Operationally Optimized Mitigation Strategies for Global Carbon Footprint: A Managerial Perspective

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Abstract: With the embedding of environmental values into the managerial philosophy, the urge to interject decarbonization strategies has become the need of the hour. Optimization & subsequent operationalization of lifestyle changes need to be reflected at managerial, industrial and personal levels for reducing the carbon footprints. The mounting pressure on biocapacity has paved way for the adoption of sustainability practices aimed at reducing carbon emissions. Obstacles in the way of carbon footprint minimization are two-fold: (i) Pertaining to the calculation of carbon footprints (ii) Development of mitigation strategies for carbon footprints. This conceptual paper engages an exploratory regime for optimized calculation and mitigation of carbon footprints at the global level from a management perspective. Deriving literature from various journals including those of environmental sciences, management & energy studies; the paper uses grounded theory embedded conceptual framework analysis for drawing inferences. This inductive approach holds the potential to open new frontiers in the field of green strategy designing, social advocacy of eco-centrism & complementary energy optimization studies for carbon footprint reduction.

Keywords: Biocapacity, Carbon footprint, Decarbonization, Eco-centrism, Sustainability.

1.0 Introduction

In contemporary scenario, sustainability yields two-fold benefits- a) In enhancing the profitable growth of the organization b) In the conservation of environmental and social values (Corbett & Klassen, 2006; Kolk &Pinkse, 2008). Mitigation of carbon footprints has gained paramount significance in the light of international, economic, political and environmental arenas. There must be the exploration of city-specific carbon footprint reduction mechanisms mediated through modulations in lifestyle changes that can eventually lead to decarbonization. Household over-consumption, which is a function of an unsustainable lifestyle that has an influence on carbon emissions which can be used as a base element to mitigate carbon footprints associated with anthropogenic activities. All the supply chain intermediaries must work in orchestration to attain sustainability goals. This can be achieved when the social, natural & financial outcomes of the business are taken into consideration. Reduction of carbon footprints can be brought in by following ways:

a) Adoption of lifestyle modulations complemented by a sufficiency strategy (mediated via optimum consumption patterns).
b) Adoption of lifestyle modifications complemented via efficiency strategy (mediated through eco-friendly end-use technologies).
c) Hybrid approach by application of a and b (stated above).

Operationalization of mitigation strategies slated towards carbon footprint reduction is of paramount importance in contemporary times. This is the only way that relentless anthropogenic interventions can be counter-attacked in the light of eco-centrism. The mounting pressures on the biocapacity can be combated via a two-fold strategy:

(i) By calculation of carbon footprint at the first instance
(ii) By developing mitigation strategies for carbon footprint

This conceptual paper is an endeavour to develop calculation cum mitigation strategies for carbon footprint so that the foundation of a sustainable decarbonized society may be laid. The attempt in this paper is to develop a conceptual framework for the same via the application of a qualitative data research approach.

2.0 Literature Review

2.1 Conceptualization of Carbon Footprint

Carbon footprint refers to the quantum of CO2 and other greenhouse gases (GHGs) emitted in the ecological environment due to anthropogenic activities (both direct and indirect). 'Carbon footprint' also is related to the emissions of all GHGs like CO2, nitrous oxide (N2O), methane (CH4) & even chlorofluorocarbons (CFCs) and may be numerically expressed in terms of the amount of CO2 (measured in tons) released during a stipulated period of time. Footprints typically exhibit geographical variation & continue to change as per the socio-ecological and political-economic scenario of that geographical area. The concept of 'carbon footprint' gained momentum towards the onset of the millennium and witnessed public eminence as the carbon component of the environmental (ecological) footprint (Seixas& Ferreira, 2022; Girvan, 2017). In the context to ecological economics, 'carbon footprint' refers to both direct & indirect exclusive amounts of CO2 generated by either anthropogenic activity or produced in the product life cycle (Wiedmann& Minx, 2008).

