a given stage, its fuel loss factor (K_i) is calculated by using the following equation:

$$K_i = 1 + (1/efficiency_i - 1) \times Loss\_Share_i$$

Figure 7.6: Fuel Loss Factor



where

$efficiency_i$ = Energy efficiency of stage i, which is calculated as fuel output from the stage divided by total energy input to the stage (including feedstock fuel and process fuels); and

$Loss\_Share_i$ = The share of fuel loss out of total energy inputs for stage i.

Figure 7.7: Overall Efficiency

Chapter 8 Energy Use and Emissions of Vehicle Operations

Energy use and emissions of vehicle operations are calculated on a per-mile basis. Energy use (in Btu per mile or Btu/mi) is calculated from vehicle fuel economy. Emissions from ICEVs powered by conventional fuels (i.e., CG, RFG, CD, and RFD) are included in the GREET model for two reasons. First, HDTs fueled with diesel or gasoline are used during upstream stages for transportation and distribution of feedstocks and fuels, and their emissions need to be taken into account in calculating overall emissions during these stages. Second, emissions of benchmark light-duty GVs and diesel vehicles (DVs) are needed for calculating vehicular emissions for both benchmark vehicles and AFVs. 29 Emissions of VOCs, CO, and NOx for benchmark GVs fueled with CG and benchmark DVs fueled with CD are calculated with EPA's Mobile 5b — the current version of EPA's Mobile model (the next version of the Mobile model, Mobile 6, will probably be released by end of 1999). Use of Mobile 5b is intended to estimate actual on-road emissions of motor vehicles. The Mobile 5b outputs are fed into GREET. PM10 emissions for benchmark vehicles are calculated by using EPA's Part 5 outside of the GREET model. Emissions of SOx for both benchmark vehicles and AFVs are calculated inside the GREET model; for these calculations, we assume that all sulfur contained in each transportation fuel is converted into SO2, except for fuel-cell vehicles, for which fuel sulfur is assumed to become solid waste. EPA's Mobile model does not estimate vehicular emissions of CH4 and N2O for any vehicle type. CH4 emissions for benchmark vehicles can be indirectly estimated with Mobile 5b by estimating emissions of total hydrocarbons (THCs) and total nonmethane hydrocarbons (NMHCs); this approach was used in our study. Emissions of N2O for benchmark vehicles are estimated in this study on the basis of existing data presented in Delucchi and Lipman (1996), a recent EPA report (EPA 1998c), and other published sources. Finally, combustion CO2 emissions for all vehicle types are calculated by using a carbon balance approach (carbon contained in the fuel burned minus carbon contained in exhaust emissions of VOC, CO, and CH4 is assumed to convert to CO2). Because of the short residence time of VOCs and CO in the atmosphere (less than 10 days), the carbon contained in VOCs and CO is converted into CO2 emissions in GREET. In GREET, vehicular VOC emissions include exhaust, evaporation, running loss, resting loss, and refueling emissions, all of which are estimated with Mobile 5b. Vehicular PM emissions include exhaust, tire wear, and brake wear emissions, all of which are estimated with PART 5. Emissions of other pollutants are exhaust only. In the GREET model, vehicular emissions of VOC, CO, NOx, PM10, CH4, and N2O from spark-ignition vehicles fueled with alternative fuel (SI-AFVs) are calculated by applying SI-AFV emission reduction rates to benchmark GV emissions. Emission reduction rates of SI-AFVs relative to those of benchmark GVs are estimated by using testing data for AFV emissions from different studies. (See Section 4 for assessment of AFV emissions reduction rates.) Vehicular emissions of VOC, CO, NOx, PM10, CH4, and N2O from compression-ignition vehicles fueled with alternative fuels such as DME, FTD, and biodiesel (CI-AFVs) are calculated by applying CI-AFV emission reduction rates to those of benchmark DVs. Energy consumption (in Btu/mi) is calculated by using the fuel economies of benchmark vehicles and AFVs. Benchmark GV fuel economies used in GREET are from the GV fuel economies predicted by DOE's EIA. The fuel economy for benchmark DVs is calculated by applying a fuel economy improvement rate — usually, conventional CI DVs can achieve a 10% improvement in gasoline-equivalent fuel economy over GVs, and CIDI DVs can improve fuel economy by 35%. The fuel economy of SI-AFVs is estimated by applying SI-AFV fuel economy changes (relative to SI GV fuel economy) to SI GV fuel economy. For CI-AFVs, the fuel economy is estimated by applying CI-AFV fuel economy changes (relative to CI DV fuel economy) to CI DV fuel economy. Fuel economy changes by DVs and AFVs are presented in 30 Section 4. Fuel economies calculated for each vehicle type in GREET are gasoline-equivalent fuel economies.

