GREENHOUSE GAS MANAGEMENT ON UNIVERSITY CAMPUSES WITHIN THE FRAMEWORK OF SUSTAINABILITY

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PREFACE

Sustainability on university campuses includes a comprehensive transformation strategy in addition to technical solutions intended to reduce environmental effects. Due to their varied usage areas and intense activity structures, universities have a significant impact on the environment in terms of energy consumption, transportation, waste generation, and resource use. Because of these characteristics, universities are strategic application areas where sustainability principles can be managed with measurable indicators and environmental performance can be monitored using carbon footprint calculations and greenhouse gas management systems. Addressing sustainability on campus enables universities to become transformative actors that act as role models for society by fusing corporate governance with environmental responsibility.

More than just an environmental issue, climate change is a global systemic problem that forces all institutions to alter their administrative, social, and economic facets. In addition to their goal of producing knowledge, universities play a crucial role in this transformation process by creating, testing, and sharing sustainability-focused practices with society. Universities offer a unique scale and diversity for monitoring and controlling greenhouse gas emissions because they encompass activities, such as energy consumption, transportation, waste management, water use, and supply chains.

In addition to determining current emission levels, corporate carbon footprint studies facilitate performance monitoring, the creation of plans for reducing emissions, and the incorporation of sustainability objectives into business decision-making processes. In this sense, developing a systematic, standards-compliant greenhouse gas management plan that functions on university have become essential for effective institutional climate governance.

University campuses are important places to accomplish sustainable development goals and pass them on to the following generation. The goal of this book is to help university campuses in becoming sustainable systems that monitor their carbon footprints, control what they monitor, and modify what they control. This book aims to provide a comprehensive roadmap for sustainability practices on university campuses, with a focus on carbon footprint calculation methods and adherence to standards such as ISO 14064 and the GHG Protocol. The basic procedures for developing a greenhouse gas inventory at the campus level are outlined in the assessment of emissions from energy use, transportation activities, waste and water management, and supply chain sources in accordance with the Scope 1, Scope 2, and Scope 3 approach.

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ABBREVIATIONS

BAS	: Building Automation System
BMS	: Building Management System
CH_4	: Methane
CNC	: Computer Numerical Control
CO_2	: Carbon Dioxide
CO_2e	: Carbon Dioxide Equivalents
COP	: Conference of the Parties
COVID-19	: Coronavirus Disease 2019
CSR	: Corporate Social Responsibility
DQI	: Data Quality Indicator
EC	: Energy and Climate
EEIO	: Environmentally Extended Input-Output
EF	: Emission Factor
GABC	: Global Alliance for Banking on Climate
GHG	: Greenhouse Gas
GRI 305	: Global Reporting Initiative Standard 305
GWP	: Global Warming Potential
HEI	: Higher Education Institution
HFCs	: Hydrofluorocarbons
ICT	: Information and Communication Technology
IEA	: International Energy Agency
IPCC	: Intergovernmental Panel on Climate Change
ISO	: International Organization for Standardization
ISMS	: Integration of Smart Management Systems
LCA	: Life Cycle Assessment

LED	: Light Emitting Diode
LPG	: Liquefied Petroleum Gas
MDGs	: Millennium Development Goals
NCV	: Net Calorific Value
N_2O	: Nitrous Oxide
NF_3	: Nitrogen Trifluoride
PFCs	: Perfluorocarbons
QS	: Quacquarelli Symonds
SDGs	: Sustainable Development Goals
SF_6	: Sulfur Hexafluoride
THE	: Times Higher Education
UI	: Universitas Indonesia
UN	: United Nations
WBCSD	:World Business Council for Sustainable Development
WRI	: World Resources Institute
WTT	: Well-to-Tank
WWF	: World Wide Fund for Nature

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INTRODUCTION

Natural systems are under growing strain from human activity, and we see firsthand how this pressure can cause irreversible changes once certain thresholds are exceeded. These days, the climate catastrophe, food and water scarcity, biodiversity loss, energy and resource issues, and social and economic difficulties are the main ways that this scenario shows up.

