Oxygen Footprint of India

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***Abstract*- In this paper, the phenomenon of atmospheric oxygen depletion has been studied, and a novel science-based target has been developed, currently titled the Oxygen Footprint Index (OFI), which measures the ratio of oxygen consumption over oxygen production. Targeted at India, it is shown that there exist unknown causes of atmospheric oxygen depletion, which correlates with the empirical observation of decline in atmospheric content in the last few decades. The results of the study indicate a significantly high oxygen consumption – India consumes 11 times more than its annual oxygen production. Additionally, a near-future projection till 2040 has been included to demand attention and recognition of the phenomenon of oxygen depletion and its impact on localized ecosystems. The gravity of the issue demands that resources be mobilized and allocated to drive concerted efforts for its advanced study.**

Index Terms- Atmosphere, Oxygen Depletion, Oxygen Footprint Index, Hypoxia, Oxygen, Life sustenance

I. Introduction

Resources are limited and when nature (the way it is designed) decides to reset itself, it is accompanied by a complete destruction of almost all major life forms. Humans have achieved the status of being the most dominant (and notorious) species. Without dwelling on the motivation behind our indomitable will to achieve new heights in everything we do as a species, most of our civilization's progress has come at the cost of over-exploitation of natural resources. As we work towards building a promising future for ourselves, our collective wisdom is also asking us to acknowledge that our current ways are destroying the very same future from the other direction. We must therefore consider the impact of human activities on atmospheric oxygen – oxygen depletion being the epicenter of the analysis – across varying scales, regional to local ecosystems, and studying its causative sources and avenues that produce and add this life-saving element back to the atmosphere.

During this research, the focus was on four main drivers of oxygen consumption directly attributable to anthropogenic activities, namely, fossil fuel combustion, forest fires, and human and livestock respiration. To assess oxygen production, our focus was on terrestrial production [1] as it is the single biggest contributor to atmospheric oxygen. Our initial research into this critical topic led to various significant findings while underpinning a dire need of a unified approach to the problem. In [2], it is stated that the oxygen levels in the atmosphere have been on a constant decline over the last three decades. And with the decline in oceanic oxygen production due to global warming, the scientists see this depletion as a hidden threat that haunts the age of the Anthropocene.
In [3], the scientists discuss that due to the abundance of atmospheric oxygen, its depletion is today largely overlooked. And through their calculations, they have put forward a prediction that in a span of only 9000 years, the oxygen in the atmosphere will decline below life-sustaining levels. Their predictive model is based only on the known levers attributable to human activities. The cut-off time span will only shorten once the complete picture is visible (referring to the 150 gigatons per annum (Gt/a) production and yet, a depletion in overall global atmospheric oxygen).

In [4], the global decline of oxygen levels is analyzed in a deeper context. It puts forward the idea that while increasing carbon dioxide levels are a matter of concern, the decline of oxygen is also important to take into consideration. Due to the population crossing the seven-billion mark, a drastic increase in respiration, along with all industrial processes and animal respiration, has led to consumption of atmospheric oxygen at an alarming rate. It emphasizes the impact of the Anthropocene on the living world.

Disagreements concerning the actual timespan of oxygen levels declining below-habitable conditions do not absolve us of the fact that the levels will decline eventually. The aim of this paper dwells on the study and assessment of atmospheric oxygen levels and projection of the same till 2040 to assess the magnitude and viable solutions that may be adopted to reduce consumption by anthropogenic activities.

II. Results

India's Oxygen Budget

Considering data from various published reports, we calculated India's Oxygen production at 225 Mt/a while India was consuming Oxygen at 3154 Mt/a, considering an upper bound ratio of 1.4 of molecular equivalents of O_2 for every molecule of CO_2. These values are arrived at considering 2016 available data. This consumption increases to 3901 Mt/a by 2040 if India is able to achieve its NDC goals. In case of BAU scenario, the consumption goes up to 4749 Mt/a by 2040.

India's Oxygen Footprint Index

Analyzing the OFI, India consumes approximately 14 times the oxygen than its production (2016 data), placing a severe deficit of oxygen over the countries' landmass. This increases to 17 by 2040 even if India is achieving its NDC targets. In case of BAU scenario this goes up further to 20.8 by 2040.

III. Discussion

With the energy sector having the major share of oxygen consumption, and given the current scenario of India's energy sector, the OFI of 14 figure is only set to increase over time. This fact amplifies the need for an OFI that will help nations gauge their oxygen consumption. While it is said that there is no immediate threat to the atmospheric oxygen, tools such as OFI will help us to assess the real scenario at hand.

