

## Guest Editorial

# Holistic Approach to Reduce Carbon Footprint: Impact of Energy Industries

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### Abstract

The increasing carbon dioxide concentration in the atmosphere has become a global issue and contributions from different sectors need to be understood in holistic manner. The invited article addresses the contributions from various sectors for global carbon dioxide issue, and identifies possible solutions, in the global and local manner.

### Introduction

#### 1.1 Carbon Footprint

The carbon footprint (CFT) is a term derived from the older term ecological footprint that was coined, in 1990s, by the ecologist William Rees and regional planner Mathis Wackernagel [1]. The ecological footprint refers to the total area of land and resources required to sustain an activity or population, including food production and water use. The CFT is defined as the total greenhouse gas caused by an individual, event, activity, service, place, or product. It is usually expressed as carbon dioxide equivalent ( $\text{CO}_2\text{e}$ ) and is usually measured in tons of carbon dioxide released per annum [2]. The Kyoto protocol identifies seven greenhouse gases (GHGs) which include carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), sulfur hexafluoride ( $\text{SF}_6$ ) and nitrogen trifluoride ( $\text{NF}_3$ ) [3]. Additionally, there are other GHG emissions black carbon, sulfur dioxide, contrails, various aerosols, or ozone precursors that are not included in these definitions [4,5]. However, the

European Emissions' Trading Scheme (EUETS) requires the reporting of only  $\text{CO}_2$  emissions [6].

There are large number of processes that are contributing to CFT which also include the natural processes that store or release carbon dioxide, and the interactions between these processes are often complex. As such, Write, Kemp and Williams described a way towards universal definition for CFT. According to them, only account for  $\text{CO}_2$  emissions would result in the omission of almost a third of GHGs and a significant gap in their global management, whilst inclusion of all GHGs is very time-consuming and expensive and should be considered only in system-specific life cycle-based assessments for which a separate definition, name and methodology is required [7]. They suggest that the CFT to make a cost-effective, practical and repeatable metric, that can be adopted by all types of organizations, across the globe, as a 'baseline' indicator, only carbon dioxide and methane should be considered for the CFT. As of 2015 statistics, the global anthropogenic greenhouse gas emissions are  $\text{CO}_2$  76%,  $\text{CH}_4$  12%,  $\text{N}_2\text{O}$  6%, HFC, PFC and  $\text{SF}_6$  2% [8] that justifies their suggestion. They also show that when non-carbon GHGs are included, the appropriate term would be climate footprint rather than CFT. This is because all GHGs contribute to climate changes particularly to increase in global average temperature by as much as 2 °C above pre-industrial levels.

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different greenhouse gases [9]. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide ( $\text{CO}_2$ ). The time period usually used for GWPs is 100 years. Therefore, the GWP represents how much a given mass of a chemical contributes to global warming, over a given time period, compared to the same mass of  $\text{CO}_2$ . The GWPs provide a common unit of measure, which allows analysts to add up emission estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to

compare emission reduction opportunities across sectors and gases over 100 years. Table 1 shows the GWP of some greenhouse

**Table 1:** The Global Warming Potential (GWP) of some greenhouse gases over 100 years.

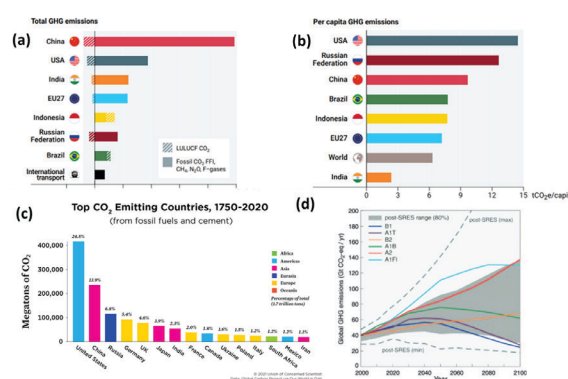
Gas	GWP	Remarks
Carbon dioxide (CO <sub>2</sub> )	1	Reference. Remains in the atmosphere for a long time and concentrations build up with time.
Methane (CH <sub>4</sub> )	27-30	Shorter lifetime in the atmosphere and higher energy absorption
Nitrous Oxide (N <sub>2</sub> O)	273	Remains in the atmosphere for more than 100 years, on average.
Chlorofluorocarbons (CFCs)	93 - 12,100	CFC-11 5000, CFC-12 8500. [10]
Hydrofluorocarbons (HFCs) and blends	92-14,800	Fluoromethane (CH <sub>3</sub> F) 92, Trifluoromethane (CF <sub>3</sub> H) 14800, others have values within this range. [11] Lifetimes in the atmosphere up to 270 years.
Perfluorocarbons (PFCs)	up to 12,200	Lifetime in the atmosphere up to 2,600–50,000 years. [12]
Nitrogen trifluoride (NF <sub>3</sub> )	17,200	Lifetime in the atmosphere up to 740 years. [12]
Sulphur hexafluoride (SF <sub>6</sub> )	22,800	Most potent GHG. Lifetime in the atmosphere up to 3,200 years. [12]

Various countries have considered and adopted different strategies to reduce carbon footprint. These include the following.