The climate crisis manifests itself in the form of global warming, drought and extreme weather events. The extinction of species and the deterioration of ecosystems are two ways that biodiversity is lost. The decline in bee populations and the death of coral reefs create chain reactions in nature and threaten the functionality of ecosystems. Energy and resource crises are a growing concern due to fossil fuel dependency and the slow transition to renewable energy. When combined with social and economic crises, these factors lead to negative consequences such as inequality and migration. The impact of COVID-19 on the world is a concrete example of the adverse situations that can arise.

These complex crises demonstrate once again how important sustainability is. Environmental sustainability plays a critical role in protecting natural resources and ensuring the healthy functioning of ecosystems. In this context, combating climate change necessitates reducing greenhouse gas emissions and consciously managing carbon footprints.

From a university perspective, the methods used to calculate carbon footprints vary between institutions. This makes comparison and standard assessment difficult. The aim of this book is therefore to develop a common, standard calculation methodology for universities. This will enable reliable comparisons between institutions, facilitate the measurement of environmental performance, and contribute to sustainability goals in a more systematic way.

Chapter 1 addresses the historical development of sustainability and its fundamental dimensions from an engineering perspective. In addition, the fundamental dimensions of sustainability are examined from an engineering viewpoint.

Chapter 2 addresses the multidimensional relationships between climate change and sustainability and evaluates the environmental impacts of climate change.

Chapter 3 addresses greenhouse gas management. It also discusses the carbon footprint approach, its areas of application, the greenhouse gas inventory used in carbon footprint calculations, and international standards, protocols, and guidelines.

Chapter 4 discusses the process of developing a greenhouse gas inventory on college campuses is covered in this section. An analysis of the consolidation techniques used to establish institutional boundaries follows an explanation of the fundamental strategies for creating a common greenhouse gas inventory for universities. The temporal framework of the process is established by defining the base year and calculation period to be used in inventory work. The procedures for data collection and quality control are then discussed; primary data, secondary data, and data collection techniques are described in detail. The study's subsequent phase involved defining operational boundaries and classifying greenhouse gas emissions into three categories. This framework outlined the principles for calculating various emission categories and explained how to calculate greenhouse gas emissions on university campuses according to standarts, guidelines and protocols. Lastly, a summary of university-conducted greenhouse gas inventory studies was provided, and methods for lowering universities' carbon footprints were assessed.

1. SUSTAINABILITY

1.1. The Evolution of Sustainability Throughout History

The concept of sustainability originated in Germany in 1713 with Hans Carl von Carlowitz's work Sylviculture Oeconomica. Carlowitz criticized short-term economic approaches, emphasizing ecological limits and the principle of conserving resources when using trees and forests. His fundamental approach was to use only the 'interest' of forests, i.e. to benefit from them sustainably without consuming their principal capital. This work is an early example of the modern understanding of sustainability, representing the concept's historical roots in Germany.

In 1962, Rachel Carson's Silent Spring revealed the devastating impact of industrialization and pesticide use on the environment, sparking the development of modern environmental awareness. In particular, this work increased environmental awareness in North America and Europe.

The Stockholm Conference held in 1972, was the first global conference to discuss the relationship between the environment and development. The aim was to achieve international policy consensus on environmental issues, with 113 countries participating. While addressing the environmental concerns of industrialized countries, the conference also sought to engage developing countries in the process. Also in 1972, the Club of Rome published its Limits to Growth report, revealing that current economic growth models would lead to resource constraints and environmental damage.

The World Charter for Nature was approved by the UN General Assembly in 1982. This sought to put environmental responsibility at the center of development plans by taking into account how human activity affects the environment.

The Brundtland Report (Our Common Future), which was published in 1987, highlighted the interdependence of development and environmental resources and formally introduced the idea of sustainable development. It brought this idea to the forefront of international development policies by highlighting the necessity of a growth model that is socially, environmentally, and economically sustainable.