Ecological footprint refers to the area comprising water & productive land eco-systems that gives resources to support the population consumption in that area & can assimilate the wastes produced by that population (Rees, 2018; Wackernagel& Rees, 1998). Biodiversity footprints are contextually similar to ecological footprints whereas carbon footprints can be partially correlated with both biodiversity & water footprints. As society progresses in terms of urbanization and positive corporate transition, the negative effect on the biological environment as a result of carbon footprints can't be neglected (Mahato, Seth, Yadav, 2023). With radical implications for the transition to a green sustainable bioeconomy, the concept of interface among footprints has grabbed attention because of the possible clash between biodiversity goals & renewable energy production (Gasparatos et al., 2017; Mc-Collum et al., 2018). Tradeoffs, co-benefits & thresholds have been identified as vital mitigation policies for targeting agroforestry & AFOLU sectors (Agriculture, Forestry & Other Land Usage Sectors) at the interface (Prasad et al., 2022; Noordwijk, 2019). Various regulatory policies & sustainable practices adopted by different countries include:

(i) Carbon cap & trade
(ii) Carbon taxation policies
(iii) Emission trading system (Gonzalez et al., 2009)

Additionally, most of the research is centred on relationships between:

(a) Energy consumption & carbon emissions
(b) Economic growth & carbon emissions
(c) Process & mechanism pertaining to carbon emissions (Lim et al., 2009; Li et al., 2017)

Carbon footprint reduction is escalated by the inclusion of the following in supply chain management:

(i) Reverse logistics
(ii) Green Purchasing
(iii) Green Manufacturing (Bai & Sarkis, 2010; Eltayeb et al., 2011).

2.2 Enabling sustainable consumption-based decarbonization tactics.

Cities vary in terms of their carbon footprints due to various factors like:

(i) Modes of transportation
(ii) Income level of residents
(iii) Household size

(iv) Urban density
(v) Consumption of energy sources

Consumption-oriented mitigation strategies need to be prioritized for designing carbon footprint reduction mechanisms. Characteristics of individual citizens need to be considered for mapping a variety of lifestyle changes & consumption patterns that can assist in building up a decarbonized society. As environmental issues increase, customer worries about ecological preservation have resulted in a variety of consumers' buying tactics towards living a sustainable lifestyle(Yadav,Seth, & Mahato, 2023).

Table 1: Methods/ Tactics of Decarbonization

No.	Method/ Tactics	Description	Propounded by
1	**Input-output analysis and Life Cycle Assessment**	▪ Studies centered on this approach have attempted to not only quantify the positive effects of lifestyle changes on carbon footprint reduction by avoiding over-consumption* but also how the product improvement can create less carbon-intensive counterparts via the adoption of the avoid-shift improve concept **.	*Salo& Nissen, 2017; Wood et al., 2018; Vita et al., 2019; Moran et al., 2020. **Creutzig et al., 2018.
2	**Household expenditure survey method**	▪ It may preclude precise observation about shifts in consumption patterns. ▪ This method limits the contrasting power in context to the decarbonization target and may often be infested with bias related to under-reporting.	LekveBjelle et al., 2018; Moran et al., 2020; Vita et al., 2019. Ihara et al., 2009; Shigetomi et al., 2014.
3	**Consumption-based accounting**	▪ It considers the household consumption accounts of the public in terms of carbon footprint in the context of their lifestyles.	Hertwich& Peters, 2009; Ivanova et al., 2016.
4	**Scenario Development &Back-casting approach.**	▪ With a futuristic outlook, the transition to sustainability can be catalyzed and subsequently guided via scenario development. ▪ This has been extrapolated to curb direct greenhouse gas emissions & energy usage using a back-casting approach.	Raskin et al., 2004. Hughes & Strachan, 2013.
5	**Integrated Assessment Model.**	▪ Significant changes in climate have been attributed to green lifestyle adoptions based on researches conducted using specific integrated assessment models of climate change.	Saujot et al., 2020; Van Den Berg et al., 2019; Van Sluisveld et al., 2016; Van Vuuren et al., 2018.

The pivotal role can be played by government bodies via the adoption of focused policy choices like:

(i) Regulation
(ii) Planning
(iii) Environmental campaigns
(iv) Service provisions
(v) Facilitating business fraternity with educational, technical & financial lending (Lo, 2014).

2.3 Mitigation Strategies for Carbon Footprints

Since global warming is anticipated to negatively impact both socioeconomic systems as well as ecological systems for the next hundred years (Solomon et al., 2009), it is imperative to reduce carbon emissions. Determination of carbon footprints via the application of various methodologies has been done in past years (Wiedmann& Minx, 2007; Carbon Trust, 2007). These methodologies are orchestrated at myriad scales like (i) Company (ii) Household (iii) Regional and at the personal level (Sovacool& Brown, 2010; Brown, et al., 2009; Kenny & Gray, 2009; Liu et al., 2008; Carbon Trust, 2007). These scales are developed at various sectoral levels viz.

(a) Water supply
(b) Transportation
(c) Medical
(d) Industrial etc. (Cole, 2009; POST 2006).

