energies

Supplementary Information

On Reduced Consumption of Fossil Fuels in 2020 and its Consequences in Global Environment and Exergy Demand

A. Rashedi [1,2,*], Taslima Khanam [1] and Mirjam Jonkman [1]

[1] College of Engineering, IT & Environment, Charles Darwin University, Ellengowan Drive, Casuarina, Northern Territory 0810, Australia
[2] Faculty of Business, Economics & Law, The University of Queensland, St Lucia, Queensland 4067, Australia
* Correspondence: mabrur.rashedi@cdu.edu.au; amma0002@e.ntu.edu.sg

S1. Global consumption of petroleum and other liquids:

The consumption data of petroleum and other liquids in USA in both the year 2019 and 2020 have been sourced from 'Short-Term Energy Outlook August 2020' report, as published by Energy Information Administration, USA [1]. Percentage share of consumption for individual oil category has been calculated based on the above data. This percentage consumption data has been assumed to be same in both US and global case study. Similarly, global total consumption data of petroleum and other liquids in both 2019 and 2020 have been sourced from 'Short-Term Energy Outlook Aug 2020' [1]. Accordingly, the global consumption data of each individual petroleum product has been quantified. Details of the US and world level consumption data of petroleum and other liquids for the year 2019 and 2020 have been presented in Supplementary Tables 1–4.

Supplementary Table S1. Consumption of petroleum and other liquids in USA in 2019 [1].

	Consumption per day on Average in 2019	**Consumption in 2019**	**Percentage of Individual Oil in 2019**
	million barrel per day	million barrel per year	%
Hydrocarbon Gas Liquids	3.13	1142.45	15.29814272
Unfinished Oils	0.05	18.25	0.244379277
Motor Gasoline	9.2725	3384.4625	45.32013685
Jet Fuel	1.74	635.1	8.504398827
Distillate Fuel Oil	4.0825	1490.1125	19.95356794
Residual Fuel Oil	0.2725	99.4625	1.331867058
Other Oils	1.9125	698.0625	9.347507331
Total US Petroleum Consumption	20.46	7467.9	100

Supplementary Table S2. Consumption of petroleum and other liquids in USA in 2020 [1].

	Consumption per Day on Average in 2020	**Consumption in 2020**	**Percentage of Individual Oil in 2020**

	million barrel per day	million barrel per year	%
Hydrocarbon Gas Liquids	3.0925	1131.855	16.76
Unfinished Oils	0.0625	22.875	0.34
Motor Gasoline	8.3525	3057.015	45.26
Jet Fuel	1.2025	440.115	6.52
Distillate Fuel Oil	3.7225	1362.435	20.17
Residual Fuel Oil	0.2175	79.605	1.18
Other Oils	1.805	660.63	9.78
Total US Petroleum Consumption	18.455	6754.53	100

Supplementary Table S3. Consumption of petroleum and other liquids in the world in 2019 [1,2].

	Consumption in 2019	**Percentage of individual oil in 2019**	**Consumption in 2019**
	million barrel per year	%	billion litre per year
Hydrocarbon Gas Liquids	5631.982557	15.30	895.43
Unfinished Oils	89.96777248	0.24	14.30
Motor Gasoline	16684.52341	45.32	2652.67
Jet Fuel	3130.878482	8.50	497.78
Distillate Fuel Oil	7345.868623	19.95	1167.92
Residual Fuel Oil	490.32436	1.33	77.96
Other Oils	3441.267297	9.35	547.13

Supplementary Table S4. Consumption of petroleum and other liquids in the world in 2020 [1,2]

	Consumption in 2020	**Percentage of individual oil in 2020**	**Consumption in 2020**
	million barrel per year	%	billion litre per year
Hydrocarbon Gas Liquids	5711.099301	16.76	908.01
Unfinished Oils	115.4223788	0.34	18.35
Motor Gasoline Product Supplied	15425.0467	45.26	2452.43
Jet Fuel	2220.726567	6.52	353.07
Distillate Fuel Oil	6874.556879	20.17	1092.99
Residual Fuel Oil	401.6698781	1.18	63.86
Other Oils	3333.398299	9.78	529.98