The 1992 Earth Summit in Rio de Janeiro brought sustainable development to the global policy agenda, with Agenda 21 and the Rio Declaration officially recognizing that disregarding environmental limits is harmful. In the context of increasing public environmental awareness and the prioritization of global issues such as the thinning of the ozone layer and climate change in politics, this conference was of great importance in the post-Cold War era.

Adopted in 1997, the Kyoto Protocol required developed countries to reduce their greenhouse gas emissions by 5% compared to 1990 levels. The protocol supported these obligations through mechanisms such as joint implementation, emissions trading and clean development.

At the 2000 United Nations Millennium Summit, sustainable development was integrated with its social dimension. Issues such as poverty, hunger and environmental degradation were addressed through the Millennium Development Goals (MDGs). The 2002 Johannesburg Summit addressed issues such as water, energy, urbanization and technology transfer, focusing on the policies and implementation of sustainable development.

The 2012 Rio+20 Conference addressed environmental, social and economic sustainability as a triple balance under the slogan 'The Future We Want', laying the foundation for the Sustainable Development Goals (SDGs). The SDGs are an evolution of the MDGs, aiming to provide an integrated and balanced framework for economic, social and environmental issues.

The SDGs were formally adopted in 2015 with the signing of the document 'Transforming Our World: The 2030 Agenda for Sustainable Development' by the Member States of the United Nations. Seventeen goals comprising 169 targets were set to be implemented by 2030. These goals represent an inclusive development approach, encompassing economic growth, social justice, and environmental sustainability.

Despite these initiatives, environmental degradation and social inequalities have persisted. UN reports published in 2018, as well as the Conference of the Parties 26 (COP26, 2021) and COP27 (2022) summits, have emphasized that time is running out and urgent action is needed. These developments demonstrate that sustainable development is a dynamic and controversial concept addressing the environmental, social, and economic needs of present and future generations (Dashoor, 2025; Elliott, 2006; Garcia et al., 2017; Haner et al., 2025; Lubk, 2017; Scoones, 2007; Strachan & Zohbi, 2025).

1.2. The Concept of Sustainability

Among the many issues giving rise to global crises and widespread concern, theories and practices of development have long focused primarily on economic growth and environmental protection. However, with the publication of the United Nations' Brundtland Report in 1987, these approaches began to acquire a stronger social dimension. From that point onward, development was increasingly discussed not only in economic or environmental terms, but also in relation to social well-being and community resilience, under the broader concept of sustainable development.

The sustainable development emphasizes the need for a more careful and responsible management of resource use, technological applications, and engineering practices, as well as the patterns of consumption that contribute to increasing emissions. Rather than opposing development itself, the concept advocates directing growth in ways that are compatible with the environmental limits and social priorities of each society, while maintaining long-term ecological integrity and human well-being.

1.3. Dimensions of Sustainability from an Engineering Perspective

Sustainability is a multidimensional concept requiring the simultaneous and balanced consideration of the social, economic, and environmental dimensions. The environmental dimension aims to protect ecosystems, ensure the efficient use of natural resources, and minimize environmental impact. The economic dimension, meanwhile, focuses on ensuring long-term economic stability and efficiency. The social dimension encompasses elements such as individuals' quality of life, social justice, equality and access to necessities. These three dimensions are strongly interlinked and not independent of each other. Since economic development is based on environmental resources, environmental degradation can threaten long-term economic sustainability. Similarly, social inequalities can negatively affect economic development and the effectiveness of environmental policies. Therefore, it is crucial that environmental protection measures are economically feasible and socially acceptable (Muniz et al., 2023).

Within this holistic framework, engineering is recognized as a key tool for achieving sustainability. Engineering activities directly impact resource consumption, emissions and environmental impact through energy production, infrastructure systems, material use and technological innovation. In this context, engineering supports environmental sustainability goals by providing technical solutions, enhancing the economic dimension through efficiency and long-term system resilience, and improving the social dimension by offering safe, accessible solutions that enhance quality of life. Therefore, the success of sustainability depends on engineering applications being designed with consideration for the limits of natural systems and societal needs, as well as performance and cost (Rosen, 2012).

