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Sustainability: Greenhouse Gas Protocol and Global GHG Emissions' Status and Trends

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Abstract
Climate change is the biggest health threat to humanity, profoundly impacting the UN Sustainable Development Goals (SDGs), demanding urgent attention and action. This study presents the evolution and domains of the ESG concept, along with the importance of sustainability reporting. The widely accepted standards for sustainability reporting have been enumerated. The Greenhouse Gas (GHG) Protocol has been discussed in detail, including Scope 1 (direct), Scope 2 (indirect), and Scope 3 (value chain) GHG emissions, along with Scope 4 (avoided emissions); and setting GHG targets. The SBTi criteria and recommendations for near-term and net-zero targets for GHG coverage of the seven GHGs covered by UNFCCC, Kyoto Protocol, and GHG Protocol are also presented. The analysis of GHG emissions shows a significant increase since the start of the 21st century, rising from 36.18 to 52.96 Giga tons of CO_2 equivalent (46.41%) between 2000 and 2023. In 2023, around 62.73% of global GHG emissions came from the top six contributors: China (30.10%), the USA (11.25%), India (7.8%), the EU27 (6.08%), Russia (5.05%), and Brazil (2.45%). The CAGR of GHG emissions with 1990 as the base year is negative for the EU27 (-1.25%), Japan (-0.71%), Russia (-0.42%, and the USA (-0.12%) against the global CAGR of +1.47%. Overall, emissions increased in 2023 compared to 2022 for the top contributors, except for the USA (-1.41%), the EU27 (-7.48%), and Japan (-6.01%). Further research is needed to assess progress toward climate change targets and to implement emission reduction strategies across all sectors in every country.

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1. Introduction

In today's ever-changing business environment, sustainability and ethical governance are not just fleeting trends; they are fundamental pillars of success and responsibility (Torelli, 2020; Zahari *et al.*, 2024) [37, 43]. Businesses or companies that embrace and demonstrate environmental, social, and governance responsibilities not only position themselves as responsible leaders but also secure a powerful competitive edge in an increasingly dynamic market. This is because of the increased focus of investors on non-financial risks and heightened expectations of customers on sustainability and ethical aspects, coupled with compliance with applicable standards and regulations (Chen *et al.*, 2024; Li *et al.*, 2025) [6, 27].

The growth of responsible investing or positive stewardship of capital has been the driving force in the integration of environmental, social and governance (ESG) principles in the functioning of companies/entities. For example – avoidance of investment in apartheid South Africa contributed to pressure on the government to end racial segregation; the establishment of the Pax World Funds (now Impax Funds), a mutual fund in the USA, to incorporate social and environmental criteria into investment decisions, specifically avoiding investments in companies involved in the Vietnam War; the publication of Rachel Carson's "Silent Spring" in 1962 that unequivocally brought attention to the alarming environmental and health consequences of pesticide use; severe financial consequences to British Petroleum (BP) after the 2010 Deepwater Horizon disaster that caused extensive environmental damage in the Gulf of Mexico; hefty fines on Volkswagen and drop in its share price due to the

emissions scandal in 2015; and many more. All these issues coupled with responsible investing over time have been pivotal to the evolution of Corporate Social Responsibility (CSR) primarily focused on social issues such as human rights and supply chain ethics culminating in broadening the scope beyond social responsibility – that is, the formulation and integration of ESG practices aligned with United Nation's Sustainable Development Goals (SDGs) (UNSDG, 2015) [39] into company's operations (Macesar, 2024; MH, 2024; RL 360, 2025) [28, 29, 32].

The environmental aspect (E) of ESG critically evaluates the impact that companies have on the environment, focusing on key issues like climate change, carbon footprint, waste generation, and energy emissions. Since climate change due to greenhouse gas (GHG) emissions is one of the most significant challenges facing humanity, GHG emissions are a crucial element in assessing and reporting in company ESG reports. The World Economic Forum (WEF) consistently identifies climate change and its far-reaching impacts as some of the most pressing global risks the planet faces today (WEF, 2024) [42]. In fact, concerns about climate change prompted the inclusion of GHG emission reporting in company ESG reports (WBG, 2017) [41].

As climate change targets typically focus on GHG emission reduction (Booth *et al.*, 2023) [1], the GHG Protocol (GHGP 2025a) [19] aims to provide a comprehensive global standardized framework for measuring and managing GHG emissions –direct (Scope 1), indirect (Scope 2) and value chain or supplemental (Scope 3). The Science Based Targets initiative (SBTi) (SBTi, 2025) [35], a corporate climate action organization, provides target validation services to companies and financial institutions to reduce GHG emissions to limit mean global temperature rise to well below 2ºC above pre-industrial levels and pursue efforts to limit global warming to 1.5°C in order to prevent the impacts of climate change.

As per SBTi, more than ten thousand companies/businesses have targets and commitments on reducing GHG emissions. Of these, over 7,000 have set emission reduction targets with science-based targets and over 3,700 have set net-zero commitments (SBTi, 2025) [35]. The companies/businesses from all over the world/region representing diverse sectors, including pharmaceuticals, biotechnology and life sciences, healthcare, aerospace and defense, air and ground transportation, automobiles, financial institutions, chemicals, consumer durables, education services, electric utilities, power producers, electrical equipment and machinery, food-agricultural production, food and beverage processing, mining, solid waste management utilities, water utilities, and many more, have set near-term/long-term/net-zero targets for GHG emissions.

In view of the global attention on sustainability with an emphatic focus on climate change and GHG emissions, the present study aims to provide an overview of ESG, the GHG Protocol, and SBTi and their role, importance, and requirements. Further, the study analyzes the global GHG emissions data, with a special focus on the top ten contributors, to study the trends.

2. ESG and Its Domains

The core concept of ESG (that is, responsible investment) has existed for centuries, dating back to religious codes – for example, Quakers forbidding investment in the slave trade, and parishioners prohibited investment in alcohol, tobacco, and weapon companies/industries. However, the work of Professor Adolf Berle (considered the father of ESG) in the 1930s established the essential framework for the modern-day social responsibility of for-profit corporations. The rise of activism further led the way towards positive stewardship of capital in the latter half of the 20th century. However, it was the last decade of the 20th century and thereafter when landmark global treaties, protocols and agreements in respect to environmental and social issues came into force, such as the Kyoto Protocol in 1997 that sets global warming goals; the establishment of Global Reporting Initiative in 1997 to address environmental concerns; the six UN Principles of Responsible Investing in 2006 (PRI, 2025) [31] dealing with ESG; the Paris Agreement of 2015 (UNCC, 2015) [40] a legally binding international treaty on climate change adopted by 196 parties; and the UN Sustainable Development Goals (SDGs) (UNSDG, 2015) [39] in 2015, replacing the eight Millennium Development Goals (MDGs) of 2000 (UNMDG, 2000) [38], outlining 17 sustainability targets for improving quality of life and achieving a more sustainable future by 2030.