Further, carbon emission reduction has been emphasized in the building & construction industry by:

(i) Developing energy-saving retrofits for already existing infrastructure
(ii) Energy-efficient designing for new constructions.
(iii) Creating waste disposal strategies

For studying the process of carbon emissions & developing plans& mitigation strategies for carbon footprint reduction, the calculation of the quantum of carbon emission is centered on:

a) Life cycle assessment & analysis
b) Carbon footprint analysis
c) Anthropogenic based (both industrial & personal) greenhouse gas (GHG) emissions (Christopher Weber, 2008).

The adequate motivation of supplier's behaviour can play a pivotal role in the reduction of carbon emissions (Tidy et al., 2016). This can help in the mitigation of carbon footprints. The supply chain can be made sustainable by minimization of environmental risk via the inclusion of green purchasing (Zsidisin&Siferd, 2001). The amount of carbon footprint embedded in the supply chain can be traced & subsequently mitigated using Lagrangian & Eulerian transport methods (Sundarkani et al., 2010). Monetary investments in carbon cap and trade systems along with emission control technologies can mitigate carbon footprints over the entire supply chain (Garcia-Alvarado et al., 2016). Carbon regulations can circumvent emissions & can assist a two-echelon supply chain in the inclusion of more sustainability-oriented products (Liu et al., 2017)

2.4 Operationalization of Carbon Footprint Mitigation Strategies through Sustainable Approach.

For attaining global sustainability and human prosperity, one of the identified requirements is an intensification of agriculture in a sustainable way (Rockstrom et al., 2017). Researchers suggest that a mediocre level of 'intensification' strategies can help in mitigating detrimental carbon footprints (Struik& Kuyper, 2022). The scale of transformation that technological advances and engineering are capable of bringing about in the path of sustainability is unprecedented. This has a significant impact on the bioeconomy(Seth,2023). The relevant relationship has been found between the volume of production and its ecological impact in mitigating the ecological footprint of food (Noordwijk &Brussaard, 2014). For decoupling resource consumption, economic prowess, and emissions of greenhouse gases for the purpose of attaining Sustainable Development Goals (SDGs), it is vital to trace both market-based and territorial pathways. Adoption of sustainable practices reduces:

a) Carbon emissions in the natural environment (Gandhi et al., 2015).
b) Greenhouse effects caused due to greenhouse gases (Luthra et al., 2014).

It is a combination of individual and national contributions towards attributable emissions that synergistically indicate the metrics of carbon footprints. As a qualifier for these metrics, footprints per unit product can be calculated by taking into consideration:

a) Consumer decisions on the adoption of lifestyles with respect to consumption
b) Product life cycle analysis & assessment (Harberl et al., 2020).

With internally consistent estimations, the five major components depicting the global carbon budget are:

a) Emissions from land usage
b) CO_2 emissions by fossil fuels
c) Increase in the growth rate of atmospheric CO_2

d) CO_2 sink (Ocean)
e) CO_2 Sink (Terrestrial) (Friedlingstein et al., 2020)

With respect to the reconciliation between supply-demand forces, three types of leverage points have been suggested that magnify the overgrowth of anthropogenic carbon footprint over the international biocapacity-

(i) Advanced multifunctionality of land usage (Van Noordwijk et al., 2018; Barbier& Burgess, 2019; Rockstrom et al., 2009; Biermann & Kim, 2020)
(ii) Lesser resource dependent means to attain the well-being of the ever-increasing population.
(iii) Reliable footprint data complemented by responsible consumption that is in line with escalating Human Development Index (Sagar & Najam, 1998).

A good brand image of being carbon-free, deforestation-free or carbon-neutral can be attained viaan avalanche of commitments & strategic eco-friendly declarations. Changes in behavioralpatterns with respect to consumption alternatives can lead to the mitigation of abrupt climatic changes (Ivanova & Wood, 2020). Carbon footprint concepts that act on either side of sensitive supply-demand pathways are:

(i) Carbon emissions as a function of economic activity
(ii) Proper life-cycle assessment of products for marking product-level carbon footprints
(iii) Comparative analysis of current versus historical per capita emissions
(iv) Wealth & lifestyle dictated individual consumption footprints.

2.5 Models advocating the mitigation strategies for carbon footprint reduction

For the sake of attaining an oriented low-carbon future for combating climate change, the globalized world has slated myriad green manufacturing practices for reducing carbon print by extrapolation to cover up the supply chain.