The sustainability performance of organizations is closely linked to how well these dimensions are managed over time. Young organizations typically have limited experience and resources with which to fully assess their environmental impact and adapt to changing sustainability expectations. By contrast, more mature organizations have the opportunity to adapt to environmental pressures, build institutional knowledge, and develop competencies focused on sustainability. Financially successful and long-lived organizations are able to prioritize environmental sustainability investments thanks to their resources. However, environmental sustainability performance depends not only on the availability of resources, but also on an organization's ability to meet stakeholder expectations and respond proactively to environmental challenges. This continuous adaptation process contributes to the simultaneous development of the environmental and economic dimensions of sustainability (Haner et al., 2025).

1.3.1. Environmental Dimension of Sustainability

The environmental dimension of sustainability is generally the first to come to mind, as well as being the most widely known among the public. It aims to protect ecosystems, use natural resources efficiently, and minimize environmental damage. As environmental issues and sustainability become increasingly important, environmental sustainability practices have become a critical research and application topic. Environmental sustainability refers to conserving natural resources to ensure they are available for future generations. Climate change, loss of biodiversity, deforestation and pollution are all problems that seriously threaten ecosystems and human life, and therefore interest in environmental sustainability practices is increasing (Lubk, 2017).

These applications include strategies, policies, and initiatives that support sustainable development, lessen the impact on the environment, and conserve resources. They can be used in a number of fields, including transportation, energy, industry, agriculture, and urban planning. Reducing carbon emissions, conserving water, cutting waste, and safeguarding ecosystems are important goals. Furthermore, because natural capital serves as a sink for waste and a source of economic resources, its conservation is essential. Waste should not be released more quickly than the environment can absorb it, and resources should be used at a rate that does not surpass the rate at which renewable resources are replenished. This guarantees biodiversity conservation, ecosystem integrity, carrying capacity, and environmental sustainability (Tennakoon et al., 2024).

Environmental sustainability practices have evolved over time. Initially, the focus was on preventing pollution and complying with regulations, but today, it encompasses broader approaches, such as corporate social responsibility, the circular economy and the United Nations' Sustainable Development Goals. The impact of these practices is complex to assess, as environmental, economic and social factors must be considered together. Positive impacts include improved environmental quality and resource conservation, while negative impacts, such as the emergence of new environmental problems in different regions, may also be observed. Furthermore, the social justice and equity dimensions of environmental sustainability practices are important evaluation criteria (Muthu, 2017).

1.3.2. Economical Dimension of Sustainability

In recent years, the climate crisis, vulnerabilities in the energy supply and the economic and social shocks caused by the pandemic have made it necessary to reassess the economic dimension of sustainability. These developments highlight the need to evaluate economic systems based not only on their growth performance, but also on their capacity to create value within the boundaries of long-term stability, resilience and the environment. In the literature, economic sustainability is defined as maintaining current levels of consumption and production without endangering future requirements, maintaining public and external debt at manageable levels, and preventing excessive imbalances in the production structure (Harris, 2003; Lubk, 2017; Muthu, 2017).

In this context, the economic dimension of sustainability is closely linked to the ecological and social dimensions. Some approaches prioritize environmental sustainability, viewing the economy as a subsystem of a limited, closed ecosystem. Other approaches argue that these three dimensions should be given equal weight. In both cases, however, the fundamental characteristic of economic sustainability is the creation of long-term value through human capital, knowledge, technology and institutional capacity, as well as natural capital. Therefore, economic sustainability is associated with not only growth rates, but also resource efficiency, the quality of the production structure and institutional stability (Filì & De Anna, 2025; Lubk, 2017; Muthu, 2017; Teixeira et al., 2025).

At the policy level, achieving economic sustainability requires addressing traditional objectives such as financial discipline, employment, price stability and the balance of external trade, while also considering environmental and social constraints. In high-income economies in particular, economic decisions are emphasized as being designed to incorporate environmental externalities, with price mechanisms being used as a guiding tool and public budgets ensuring not only fiscal balance, but also the continuity of collective goods such as education, infrastructure and human capital. According to the literature, material efficiency and reducing resource intensity are key policy areas that support economic stability while limiting environmental pressure in developed economies (Celik et al., 2024; Filì & De Anna, 2025).