The term "ESG" was officially introduced with its first significant appearance in the UN-commissioned report titled "Who Cares Wins" (WBG, 2017) [41], which demonstrated how to integrate environmental, social, and governance aspects of responsibility into a company's operations. The three domains of ESG are briefly presented hereunder.

2.1 Environmental

The environmental aspect (E) in ESG comprises monitoring and managing the impact of a company's operations on the natural or physical environment. It is related to the utilization of natural resources, energy emissions, GHG emissions, waste reduction, water conservation, carbon footprint, biodiversity impacts, and pro-environmental practices and policies – such as the use of sustainable/renewable energy, eliminating/reducing waste, and recycling efforts for transition to a circular economy. The assessment of all such environmental elements of ESG is a prerequisite for environmental sustainability and combating climate change. In the current scenario, it is expected that a company that is harnessing resources effectively, adapting swiftly to regulatory changes, and capitalizing on societal shifts related to the environment will protect its shareholder value; whereas, the one that acts recklessly regarding its environmental impacts will inevitably face sanctions, reputational damage, and significant financial losses.

2.2 Social

The social aspect (S) in ESG refers to a company's social practices – that is, interaction with the people around it. Social practices focus on inclusive work culture, and upholding human rights, equality, and safety for all (employees, customers, suppliers, and communities). The elements of responsible social practices include equal and fair working conditions for employees without discrimination based on gender, race, or belief; responsible health, remuneration, and labor practices; responsible supply chain practices; and other social values. A company that fosters fair and sustainable relationships with stakeholders significantly reduces its social risks.

2.3 Governance

The governance aspect (G) in ESG pertains to a company's governance structure, culture, decision-making process, and compliance checks. The key features of responsible corporate governance include gender representation and diversity in board composition, management track record, executive

compensation, anticorruption policies, compliance with ethical and legal standards, relationship with shareholders, data policy and security, etc. Evaluating a company's governance is essential for understanding its ESG risks, as strong governance reduces exposure to these risks.

ESG data management is essential for corporate responsibility and sustainability because investors actively rely on ESG criteria to evaluate investment opportunities. Therefore, it is increasingly important for organizations to publish clear sustainability reports that communicate their environmental risks, opportunities, and practices to stakeholders, enhancing their reputation and providing them with a competitive advantage.

3. Importance and Benefits of Sustainability Reporting

Governments, companies, investors, and NGOs actively use sustainability reporting to convey and assess performance and impacts on critical sustainability issues. These issues encompass climate change and GHG emissions, biodiversity effects, resource utilization, and the sustainability of supply chains. Sustainability reports are essential instruments through which companies/entities responsibly communicate their environmental risks, opportunities, and practices to key stakeholders—investors, regulators, partners, employees, and customers—empowering them to make informed and impactful decisions.

For companies, sustainability reporting is essential to demonstrate their commitment to responsible practices and gain a competitive edge. It highlights efforts to reduce GHG emissions and climate change impacts, conserve resources, and enhance operational efficiency, thereby solidifying corporate reputation and market trust. Furthermore, sustainability reporting uncovers significant cost-saving opportunities and attracts environmentally conscious employees, consumers, partners, and investors. Embracing sustainability is not optional; it is a strategic necessity for success in today's marketplace.

For investors, sustainability reporting is essential as it provides them with a clear assessment of a company's environmental and social impacts, along with its opportunities and risks. This information is vital for making informed decisions and enables stakeholders to fully understand the risks and rewards of engaging with the company. By prioritizing sustainability, companies can effectively manage risks, cut costs, and significantly enhance long-term shareholder value.

Customers are now becoming more and more aware of climate change and other socio-environmental issues and have heightened expectations of sustainability disclosures. They are more likely to purchase ethically sourced and sustainable products. By tackling environmental issues and showcasing their commitment to sustainable practices, companies can engage consumers who value eco-friendly products and services.

For rating agencies, sustainability reporting helps them to rigorously evaluate and rank companies based on their environmental, social, and governance (ESG) practices. Their assessments are essential for stakeholders to clearly understand a company's ESG performance.

For society, sustainability reporting is essential for driving awareness and establishing performance baselines, prompting future investments. It compels companies to set ambitious sustainability targets and adopt circular business practices, delivering significant benefits for both the environment and society.

3.1 Standards for sustainability reporting

To measure and report sustainability performance, there are many established sustainability reporting standards at both national and international levels. Some of the most comprehensive and widely used standards are –

- *The GHG Protocol:* It is the most widely used worldwide standard to measure and report on climate change effects or GHG emissions. A complete overview of its provisions has been presented in the following section (GHGP, 2025a) [19].
- *European Sustainability Reporting Standards (ESRS) / EU CSRD (The EU Corporate Sustainability Reporting Directive)*: These are comprehensive sustainability reporting standards required for EU companies and large international companies doing business in the EU starting in 2028. These standards complement existing global reporting frameworks like the GHG Protocol and the Global Reporting Initiative (GRI). Companies can use the GHG Protocol with the ESRS to report their greenhouse gas emissions and set reduction targets (EU 2022) [9].
- *Global Reporting Initiative (GRI)*: GRI is an NGO that offers a leading framework for corporate sustainability reporting, encompassing various standards related to ESG pillars (GRI, 2025) [22].
- *Sustainability Accounting Standards Board (SASB)*: The SASB is an NGO that has developed a framework for corporate sustainability reporting by integrating it with financial reporting (SASB, 2025) [33].
- *IFRS Sustainability Disclosure Standards / International Sustainability Standards Board (ISSB)*: The IFRS Sustainability Disclosure Standards were created by the ISSB to serve as a global format for sustainability and climate reporting (IFRS, 2025) [24].
- *Carbon Disclosure Project (CDP)*: Established in 2000, CDP operates an environmental disclosure system that enables companies to report on business risks and opportunities related to climate change, water security, and deforestation (CDP, 2025) [4].
- *CDSB Framework*: The Climate Disclosure Standards Board (CDSB) created a framework for integrating ESG reporting into mainstream corporate reports. However, the CDSB was absorbed by the IFRS Foundation in 2022, and the IFRS climate disclosure standard now replaces the CDSB Framework (CDSB, 2025) [5].
- *TCFD Standards*: The Task Force on Climate-related Financial Disclosures (TCFD) was established in 2015 by the Financial Stability Board to assist companies in disclosing climate-related financial risks to investors, lenders, insurers, and other stakeholders. Its recommendations were integrated into the IFRS disclosure standards, leading to the disbandment of the TCFD in October 2023 (TFCD, 2025) [36].