8.1 Total Fuel-Cycle Energy Use and Emissions for a Combination of Fuel and Vehicle Type

Section before presents calculations of upstream energy use and emissions in Btu and g/106 Btu of fuel delivered at the fuel pump. Section 3.3.5 presents calculations of energy use and emissions in Btu and g/mi traveled by each vehicle type. (Note that energy use by vehicles is calculated for total energy, fossil energy, and petroleum.) Now, energy use and emissions of upstream stages and downstream vehicle operations can be combined by converting upstream energy use and emissions from the per-106 Btu basis to the per-mile basis. The conversion is accomplished by dividing upstream energy use and emissions by vehicular per-mile energy use, which is calculated from vehicle fuel economy. Note that in the GREET model, the total energy use (not fossil energy use or petroleum use) by vehicles is used to convert the per-106 Btu upstream results into per-mile results in order to avoid potential under-accounting of energy use by vehicles fueled with non fossil or nonpetroleum fuels. GREET's fuel-cycle results are presented on a per-mile basis. That is, the model estimates total fuel-cycle energy use and emissions for each mile traveled according to vehicle type fueled with a given fuel. In this regard, GREET is similar to Mobile — both GREET and Mobile estimate per-mile rates, rather than total energy use and emissions of a fleet of vehicles in a given year. To estimate the total emissions or energy use (often called emission and energy inventory), GREET per-mile results can be input into some vehicle stock and usage models. Because per-mile upstream energy use and emissions are the per-million Btu energy use and emission result divided by Btu-per-mile fuel use (which is directly determined by vehicle fuel economy), vehicle fuel economy is one of the most significant factors in determining total fuel cycle energy use and emissions.

8.2 Total and Urban Emissions for Five Criteria Pollutants

For the five criteria pollutants (VOC, CO, NOx, PM10, and SOx) included in the GREET model, both the location and the amount of emissions are important, because these pollutants usually pose localized air pollution problems. (SOx causes acid rain and poses other regional air

pollution problems.) To account for the importance of emission locations, GREET is designed to estimate total emissions and urban emissions for the five criteria pollutants. The term "total emissions" refers to total fuel-cycle emissions occurring everywhere, at every stage of a fuel cycle (calculated as described in the above sections). "Urban emissions" occur only within the boundaries of a given metropolitan area. GREET calculates urban emissions on the basis of these boundaries. The boundaries of an air control district can be used as the boundaries of an urban area in order to use the results from GREET to analyze air quality implications in an area. Readers should keep in mind that GREET estimates total and urban emission *rates*, not total and urban emission *inventory*. The estimated urban emission rates and estimated urban activity level from some other transportation activity models are needed in order 31 to estimate the urban emission inventory that will occur with introduction of a transportation fuel or technology. Estimation of emission inventory is beyond the scope and capability of GREET.

