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On reduced consumption of fossil fuels in 2020 and its consequences in global environment and exergy demand

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Abstract

As the world grapples with the COVID-19 pandemic, there has been a sudden and abrupt change in global energy landscape. Traditional fossil fuels that serve as the linchpin of the modern civilization have found their consumption rapidly fell across the most categories due to strict lockdown and stringent measures that have been adopted to suppress the disease. These changes consequently steered various environmental benefits across the world in recent time. The present article is an attempt to investigate these environmental benefits and reversals that have been materialized in this unfolding situation due to reduced consumption of fossil fuels. The life cycle assessment tool has been used hereby to evaluate nine environmental impacts and one energy based impact. These impacts include: ozone formation (terrestrial ecosystems), terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, land use, mineral resources scarcity and cumulative exergy demand. Outcomes from the study demonstrate that COVID-19 has delivered impressive changes in global environment and life cycle exergy demand with about 11-25% curtailment in all above-mentioned impacts in 2020 in comparison to their corresponding readings in 2019.

Keywords: fossil fuels, life cycle assessment (LCA), COVID-19, environment, resources, exergy

List of abbreviations:

1,4-DCB eq	1,4-dichlorobenzene equivalent	ME	Marine eutrophication
kg Cu eq	kg copper equivalent	MET	Marine ecotoxicity
kg N eq	Kg nitrogen equivalent	MRS	Mineral resources scarcity
kg P eq	kg phosphorus equivalent	NASA	National Aeronautics and Space Administration
CHP	Combined heat and power	NMVOC	Non-methane volatile organic compounds
EIA	Energy Information Administration	NO_x	Nitrogen oxides
ESA	European Space Agency	OFTE	Ozone formation (terrestrial ecosystems)

FE	Freshwater eutrophication	PM2.5	Particulate matter with diameter less than 2.5 micron
FET	Freshwater ecotoxicity	SO_2	Sulphur dioxide
GHG	Greenhouse gas	TA	Terrestrial acidification
LCA	Life cycle assessment	TET	Terrestrial ecotoxicity
LCI	Life cycle inventory	VOC	Volatile organic compounds
LU	Land use		

1. Introduction

The Novel Coronavirus disease 2019 (COVID-19), which was first reported in Wuhan, China, in December 2019, has since spread rapidly across the globe. The World Health Organization declared the outbreak a Public Health Emergency of International Concern on 30th January, 2020, and a pandemic on 11th March, 2020 [1]. So far, the pandemic has significantly altered the anthropogenic activities around the world. In a matter of months, 81% of the global workforce of 3.3 billion people have had their workplace fully or partly closed [2] and most of the countries or territories went into lockdown in order to contain the disease. These changes, however, initiated sudden changes in global environment in numerous ways. In one instance, the residents of the state of Punjab, India, had been able to see the snow-capped peaks of the Himalayas for the first time in 30 years from about 100 miles away due to a massive drop in air pollution [3]. In another instance, Li et al. (2020) discovered that several primary pollutants; viz., SO_2, NO_x, PM2.5 and volatile organic compounds (VOCs), have diminished by approximately (abbreviated as, approx. later) 16-26%, 29-47%, 27-46% and 37-57%, respectively, between Jan-Mar, 2020, over the entire Yangtze River Delta region in Eastern China, based on the meteorological data obtained from National Climate Data Center of National Oceanic and Atmospheric Administration and National Data Center of the Chinese Meteorology Agency [4]. Wang and Su (2020) additionally reported that COVID-19 suppressed the Chinese consumption of coal by about 20% and diminished the consumption of energy and emission of CO_2, NO_2 sharply in many regions of China [5]. Moreover, Muhammad et al. (2020) reported that NO_2 emission declined by up to 30% in Italy, Spain, France and the USA in different months of 2020. The latter two studies focused on dedicated satellite imagery data from National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) [6]. Likewise, there is a remarkable improvement in aquatic environment in different regions of the world. An unprecedented level of water transparency has been observed in canals and lagoons of Venice, Italy, based on the satellite imagery data of ESA in Mar-Apr, 2020 [7]. In addition, an impressive level of improvement in surface water quality has been reported in the Vembanad lake, the longest freshwater lake of India, with consequential reduction in the concentration of suspended particulate matter since Apr, 2020 [8]. All these changes have been recorded at a time when the world has been grappling with so many environmental issues. A short list of these issues includes climate change, air pollution, fine particulate matter formation, ionizing radiation, water pollution, acidification, eutrophication, toxicity, hazardous waste, radioactive waste, tropospheric ozone formation, stratospheric ozone layer depletion, depletion of water, mineral, fossil fuel and other natural resources, etc. However, as concentrations of the primary air and water based pollutants reduced impressively in COVID-19 pandemic situation [3-8], it is expected to carry distinctive changes in many of the corresponding environmental concerns. As such, a holistic study on the environmental changes is unequivocally necessary at this unique time.

However, the above-mentioned studies that are mostly based on the data from satellite imagery or ground-based measurement stations are more applicable for a localized zone rather than for a whole country or global basis. In addition, satellite measurements have large uncertainties and demonstrate high variability in concentration fluxes due to diverse meteorological parameters [9,10]. Accordingly, it is unconventional to determine the global scale anthropogenic emissions just based on the satellite imagery data. Evidence of this can be seen from the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) which quantify the global greenhouse gas emission on the basis of various anthropogenic activities rather than focusing on worldwide satellite data [11]. Hence, changes in global anthropogenic activities will stand as a strong basis for estimating the change in global environment in this unique time. However, in a practical situation, most of these activities are not updated instantaneously. In COVID-19 situation, this process has been further challenging due to sudden, unexpected and tremendous changes in anthropogenic activities and their associated uncertainties.

Nevertheless, few countries and organizations have reported near-real time and/or projected data for both fossil fuel and renewable energy usage both for national and global scenarios [12-17]. Out of these, the fossil energies shape almost all sectors of modern life, living and society whether it is food, accommodation, electricity, transportation or industrial use. A relevant industry report states that three major fossil fuels; viz., petroleum, coal and natural gas, contributed to approx. 34%, 27% and 24% of the total primary energy consumption of the world, respectively, in 2019 [17]. Another example from the 5th Assessment Report of IPCC (IPCC AR5) states that the fossil fuels issued about 32±3.7E+09 metric ton CO_2 eq greenhouse gas (GHG) emission in 2010 which amounted to ~61.54% of the total worldwide GHG emission in the same year [18]. Accordingly, the fossil fuels hold the potential to upend or fluctuate the global environment immensely. The authors, therefore, focus on the change in the consumption of fossil fuels to determine the changes in global environment and exergy demand in 2020.