The Forest cover of the country is not spread throughout the landmass evenly rather it is concentrated in certain regions. The major cities don't have adequate forest cover within city's boundary nor are these cities surrounded with dense forests. Together this means that oxygen enrichment of cities would depend upon air currents / winds traveling over a long distance. While the consumption will always assume a steady state, the renewing of atmospheric oxygen would then depend upon weather and may not be steady owing to changes in temperature, wind and overall climate. Seasonal effect needs to be studied to assess the duration of oxygen deficit as that will have direct implication on general health and wellbeing of people residing in such cities.

While our research indicates we need further studies on the advection timeline for oxygen enrichment, nevertheless the OFI should be adopted and developed into a comprehensive yardstick to be used for assessment of a landmass' development plans, gauging impact of industrial activities and adopting various measures to protect a minimum atmospheric oxygen baseline for various sub-sectors of a region.

As seen in the case of India, there may be other countries consuming oxygen beyond their budget or production capacity. Moreover, if a similar trend of overconsumption is prolonged, the global production may get surpassed a lot sooner than predicted. The Oxygen Footprint Index is an attempt to establish people's basic right to breath at the center of all planning and implementation activity.

IV. Methodology

Global Annual Atmospheric Oxygen Production

The global annual atmospheric oxygen production capacity is calculated to be 150 Gt/a. This value is obtained through the calculation of net primary production (NPP) values that contribute to the sequestration of terrestrial CO_2 [5].

$$\text{Terrestrial NPP} = 56.4 \text{ Pg } (56.4 \times 10^{15} \text{ g})$$

For every 1g of carbon sequestered, 2.67 g (32/12) O_2 is produced. Therefore,

$$\text{Annual Terrestrial Oxygen Production} = 56.4 \times 10^{15} \times 2.67 = 150.59 \times 10^{15} = 150.59 \text{ Gt/a}$$

In [6], the global atmospheric oxygen reservoir quantity is also estimated to be around 1,184,000 Gt, and the global oxygen consumption is estimated to be in the range of 14 to 20 Gt/a. Given that the oxygen ratio in the atmosphere is constant at 20.9%, an assumption is made that the oxygen being produced annually (150 Gt) is also being consumed to keep the global average constant at 20.9% (ignoring atmospheric losses to space). Further, since atmospheric oxygen loss has been reported via observational data, the fact that there is oxygen loss, although small, only strengthens the assumption that the entire annual oxygen production of 150 Gt is also getting consumed, and that overall global atmospheric oxygen consumption is greater than all sources of oxygen production put together.

From the observational data points, because oxygen consumption is greater than overall terrestrial production, it is important that countries aim for an 'Oxygen Neutral' environment whereby the anthropogenic activity consumption is less than or equal to the amount being produced by their own green cover.

Oxygen Production and Consumption of India

In the following sections, the oxygen production (in megatons per annum, or Mt/a) and the oxygen consumption is calculated using a simple methodology, with India as an example. All data is sourced directly from the government and other internationally recognized institutions. This leads to the calculation of the Oxygen Footprint Index (OFI), which is defined as the ratio of the oxygen consumption to the oxygen production. A lower OFI will be considered better.

Production

For calculating oxygen production potential of India, we shall utilize the method of carbon sequestration [7]. The total amount of CO_2 absorbed in India is 309.48 Mt/a. For each molecule of CO_2 absorbed, one molecule of O_2 is released into the atmosphere and each gram of CO_2 absorbed would, therefore, add 0.727 g of O_2 to the atmosphere. Therefore,

$$\text{Annual } O_2 \text{ production in India } = 309.48 \times 0.727 = \mathbf{225.07} \text{ Mt/a}$$

Consumption

From [2], the methodology adopted for the assessment of oxygen consumption is classified into the following broad categories:

1. CO_2 Emissions

CO_2 emissions (rather than sequestration) are taken as the basis for calculating oxygen consumption. Hence, for 44 g of CO_2 emitted, 32 g O_2 is consumed; a ratio of 1 g CO_2: 0.727 g O_2.

The energy sector emissions (2064.84 Mt/a) and the Industrial Processes and Product Use (IPPU) emissions (166.23 Mt/a) add up to a net consumption of 2231.07 Mt/a. Accounting for LULUCF (-309 Mt/a), India's Net emissions stands at 1922 Mt/a for 2016.