3.2 Sustainability consultants

Sustainability consultants assist businesses in adopting responsible practices to achieve their sustainability goals more effectively. Some of the largest sustainability consultants that provide services on ESG and net-zero strategy – sustainability assurance, sustainability finance, climate, energy transition, and socio-environmental impact are – EY (Ernst & Young, UK), McKinsey & Company (USA), Boston Consulting Group (USA), Deloitte (Deloitte Touche Tohmatsu Limited, UK), KPMG (Netherlands, ERM (Environmental Resources Management, UK), Bain & Company (USA), WSP & Golder (Canada), Accenture (Ireland), dss+ (DuPont Sustainability Solutions,

Switzerland), and many others.

4. GREENHOUSE GAS (GHG) PROTOCOL

The GHG Protocol is a comprehensive global standardized framework for accurately measuring and managing GHG emissions. It has been designed to be program- or policy-neutral, and many existing GHG programs have been using it for their own accounting and reporting requirements and it is compatible with most of them. The GHG tools are consistent with those proposed by the Intergovernmental Panel on Climate Change (IPCC) for the compilation of emissions at the national level. Its significance cannot be overstated – in 2016, 92% of Fortune 500 companies responding to the Carbon Disclosure Project (CDP) reported utilizing the Protocol directly or through a related initiative; and by 2023, this figure rose to 97% among disclosing S&P 500 companies using the GHG Protocol. Further, many carbon accounting standards and frameworks are also based on the GHG Protocol, such as ISO 14064-1 and the recommendations of TCFD (GCI, 2025a) [10]. This widespread adoption demonstrates the GHG Protocol's pivotal role in empowering organizations to effectively manage their environmental impact.

4.1 Development of GHG Protocol

The GHG Protocol was developed through a collaborative partnership of multiple stakeholders – businesses, non-governmental organizations (NGOs), governments, and various other entities. This effort was coordinated by the World Resources Institute (WRI), a US-based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), a Geneva-based coalition of nearly 200 international companies. The Protocol focuses on the accounting for and reporting of seven greenhouse gases (GHGs) that are currently covered by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF3). The Global Warming Potential (GWP) of these GHGs, along with their lifetime in the atmosphere, has been presented in Table 1 (Hull, 2009; IPCC, 2007) [23, 25]. The GWP of GHGs has been computed over a 100-year time horizon to convert the gases into carbon dioxide equivalent (CO_2e).

Table 1: Lifetime and 100-year global warming potentials (GWP) relative to CO2 of GHGs

S. No.	Greenhouse Gas (GHG)	Formula	Lifetime (in years)	100-year GWP as per AR4 (in CO_2e)
1	Carbon dioxide	CO_2	-	1
2	Methane	CH_4	12	25
3	Nitrous oxide	N_2O	114	298
4	Hydrofluorocarbons (HFCs)			
	HFC-23	CHF_3	270	14,800
	HFC-32	CH_2F_2	4.9	675
	HFC-125	CH_2FCF_3	29	3,500
	HFC-134a	CH_2FCF_3	14	1,430
	HFC-143a	CH_3CF_3	52	4,470
	HFC-152a	CH_3CHF_2	1.4	124
	HFC-227ea	CF_3CHFCF_3	34.2	3,220
	HFC-236fa	$CF_3CH_2CF_3$	240	9,810
	HFC-245fa	$CHF_2CH_2CF_3$	7.6	314
	HFC-365mfc	$CH_3CF_2CH_2CF_3$	8.6	241
	HFC-43-10mee	$CF_3CHFCF_2CF_3$	15.9	1,640
5	Perfluorocarbons (PFCs)			
	Perfluoromethane (PFC-14)	CF_4	50,000	7,390
	Perfluoroethane (PFC-116)	C_2F_6	10,000	12,200
	Perfluoropropane (PFC-218)	C_3F_8	2,600	8,830
	Perfluorobutane (PFC-3-1-10)	C_4F_{10}	2,600	8,860
	Perfluorocyclobutane (PFC-318)	c-C_4F_8	3,200	10,300
	Perfluoropentane (PFC-4-1-12)	C_5F_{12}	4,100	13,300
	Perfluorohexane (PFC-5-1-14)	C_6F_{14}	3,200	9,300
6	Sulphur hexafluoride	SF_6	3,200	22,800
7	Nitrogen trifluoride	NF_3	740	20,700

The following standards and related guidance are collectively referred to as the GHG Protocol:

- *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard*. First issued in 2001, and revised in 2004 (GHGP, 2004) [12], the Corporate Standard establishes a unified framework for both business and non-business entities. It provides businesses with a universal method for preparing GHG inventory statements for internal and external use. For other entities, it enhances the consistency, transparency, and understandability of reported information, simplifying the tracking and comparison of progress over time.
- *GHG Protocol Scope 2 Guidance: An Amendment to the GHG Protocol Corporate Standards (the Scope 2 Guidance)*. Issued in 2015 (GHGP 2015) [18], the Scope 2 Guidance amends the Corporate Standard by providing updated requirements and best practices for Scope 2 accounting and reporting. It introduces new accounting and reporting requirements that enhance those in the Corporate Standard. Companies must follow all additional requirements in the Scope 2 Guidance to prepare a compliant inventory.
- *Corporate Value Chain (Scope 3) Accounting and Reporting Standard: Supplement to the GHG Protocol Corporate Accounting and Reporting Standards (the Scope 3 Standard)*. Issued in 2011 (GHGP, 2011a)[14], the Scope 3 Standard is a supplement to the Corporate Standard, aimed at enhancing the completeness and consistency of how companies account for and report indirect emissions from their value chain activities.
- *Scope 3 Technical Guidance: Making Corporate Value Chain Accounting Easier Than Ever*. Issued in 2013 (GHGP, 2013a) [16], it supplements the Scope 3 Standard

and explains how to calculate emissions for each of the Scope 3 categories. Version 1.0 supplements the Corporate Value Chain (Scope 3) Accounting & Reporting Standard.