The changes in the worldwide consumption of the fossil fuels have particularly been demonstrated in various reports from the Energy Information Administration (EIA) which is the leading statistical and analytical agency of the US Department of Energy and is one of the most reputable organizations of its kind worldwide. Particularly, the Short Term Energy Outlook Aug 2020 report by EIA highlights about the impacts of COVID-19 on fossil fuels as "Reduced economic activity related to the COVID-19 pandemic has caused changes in energy supply and demand patterns in 2020. Uncertainties persist across the U.S. Energy Information Administration's (EIA) outlook for all energy sources, including liquid fuels, natural gas, electricity, coal, and renewables" [15,16]. In another instance, the same report focuses on the fundamental cause of declining consumption of petroleum products as such: "The decline reflects travel restrictions and reduced economic activity related to COVID-19 mitigation efforts" [16]. Similarly, about impact of COVID-19 on natural gas, the report states that "The largest decline in consumption occurs in the industrial sector … as a result of reduced manufacturing activity" [15,16]. In another instance, the report mentions that, "EIA expects that US LNG exports will decline through the end of the summer as a result of reduced global demand for natural gas" [15,16]. In addition, the Short Term Energy Outlook Aug 2020 report states that "coal consumption will decrease by 26% in 2020 and increase by

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20% in 2021" after an estimated recovery from COVID-19 [16]. In another note, the coal production will decrease by 25% to 530 million short tons (MMst) in 2020 based on reduced demand from global steel production, coking coal and steam coal [15]. Therefore, it is unequivocally necessary to reflect on how the change in fossil fuel consumption shapes the global environment in our time.

Life cycle assessment (LCA) has been used hereby as the methodological tool to calculate the changes in various environmental impacts and exergy demand. LCA is one of the most powerful environmental impact assessment tools that models the entire life cycles of fossil fuels starting from its extraction from nature to all life cycle phases, including, refining, transportation, end-use to until the final end-of-life emission while most of the other tools, such as, environmental impact assessment, cost-benefit analysis or material intensity per unit service estimates the environmental impacts mostly for the operational phase of the system [19-22]. In addition, LCA offers a robust, unbiased, quantitative and objective analysis of the environmental impacts of a technology or a product.

Overall, the present study accompanies at least two novelties in respective domains of knowledge, which are as follows:

1) this is the first LCA based study that has evaluated the changes in 9 environmental impacts in 2020 due to the reduced consumption of fossil fuels – these include: a) ozone formation (terrestrial ecosystems), b) terrestrial acidification, c) freshwater eutrophication, d) marine eutrophication, e) terrestrial ecotoxicity, f) freshwater ecotoxicity, g) marine ecotoxicity, h) land use, and, i) mineral resources scarcity;

2) the study additionally evaluates the changes in cumulative exergy demand due to the reduced consumption of fossil fuels from the life cycle perspective; so far, no scholarly article focused on this theme to evaluate the changes occurring in COVID-19 period. The cumulative exergy demand calculates the exergy removed from nature in the process of all life cycle steps of the fossil fuels; accordingly, it determines how much exergy savings is achievable in 2020 due to the change in fossil fuel consumption.

Finally, both of these novelties have been affirmed based on the systematic literature search studies conducted in three prominent databases; such as, Scopus, ScienceDirect and Web of Science, latest on 8th Nov, 2020.

2. Methodology

2.1 Goal and scope definition

This study conducts a cradle to end-user/gate LCA of various fossil fuels based on their consumption data in the year 2019 and 2020. Three major fossil fuels; viz., petroleum and other liquid, natural gas and coal, have been studied in this context. Relevant consumption data have been sourced from EIA reports [14-16]. As the year 2020 has not finished yet, the consumption data of the first half of the year indicate the actual readings while the same for the latter half is based on the reliable estimates of EIA. Accordingly, consumption data of petroleum include different categories of petroleum end-products, crude oil and unfinished oil. The petroleum end-products include hydrocarbon gas liquid, motor gasoline, jet fuel, distillate fuel oil, residual fuel oil, and other oils. Consumption data of these petroleum end-products have been computed as follows: field production, plus imports, plus refinery and blender net production, plus net receipts, plus adjustments, minus stock change, minus refinery and blender net inputs, minus exports [14-16]. Likewise, for natural gas, the consumption data include the following: a) residential use; b) commercial sector use, including use in commercial combined-heat-and-power (CHP) and commercial electricity-only plants; c) industrial sector use: lease and plant fuel use, and other industrial deliveries, including use in industrial CHP and industrial electricity-only plants; d) transportation sector use including pipelines and distribution use, and vehicle fuel use; and e) electric power sector: electric utility and independent power producer use [14-16]. Consequently, the consumption of coal has been based on: a) residential use, b) commercial use, c) industrial sector, d) power production, and, e) coke plants [14-16]. Details of the end-products, their components and the end-uses have been discussed more comprehensively in EIA reports [14-16].

2.2 Life cycle inventory and life cycle assessment process

The worldwide consumption data of fossil fuels in the year 2019 and 2020 have been highlighted in Table 1. Details of these consumption have been discussed in Supplementary Information (S1, S2). Additionally, consumption data of all fossil fuels have been displayed in Supplementary Tables 1-6.

Table 1: Global fossil fuel consumption in 2019 and 2020 [14-16]

Fuel type	**Unit**	**Consumption in 2019**	**Consumption in 2020**
Hydrocarbon gas liquid	litre per year	895.43E+09	908.01E+09
Unfinished oil	same as above	14.30E+09	18.35E+09
Motor gasoline	same as above	2.65E+12	2.45E+12
Jet fuel	same as above	497.78E+09	353.07E+09
Distillate fuel oil	same as above	1.17+12	1.09E+12
Residual fuel oil	same as above	77.96E+09	63.86E+09
Other oils	same as above	547.13E+09	529.98E+09
Natural gas	m^3 per year	3.83E+12	3.72E+12
Coal	kg per year	7.80E+12	5.78E+12