Table 2: Modelsfor Carbon Footprint Reduction

No.	Model	Description	Propounded by
Mathematical Models			
1	**Genetic Algorithms**	For gaining insight into the logistics pertaining to optimum utilization of vehicles in biomass supply chain viz. warehousing for refiners & inventories, delivery etc.	Sadehi&Haapala, 2019.
2	**Single-item incapacitated lot-sizing**	This model can help in mitigating CO_2 emissions by application of certain carbon emission constraints like- a) Cumulative b) Periodic c) Rolling carbon emissions d) Global carbon emissions	Benjaafar et al., 2012.
3	**Multiple-objective sustainable supply chain model**	By adopting weighted-goal programming approach for minimization of cost of energy & resources, this model was applied to the automobile sector. This model also proposes the inclusion of escalated socio-ecological responsibilities linked to the usage of renewable energy sources (like biofuels), resorting to carbon trading & minimization of ecological loss. The model also used fuzzy modellingtechniques for determining the uncertainty in market demands & variable costing concepts.	Sarkar et al., 2018. Ahmed & Sarkar, 2019.

4	**Mixed-integer linear programming (M-I-L-P) model**	Handling of carbon emission trading via M-I-L-P approach can help in attainment of supply chain sustainability thereby acting as a narrative for carbon footprint reduction.	Chaabane et al., 2012.
5	**Traditional EOQ model**	This model necessitates various solutions for carbon footprint reduction & for escalating organizational profits for considering environmental demands, ecological policies, pricing & carbon reduction mechanisms.	Hovelaque&Bironneau, 2015.
Managerial &Computer-aided Models			
6	**Strategic decision-making model**	This model superimposed the conventional operational supply chain network costs over the social cost of CO2 emission for arriving at the final deduction that carbon footprint is inversely proportional to social cost.	Tseng & Hung, 2014.
7	**Combination of genetic algorithms & mixed integer sustainable vehicle routing model**	This model proposed the optimization of delivery system through drones & the way these drones can reduce the costs associated with: a) Fuel used in logistics b) Supply chain	Galve et al., 2016.
8	**Multi-objective goal programming model**	The solution provided by this model optimized logistics costs, direct & indirect carbon footprints in the form of emissions & helped in minimization of entire supply chain costs. This was conducted in the costume & apparel industry.	Shaw et al., 2013; Mari et al., 2014.
9	**Bender decomposition aided carbon cap-constrained (sustainable) supply chain model**	Flow of energy & materials as a spread over supply chain network was deciphered using this model.	Shaw et al., 2016.

3.0 Research Objective

To develop a sustainability slated optimized operational framework justifying the strategic approaches for calculation & mitigation of carbon footprints.

4.0 Research Methodology

Because of its exploratory nature, this study's research technique is innovative. The content was extracted utilizing a thorough search and extraction technique from a database of credible secondary sources (by employing topic-specific keywords). The whole corpus of literature (derived from journals comprising environmental sciences, management & biotechnology) is categorized into five groups (or conceptual frames) based on their degree of resemblance (parity or commonality). Grounded theory-embedded conceptual framework analysis is utilized as a qualitative research tool to examine the consistency discovered across all five conceptual frames. Because the findings are presented in a linear form, progressing from particular to more universal conclusions based on the authors' assumptions, this conceptual paper employs an inductive reasoning approach.

5.0 Findings & Research Implications

The application of the proposed research methodology on the filtered literature yielded the following probable outcomes-

- Industrial and anthropogenic activities cause immense pressure on biocapacity & subsequently increase the carbon footprint.

- Increased carbon footprint causes staggering of the ecological equilibrium thereby calling for immediate mitigation strategies to be designed so that environmental equilibrium can be restored.
- Strategic approaches for calculation & mitigation of carbon footprints can take three forms as follows:
  a) Managerial approach
  b) Scientific approach
  c) Personalized approach
- Each mitigation approach can further engage plethora of optimization techniques for tracing & reduction of carbon footprint as discussed in figure 1 by means of a conceptual framework.
- The research leaves room for framework validation via empirical testing so that new frontiers can be heralded in the area.

6.0 Conclusion

Relentless pressures on the natural resources due to increasing population & alarming anthropogenic activities have overburdened the biocapacity. The staggered ecological environment needs a resurgence from the turmoil caused by industrial & domestic pollution. A synergistic approach towards the calculation of carbon footprint is imperative. Subsequently crucial is deciphering the mitigation strategies that may converge into sustainability. It is a combination of managerial, scientific and personalized approaches that may fulfill this task adequately. Several approaches (some management-related& others of mathematical origin) were found to be advocating the mitigation strategies for the carbon footprint. Carbon footprints exhibit tremendous geographical variation &their continuum changes abruptly as per the socioeconomic& politico-environmental scenario of various countries/ continents. However, with small changes in mitigation strategies, the problem can be evenly managed. The millennials have been observed to be typically sensitive to the concept of corporate environmental stewardship & carbon footprint reduction remains their priority. Therefore, the dire need for putting into practice the optimized operational mitigation strategies for carbon footprint remains paramount. The paper was drafted with the objective of addressing the issue and prescribing not just the calculation mechanisms for carbon footprints but also preventive measures that can minimize the carbonization of the earth. The paper heralds promise not just for environmental strategists & eco-engineers but also for green marketers and business policy influencers who are inclined towards finding greener solutions to their business approaches.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