- *Required Greenhouse Gases in Inventories: Accounting and Reporting Standard Amendment*. Issued in 2013 (GHGP, 2013b) [17], it updated the GHG Protocol to include NF_3 among the list of GHGs that must be reported.
- *The GHG Protocol for Project Accounting (the Project Protocol)*. Issued in 2005 (GHGP, 2005) [13], it provides specific principles, concepts, and methods for quantifying and reporting GHG reductions or increases in removals and/or storage—from climate change mitigation projects (i.e., GHG projects).
- *Product Life Cycle Accounting and Reporting Standard (the Product Standard)*. Issued in 2011 [GHGP 2011 b) [15], it provides guidance to understand the full life cycle emissions of a product and focus efforts on the greatest GHG reduction opportunities.
- *The GHG Protocol: Land Sector and Removals Standard (Under development)*. (GHGP 2025b) [20]. It aims to explain "how companies should account for and report GHG emissions and removals from land management, land use change, biogenic products, carbon dioxide removal technologies, and related activities in GHG inventories, building on the Corporate Standard and Scope 3 Standard." The Land Sector and Removals Standard along with accompanying Guidance is expected to be publicly released in 2025.
- *The GHG Protocol: Corporate Suite of Standards and Guidance (under development)*. (GHGP 2025c) [21].

In view of the significant recent developments in GHG accounting and reporting, such as the Science Based Targets initiative (SBTi), the movement toward net-zero targets, mandatory climate disclosure regulations, and the adoption of these standards by thousands of companies. The GHG Protocol aims to address several important topics, including the Corporate Standard, Scope 2 and Scope 3 emissions, and the actions and market instruments workstream. Additionally, it reflects on academic research regarding their use and impact.

4.2 Objectives

The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard has been designed for the following five objectives –

- to help companies prepare a GHG inventory that represents a true and fair account of their emissions, through the use of standardized approaches and principles;
- to simplify and reduce the costs of compiling a GHG inventory;
- to provide businesses with information that can be used to build an effective strategy to manage and reduce GHG emissions;
- to provide information that facilitates participation in voluntary and mandatory GHG programs; and
- to increase consistency and transparency in GHG accounting and reporting among various companies and GHG programs.

4.3 Principles

The GHG Protocol is founded on five principles derived in part from generally accepted financial accounting and reporting standards. This foundation results from a collaborative process involving stakeholders across various technical, environmental, and accounting fields. These are –

1. **Relevance:** "Ensure the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users – both internal and external to the company." It means that the emission metrics must fulfill the requirements of the regulations they are used for (financial or other implications) to optimize the decision-making. Choosing the right inventory boundary is a crucial aspect of relevance as it reflects the true substance and economic reality of the company's business relationships, rather than just its legal structure.
2. **Completeness:** "Account for and report on all GHG emission sources and activities within the chosen inventory boundary. Disclose and justify any specific exclusions." This requires the identification of assets and activities owned or controlled by the organization, the necessary data from those assets, and the way to convert this data into emission estimates.
3. **Consistency:** "Use consistent methodologies to allow for meaningful comparisons of emissions over time. Transparently document any changes to the data, inventory boundary, methods, or any other relevant factors in the time series." Users of GHG information will find it useful to track and compare GHG emissions data over time to identify trends and assess the performance of the reporting company.
4. **Transparency:** "Address all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used." The information should be clear and sufficient enough to enable a third party to derive the same results if provided with the same source data. Transparency is crucial for stakeholders who must trust the reported emission metrics. Without confidence in the data and methodology, they are less likely to consider them when making decisions.
5. **Accuracy:** "Ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information." Estimates of GHG emissions have more uncertainties than financial reporting. To achieve accurate results, it is crucial to reliably convert the data into GHG emissions using the most appropriate methodology, calculations, and emission factors.

4.4 Operational boundaries: identifying Direct (Scope 1), Indirect (Scope 2) and Supplemental (Scope 3) emissions

Operational boundaries refer to a company's owned or controlled operations that fall within a company's established organizational boundary. An operational boundary involves identifying emissions associated with its operations, categorizing them as direct and indirect emissions, and choosing the scope of accounting and reporting for indirect emissions. Direct GHG emissions are emissions from sources that are owned or controlled by the company; whereas, Indirect GHG emissions are emissions that are a consequence of the activities of the company but occur at sources owned

or controlled by another company. To clarify the distinction between direct and indirect emission sources, enhance transparency, and serve the needs of various organizations and climate policies and business goals, three scopes are defined for GHG accounting and reporting purposes – Scope 1, Scope 2, and Scope 3. It is mandatory for the companies/organizations to separately account for and report on Scope 1 and 2 at a minimum. The reporting of Scope 3 is optional. The companies may further subdivide GHG emissions data within scopes to enhance transparency and facilitate comparability over time. The sources/activities of GHG emissions under different Scopes have been summarized in Fig. 1 and discussed hereunder.