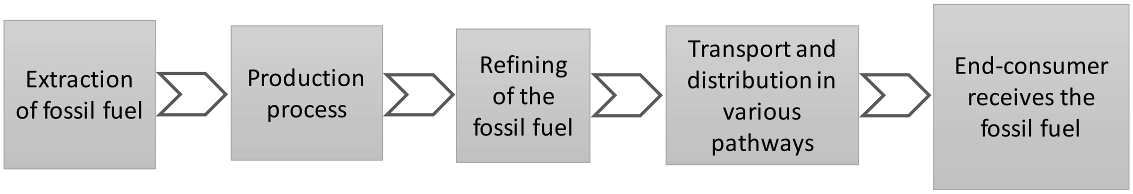


Figure 1: Life cycle processes of the fossil fuels

Some of the fossil fuels; viz., unfinished oil, motor gasoline, jet fuel, distillate fuel oil, residual fuel oil, and natural gas, have been modelled with existing life cycle inventory (LCI) processes available in Ecoinvent database version 3.6 [23]. Some other fossil fuels; such as, hydrocarbon gas liquid, other oil and coal, have been modelled by defining new LCI processes out of the existing ones, as available in aforesaid database. Typical life cycle stages of the fossil fuels have been shown in Figure 1 and details of the LCI processes have been presented in Supplementary Information S3. Additionally, ReCiPe 2016 mid-point (H) method version 1.03 and Cumulative Exergy Demand method version 1.05 have been used in the study [19,24]. The environmental impacts have been calculated based on the characterization factor of each individual emission issued in various life cycle processes and end-of-life stages. Characterisation factor for the same emission or component varies across the impact indicators [19]. Besides, the impact values are indicative of actual, characterized results rather than comparative or normative ones as no normalization reference has been used in the study to compare the results of environmental and exergy based impacts. In addition, 'hierarchist' LCA theme has been applied in evaluating all the environmental impacts which focuses on a moderate time horizon rather than the 'individualist' or 'egalitarian' perspective that deals with short term or very long-term evaluation, respectively [19-21]. This time horizon is not the same for all impacts; moreover, it varies based on 'individualist', 'egalitarian' and 'hierarchist' perspective. Details of these time horizons are discussed in manuals of ReCiPe method [19,22]. Additionally, the exergy of both renewable and non-renewable energy and material resources consumed in different life cycle phases of the fossil fuels have been quantified in cumulative exergy demand evaluation process [24]. These energy and material based resources include potential, kinetic, solar, biomass, water, fossil, nuclear, primary energies and metal and mineral resources. Lastly, the overall LCA modelling has been conducted in SimaPro LCA software platform version 9.0.0.49 [25].

3. Results and discussion

The Results and discussion section covers two sub-sections where the first one highlights the results of nine environmental impacts; while the next one focuses on cumulative exergy demand savings by all fossil fuels in 2020.

3.1. Results of nine environmental impacts

3.1.1. Ozone formation (terrestrial ecosystems)

The results of ozone formation (terrestrial ecosystems) display a drastic reduction of 16% impact in 2020 in comparison to the same in 2019 as a result of the reduced consumption of the fossil fuels. The ozone formation impact has been evaluated based on the ecosystem ozone formation potential (EOFP) of various environmental pollutants [26,27]. Air pollution intensifies photochemical reaction of NOx and non-methane volatile organic compounds (NMVOCs) which ultimately results in increased concentration of ozone in the atmosphere. This photochemical ozone inhibits the growth of seeds, crops and vegetables and decreases the productivity of plant species. Based on the evaluation of EOFPs of various pollutants throughout the life cycle processes of above-mentioned fossil fuels, it appears that per m^3 natural gas issues the lowest ozone formation (terrestrial ecosystems) impact of ~0.00093 kg NOx eq where NOx refers to various nitrogen oxides. This can be attributed to its root LCI processes; viz., high pressure natural gas production, natural gas sweetening and medium voltage electricity required in various life cycle processes carrying lower ozone formation (terrestrial ecosystems) impact. All the contributing emissions hereby are expressed in the unit of NOx due to its well-developed environmental fate and chemistry in relation to the ozone formation. Comparatively, per litre heavy fuel oil, motor gasoline, other oil, distillate fuel oil, jet fuel, hydrocarbon gas liquid and unfinished oil carry approximately (approx.) 2.05, 2.02, 1.95, 1.89, 1.81, 1.76 and 1.26 times impact, respectively, in comparison to per m^3 natural gas. In addition, 1 kg coal exudes ~1.91 times ozone formation impact in comparison to per m^3 natural gas – here blasting process is one of the largest impact contributors which exploits varieties of explosives to break the rocks and excavate the coal mines. Corresponding results of the ozone formation (terrestrial ecosystems) impact have been illustrated in Fig. 1 (a) which demonstrate ~4.46E+09 kg NOx equivalent (eq) reduction in 2020 with respect to the same in 2019. In overall consumption scale, majority of this impact has been curtailed by diminishing use of three fossil fuels; viz., coal, motor gasoline and distillate fuel oil, contributing about 3.58E+09, 3.76E+08 and 1.32E+08 kg NOx eq impact reduction, respectively. By contrast, consumption of unfinished oil and hydrocarbon gas liquid increases by about 28.29% and 1.40%, respectively, in 2020 which consequently increases the ozone formation (ecosystem) impact by total ~2.53E+07 kg NOx eq. It is noteworthy to mention here that although in percentage scale the consumption of 'unfinished oil' exhibits a remarkable increase in 2020; its actual market share is just 0.3% within all liquid fossil fuels in the same year. Hence, its high percentage increase in consumption does not deliver an impressive change in environmental impacts.