- Improve and promote energy conservation and efficiency.
- Use fuels with low carbon output such as nuclear and hydrogen fuels.
- Change to renewable energy (Solar, hydropower, wind, and bioenergy)
- Promote carbon capture and storage.
- Use and promote geoengineering approaches (reforestation, afforestation).

The Closing Window Climate Crisis calls for rapid transformation of societies of the UN Environmental Program (EGR2022.pdf) shows the countries contributing to the total and per capita GHG emissions of major emitters in 2020, including inventory-based emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities (LULUCF). Figure 1 (a) shows the total GHG emissions by different countries in 2020, and Figure 1 (b) compares them as per capita GHG emissions. Figure 1 (c) shows the carbon emission in megatons of carbon dioxide from fossil fuel and cement by top 15 counties countries during 1750 to 2020 [13]. Figure 1

(d) shows the predicted global greenhouse gas emissions by SRES scenario, demonstrating the wide disparity of outcomes determined by the pathway of human development adopted in the 21<sup>st</sup> century [Assessment of the ecological vulnerability of the East Coast Otter Trawl Fishery to climate change: a brief synthesis of information and results of an expert workshop. Available from: [14].



**Figure 1:** (a) The total GHG emissions by different countries in 2020, (b) comparison of the data in (a) as per capita GHG emissions, (c) the carbon emission in megatons of carbon dioxide from fossil fuel and cement by top 15 counties countries during 1750 to 2020 and (d) the predicted global greenhouse gas emissions by SRES scenario, demonstrating the wide disparity of outcomes determined by the pathway of human development adopted in the 21<sup>st</sup> century

(Creative Commons License [13,14]).

### Greenhouse Gas Emissions by Sector

The GHG emissions by sector include energy, direct industrial processes, waste, and agriculture, forestry and land use. The energy sector includes electricity, heat and transport which accounts for 73.2% global GHG emissions. Direct industrial processes, waste, and agriculture, forestry and land use contribute to 5.2%, 3.2% and 18.4%, respectively, as per 2016 data [15]. Their figure reproduced here as Figure 2 (with permissions) show the contributions from subdivisions of each sector.

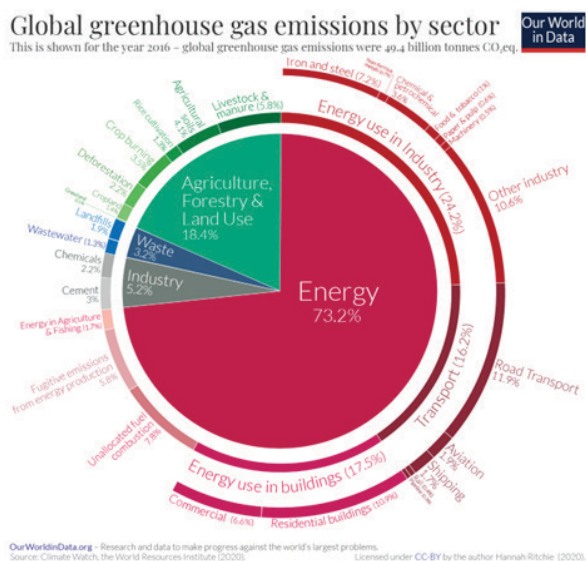
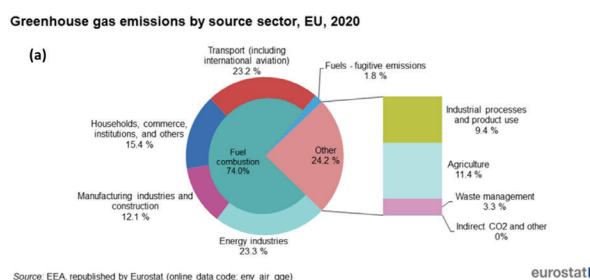


Figure 2: Global greenhouse gas emissions by sector (Reproduced with permission from [15]).