S2. Global consumption of natural gas and coal:

As like petroleum and other liquids, the US based consumption data of natural gas and coal for 2019 and 2020 have been sourced from 'Short-Term Energy Outlook August 2020' report, as

published by Energy Information Administration, USA [1,2]. The global consumption data of the same have been sourced from the website of the Energy Information Administration, USA, for up to the year of 2017 [3]. Percentage per year increases in global consumption of natural gas and coal have been sourced from 'International Energy Outlook 2019', as published by Energy Information Administration, USA [4]. Accordingly, the global consumption data of natural gas and coal for the year 2018 and 2019 have been calculated.

Later on, it has been assumed that the percentage decrease in natural gas and coal consumption in the world will be equal to the same of USA in 2020. Accordingly, details of the world level consumption data of natural gas and coal for the year 2019 and 2020 have been presented in Supplementary Tables 5 and 6, respectively.

Supplementary Table S5. Consumption of natural gas in the world in 2019 and 2020 [1-5].

Consumption in 2019	Consumption in 2020
billion cubic meter per year	billion cubic meter per year
3829.41385	3722.607252

Supplementary Table S6. Consumption of coal in the world in 2019 and 2020 [1-5].

Consumption in 2019	Consumption in 2020
billion kg per year	billion kg per year
7796.418362	5778.959065

S3. Life cycle inventory and life cycle assessment model:

Herein, the authors aim to discuss the life cycle inventories of the aforesaid fossil fuels in details. Out of the fossil fuels, hydrocarbon gas liquid, unfinished oil, distillate fuel oil, other oil, and natural gas have been modelled based on global average scenario which separately quantifies the LCA impact of respective fossil fuel technologies in many different locations of the world and then evaluates the global average. For the rest of the fossil fuels, the Ecoinvent database lacks a global average LCI. However, very representative LCI processes with the regional code of "rest of the world" (abbreviated as, ROW) are available for the remaining fossil fuels which have been chosen for these remaining fuels. Accordingly, it is clear that the present study assumes the fossil fuel technologies vary considerably in different locations.

Out of these, hydrocarbon gas liquid consists of: (i) liquefied petroleum gas (primarily ethane, propane, butane, isobutane, and refinery olefins, such as, ethylene, propylene, butylene, and isobutylene), and, (ii) natural gasoline [2]. Percentage consumption of these gases have been sourced from EIA report [1,2]. Accordingly, the life cycle processes of hydrocarbon gas liquid have been modelled based on the percentage consumption of above fuels. Ultimately, 1 litre hydrocarbon gas liquid consists of 0.373 litre propane equivalent and 0.627 litre gasoline equivalent. Hydrocarbon gas liquid necessitates various inputs from the technosphere; such as, onshore natural gas field infrastructure, onshore gas well, diesel burned in diesel-electric power generation process, medium voltage electricity, heating energy, steam, ethylene glycol, methanol, sour gas, sweet gas, sweetening process of natural gas, drying of natural gas, liquid ammonia, calcium chloride, organic chemical, liquid chlorine, heavy fuel oil, hydrochloric acid, iron sulfate, hydrated lime, lubricating oil, methyl tert-butyl ether, molybdenum, naphtha, nickel, liquid nitrogen, palladium, petroleum, platinum, liquid propylene glycol, rhodium, soap, sodium hypochlorite, sulfuric acid, zeolite, zinc and water. Whereas major outputs to the technosphere include average incineration residue, hazardous waste, municipal solid waste, refinery sludge, spent catalytic converter NO_x reduction, spent antifreezer

liquid, spent solvent mixture, waste emulsion paint, waste refinery gas, waste mineral oil, waste sour natural gas, waste sweet natural gas, waste textile, waste wood, discharged water from natural gas extraction, etc.