Consumers play a key role in shaping economic sustainability, acting as market participants and indirectly influencing political processes. Consumption patterns directly influence production structures and corporate investment decisions. However, the literature emphasizes that consumption, particularly in developed countries, often exceeds basic needs and is influenced by marketing and perception management. This leads to a weakening of the link between economic growth and welfare, as well as increasing environmental pressure. Therefore, conscious consumption, reducing excessive consumption and increasing demand for sustainable products are considered important elements that complement economic sustainability (Lubk, 2017; Teixeira et al., 2025).

For companies, economic sustainability encompasses more than just profitability and legal compliance; it also involves long-term risk management and consideration of stakeholder expectations. Approaches such as Corporate Social Responsibility (CSR) and Corporate Sustainability encourage companies to consider their environmental and social impacts when making economic decisions. Carroll's framework of economic, legal and ethical responsibilities, and the integrated CSR models developed subsequently, demonstrate that sustainability permeates the entire decision-making process, rather than being a separate area of corporate strategy. Sustainability certifications, indices and investment criteria also help to create a market structure that evaluates companies' economic performance alongside environmental and social factors (Carroll, 1991; Lubk, 2017).

Another important aspect of economic sustainability is the labor market. The literature shows that the traditional assumption that environmental regulations have a negative effect on employment is becoming less robust. Increased employment in green sectors and higher job satisfaction in companies that embrace sustainability have been observed. These findings demonstrate that economic activities that are environmentally sensitive do not necessarily conflict with social and economic stability. In general, the literature addresses economic sustainability as the outcome of the interplay between policymakers' long-term, comprehensive regulations; consumers' conscious choices; and companies' responsible production and investment strategies. This approach emphasizes that economic systems should be evaluated not only by their growth performance, but also by their ability to generate stable, inclusive and resilient value within environmental limits (Filì & De Anna, 2025; Lubk, 2017; Muthu, 2017; Teixeira et al., 2025).

1.3.3. Social Dimension of Sustainability

The social dimension of sustainability is closely intertwined with economic and ecological systems. Social sustainability is considered an area that can only be realized when ecological and economic criteria are met. Social capital encompasses concrete elements, such as structures that support production and public institutions, as well as more abstract qualities that promote social integration, human rights and societal development (Lubk, 2017).

Social values are the collective beliefs, norms and attitudes that influence individuals' behavior and decision-making within society. These values form fundamental components of social systems, are passed down through generations and contribute to the formation of social identity. Research shows that social values are strongly linked to areas such as education, health, quality of life, and social cohesion. They provide guidance in the formation of ethical business practices, social responsibility, and fair production and consumption systems (Abbas et al., 2019; Leal Filho et al., 2025; Manfredo et al., 2017; Toye et al., 2025).

Individual behaviors are one of the cornerstones of social sustainability. Choices such as volunteering, philanthropy and moderate, conscious consumption can strengthen societal values such as justice and equality. Higher education and vocational training enable students to develop an awareness of social issues and an understanding of their ethical responsibilities, equipping future leaders to make socially sensitive decisions (Abbas et al., 2019; Hoffman, 2021; Leal Filho et al., 2025; Toye et al., 2025).

Social sustainability is multidimensional at both the individual and organizational levels. Evaluating organizational social sustainability practices through the perceptions of employees provides more accurate information about their effectiveness and scope. As the group directly targeted by these practices, employees reflect the actual situation within the organization and the effects of social sustainability. The scope and intensity of social sustainability practices are shaped by legal regulations, social sensitivity and cultural norms, and this varies according to the national context (Karataş, 2025).

In the context of social sustainability management, principles such as good governance, social security, equal opportunities, conflict prevention and the avoidance of risky technologies take center stage. The purpose of these principles is to ensure social justice and welfare for current and future generations (Lubk, 2017).