Figure 3(a) shows the GHG emissions by source sector in EU countries during 2020 [16]. It is interesting to note that there is a considerable reduction in GHG emissions from the year 1990 to 2020 in most sectors except in fuel combustion in transport, including international aviation as shown in Figure 3(b). The fuel combustion in transportation has a significant increase in by 50 million tonnes of CO<sub>2</sub>-equivalents (CO<sub>2</sub>-eq) (+7%) in 2020 compared with 1990 [17].



Source: EEA, republished by Eurostat (online data code: env\_air\_gge)

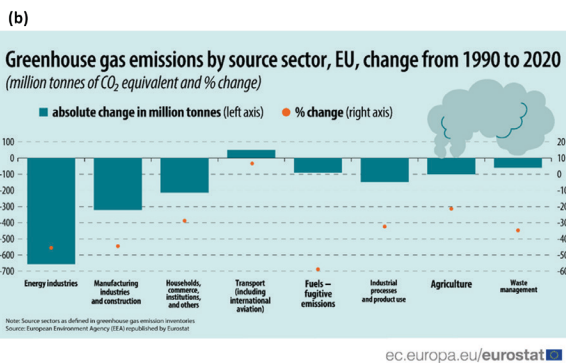


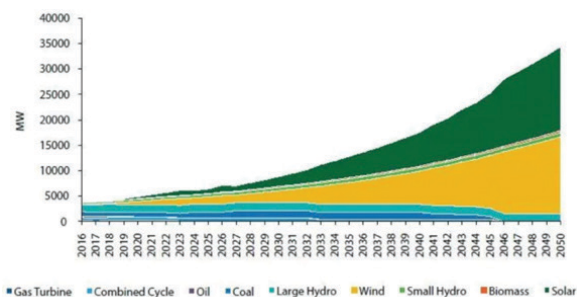
Figure 3: (a) The greenhouse gas emissions by source sector in EU countries during 2020 [18]. (b) The greenhouse gas emissions by source sector, in EU, changes from 1990 to 2020, in million tonnes of CO<sub>2</sub> equivalent and percentage change [17].

### Recommendations to Reduce Greenhouse Gas Emissions

It is important to take a holistic approach to reduce carbon footprint. However, the energy sector dominates over all other sectors in contributing to global and local CFP. Therefore, it is important to take measures to reduce emissions from energy sectors including electricity generation and transportation.

There were plans in Sri Lanka to achieve 70% of total electricity production from renewable resources by 2030 and to go for net carbon zero by 2050 [18]. The power generation capacity of the country is 4,043 MW in 2022 and there are plans to increase it to 6,900 MW by 2025 mainly through utilizing renewable energy sources. Sri Lanka is unique in the South Asia in the sense that it has achieved 98% grid connectivity to its 22 million population. The annual total electricity demand is about 14,150 GW h and is increasing at a CAGR of 4.9% over the next 20 years. As of now, thermal power (which includes coal and fuel oil), hydropower, and other non-conventional renewable energy sources (solar power and wind power) are the three primary sources of energy generation. There are plans to add 842 MW of major hydro, 215 MW of mini hydro, 1,389 MW of solar, 1,205 MW of wind, 85 MW of biomass, 425 MW of oil-based power, 1,500 MW of natural gas, and 2,700 MW of coal power into the electricity generation system by 2037. Sri Lanka is among the forty three countries that are vulnerable to sea-level rise due to increased global temperature. Just like other two forty two countries,

it is mandatory to commit to 100% renewables by the year 2050. The Sri Lanka Institute of Nanotechnology (SLINTEC) report on “Renewable Energy-Leveraging renewable energy for Sri Lankan advantage” [19] is a comprehensive report describing all the possibilities as depicted in Figure 4.



**Figure 4:** Predicted energy generation by source in Sri Lanka from 2016 to 2050 [19].

The report highlights emerging technologies such as solar window, waste to energy, tidal turbines, biofuels, enhanced geothermal system, floating solar arrays, concentrated solar power and hydrogen as fuel.

It is interesting to note that Uruguay is the country that generates over 98% of all electricity from renewable resources such as wind and hydropower. It is the

highest electrified countries with 99.9% of homes having electricity from their national grid. According to 2021 statistics, Uruguay generated 14.04 TW of electricity in this year from the renewable sources (37% hydropower, 35% wind, 18% fossil, 7% biomass and 3% solar) which is 20% higher than that generated in the year 2020. This is higher than their internal demand and the excess has been sold to neighbouring countries like Brazil and Argentina, earning USD 529 million from electricity export. They are also working on developing green hydrogen projects [20].