Unfinished oil has been modelled with equivalent 'petroleum' {GLO} process based on Ecoinvent database version 3.6 [6]. Accordingly, the unfinished oil process models the petroleum LCIs all over the world in both onshore and offshore sectors and encompass materials, minerals, chemicals, energy use, infrastructures and other life cycle emissions to air, water and soil. Herein, inputs from technosphere include inorganic chemicals, organic chemicals, vented natural gas, onshore well platform, onshore petroleum field infrastructure, offshore platform, petroleum pipeline infrastructure, sweet gas burned in gas turbine, etc. An inconclusive list of inorganic chemicals includes powdered aluminium sulfate, liquid ammonia, ammonium nitrate, ammonium sulfate, calcium chloride, liquid chlorine, hydrochloric acid, hydrogen fluoride, nitric acid, liquid oxygen, liquid nitrogen, industrial grade phosphoric acid, milled quicklime, light soda ash, sodium chlorate, sodium hydroxide, sodium silicate, sodium sulfate, sulphuric acid, titanium dioxide, etc. Major organic chemicals include acetic acid, acetone, benzene, butadiene, ethyl benzene, ethylene dichloride, ethylene oxide, ethylene, ethylene glycol, formaldehyde, methanol, methyl tert-butyl ether, phenol, propylene, styrene, toluene, urea, vinyl acetate, vinyl chloride, xylene, naphtha, etc. Onshore petroleum field infrastructure necessitates reinforcing steel, electricity, diesel (to operate various construction machinery), etc. Petroleum pipeline construction process mostly accompanies materials like reinforcing steel, hot rolled low-alloy steel, sand, and processes such as drawing of steel pipe and use of diesel in various mobile machinery, etc. Similarly, onshore oil/gas well production process necessitates activated bentonite, barite, Portland cement, inorganic chemical, organic chemical, diesel, lignite, lubricating oil, reinforcing steel, etc. Major materials included in offshore oil exploration platforms are cast aluminium alloy, cast iron, concrete, low-alloyed steel, hot roller chromium steel, zinc, copper, metallurgical grade silicon, etc. Whereas outputs to the technosphere include radioactive waste, hazardous waste, waste concrete, municipal solid waste, waste discharge from onshore extraction, fraction 1, 7, 8 from naphtha separation, etc.

Usually petroleum is produced as a co-product of 'combined gas and oil production' process. Therefore, the principle of co-product allocation has been applied in these Ecoinvent processes.

Next, motor gasoline has been modelled with equivalent 'petrol' process based on Ecoinvent database version 3.6 that includes petrol production, all necessary infrastructure processes, transportation, and various form of energy usages; such as, electricity, heat, etc. [6]. Unleaded petrol refinery operation requires liquid ammonia, calcium chloride, organic chemical, liquid chlorine, heavy fuel oil, hydrochloric acid, iron sulfate, hydrated lime, lubricating oil, methyl tert-butyl ether, molybdenum, naphtha, nickel, liquid nitrogen, palladium, petroleum, platinum, liquid propylene glycol, rhodium, soap, sodium hypochlorite, sulfuric acid, zeolite, zinc and water from the technosphere. Whereas outputs to the technosphere include refinery sludge, spent catalytic converter NOx reduction and waste refinery gas. The motor gasoline process includes the transportation of the product from the refinery to the end user. It also includes the operation of storage tanks and petrol stations and emissions from evaporations or treatment of effluents. However, emissions from car-washing at petrol stations during transportation is not included.