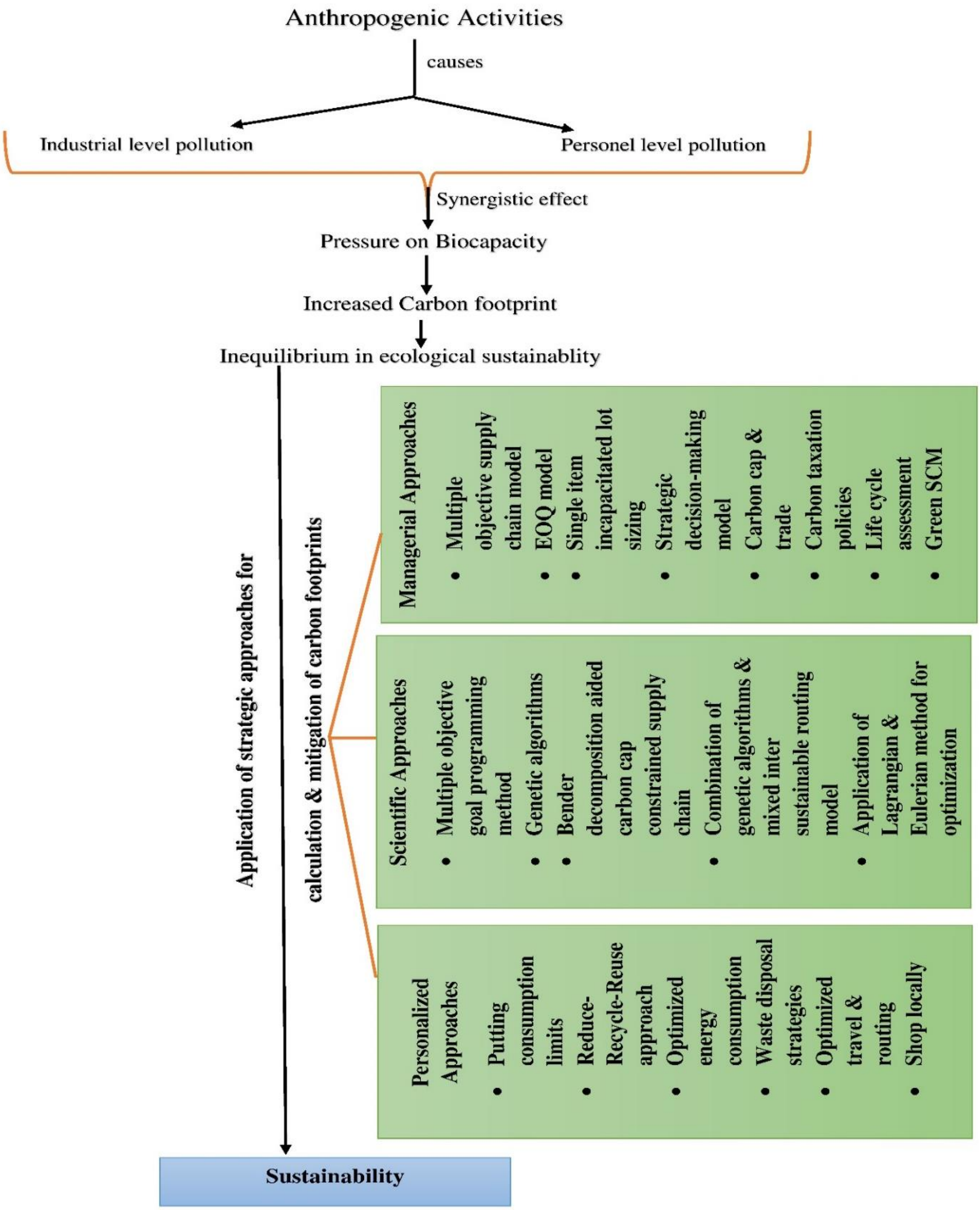

Figure 1: Sustainability slated application of strategic approaches for calculation & mitigation of carbon footprints

[Source: Authors' Conceptualization]

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