Sri Lanka is a country that used wind power in the ancient times even before 500 BC. The ancient Sri Lankans used monsoon winds to power furnaces in 300 BC where they produced iron from iron ores. The iron nanoparticles used to make super-hard Damascus sword have been imported from Sri Lanka [21]. The current electricity demand of Sri Lanka is met by nine thermal power stations, fifteen large hydroelectric power stations, and fifteen wind farms, with a smaller share from small hydro facilities and other renewables such as solar [22]. Table 2: (a) depicts the installed generation capacity by year (in MW) from 2005 to 2018 and (b) shows annual generation by year in MW h in Sri Lanka [23].

**Table 2:** (a) The installed generation capacity by year (in MW) from 2005 to 2018 and (b) annual generation by year in MW h in Sri Lanka [23].

(a)

Installed generation capacity by year (in megawatts)

Source	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Hydropower	1,293	1,316	1,326	1,357	1,379	1,382	1,401	1,584	1,628	1,665	1,684	1,726	1,745	1,793
Fuel oil	1,115	1,115	1,115	1,285	1,290	1,390	1,390	1,338	1,335	1,215	1,115	1,215	1,233	1,137
Coal	0	0	0	0	0	0	300	300	300	900	900	900	900	900
Other renewables	3	3	3	3	15	45	50	90	99	152	148	176	208	216
<b>Total capacity</b>	<b>2,411</b>	<b>2,434</b>	<b>2,444</b>	<b>2,645</b>	<b>2,684</b>	<b>2,817</b>	<b>3,141</b>	<b>3,312</b>	<b>3,362</b>	<b>3,932</b>	<b>3,847</b>	<b>4,017</b>	<b>4,086</b>	<b>4,046</b>

(b)

Annual generation by year (in gigawatt-hours)

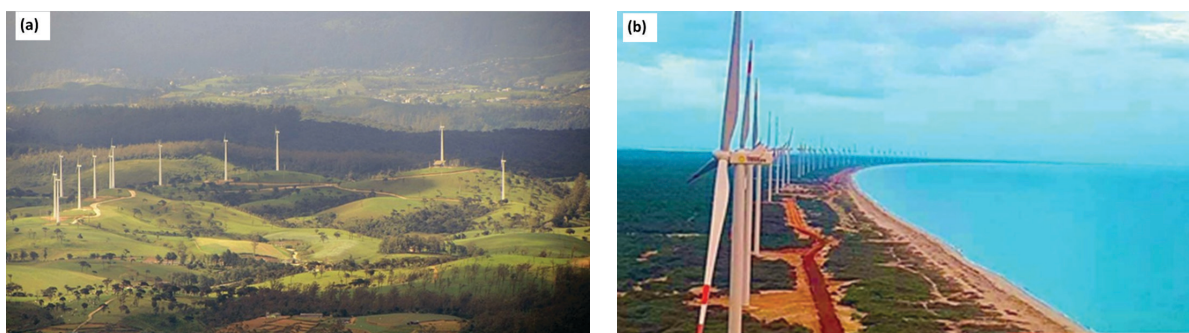
Source	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Hydropower	3,453	4,636	3,948	4,135	3,905	5,634	4,622	3,292	6,926	4,534	5,969	4,220	4,004	6,381
Fuel oil	5,314	4,751	5,865	5,763	5,975	4,994	5,748	6,935	3,303	4,306	2,275	4,461	5,045	3,626
Coal	0	0	0	0	0	0	1,038	1,404	1,469	3,202	4,443	5,047	5,103	4,764
Other renewables	2	2	2	3	27	86	121	171	262	315	402	421	519	511
<b>Total generation</b>	<b>8,769</b>	<b>9,389</b>	<b>9,815</b>	<b>9,901</b>	<b>9,907</b>	<b>10,714</b>	<b>11,529</b>	<b>11,802</b>	<b>11,960</b>	<b>12,357</b>	<b>13,089</b>	<b>14,149</b>	<b>14,671</b>	<b>15,282</b>

The Aitken Spence Wind Power Plant at Ambewela, which was established in September 2012 is shown in Figure 5 (a) By Rehman Abubakr, CC BY-SA 4.0 [24].