Ideally, urban emissions can be further disaggregated into grids of an urban area, and grid specific emissions can be then used in air quality models to simulate air quality impacts of emissions that result from introducing an AFV. Separation of emission rates into total and urban rates in GREET is a simple, first step to provide some general idea of the differences in population exposure of emissions generated from a given fuel cycle. Emissions from vehicle operations can occur within or outside of urban areas, depending on where vehicles are introduced and where they travel. In GREET, to calculate emission rates, we assumed vehicle miles traveled (VMT) by an AFV type occur in urban areas. That is, we assumed that AFVs are to be introduced to urban areas to make urban VMT. So, all emissions from vehicle operations are treated as urban emissions. In estimating urban emission inventory from mass introduction of a transportation fuel or vehicle technology, researchers must make assumptions regarding splits of urban VMT and rural VMT and consider only the urban VMT using the fuel or the technology. Wang et al. (1998) provides an example for calculating urban emission inventory with GREET-estimated urban emission rates. Urban emissions of a given upstream stage are determined by facility locations, which are determined by feedstock availability, cost of transporting feedstock, and stationary emission regulations in urban areas. Because feedstocks (petroleum, NG, biomass, etc.) are usually located outside urban areas and because the cost of transporting them is usually much higher than that of transporting fuel (on the basis of the same amount of Btu delivered in the final fuel), upstream stages (except fuel distribution) are often located outside urban areas. Nonetheless, the split of upstream facilities located inside and outside the metropolitan area is fuel-, stage-, and region-specific. In GREET, a default split between urban and nonurban areas is provided for each upstream stage. The default splits were estimates for the United States as a whole. To use GREET to estimate emission rates for a specific area, data regarding the split of facility locations for that area must be collected. For example, to estimate urban emissions of gasoline production from petroleum refineries in Chicago, researchers must know how much gasoline that is consumed in the Chicago area is produced within and outside the Chicago area. Gasoline production within the Chicago area can be estimated on the basis of the capacity of the petroleum refineries located within the Chicago area minus the amount of gasoline shipped out of Chicago by petroleum refineries (net production in Chicago). The amount of gasoline produced outside the Chicago area (for Chicago consumption) can be estimated as the difference between the total gasoline demand and the net gasoline production in the Chicago area.

Direct use of emission rates estimated with GREET for air quality simulations may not be
appropriate because emissions occur in different locations (as discussed above) and at different times. For a given quantity of fuel, production (upstream activities) occurs far ahead of consumption (vehicle operations). To accurately simulate air quality impacts, emissions that occurred at different times need to be differentiated; the exception is if a fuel has already achieved equilibrium in terms of production and consumption (i.e., the level of production and consumption stay relatively constant over time), which is not common for new fuels.

Chapter 9 Results

9.1 From Natural Gas to LPG

Natural Gas to LPG

Emissions

Well to Use

Emissions

Emissions	**Value**	**Unit**
CO2 Total	7.78	g
CH4	0.1	g
CO2	7.78	g
CO2_Biogenic	6.74E+00	mg
VOC	12.4	mg
CO	16.61	mg
NOx	25.58	mg
PM10	0.85	mg
PM2.5	0.75	mg
SOx	22.49	mg
N2O	0.16	mg
BC	0.18	mg
POC	0.31	mg
CH4	0.1	
CO2	7.78	
GHG-100	**10.91**	**g**
Flow properties		
Biogenic carbon mass ratio	0	%
Resources		
Well to Use		
Resources	1121	kJ
Water Total	16.8	cm^3

Water Mining	6.92	cm^3
Water Process	6.79	cm^3
Water Reservoir Evaporation	1.73	cm^3
Water Cooling	1.36	cm^3
Crude Oil	7134.33	J
Natural Gas	1106	kJ
Coal Average	3496.81	J
Forest Residue	73.48	J
Pet Coke	7.89	J
Renewable, Other	24.22	J
Uranium Ore	9.89	ug
Hydroelectric Power	372.66	J
Nuclear Energy	1043.89	J
Geo Thermal Power	21.24	J
Solar	93.99	J
Wind Power	382.03	J
Bitumen	669.88	J
Shale Oil (Bakken)	678.84	J
Shale Oil (Eagle Ford)	760.25	J
Groups	...	
Fossil Fuel	1119	kJ
Natural Gas Fuel	1106	kJ
Petroleum Fuel	9251.2	J
Coal Fuel	3496.81	J
Non Fossil Fuel	2011.52	J
Nuclear	1043.89	J
Renewable	967.63	J
Biomass	73.48	J
Water	16.8	cm^3