3.1.2. Terrestrial acidification

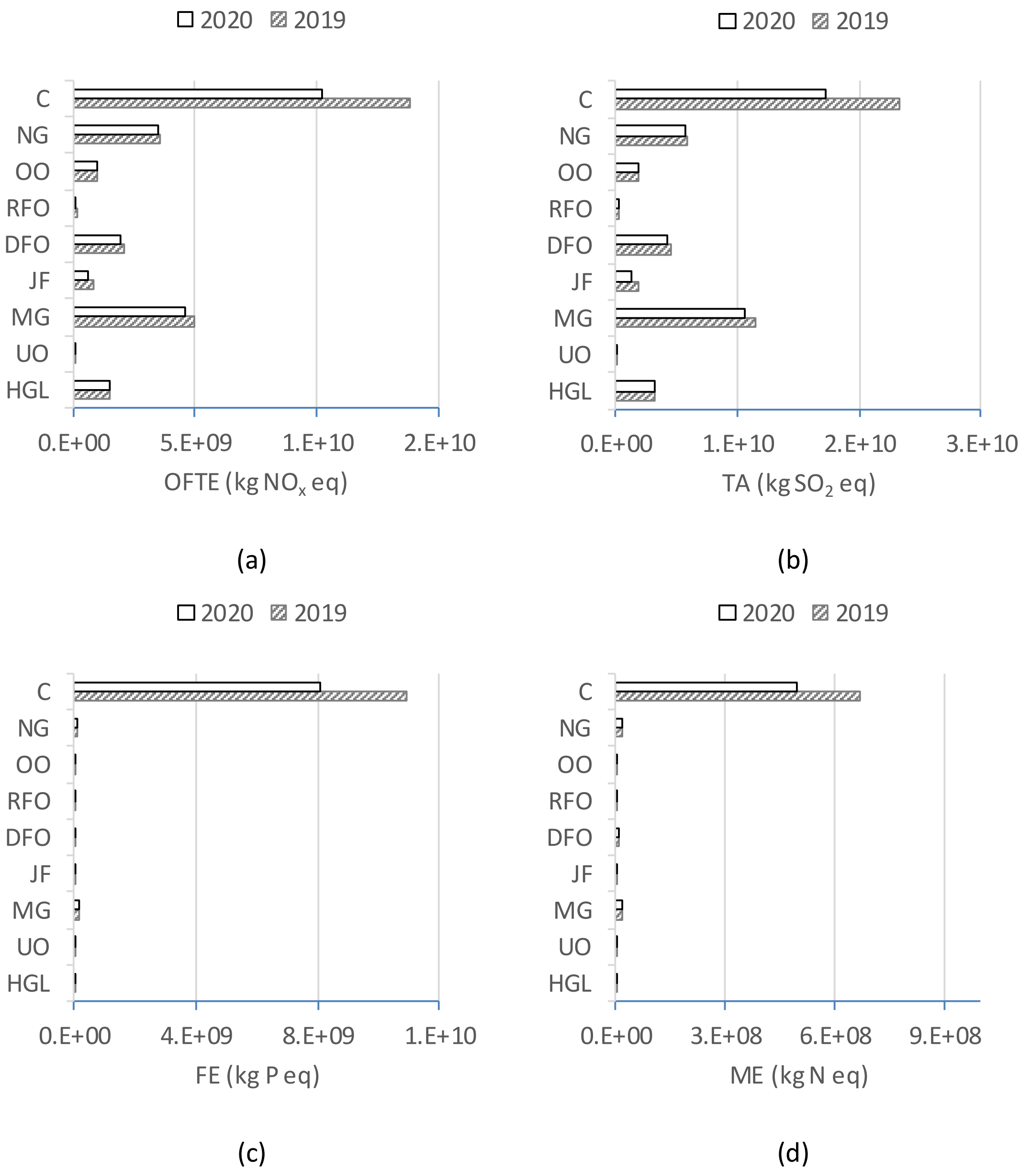
As like ozone formation (terrestrial ecosystems) impact, terrestrial acidification abates by ~15.16% in 2020. Some inorganic substances, such as, sulphates, nitrates and phosphates change the acidity level of soil and consequently affect the growth of plant species [19,28]. Associated acidification potential of each substance is expressed in the unit of kg SO_2 eq where SO_2 represents sulphur dioxide. Out of the above-mentioned fossil fuels, coal delivers the highest reduction in terrestrial acidification impact of ~6.04E+09 kg SO_2 eq. This can be attributed to three factors – i) coal was one of the most widely consumed fossil fuels in the world in 2019; ii) there is an impressive reduction of ~25.88% in coal consumption in 2020 with respect to the 2019 level; and, iii) per kg coal carries ~0.00299 kg SO_2 eq terrestrial acidification impact which represents a considerably high value among all fossil fuels. In a comparative scale, per m^3 natural gas issues the lowest terrestrial acidification impact of about 0.001521 kg SO_2 eq – here, 'sour gas' processing and natural gas sweetening process contribute the most significant impacts of about 0.000505 and 6.14E-5 kg SO_2 eq impact, respectively. By contrast, the life cycle processes of per litre motor gasoline, residual fuel oil, distillate fuel oil and jet fuel issue ~2.83, 2.67, 2.55 and 2.43 times impact of per m^3 natural gas, respectively. Overall, there is a significant decline in the consumption of jet fuel (~29.07%) and residual fuel oil (~18.08%) globally in 2020 owing to COVID-19 pandemic situation. Out of these, jet fuel and residual fuel oil have a market share of ~6.52% and ~1.18% in 2020, respectively, within all liquid fuels which are not significant enough. Thus these fuels do not yield in a significant reduction of terrestrial acidification impact.

3.1.3. Freshwater eutrophication

There is a remarkable decline of ~25.07% in freshwater eutrophication impact in 2020 with respect to the same in 2019. Freshwater eutrophication generally occurs due to the discharge of phosphorus and nitrogen into soil or freshwater which increases the uptake of nutrients by various autotropic organisms and heterotrophic species – this ultimately results in relative loss of freshwater species [19,29]. Out of the fossil fuels, per litre unfinished oil contributes the lowest freshwater eutrophication impact of ~2.8E-05 kg P eq where P refers to phosphorus. Per litre other oil, motor gasoline, residual fuel oil and hydrocarbon gas liquid issue about 2.7, 2.25, 2.18 and 2.02 times impact of the same volume of unfinished oil, respectively. By contrast, the LCI processes of per m^3 natural gas deliver freshwater eutrophication impact of ~2.9E-05 kg P eq only. In addition, per kg coal carries ~49.59 times impact of per litre unfinished oil; therefore, a massive reduction in the consumption of coal ensures an intense drop in freshwater eutrophication impact in 2020. All total, coal reduces the freshwater eutrophication impact by ~2.82E+09 kg P eq. Comparatively, natural gas reduces the impact by only ~3.10E+06 kg P eq which is 0.11% of the reduction by coal. One of the reason behind this is associated with ~2.79% reduction in natural gas consumption in 2020 which is insignificant with respect to the reduction in coal consumption (~25.88%) in the same year. In addition, leachate spoils from lignite and hard coal mining carry short and long term emissions to groundwater through rainwater infiltration leaching – these emissions carry significant freshwater eutrophication of ~0.000719 and ~0.000674 kg P eq for per kg lignite and hard coal, respectively. No LCI process in natural gas contributes such large scale freshwater eutrophication impact. Lastly, combining the contribution of all liquid fuels, net freshwater eutrophication impact reduces by ~2.69E+07 kg P eq after balancing the impact increase by hydrocarbon gas liquid and unfinished oil.