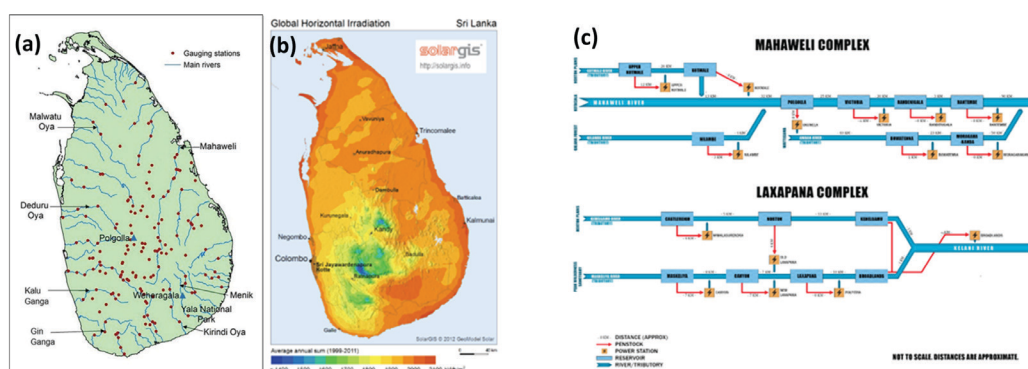
The wind farm consists of 12 wind turbines of 250 KW each, totalling the plant installed capacity to 3 MW. A new wind farm project commenced in 2019, in Mannar

bay comprises 30 numbers of state-of-the-art wind turbines, each rated to 3.45 MW and the total installed capacity of this wind farm is 103.5 MW (Figure 5 (b)).

The project is aiming at exploiting the major monsoonal wind systems in Sri Lanka and is expected to generate 400 GWh of electricity annually [25].



**Figure 5:** (a) The Aitken Spence Wind Power Plant at Ambewela, which was established in September 2012 and (b) new wind farm project commenced in 2019, in Mannar bay comprises 30 numbers of state-of-the-art wind turbines, each rated to 3.45 MW and the total installed capacity of this wind farm is 103.5 MW.



**Figure (6):** (a) Sri Lanka River map [26], (b) the solar irradiance incident on Sri Lanka [27] and (c) two major hydroelectricity power stations, namely, Laxapana complex and Mahaweli complex in Sri Lanka [28].

The solar irradiance incident on most parts of Sri Lanka exceeds  $2000 \text{ kWh m}^{-2}$ . However, harvesting solar energy for electricity generation is only 2.3% of the total electricity produced which is below the average global value of 2.7%. It is, therefore, important to increase at least isolated household and industry based solar panels to make the domestic and industrial electricity requirements self-sufficient. One of the issues of grid connection is the inability of manual power balancing due to unpredictable nature of solar and wind energies. To circumvent this problem, either the national grid should be converted to a smart grid or else the electricity generated at isolated points should be stored in suitable battery packs. We are currently developing zinc/bromine flow and gel battery packs aiming to store electricity generated from solar panels.

Apart from electricity generation, another important issue is the transportation, that is currently running on fossil fuels (98%) with electric vehicles accounting for

less than 2%. Popularization of electric vehicles is an important issue for reducing  $\text{CO}_2\text{e}$ . It is interesting to note that the VEGA car manufactured by the CodeGen International Pvt. Ltd. that is a fully electrical latest technology sports car, and electric three-wheeler vehicles have been recognized in Sri Lanka and has been registered recently [29]. The newswire.lk reports that “The Department of Motor Traffic has approved the registration of the Vega EVX, Sri Lanka, and South Asia’s first fully electric supercar. The registered license plate of the vehicle was handed over to Harsha Subasinghe of VEGA Innovations in the presence of the Minister of Transportation Bandula Gunawardena. The Vega EVX is the first-ever vehicle in history entirely designed and engineered in Sri Lanka. This all-electric supercar is powered by a dual-motor all-wheel-drive drivetrain delivering 804 HP and 720 NM of torque. With a 40-kWh battery pack, test drives have confirmed a staggering 0 to 100 kmph acceleration in 3.1 seconds, an estimated range

of 250 km and a top speed of 240 kmph, displaying the overall performance of the Vega EVX Supercar. This two-seater supercar showcases advanced multidisciplinary technology applications and a skilfully fabricated lightweight carbon fibre body. (Newswire)". A video of the VEGA test run is available in [30].

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## Cover Page

The January issue of Chemistry in Sri Lanka of the year 2023 is dedicated to the theme, Ensure access to affordable, reliable, sustainable and modern energy for all which is the Seventh Sustainable Developmental Goal (SDGs) of the United Nations to be achieved by the year 2030. Renewable energy sources like solar power and wind power have drawn much attention from countries all over the world with the intention that air pollution and climatic change can be kept to a minimum.

cover page diagrams

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