Urban Emissions

Well to Use

Emissions

CO2 Total	0.35	g
CO2	0.35	g
CO2_Biogenic	-8.76E-08	kg
VOC	0.11	mg
CO	0.2	mg
NOx	0.71	mg
PM10	43.36	ug
PM2.5	35.82	ug
SOx	0.55	mg
CH4	0.13	mg
N2O	4.34	ug
BC	4.12	ug
POC	13.57	ug
Groups		
GHG-100	**0.35**	**g**

From Crude Oil to LPG

Crude Oil to LPG

Emissions

Well to Use

Emissions

CO2 Total	14.69	g
CO2	14.71	g
CO2_Biogenic	-2.24E-05	kg
VOC	7.84	mg
CO	13.37	mg
NOx	24.76	mg
PM10	2.03	mg
PM2.5	1.72	mg

SOx	9.45	mg
CH4	99.58	mg
N2O	0.23	mg
BC	0.23	mg
POC	0.39	mg
Groups		
GHG-100	**17.78**	**g**
Flow properties		
Biogenic carbon mass ratio	0	%
Resources		
Well to Use		
Resources	1200	kJ
Water Total	92.52	cm^3
Water Mining	63.5	cm^3
Water Process	18.93	cm^3
Water Reservoir		
Evaporation	5.63	cm^3
Water Cooling	4.46	cm^3
Crude Oil	823.69	kJ
Natural Gas	114.02	kJ
Coal Average	11.32	kJ
Forest Residue	243.7	J
Pet Coke	911.41	J
Renewable, Other	80.33	J
Uranium Ore	32.8	ug
Hydroelectric Power	1214.89	J
Nuclear Energy	3461.98	J
Geo Thermal Power	70.45	J
Solar	311.71	J
Wind Power	1266.99	J
Bitumen	77.35	kJ
Shale Oil (Bakken)	78.38	kJ

Shale Oil (Eagle Ford)	87.78	kJ
Groups	...	
Fossil Fuel	1193	kJ
Petroleum Fuel	1068	kJ
Natural Gas Fuel	114.02	kJ
Coal Fuel	11.32	kJ
Non Fossil Fuel	6650.03	J
Nuclear	3461.98	J
Renewable	3188.05	J
Biomass	243.7	J
Water	92.52	cm^3

Urban Emissions

Well to Use

Emissions

CO2 Total	6.79	g
CO2	6.79	g
CO2_Biogenic	-2.91E-07	kg
VOC	2.37	mg
CO	2.81	mg
NOx	3.91	mg
PM10	0.89	mg
PM2.5	0.77	mg
SOx	3.18	mg
CH4	2.55	mg
N2O	67.14	ug
BC	62.41	ug
POC	86.47	ug
Groups		
GHG-100	**6.9**	**g**

From the bar chart we can see how much emissions are occurring we extract LPG from natural gas