3.1.4. Marine eutrophication

Marine eutrophication generally occurs due to the enrichment of nutrients in marine ecosystems. Usually, most of the industrial runoffs and leaching processes consequently end up in soil, riverine and marine systems which raise the nutrient levels in corresponding ecosystems and thus agitate and perturb these environments. The LCA study of the fossil fuels shows that about 97% reduction in marine eutrophication impact in 2020 is associated with scaled-down consumption of coal, as illustrated in Fig. 1 (d). This amounts to ~1.73E+08 kg N eq where N refers to nitrogen. By contrast, the reduction in natural gas consumption reduces the marine eutrophication impact merely by ~5.05E+05 kg N eq. The same group of leachate based processes, as in freshwater eutrophication impact, again emit the largest marine eutrophication impacts in coal based LCI processes whereas the treatment of dross as a result of electrolysis of aluminium and off-site treatment of sulfidic tailings required in natural gas LCI processes issue highest marine eutrophication of ~2.6E-6 and ~1.99E-7 kg N eq, respectively. Within all liquid fuels, larger reductions in marine eutrophication impact are contributed by motor gasoline, jet fuel and distillate fuel oil with about 1.46E+06, 9.13E+05 and 5.43E+05 kg N eq reduction, respectively. By contrast, per litre unfinished oil entails the lowest marine eutrophication impact of ~2E-06 kg N eq. Other liquid fuels can be sequentially arranged as motor gasoline, distillate fuel oil, other oil, residual fuel oil, hydrocarbon gas liquid and jet fuel issuing about 3.97, 3.94, 3.90, 3.51, 3.47 and 3.43 times marine eutrophication impact of the same volume of unfinished oil, respectively. Unfinished oil necessitates series of downstream processes to transform to final end-products and these downstream processes carry significant marine eutrophication impact. By definition, these additional LCI processes are not accounted for estimating marine eutrophication impact of unfinished oil. In addition, other oil and residual fuel oil had low market share of about 1.33% and 9.35% in 2019. Due to this, their high marine eutrophication impact in per litre LCI process yielded only a marginal reduction of about 1.23E+05 and 9.11E+04 kg N eq impact, respectively, in 2020. Other than these, unfinished oil and hydrocarbon gas liquid increase the marine eutrophication impact by about 7.45E+03 and 8.04E+04 kg N eq, respectively, due to their associated rise in consumption in the same time.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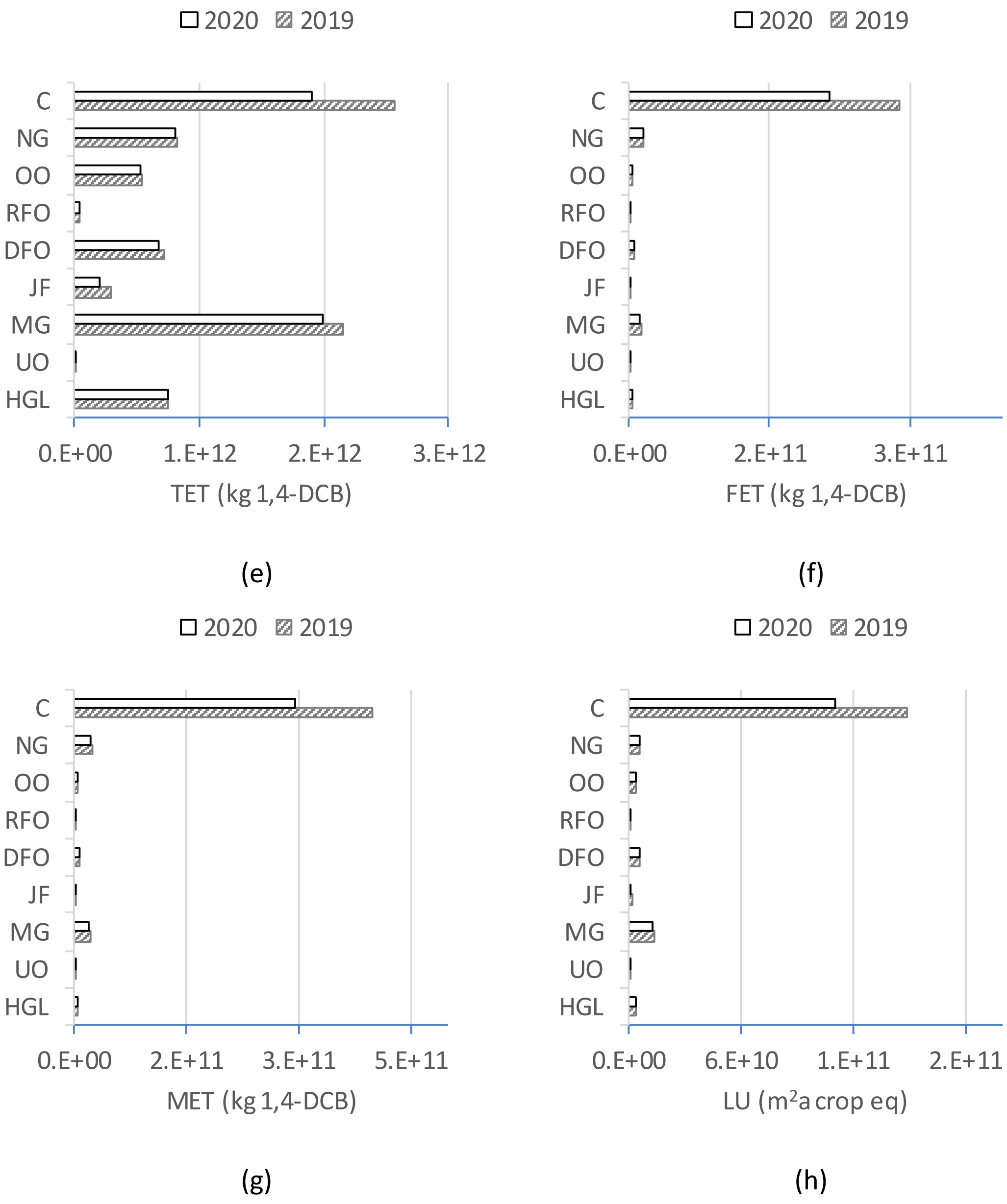
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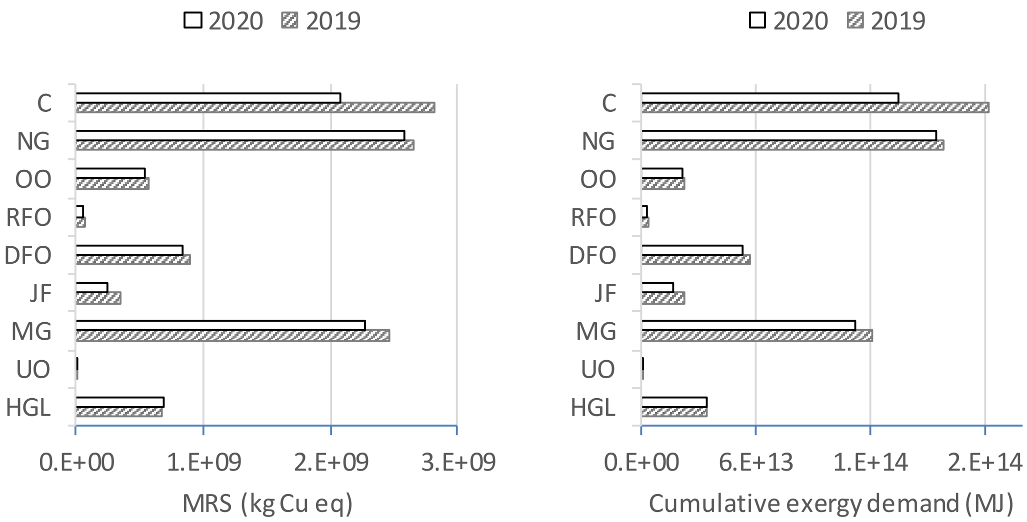