For converting the CO2 emissions to equivalent oxygen consumption, one ratio is mentioned above (= 0.727, direct molecular weight equivalents and this scenario is referred to as 0.73f hereon). However, this is a conservative estimate and incorporates only the carbon atom in the combustion process. Since fossil fuels are hydrocarbons mostly, the combustion process can be depicted by following equation more accurately:

$$C_xH_y + (x + 0.25y)\, O_2 \rightarrow x\, CO_2 + 0.5y\, H_2O$$

Owing to the data challenge to estimate exact quantity of fuel mixture being combusted, in [15] the authors have assumed an oxidative ratio of 1.4 to calculate this estimate. We have also considered the same factor and presented in our analysis this O_2 consumption as an upper bound number. This molar ratio of 1.4 gives a weight ratio of 32 × 1.4 / 44 = 1.02 (referred to as 1.02f scenario hereon)

Thus, using the ratio 0.727, the total oxygen consumption from emissions is: $2231.07 \times 0.727 = \mathbf{1622.59}$ Mt/a,

And using the ratio of 1.02, the total oxygen consumption from emissions is: $2231.07 \times 1.02 = \mathbf{2271.63}$ Mt/a,

2. Human Respiration

Taking the average oxygen consumption per person at 1.17 kg/day (or 0.427 tons/year) and the population of India, the annual oxygen consumption of humans is calculated to be:

$$1{,}32{,}45{,}17{,}250 \times 0.427 \text{ t/a} = \mathbf{565.64} \text{ Mt/a}$$

3. Livestock Respiration

Taking data from [5], the oxygen consumption is calculated by multiplying the individual average weights of the animals by their basal metabolic rate (BMR):

Type of Livestock	Weight (kg)	BMR (kcal/ day)	Oxygen Consumed (liters/year)	Population (millions)	Oxygen Consumed (million tons/year)
Cattle	850	9,949	7,52,596	193.5	208.1
Buffalo	500	6,739	5,09,815	109.9	80.0
Yak	500	6,739	5,09,815	0.1	0.0
Mithun	570	7,420	5,61,281	0.4	0.3
Sheep	30	855	64,651	74.3	6.9
Goat	35	957	72,396	148.9	15.4
Pig	120	2,364	1,78,849	9.1	2.3
Others	-	-	-	0.8	-
				Total	313.0

Table 1: Oxygen Consumption of Livestock

From Table 1, it can be seen that the total oxygen being consumed by livestock is about **313.02** Mt/a.

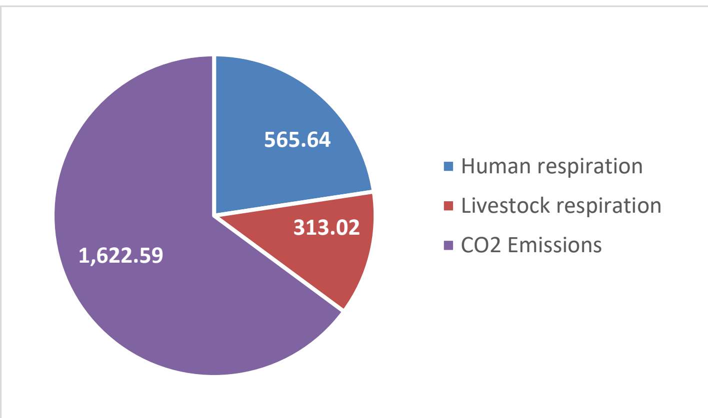

Figure 1a: Oxygen Consumption of India with 0.73 factor (Mt/a)

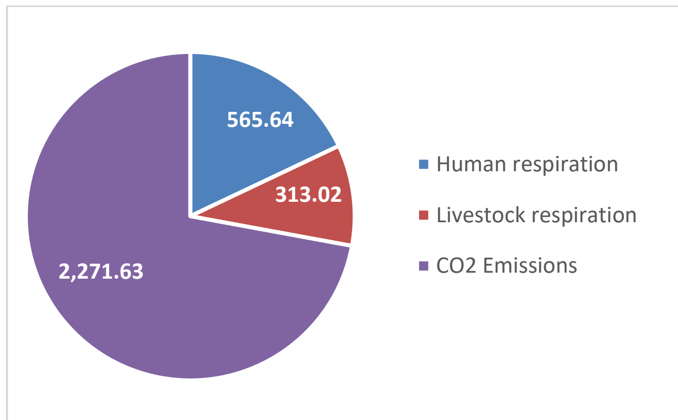

Figure 2b: Oxygen Consumption of India with 1.02 factor (Mt/a)

Adding all the categories up, the total annual oxygen consumption in India from all the above-mentioned activities comes out to be **2501.25 Mt/a,** at a conservative estimate while it has an upper bound estimate of **3150.29 Mt/a**. The total oxygen consumption in India (2501 to 3150 Mt/a) exceeds the total oxygen production in India (225.07 Mt/a). This leads to an OFI for India ranging between **11.11 to 14**.