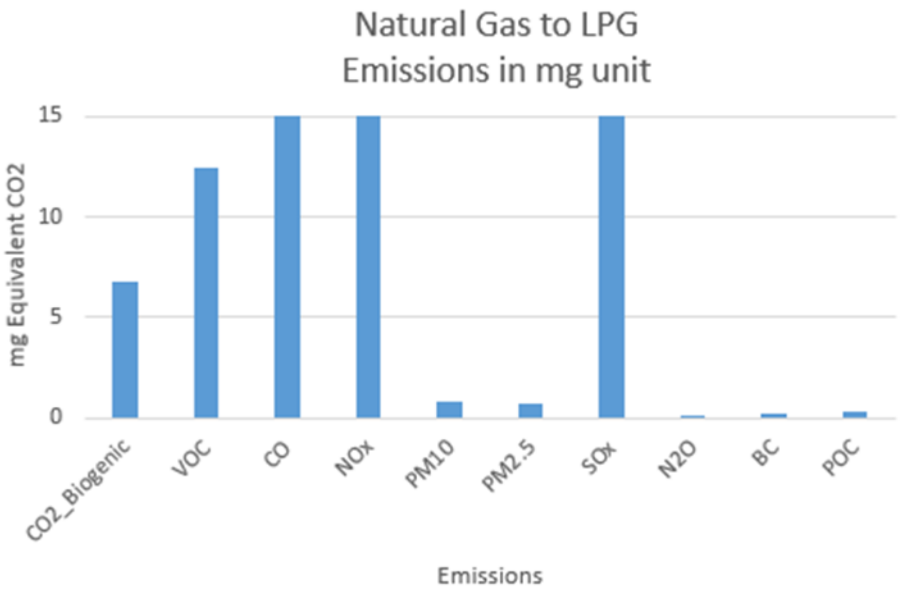


Figure 9.1: Natural Gas to LPG Emission in mg Unit

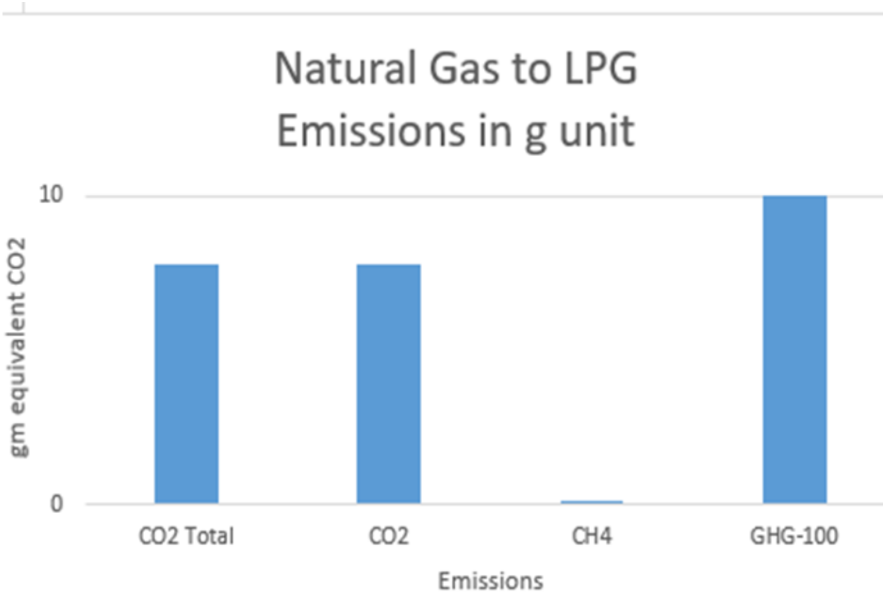


Figure 9.2: Natural Gas to LPG Emission in g Unit

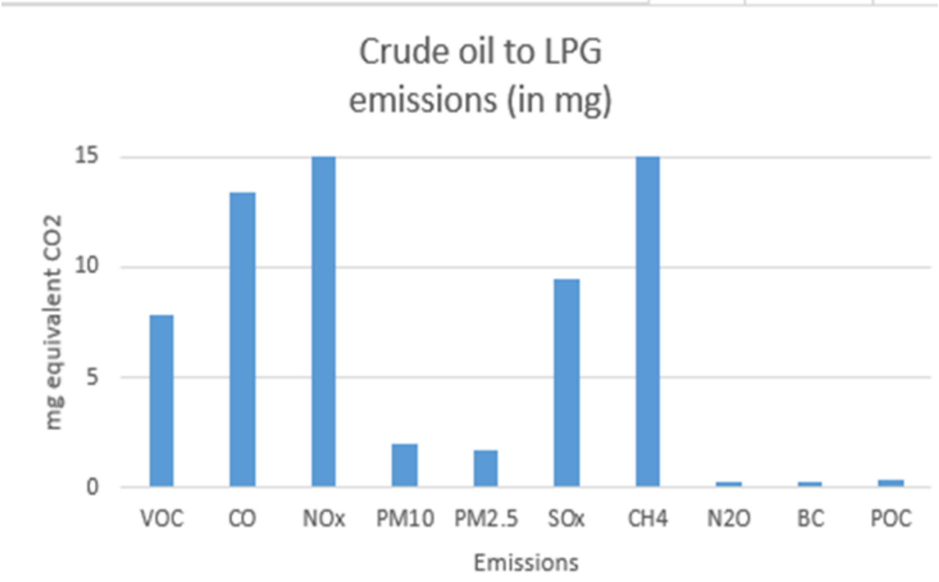


Figure 9.3: Crude Oil to LPG Emission (in mg)