(i) (j)

Figure 2: Changes in LCA impacts due to reduced consumption of fossil fuels owing to COVID-19 situation – a) ozone formation (terrestrial ecosystems) [OFTE], b) terrestrial acidification [TA], c) freshwater eutrophication [FE], d) marine eutrophication [ME], e) terrestrial ecotoxicity [TET], f) freshwater ecotoxicity [FET], g) marine ecotoxicity [MET], h) land use [LU], i) mineral resources scarcity [MRS], and, j) cumulative exergy demand

3.1.5. Terrestrial ecotoxicity, freshwater ecotoxicity, and, marine ecotoxicity

Next, three ecotoxicity based impacts, namely, terrestrial ecotoxicity, freshwater ecotoxicity and marine ecotoxicity, have been evaluated based on the toxicity potential of total 3094 organic and inorganic substances over the life cycle processes of fossil fuels for a time horizon of 100 years [19,30,31]. The ecotoxicity impact of 1 kg 1,4-dichlorobenzene (1,4-DCB) has been used as the reference unit in the associated calculation [19]. Companion fate, exposure and toxicity of chemicals have been simulated based on the global scenarios of USES-LCA model version 3.0 [30,31]. The results of the terrestrial ecotoxicity modelling show that 1 m^3 natural gas carries the lowest impact of ~0.216227 kg 1,4-DCB eq. Most of this terrestrial ecotoxicity impact in natural gas originates from the LCI processes of various metals used in its different life cycle stages. Obviously, these material based processes are not the core LCI processes in natural gas production; hence, the corresponding terrestrial ecotoxicity impact of natural gas is low. The core natural gas based LCI processes; viz., high pressure natural gas production or sweet gas processing only deliver ~0.00118 and ~0.00216 kg 1,4-DCB eq, ecotoxicity impact respectively. A full-fledge process scale impact contribution for all the fossil fuels is out of scope of this study. Nevertheless, it is worthwhile to mention here that per litre jet fuel, residual fuel oil, distillate fuel oil, motor gasoline, hydrocarbon gas liquid and other oil issue about 170%, 180%, 187%, 275%, 284% and 363% more impact than the aforesaid volume of natural gas as their core LCI processes of corresponding liquid fuel production contribute to larger terrestrial ecotoxicity impacts. By contrast, per kg coal delivers about 52% higher impact than natural gas. Herein, the process scale contributions demonstrate that various transport based LCI processes deliver the largest terrestrial ecotoxicity impact in coal. In overall consumption scale, coal delivers a drastic reduction of terrestrial ecotoxicity impact, amounted to about 6.63E+11 kg 1,4-DCB eq, in 2020, due to its impressive cut in consumption in the same time period. In addition, motor gasoline maintains the largest market share of about 45.3% within all liquid fuel consumption; hence, the second largest cut in terrestrial ecotoxicity impact is contributed by motor gasoline, as illustrated in Fig. 1 (e).

Comparatively, the results of freshwater ecotoxicity impact unveil a much different scenario – here, the life cycle processes of per litre unfinished oil carries the lowest impact of ~0.00253 kg 1,4-DCB followed by jet fuel (~0.00392 kg 1,4-DCB), distillate fuel oil (~0.00428 kg 1,4-DCB), hydrocarbon gas liquid (~0.00433 kg 1,4-DCB), residual fuel oil (~0.00477 kg 1,4-DCB), motor gasoline (~0.005 kg 1,4-DCB), and other oil (~0.00737 kg 1,4-DCB), respectively. Accordingly, motor gasoline and jet fuel appear as the leading contributors in freshwater ecotoxicity impact reduction, owing to their: i) associated large scale impact in per litre LCI process, ii) large scale annual consumption, and, iii) significant drop in consumption in 2020. This holds true in marine ecotoxicity impact as well where motor gasoline and jet fuel again deliver significant impact reduction in 2020 owing to COVID-19 situation. However, by considering all the fossil fuels, coal reduces both of the freshwater ecotoxicity and marine ecotoxicity impacts the most, as illustrated in Fig. 1 (f, g). By comparison, natural gas reduces both of the impacts by only about 4.28E+08 and 6.8E+08 kg 1,4-DCB eq, respectively. The consumption of natural gas only reduces by 2.79% in 2020 which is not significant enough to result in a large scale reduction of any of the impacts except when unit LCI processes of natural gas carry tremendously larger impact in comparison to the other fossil fuels.

3.1.6. Land use

Next, diminishing use of fossil fuels induces ~21.89% reduction in land uses in 2020 with respect to 2019. Herein, land use encompasses the process of land transformation, land occupation and land relaxation – the latter models the end-of-life scenarios of land use whereby a land is assumed to return to its pre-transformation phase or (semi-) natural state. Associated characterization factors of various land systems; such as, used forest, pasture and meadow, annual crop based land, permanent crop based land, mosaic agricultural land, urban, industrial and others, have been based on De Baan et al. (2013) and Curran et al. (2014) [32,33]. Out of all the fossil fuels, coal contributes the most in reducing the land use impact in 2020. This amounts to the reduction of ~3.86E+10 m^2 crop eq land area. The coal mining operation requires large swathes of land; in addition, construction of railway track and underground mining infrastructure necessitate about 0.0015 and 0.000682 m^2 crop eq land area for per kg coal production, respectively. The next major land use impact reduction is contributed by motor gasoline with ~1.08E+09 m^2 crop eq land area, as displayed in Fig. 1 (h). Here, LCI processes relevant to the construction of onshore petroleum field infrastructure, regional distribution infrastructure and roads contribute the largest impacts of about 0.00154, 0.000505 and 0.000451 m^2 crop eq land area, respectively. All other fossil fuels deliver a negligible change in land use impact in 2020.