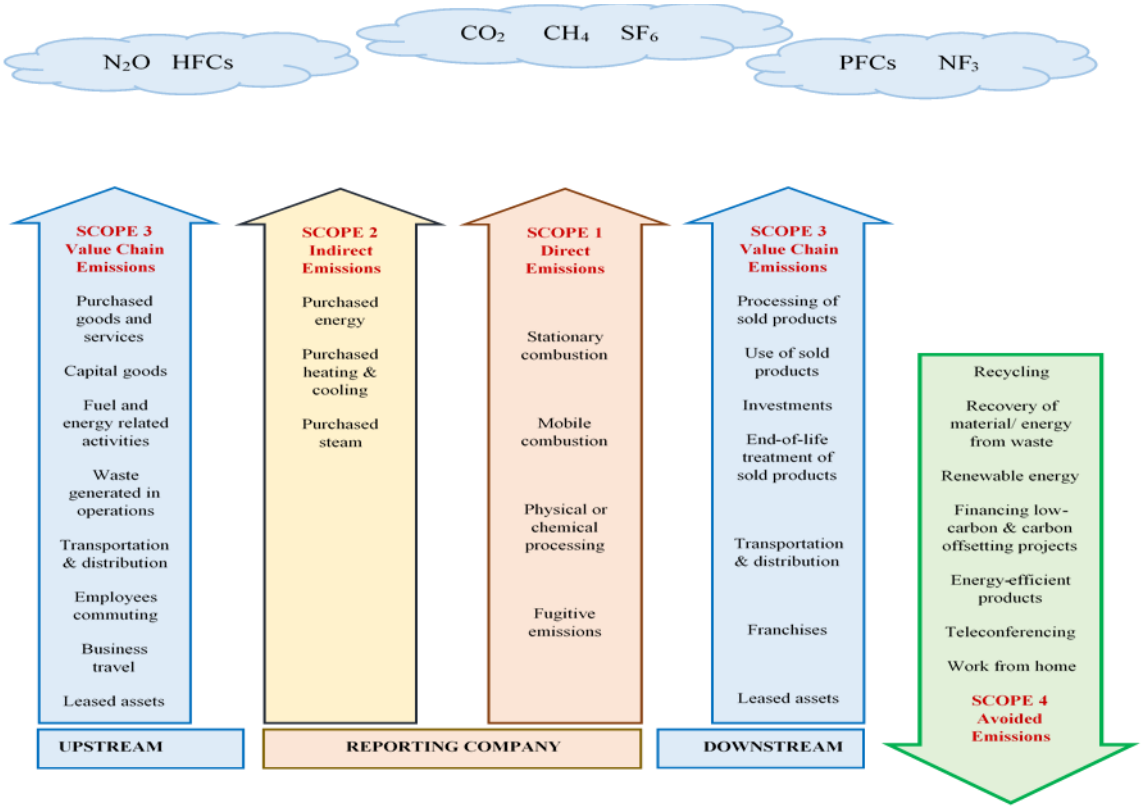

Fig. 1: Sources and/or activities of GHG emissions under Scope 1, 2, 3 and 4.

4.4.1 Scope 1: direct GHG emissions

Scope 1 accounts for direct GHG emissions from sources or process equipment that are owned or controlled by the company. These are principally a result of the following activities undertaken by the company –

- *Stationary combustion of fuels for generation of electricity, heat or steam*: It includes emissions from the combustion of fuels in stationary sources/equipment, such as boilers, furnaces, burners, turbines, heaters, incinerators, engines, flares, etc.;
- *Physical or chemical processing*: It includes emissions from chemical production or material processing, such as emissions during cement manufacturing, aluminum smelting, ammonia manufacturing, petrochemical processing, and waste processing, etc.;
- *Mobile combustion of fuels for transportation of materials, products, waste, and employees*: It includes emissions from the combustion of fuels in company-owned/controlled mobile sources (vehicles), such as automobiles, cars, buses, trucks, lorries, trains, airplanes, boats, ships, barges, vessels, etc.; and
- *Fugitive emissions*: These emissions include intentional or unintentional releases, such as leakages from equipment, HFC emissions from refrigeration and air conditioning, methane leakages from gas transport, emissions from wastewater treatment, methane emissions from coal mines and venting, etc.

Direct CO_2 emissions from biomass combustion need to be reported separately and not included in Scope 1.

4.4.2 Scope 2: electricity indirect GHG emissions

Scope 2 emissions are a special category of indirect emissions. It accounts for GHG emissions from the generation of purchased electricity that is consumed by the company in its owned or controlled equipment or operations. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. It is to be noted that Scope 2 emissions physically occur at the facility where electricity is generated. In the case of electric utility companies, that purchase electricity from an independent power generator or the grid and resell it to end-consumers, the emissions from the generation of purchased electricity that is consumed during transmission and distribution (i.e. T&D losses) are to be reported in Scope 2 by the electric utility company only, not by the end-consumers of purchased electricity. This not only prevents any double counting but adds simplicity to the reporting within Scope 2.

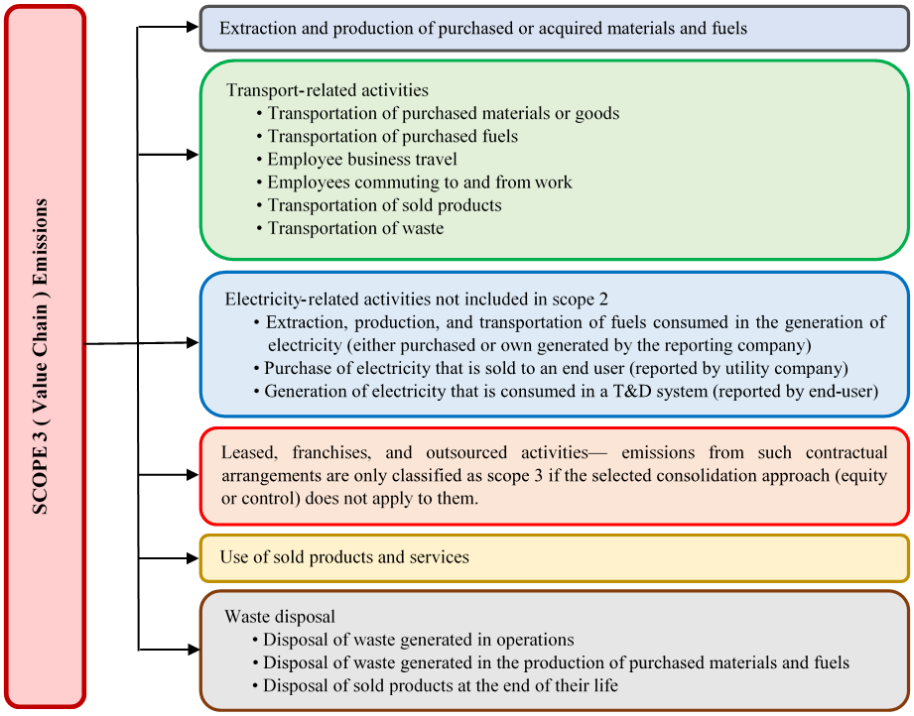

Fig 2: Categories or activities under Scope 3 GHG emissions as per the GHG Protocol.

4.4.3 Scope 3: other indirect GHG emissions

Scope 3 emissions are a consequence of the activities of the company but occur from sources not owned or controlled by the company. These GHG emissions are also called "value chain emissions" or "supplemental emissions" as they result from a company's value chain. For example, GHG emissions from extraction and production of purchased materials and fuels, transportation-related activities, electricity-related activities not included in Scope 2, leased assets and outsourced activities, use of sold products and services, and waste disposal. The fifteen indicative activities/categories that have been included under Scope 3 emissions are shown in Fig. 2.

Accounting for Scope 3 emissions does not require a comprehensive GHG life cycle analysis of all products and operations. It is often more beneficial to concentrate on one or two types of significant upstream or downstream GHG-generating categories/activities that might be relevant to the company. Relevance may be for several reasons, such as large categories relative to the company's Scope 1 and Scope 2 GHG emissions, contribute to the company's GHG risk exposures, deemed critical by key stakeholders (customers, suppliers, investors or civil society), or potential emissions reductions that the company could undertake. Upstream Scope 3 emissions refer to the suppliers, raw materials, and other inputs that go into making a product, that is the emissions generated during the production and transportation of goods and services purchased by a company. In contrast, downstream Scope 3 emissions refer to the processes, distribution, and customers on the other end, that is the emissions occurring when customers use the company's products or services (BPL, 2025; Britt, 2024) [2, 3]. The upstream and downstream emissions categories, as defined by the GHG Protocol, are presented in (Table 2) (BPL, 2025; Britt, 2025; EPA, 2025) [2, 3, 8].