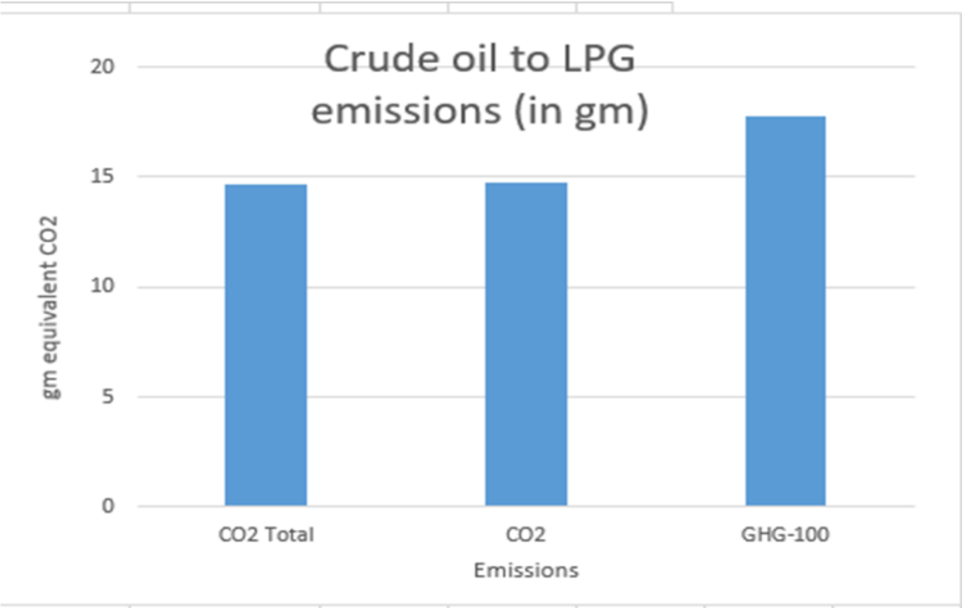


Figure 9.4: Crude oil To LPG Emission (in gm)

So, it is clearly visible that GHG emission is much higher when we extract LPG from Crude Oil but GHG emission is less when we extract LPG from Natural Gas.