Distillate fuel oil and residual fuel oil have been modelled with equivalent 'diesel' and 'residual fuel oil' based life cycle inventory (LCI) processes, respectively, based on Ecoinvent database [6]. In addition, the LCI of jet fuel mimics the LCI of motor gasoline except avoiding the technospheric inputs like methyl tert-butyl ether, palladium and rhodium. The same group of materials, processes and energy inputs are needed for distillate fuel oil as well except methyl tert-butyl ether, nickel, palladium, platinum, and rhodium. It is however noteworthy to mention that although various materials, processes or energy inputs are similar across petroleum derivatives, amount of these vary significantly within the fossil fuels. Similarly, emissions to air, water, soil or final waste flows and output to the technosphere vary significantly with respect to the fossil fuels. Full details of these LCI processes are discussed in Ecoinvent database as copyrighted materials.

Other oil consists of few components; as such, asphalt and road oil, naphtha-type jet fuel, special naphtha, kerosene, petroleum coke, waxes, and miscellaneous products [2]. All these components have been assumed to share equal volume percentage in per litre 'other oil' as there is no information on the percentage data of each individual component in EIA reports [1-4]. Accordingly, 0.2 litre asphalt and road oil, 0.2 litre naphtha, 0.2 litre kerosene, 0.2 litre petroleum coke and 0.2 litre wax have been modelled for each litre 'other oil'.

The life cycle processes of natural gas and coal have been modelled based on equivalent 'natural gas' and 'coal' process out of the Ecoinvent database version 3.6 [6]. As for natural gas LCI process, the core processes include onshore gas well, onshore natural gas field infrastructure, offshore gas well, offshore platform infrastructure, natural gas processing plant processes, liquefied natural gas processes, sweetening of natural gas, high pressure natural gas processes, high pressure distribution network, pressure reduction from high to low pressure, low pressure distribution network, etc. An inconclusive list of technospheric inputs include ethylene glycol, methanol, activated bentonite, barite, inorganic chemical, organic chemical, lignite, lubricating oil, reinforcing steel, concrete, cement, cast iron, sand, pitch, gravel, plastic mix, water, soda ash, excavation process, pipe drawing process, transportation process, electricity, diesel, etc. Similarly, major outputs to the technosphere include decommissioned pipeline, waste natural gas, waste bitumen, waste concrete, waste plastic, waste reinforcement steel, hazardous waste, municipal waste, radioactive waste, etc.

Lastly, the Ecoinvent processes of lignite {ROW} and hard coal {ROW} have been used in coal LCI modelling. Hard coal represents both anthracite and bituminous coal. Herein, the LCI processes include few core processes; such as, lignite coal mining operation, lignite coal preparation, hard coal mining operation, hard coal preparation, open cast mining infrastructure, underground mining infrastructure, etc. The inputs from nature include hard coal, lignite coal, off-gas, water, etc. The inputs from technosphere include reinforcing steel, alloy steel, aluminium, cement, concrete, copper, zinc, wood, rubber, plastic, water, organic, inorganic chemicals and other process inputs, such as, electricity, transportation, blasting process, diesel, heat energy, etc. In addition, the outputs to the technosphere include spoils from lignite and hard coal mining in the form of landfill, incinerated waste, hazardous waste, coal slurry, waste wood, etc.

Finally, a licensed copy of SimaPro LCA software version 9.0.0.49 has been used for LCA modelling [7].

Supplementary References

1. US Energy Information Administration. Short-Term Energy Outlook August 2020.
2. Office of Energy Statistics, U.S. Department of Energy, Washington, USA (2020).
3. US Energy Information Administration. Monthly Energy Review April 2020. DOE/EIA-0035(2020/4). Office of Energy Statistics, U.S. Department of Energy, Washington, USA (2020).
4. US Energy Information Administration. As available in https://www.eia.gov/. Accessed on 12 September 2020.
5. U.S. Energy Information Administration. International Energy Outlook 2019. Office of Energy Statistics, U.S. Department of Energy, Washington, USA (2019).
6. Ecoinvent version 3.6. As available in https://www.ecoinvent.org/database. Accessed on 10 September 2020.
7. SimaPro version 9.0.0.49. PRé. Quantifying sustainability. As available in https://www.presustainability.com/. Accessed on 10 September 2020.



© 2020 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).