Reporting of Scope 3 is strongly encouraged but it is optional and companies have discretion over which categories they choose to report. Therefore, Scope 3 may not be suitable for comparisons across different companies. Further, the flexibility in reporting Scope 3 GHG emissions has drawn some criticism. Many stakeholders believe that without the requirement to report Scope 3 emissions, companies might overlook a significant portion of their overall impact. In fact, Scope 3 emissions typically account for 70% to 80% of a company's total emissions (GCI, 2025a) [10]. The Carbon Disclosure Project (CDP) estimates that Scope 3 emissions are 5.5 times greater than those from Scope 1 and 2 combined (GCI, 2025a) [10]. However, this flexibility could be viewed as an incentive rather than a strict limitation, allowing companies to progressively commit to addressing their indirect emissions.

4.4.4 Scope 4: avoided emissions

According to GHG Protocol, Scope 4 covers emissions avoided when a product is used as a substitute for other goods or services, fulfilling the same functions but with a lower carbon intensity (GCI, 2025b) [11]. However, several reference frameworks such as the ISO standards, the French regulatory method, and the GHG inventory method do not use the term "Scope 4", instead only refer "Avoided Emissions". Whether considering Scope 4 or avoided emissions, the calculation methodology and reporting are similar. Contrary to Scope 1, 2 & 3 emissions generated from a company's activities, Scope 4 balances out the generated emissions by saved emissions or how much carbon was not emitted due to a business's actions.

It's important to distinguish between reduced emissions and avoided emissions. Reduced emissions are the actual decrease in a company's greenhouse gas (GHG) emissions over a given period due to an action plan. Avoided emissions, on the other hand, are calculated by comparing a low-carbon product or service to a reference scenario. Avoided emissions can be achieved by embracing carbon-reducing measures such as recycling products, sale of low-carbon products that replace more emission-intensive products or that reduce emissions elsewhere, financing low-carbon and carbon offsetting projects, recovering material/energy from waste, producing renewable energy/steam, production of energy-efficient products and services, working from home, teleconferencing, etc. The avoided emissions should be

reported separately, and must never be accounted for (subtracted) or declared in the GHG balance sheet.

4.5 Tracking GHG emission

The selection of a "base year" is the first step in tracking emissions. Companies should select the earliest relevant year with reliable data as the base year and provide reasons for their choice. Most companies choose a single year as their base year; however, it is also possible to select an average of annual emissions over several consecutive years. Thereafter, the companies should develop a policy for recalculating base year emissions and clearly explain the criteria and context for any adjustments made. If relevant, this policy should specify any "significance threshold" used to determine whether the historic emissions should be recalculated. The cases that will necessitate the recalculation of base year emissions are – structural changes (such as mergers, acquisitions, divestments, or the outsourcing and insourcing of emitting activities), changes in calculation methodologies, or improvements in the accuracy of emission factors or activity data that significantly affect the base year emissions data. However, the base year emissions and any historic data are not recalculated for organic growth or decline – that is for increases or decreases in production output, changes in product mix, and closures and openings of operating units that are owned or controlled by the company.

Table 2: Indicative list of upstream and downstream activities under Scope 3 GHG emissions.

Upstream Activities		Downstream Activities	
Purchased goods and services	Extraction, production, and transportation of goods and services purchased or acquired by the company	Processing of sold products	Processing of intermediate products sold by downstream companies, e.g. manufacturing.
Capital goods	Extraction, production, and transportation of capital goods purchased or acquired by the company	Use of sold products	The end use of goods and services sold by the company
Fuel and Energy related activities	Extraction, production, and transportation of fuels and energy purchased or acquired by the company not already accounted for in Scope 1 or Scope 2	Investments	Operation of investments, including equity and debt investments and project finance not included in Scope 1 or Scope 2.
Waste generated in operations	Disposal and treatment of waste generated in the company's operations in facilities not owned or controlled by the company.	End-of-life treatment of sold products	Waste disposal and treatment of products sold at the end of their life
Transportation and distribution	Transportation and distribution of products purchased by the company between its tier suppliers and its operations, in addition to other services such as inbound logistics, outbound logistics, and transportation and distribution between a company's own facilities.	Transportation and distribution	Transportation and distribution of products the company sells between its operations and the end consumer, including retail and storage.
Business travel	Transportation of employees for business-related activities in vehicles not owned or operated by the company.		
Employees commuting	Transportation of employees between their homes and worksites in vehicles not owned or operated by the company.	Franchises	Operation of franchises in the reporting year, not included in Scope 1 or Scope 2.
Leased assets	Operation of assets leased by the company and not included in Scope 1 and Scope 2.	Leased assets	The operation of assets owned by the company and leased to other entities not included in Scope 1 and Scope 2.

4.6 Identifying, calculating and reporting of GHG emissions

Identification of emission sources includes step-wise identification of Scope 1 and 2 emissions followed by Scope 3 emissions (from upstream and downstream activities). The emissions are then calculated based on a mass balance or stoichiometric basis specific to a process or facility. The most common approach for calculating GHG emissions is through the application of documented emission factors. Emission factors are ratios relating GHG emissions to a proxy measure of activity at an emission source. The use of GHG calculation tools (cross-section as well as sector-specific) (GHGP 2025a) [19] is recommended as these have been peer-reviewed by experts and are regularly updated. Its automated worksheet requires activity data insertion and selecting an appropriate emission factor or factors. The emissions of each GHG are calculated separately and then converted to CO_2 equivalents based on their global warming potential (Table 1). Although default emission factors are provided for the sectors covered, an optional insertion of customized emission factors that are more representative of the reporting company's operations is also available.

The reported information should be relevant, complete, consistent, transparent, and accurate. A public GHG emissions report should include a description of the company and operational boundaries chosen, separate GHG emissions data for each scope, separate emissions data for all GHGs in metric tons and tons of CO_2 equivalent, methodologies used to calculate or measure emissions, optional information when applicable (such as relevant Scope 3 emissions activities for which reliable data can be obtained, emissions from GHGs not covered by the Kyoto Protocol, an outline of any GHG management/reduction program or strategies, GHG emission data for all years between the base year and the reporting year, etc.), and information on reductions at source inside the inventory boundary and on offsets that have been purchased or developed outside the inventory boundary.