3.1.7. Mineral resources scarcity

Next, the life cycle processes of coal, motor gasoline and jet fuel bring noticeable reduction in 'mineral resources scarcity' impact in 2020. The extraction of mineral resources generally decreases the quality of ores; thus future extraction of minerals necessitates production of increased volume of ores in comparison to the previous extraction [19,20]. The LCI processes of fossil fuels consume diverse kind of materials and minerals; therefore, a reduction in consumption of these fossil fuels carries consequential changes in 'mineral resources scarcity' impact. The surplus ore potentials of 74 different mineral resources have been used hereby to quantify the 'mineral resources scarcity' impact in the equivalence of copper (Cu) [34,35]. Cu is one of the most commonly available material resources in various deposits and mines across the world although its percentage amount varies widely. Hence, it is convenient to quantify the characterizing factors of mining yield and expenses of other minerals with reference to Cu – this yield data is subsequently used in evaluating material resources scarcity impact. Relevant results have been illustrated in Fig. 1 (i) which demonstrates that a reduction in coal consumption ensures a sharp reduction of ~7.28E+08 kg Cu eq impact in 2020 with respect to the same in 2019. Moreover, motor gasoline and jet fuel slash the impact by about 1.86E+08 and 1.01E+08 kg Cu eq, respectively, which are the largest contributors in mineral resources scarcity impact reduction within petroleum and other liquids. Apart from these, hydrocarbon gas liquid and unfinished oil increase the impact by ~9.54E+06 and ~2.16E+06 kg Cu eq due to their associated rise in consumption in 2020. On the basis of per unit LCI process, per kg coal, however, exudes the lowest amount of mineral resource scarcity impact of 0.000361 kg Cu eq within all fossil fuels. This can be attributed to a comparatively lower usage of metal resources in the life cycle processes of coal. Only iron ore mining operation (46% iron), ferronickel production (25% Nickel), molybdenite and bauxite mining operations contribute larger mineral resources scarcity impacts in this fossil fuel. By contrast, per m^3 natural gas carries 1.92 times impact while, for liquid fuels, it varies in the range of 1.48 (unfinished oil) to 2.88 (other oil) times with respect to per kg coal. The LCI processes of iron mining operation, ferronickel and barite production deliver the larger impacts in these liquid fuels.

3.2. Cumulative exergy demand of fossil fuels

Unlike energy, exergy of a system does not follow the law of the conservation of energy. Hence, exergy can be partly or completely lost or destroyed due to the irreversibility in associated thermodynamic processes [36,37]. Accordingly, it is possible to reduce the exergy loss of a system which simultaneously diminishes the consumption of accompanying energy and/or mineral resources by the system and this ultimately abates various environmental impacts. As illustrated in Fig. 1 (j), total cumulative exergy demand by all fossil fuels reduces by ~7.21E+13 MJ in 2020 with respect to the level in 2019 (here, MJ refers to Mega joule; joule is the unit of work or energy). Out of this, coal leads the reduction in exergy demand by ~4.72E+13 MJ in 2020 which represents ~65.42% of the total reduction by all fossil fuels. A change in the consumption of 1 kg coal corresponds to ~23.38 MJ cumulative exergy demand. Obviously, majority of this exergy demand is associated with non-renewable fossil sources, as derived from coal (~98.80%). Biomass based exergy has the next important share (~0.775% of total exergy) in coal followed by nuclear, potential and kinetic resources. The unit LCI processes of all liquid petroleum products and natural gas necessitate much higher cumulative exergy than per kg coal; which vary in the range of ~38.26 MJ/litre (for hydrocarbon gas liquid) to ~54.31 MJ/litre (for heavy fuel oil). This establishes the coal based life cycle processes as more exergy efficient than other fossil fuel based processes. However, based on the individual fuel consumption pattern in 2019 and 2020, only four remaining fossil fuels other than coal; viz., motor gasoline, jet fuel, natural gas and distillate fuel oil, share a significant cut of about 12.75%, 9.42%, 6.14% and 5.12% in total cumulative exergy demand reduction, respectively. It is noteworthy to mention here that although per kg coal carries a lower cumulative exergy demand, its significant level of consumption in the year 2019 and a sharp cut in consumption in 2020 (~25.88%), as shown in Table 1, establish it as the leading contributor in exergy demand reduction in comparison to the remaining fossil fuels.

4. Conclusion

COVID-19 has spread at a time when the human civilization has been in its peak of progression in the known history. Accordingly, this pandemic has been able to trigger far-reaching and extensive changes in the world, economy and environment than any other natural phenomenon in the recent history. This article investigates the remarkable changes that are emerging in the global environmental landscape in this significant time through the lens of LCA study. The restoration of environment evidenced in this study suggests future researches to focus on whether some form of temporary shutdown measures carry ample potential to restore the global environment. In summary, this study illustrates manifestations of meaningful changes in global environment in 2020, as such:

- ozone formation (terrestrial ecosystem) impact reduces by ~16.00% in 2020 with respect to the 2019 level with a corresponding reduction of ~4.46E+09 kg NO_x eq;
- terrestrial acidification impact reduces by ~15.16% in 2020 with respect to the 2019 level with a corresponding reduction of ~7.95E+09 kg SO_2 eq;
- freshwater eutrophication reduces by ~25.07% in 2020 with respect to the 2019 level with a corresponding reduction of ~2.85E+09 kg P eq;
- marine eutrophication reduces by ~24.26% in 2020 with respect to the 2019 level with a corresponding reduction of ~1.77E+08 kg N eq;
- terrestrial ecotoxicity reduces by ~12.59% in 2020 with respect to the 2019 level with a corresponding reduction of ~9.94E+11 kg 1,4-DCB eq;
- freshwater ecotoxicity reduces by ~23.20% in 2020 with respect to the 2019 level with a corresponding reduction of ~7.71E+10 kg 1,4-DCB eq;
- marine ecotoxicity reduces by ~22.77% in 2020 with respect to the 2019 level with a corresponding reduction of ~1.07E+11 kg 1,4-DCB eq;
- land use reduces by ~21.89% in 2020 with respect to the 2019 level with a corresponding reduction of ~4.11E+10 m^2 area crop eq;
- mineral resource scarcity reduces by ~11.10% in 2020 with respect to the 2019 level with a corresponding reduction of ~1.16E+09 kg Cu eq;
- cumulative exergy demand reduces by ~11.90% in 2020 with respect to the 2019 level with a corresponding reduction of ~7.21E+13 MJ through reduced use of fossil fuels.

A limitation of the study lies in the estimated data of the 2020 consumption of the fossil fuels by EIA for the second half of the year which typically fluctuates in an ideal case. In addition, the COVID-19 outbreak is still an evolving scenario. Accordingly, worsening of the corresponding situation together with enhanced lockdowns or reduced anthropogenic activities may contribute to further curtailment of the consumption of fossil fuels and simultaneously intensify the environmental benefits. The opposite scenario is also not unexpected if the governments or industries plan to restart the economy expeditiously or a COVID-19 vaccine is developed soon. Finally, we recommend conducting more LCA studies for investigating various environmental changes originating in different industry sectors, economic zones, regional and national level, due to COVID-19, by exploiting different environmental assessment methods.