Oxygen Footprint Projection for India till 2040

In this section, predictions are made for the future (till 2040), considering the following assumptions:

1. The GDP projection is considered at 7.2% (current) [7].
2. India will hit all its nationally determined contributions (NDC) goals. In [8], India has also committed to keeping its emission intensity to 30%–35% lower than 2005. A conservative number of 30% reduction is used here to portray the 2040 scenario.
3. A 1.4:1 as well as 1:1 substitution is considered between oxygen and carbon dioxide, implying that for every 1.4 (or 1) molecule of O_2 consumed, one molecule of CO_2 is produced. This weight ratio is 1.02:1 (or, 0.73:1) for O_2: CO_2. It is also being pointed out here that when considering Oxygen production scenario, the ratio of 0.73:1 is only considered because in that equation only 1:1 ratio exists between CO_2 being consumed to give off O_2.

4. As in [9], the forest cover growth is 0.56% per 2 years. A 1.12% growth in forest cover is thus assumed every 4 years continuing until 2040.
5. India's population growth estimates are taken from [10]. A straight-line interpolation method is used for values in intermediate years.
6. Livestock population is extrapolated based on past trend, which is taken from [11].
7. In addition, a business-as-usual (BAU) scenario is also projected, defined as follows:
   a. Emissions: India is unable to meet its NDC goal of decoupling emissions from its GDP or is unable to keep the emission intensity below 2005 intensity values. However, it is assumed that there is no increase in the intensity from 2016 till 2040.
   b. Production: Oxygen production is still assumed to be same as the first scenario. This is firstly because of the strict forest laws of India and secondly because there is no link between economic growth and forest area for India.

The calculation methodology for the OFI is the same for all data points as for 2016. The inputs which are in line with the assumptions above are suitably used to calculate these projections.

Table below shows the projections in the NDC as well as BAU scenarios.

Year	**2016**	**2020**	**2024**	**2028**	**2032**	**2036**	**2040**
GDP ($b)	2295	2668	2860	3066	3286	3523	3777
Emissions Intensity	0.97	0.94	0.90	0.86	0.83	0.79	0.75
Total Emissions (exc. LULUCF, mn tons)	2,231	2,496	2,570	2,643	2,712	2,778	2,839
Oxygen Consumption via Emissions, 0.73 f (mn tons), NDC scenario	1,623	1,815	1,869	1,922	1,972	2,020	2,065
Oxygen Consumption via Emissions, 1.02 f (mn tons), NDC scenario	2,272	2,541	2,617	2,691	2,761	2,829	2,891
Oxygen Consumption via Emissions, 0.73 f (mn tons), BAU scenrio	1,623	1,886	2,022	2,168	2,324	2,491	2,670
Oxygen Consumption via Emissions, 1.02 f (mn tons), BAU scenario	2,272	2,641	2,831	3,035	3,253	3,487	3,739
Population of India (billions)	1.338	1.396	1.442	1.491	1.536	1.577	1.612
Oxygen Consumption via Human Respiration (mn tons)	572	596	616	637	656	673	688
Oxygen Consumption via Livestock Respiration (mn tons)	310	312	314	316	318	320	322
Total Oxygen Consumption, 0.73 f (mn tons), NDC scenario	**2505**	**2724**	**2799**	**2875**	**2947**	**3014**	**3075**
Total Oxygen Consumption, 1.02 f (mn tons), NDC scenario	**3154**	**3450**	**3547**	**3644**	**3736**	**3822**	**3901**
Total Oxygen Consumption, 0.73 f (mn tons), BAU scenario	**2505**	**2795**	**2952**	**3121**	**3298**	**3484**	**3681**
Total Oxygen Consumption, 1.02 f (mn tons), BAU scenario	**3154**	**3549**	**3761**	**3988**	**4227**	**4481**	**4749**
Oxygen Production by Forests (mn tons)	56	57	57	58	59	59	60
Oxygen Production by Cropland (mn tons)	183	183	183	183	183	183	183
Oxygen Production by Grassland (mn tons)	-15	-15	-15	-15	-15	-15	-15
Oxygen Production by Settlements (mn tons)	1	1	1	1	1	1	1
Total Oxygen Production (mn tons)	**225**	**226**	**226**	**227**	**228**	**228**	**229**
Oxygen Footprint Index ($OFI_{0.73}$), NDC scenario	**11.1**	**12.1**	**12.4**	**12.7**	**12.9**	**13.2**	**13.4**
Max Oxygen Footprint Index ($OFI_{1.02}$), NDC scenario	**14.0**	**15.3**	**15.7**	**16.1**	**16.4**	**16.7**	**17.0**
Oxygen Footprint Index ($OFI_{0.73}$), BAU scenario	**11.1**	**12.4**	**13.0**	**13.7**	**14.5**	**15.3**	**16.1**
Max Oxygen Footprint Index ($OFI_{1.02}$), BAU scenario	**14.0**	**15.7**	**16.6**	**17.6**	**18.6**	**19.6**	**20.8**