4.7 Performance evaluation

Two main aspects of greenhouse gas (GHG) performance are important to management and stakeholders. The first aspect focuses on the total GHG impact of a company, which refers to the absolute amount of GHG emissions released into the atmosphere. The second aspect looks at the company's GHG emissions in relation to a business metric, creating a ratio indicator. The GHG Protocol Corporate Standard requires companies to report their absolute emissions while reporting ratio indicators is optional. Ratio indicators offer insights into performance by business type and allow for comparisons of similar products and processes over time. Intensity ratios

express GHG impact per unit of physical activity or unit of economic output. These include product emission intensity (for example, tons of CO_2 emissions per electricity generated), service intensity (for example, GHG emissions per function or service), and sales intensity (for example, emissions per sale). A physical intensity ratio is suitable when aggregating or comparing across businesses that have similar products; whereas, an economic intensity ratio is suitable when aggregating or comparing across businesses that produce different products. A declining intensity ratio reflects a positive performance improvement.

A percentage indicator is a ratio between two similar issues (with the same physical unit in the numerator and the denominator). The percentage indicator can be meaningful in performance reports that include current GHG emissions expressed as a percentage of base year GHG emissions.

4.8 Verification of GHG emissions

Verification involves an objective assessment of the accuracy and completeness of reported GHG information, as well as its conformity to established GHG accounting and reporting principles. It aims to instill confidence in users that the reported information and associated statements provide a true, fair, and accurate account of a company's GHG emissions. Verification is often undertaken by an independent external third party.

4.9 Setting a GHG target

Like revenues, sales, and other core business targets, effective GHG management also involves setting a GHG target. There are two broad types of GHG targets namely, absolute and intensity-based targets.

An absolute target typically defines a specified quantity of reduction in greenhouse gas emissions (in tons of CO_2e) over time. An intensity target defines a reduction in the ratio of GHG emissions relative to another business metric, which may be the output of the company (in tons CO_2e per tonne product, per kWh, per tons mileage) or some other metric such as sales, revenues or office space. Further, to establish credibility, a target must clearly define its emissions in relation to past emissions. Most GHG targets are defined as a percentage reduction in emissions below a fixed target base year (for example, reduce Scope 1 emissions 40% below 2014 levels by 2030). However, companies may consider using a rolling base year, in cases where obtaining and maintaining reliable and verifiable data for a fixed target base year is likely to be challenging (for example, due to frequent acquisitions/divestitures or changes in measurement and calculation methodologies). Further, companies may use single-year commitment periods or multi-year commitment periods (short-term and long-term targets).

5. Science Based Targets initiative (SBTi)

Science-based targets aim to provide a clearly defined pathway for companies and other entities to reduce GHG emissions, helping prevent the worst impacts of climate change and future-proof business growth (SBTi, 2025) [35]. Targets are considered 'science-based' if they are in line with what the latest climate science deems necessary to limit global temperature rise to well below 2°C above pre-industrial levels and pursue efforts to limit global warming to 1.5°C as per Paris Agreement-2015 and IPCC-2018 to avoid the catastrophic impacts of climate change. And to achieve this, the GHG emissions must halve by 2030 and drop to net-zero by 2050.

The Science Based Targets initiative (SBTi) is a corporate climate action organization that defines and promotes best practices in emissions reductions and net-zero targets (refers to the balance between the amount of GHGs that's produced and the amount that's removed from the atmosphere) in line with climate science. It also provides GHG emissions reduction target validation services for companies. Presently, it does not assess targets for cities, local governments, public sectors, educational institutes or NGOs. It was formed as a collaboration between the CDP, the United Nations Global Compact, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF). The SBTi performs the following functions –

- Defines and promotes best practices in emissions reductions and net-zero targets in line with climate science.
- Develops standards, tools, and guidance to enable companies and financial institutions to set science-based GHG targets in line with the latest climate science.
- Through its wholly-owned subsidiary, SBTi Services, assesses and validates companies' and financial institutions' GHG targets.

5.1 Criteria and recommendations for near-term and net-zero targets for GHG coverage

The SBTi Corporate Net-Zero Standard Criteria (version V1.2 effective from 13th March, 2024) (SBTi, 2024) [34] provides the criteria and recommendations for near-term and net-zero targets for all relevant emissions of the seven GHGs required by the GHG Protocol Corporate Standard. It covers Scope 1, Scope 2, and Scope 3 emissions as defined by the GHG Protocol and states allowable exclusions for total combined Scope 1 and Scope 2 (not more than 5%) and for Scope 3 (not more than 5%) from the GHG inventory boundary or target boundary as applicable. The document outlines the criterion and recommendation on every aspect of GHG coverage, including GHG, Scope, Emissions, and Net-zero Formulation (base year – not earlier than 2015; short-term targets – must cover a minimum of 5 and a maximum of 10 years; long-term targets – target year no later than 2050; intensity targets for Scope 1 & 2 – only eligible when modeled using an approved 1.5ºC sector pathway). Scope 3 targets are not required to use the same base year as scope 1 and scope 2 targets, but base years across the different Scope 3 targets must be the same.

As per the SBTi standards, the company is required to publicly report its GHG emissions inventory and progress made on an annual basis. Further, the companies with approved targets must announce their targets on the SBTi website within six months of the approval date.

6. Analysis of Global GHG Emissions

GHG emissions have been on an increasing trend since the beginning of the 21st century, increasing from 36.18 to 52.96 Giga tons CO_2e (46.41%) from 2000 to 2023 according to the latest estimates, with only two exceptions – 2009 (global financial crisis) and 2020 (COVID-19) (EU Report, 2024) [9]. The main reasons for the reduction in GHG emissions during 2009 and 2020 are the significant slowdown in economic activities, limited mobility (travel), and other human activities (Naderipour *et al.*, 2020; Kumar *et al.*, 2022) [30, 26].

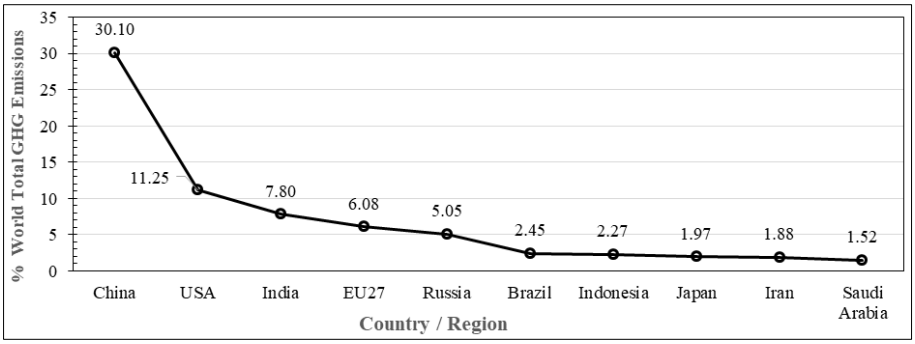

Fig. 3: Percentage contribution of GHG emissions by the top ten countries/regions in 2023.