Author contributions:

Conceptualization, A.R.; methodology, A.R.; software, A.R.; validation, A.R., T.K. and M.J.; formal analysis, A.R. and T.K.; investigation, A.R. and T.K.; data curation, A.R. and T.K.; writing—original draft preparation, A.R.; writing—review and editing, A.R., T.K. and M.J.; visualization, A.R. and T.K.; project administration, A.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A. Supplementary information

Supplementary information is available separately.

References

1. World Health Organization. As available in: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen. Accessed in Sep, 2020.
2. International Labor Organization. As available in: https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_740893/lang--en/index.htm. Accessed in Sep, 2020.
3. Cable News Network International. As available in: https://edition.cnn.com/travel/article/himalayas-visible-lockdown-india-scli-intl/index.html. Accessed in Sep, 2020.
4. Li, L. et al. Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. Science of the Total Environment, 732 139282 (2020).
5. Wang, Q., & Su, M. A preliminary assessment of the impact of COVID-19 on environment – A case study of China. Science of the Total Environment, 728 138915 (2020).
6. Muhammad, S., Long, X., Salman, M. COVID-19 pandemic and environmental pollution: A blessing in disguise? Science of the Total Environment, 728 138820 (2020).
7. Braga, F. et al. COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon. Science of the Total Environment, 736 139612 (2020).
8. Yunus, A., Masago, Y., Hijioka, Y. COVID-19 and surface water quality: Improved lake water quality during the lockdown. Science of the Total Environment, 731 139012 (2020).
9. Le Quéré, Q. et al. Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. Nature Climate Change. https://doi.org/10.1038/s41558-020-0797-x (2020).
10. Ballantyne, A., Alden, C., Miller, J. et al. Increase in observed net carbon dioxide uptake by land and oceans during the last 50 years. Nature, 488, 70–72 (2012).

11. IPCC 2019. 2019 refinement to the 2006 IPCC guidelines on national greenhouse gas inventories. As available in: https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/.
12. Organization of the Petroleum Exporting Countries. As available in: https://www.opec.org/opec_web/en/publications/338.htm. Accessed in Sep, 2020.
13. International Energy Agency. World Energy Balances: Overview. Complete energy balances for over 180 countries and regions Statistics report - July 2020. As available in: https://www.iea.org/reports/world-energy-balances-overview. Accessed in Sep, 2020.
14. 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).
15. US Energy Information Administration. Short-Term Energy Outlook June 2020. Office of Energy Statistics, U.S. Department of Energy, Washington, USA (2020).
16. US Energy Information Administration. Short-Term Energy Outlook August 2020. Office of Energy Statistics, U.S. Department of Energy, Washington, USA (2020).
17. British Petroleum. BP Statistical Review of World Energy 2019. As available in: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf. Accessed in Sep, 2020.
18. Edenhofer, O. et al. IPCC 2014. Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, UK, and New York, NY, USA (2014).
19. ReCiPe 2016 v1.1. A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization. RIVM Report 2016-0104a. National Institute for Public Health and the Environment, Bilthoven, The Netherlands (2017).
20. Rashedi, A., Khanam, T. Life cycle assessment of most widely adopted solar photovoltaic energy technologies by mid-point and end-point indicators of ReCiPe method. Environmental Science & Pollution Research. https://doi.org/10.1007/s11356-020-09194-1 (2020).
21. Rashedi, A., Sridhar, I., & Tseng, K. Life cycle assessment of 50 MW wind firms and strategies for impact reduction. Renewable & Sustainable Energy Reviews, 21, 89-101 (2013).
22. Goedkoop, M. et al. ReCiPe 2008 Report I: characterisation (v 1.08), Amsterdam, The Netherlands.
23. Ecoinvent version 3.6. As available in https://www.ecoinvent.org/database. Accessed in Aug, 2020.
24. Huijbregts, M. et al. Cumulative Energy Demand: as Predictor for the Environmental Burden of Commodity Production. Environmental Science and Technology, 44, 6, 2189-2196, 2010.
25. SimaPro version 9.0.0.49. PRé. Quantifying sustainability. As available in https://www.presustainability.com/. Accessed in Sep, 2020.
26. Van Zelm, R. et al. Regionalized life cycle impact assessment of air pollution on the global scale: damage to human health and vegetation. Atmospheric Environment, 134, 129-137, 2016.
27. Van Goethem, T. et al. European characterization factors for damage to natural vegetation by ozone in life cycle impact assessment. Atmospheric Environment, 77, 318-324, 2013.

28. Roy, P. et al. Characterization factors for terrestrial acidification at the global scale: A systematic analysis of spatial variability and uncertainty. Science of the Total Environment, 500, 270-276, 2014.
29. Azevedo, L. et al. Assessing the Importance of Spatial Variability versus Model Choices in Life Cycle Impact Assessment: The Case of Freshwater Eutrophication in Europe. Environmental Science & Technology, 47(23), 13565-13570, 2013.
30. Van Zelm, R., Huijbregts, M., Van de Meent, D. USES-LCA 2.0: a global nested multi-media fate, exposure and effects model. The International Journal of Life Cycle Assessment, 14 (30), 282-284, 2009.
31. Van Zelm, R. et al. Making fate and exposure models for freshwater ecotoxicity in life cycle assessment suitable for organic acids and bases. Chemosphere, 90 (2), 312-317, 2013.
32. De Baan, L., Alkemade, R., and Köllner, T. Land use impacts on biodiversity in LCA: A global approach. International Journal of Life Cycle Assessment, 18 (6), 1216-1230, 2013.
33. Curran, M., Hellweg, S., and Beck, J. Is there any empirical support for biodiversity offset policy? Ecological Applications, 24 (4), 617-632, 2014.
34. Vieira, M. et al. Surplus cost potential as a Life Cycle Impact Indicator for metal extraction. Resources, 5 (1), 1-12, 2016.
35. Vieira, M. et al. Surplus ore potential as a scarcity indicator for resource extraction. Journal of Industrial Ecology, 21(2), 381-390, 2016.
36. Ahamed, J., Saidur, R., Masjuki, H. A review on exergy analysis of vapor compression refrigeration system. Renewable and Sustainable Energy Reviews, 15 (3), 1593-1600, 2011.
37. Dincer, I. The role of exergy in energy policy making. Energy policy, 30 (2), 137-149, 2002.