9.2 Calculation done on other fuels summarized

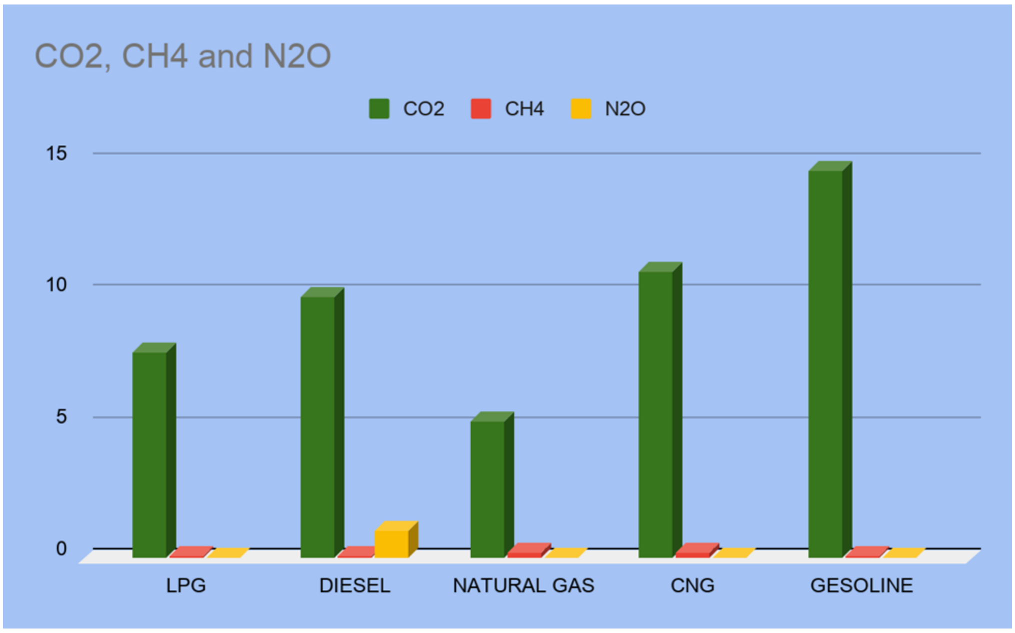


Figure 9.5: GHG Emission of Different Fuels (gram per MJ)

Chapter 10 Conclusion

10.1 Future Scope of Study

It is clearly observed that Bangladesh does not have database for Life Cycle Analysis (LCA) like other countries. It is now a necessity to create a LCA database nationwide. With the database all necessary data for conducting LCA of any products of gases could be found easily. In this project we could not collect all data. During this pandemic it was inconvenient to collect all of them as well. If we had a database of our own it would be really easy for us to conduct LCA.

LCA consultancy firms could also be opened. Consultancy firms could be useful to understand which gas or products can be used. It would also be easy to compare among other products and choose the suitable one. It would be really helpful for future researchers for conducting LCA of products.

Bangladesh has always been a gas-dependent nation. Usage of LPG as a transportation fuel in Bangladesh is quite low. So this can be an emerging opportunity to promote the usage of LPG as transportation fuel as its GHG emission is quite lower than any other gas and people are not aware of the benefit of LPG. With this study we can influence people of Bangladesh to increase the usage rate of LPG.

In this project we have emphasized on LCA of LPG as transportation fuel. If we can create a LCA database and consultancy firm nationwide it is possible to conduct LCA of LPG as cooking fuel as well.

There are different categories for vehicles such as light weighted vehicle, heavy weighted vehicles etc. With having LCA database and consultancy firm in Bangladesh it is possible to calculate GHG emissions of different types of vehicles.

10.2 Conclusion

We can conclude that it is not possible to remove emissions altogether immediately. There are a lot of products are involved with emissions like CO_2, SO_2, CH_4 etc. There are always some emissions involved with every fuel. We cannot remove every harmful emission from the production of fuel. Hence we must reduce emission rates as much as possible. Otherwise this can be really harmful and dangerous for world. So to reduce the emission rate LPG can be a good alternative solution as its emission rate is quite lower comparing to other fuels like petroleum, CNG (compressed natural gas), diesel etc. LPG market is also on the rise because of its very clean burning, cost effectiveness, easy transportation facilities. Also in Bangladesh price of LPG is really lower than the international market price. Natural Gas has the lowest emission among all the fuels. So, LNG is a better option comparing to LPG but it is not a reliable alternative unfortunately. Because it is really difficult to Import natural gas and also it has a higher price rate than LPG. Though Natural gas is the main energy source in Bangladesh but unfortunately it is a non-renewable energy source. So it is time to understand the importance of LPG as transportation fuel and the government of Bangladesh should promote more to use LPG as transportation fuel as it is a better alternative solution than any other available fuels.

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