The GHG emission data is obtained from the European Union's EDGAR-Emission Database for Global Atmospheric Research site (Crippa *et al.*, 2024) [7] and analyzed as per the need of the present study. The analysis revealed that about 62.73% of global GHG emissions in 2023 is from the top six contributors, namely China (30.10%), the USA (11.25%), India (7.8%), the EU27 (6.08%), Russia (5.05%), and Brazil (2.45%). The percentage contribution of GHG emissions by the top ten countries/regions in 2023 is shown in Fig. 3. Analysis of GHG emissions of these top ten countries/regions from 1990 till 2023 (Fig. 4) revealed that the emissions increased in 2023 from 2022 levels, except

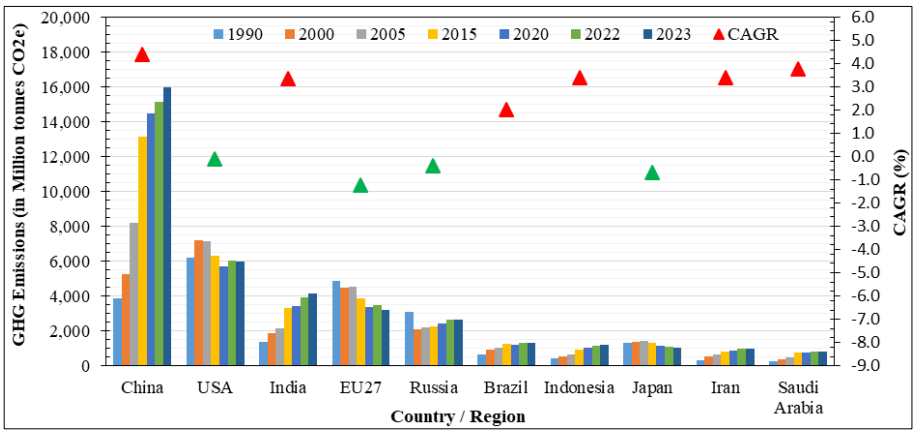

Fig. 4: GHG emissions of top ten countries/regions from 1990 to 2023.

for the USA (-1.41%), the EU27 (-7.48%), and Japan (-6.01%). The GHG emissions of Japan have been declining since 2005. Considering 1990 as the base year, the GHG emissions of China, India, Russia, Brazil, Indonesia, Iran, and Saudi Arabia have been increasing, baring the exception of Russia (during 1990-2000), Brazil (during 2015-2020), and Saudi Arabia (2015-2020).

Cumulative annual growth rate (CAGR) is a valuable metric to assess growth rate over a longer time against a benchmark by smoothing out annual growth. In terms of CAGR with 1990 as the base year, the global CAGR of GHG emissions is +1.47%. China (+4.38%), Saudi Arabia (+3.78%), Indonesia (+3.41%), Iran (+3.38%), India (+3.37%), and Brazil (+2.02%) have positive and above global CAGR, that is an increasing trend of GHG emissions; whereas the EU27 (-1.25%), Japan (-0.71%), Russia (-042%), and the USA (-0.12%) have negative CAGR, that is decreasing trend in the GHG emissions in terms of cumulative annual growth rate (Fig. 4).

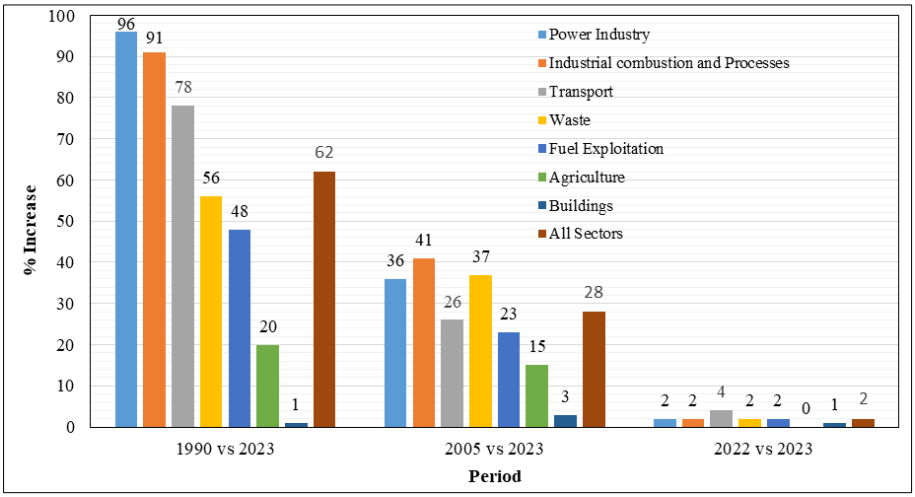

Fig. 5: Sector-wise percentage increase in GHG emissions.

The sector-wise analysis of GHG emissions, in terms of percentage change up to 2023 since 1990, 2005, and 2022 GHG emission levels, is shown in Fig. 5. Every sector has exhibited increased percentage contribution, except agriculture during the 2022 vs 2023 period (about 0%). Unlike in 1990 vs 2023 and 2005 vs 2023, the transport sector exhibited the highest percentage increase (4%) during 2022-23.

7. Conclusions and Recommendations

Numerous efforts have been made at the global level to address climate change through various treaties, agreements, protocols, guidelines, and standards. Notable examples include the Montreal Protocol of 1987; the six IPCC Reports (FAR 1990, SAR 1995, TAR 2001, AR4 2007, AR5 2014, and AR6 2023), the Kyoto Protocol of 1997; the Paris Agreement of 2015, the GHG Protocol, and the SBTi standard criteria. All these initiatives aim to prevent the impacts of climate change by reducing GHG emissions and adopting science-based targets. Despite all the efforts, GHG emissions have exhibited an increasing trend over the last many decades – the global CAGR is +1.47% with 1990 as the base year.

It is recommended and expected from all sectors and all countries to act fast on the reduction of GHG emissions to limit mean global temperature rise to well below 2ºC above pre-industrial levels and pursue efforts to limit global warming to 1.5°C as per the Paris Agreement-2015 and IPCC-2018 respectively to avoid the catastrophic impacts of climate change.

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