Table 2: Oxygen Footprint Projection for India in NDC and BAU Scenarios

From table 2, the following key observations are made:

1. Examining various levers that contribute to the OFI calculation, the oxygen consumption via emissions is about 1.7 times the oxygen consumed by respiration (humans and livestock combined) at 0.73 f. This ratio becomes 2.4 at 1.02 f. Under the scenario of India achieving its NDC goals and keeping the emissions intensity under 30% of 2007 emissions intensity, the ratio is still increasing to 1.77 (0.73 f) ~ 2.47 (1.02 f) times through till 2040. In the BAU scenario, this ratio jumps from 1.7 times for 2020 to about 2.27 (0.73 f) ~ 3.18 (1.02 f) times through till 2040.

2. In the calculations, a continued growth in forest cover is also assumed. However, it is important to point out that should this growth cease, i.e., India maintains the same area of forest cover till 2040, the production capacity of India will be stagnant to 2020 levels. Further, this does not cause any observable change in the OFI until 2040. This highlights the importance of control on emissions, which in turn strengthens our suggestion of developing tighter controls on oxygen as an input variable in anthropogenic activities via development and adoption of OFI.

Figures 2 and 3 represent the key rows of table 2 in graphical form to show the increasing OFI under both scenarios (NDC and BAU).

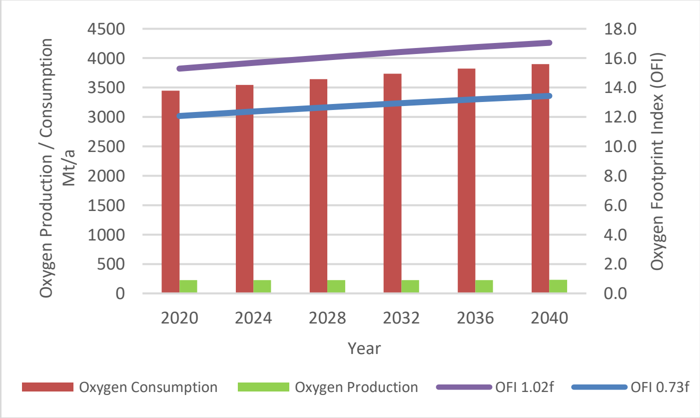

Figure 3: Future Projections under NDC Scenario

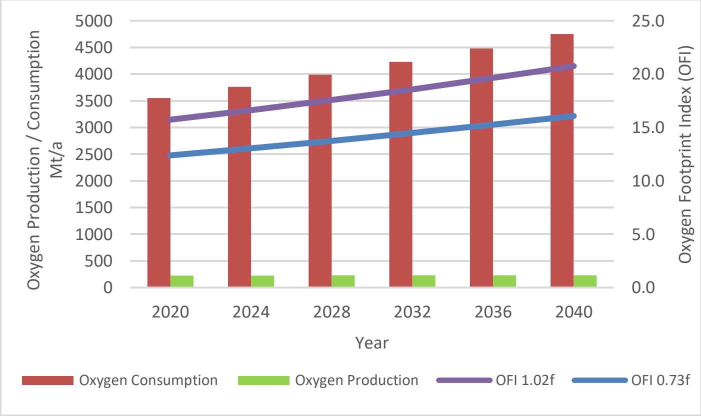

Figure 4: Future Projections under BAU Scenario

From Figure 2, it is clear that even if India achieves its NDC goals, the consumption is going to increase at a significant rate, which is not matched by production. In Figure 3 (BAU), the situation is even worse, and the increase in consumption is starker.

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