In conclusion, social sustainability emerges as a multidimensional approach that seeks to balance welfare, justice, security, education, ethical values and individual responsibility within society, alongside economic and ecological considerations. Critical to the implementation of social sustainability are the transfer of social values, the support of individual behaviors, and the consideration of employee perceptions (Karataş, 2025; Leal Filho et al., 2025; Lubk, 2017; Toye et al., 2025).

2. THE RELATIONSHIP BETWEEN CLIMATE CHANGE AND SUSTAINABILITY

A multigenerational strategy, sustainable development aims to satisfy current demands while preserving the capacity of future generations to satisfy their own. From this view, climate change should not be viewed merely as a natural process, but rather as a phenomenon largely driven by human-induced changes in atmospheric greenhouse gas concentrations. These changes generate long-term consequences for ecosystems, economic systems, and human well-being. Increasing global temperatures, heightened climate variability, and the growing frequency of extreme weather events pose substantial risks to agriculture, water availability, and public health.

At the global level, achieving climate-related objectives requires structural transformations in emission-intensive sectors such as energy, industry, agriculture, transportation, and construction. In parallel, the adoption of cleaner production practices and the strengthening of governance mechanisms play a crucial role in ensuring effective implementation. Adaptation to climate change has become an urgent priority, particularly in developing regions where economic limitations and restricted access to technology significantly shape adaptive capacity. In response, multiple sectors have begun to implement adaptation strategies, including climate-responsive agricultural practices, sustainable urban planning, and the development of resilient infrastructure systems. Moreover, emerging technologies—such as artificial intelligence, remote sensing, and big data analytics—are increasingly integrated into early warning systems and decision-support tools, enhancing adaptive responses to climate-related risks.

By increasing temperatures, changing precipitation patterns, and increasing the frequency of extreme weather events, climate change also significantly strains agricultural systems and water resources. In addition to endangering food security, agricultural productivity, and the livelihoods of farming-dependent communities, these pressures also disrupt regional and global agricultural supply chains. Existing research indicates that long-term sustainability and resilience can be strengthened through targeted adaptation measures, including the use of drought-tolerant crop varieties, precision agriculture applications, digital supply chain management, expanded cold storage capacity, and improved transportation infrastructure (Baidya & Saha, 2024; Demir, 2025; Sahar et al., 2025).

Within the framework of the SDGs, climate change is addressed directly under SDG 13 (Climate Action) and indirectly through several interconnected goals, such as SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 14 (Life Below Water), and SDG 15 (Life on Land). This interlinkage underscores the cross-cutting nature of climate action and highlights its relevance across environmental, economic, and social dimensions of sustainable development.

The increase in greenhouse gases in the atmosphere is widely accepted as the main cause of climate change. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) play a primary role in this process. Climate policies and emissions inventories typically prioritize these seven greenhouse gases. The Earth's surface absorbs some of the Sun's short-wave radiation, while the atmosphere reflects some of it. These gases trap this energy, preventing heat loss and causing atmospheric temperatures to rise. The effects of oceans, biota and soil carbon on the greenhouse gas balance are still being researched, as they also play an important role in the carbon cycle (Rani et al., 2025; Seymenler, 2025).

Having explored the link between climate change and sustainability, it is crucial to examine the specific environmental impacts that climate change triggers.

2.1. Environmental Impacts of Climate Change

According to the UN Framework Convention on Climate Change, it is defined as 'changes resulting from human activities that alter the composition of the atmosphere and add to natural climate variability' (Bodansky, 1993). This definition helps us to distinguish between climate change and natural climate variability. The latter arises from temporary and local natural factors that are independent of human influence, whereas climate change is primarily caused by human activities and emerges because of many complex interactions (Chen et al., 2023; Falk et al., 2024; Rainard et al., 2023; Schena et al., 2025).

Both direct and indirect effects of climate change are being felt. Droughts, floods, forest fires, severe tropical storms, and extreme weather events like heatwaves and cold snaps are the main consequences. Global warming is causing glaciers to melt rapidly, sea levels to rise, and ocean temperatures to increase. These changes lead to an increased risk of storms and flooding, which poses a serious threat to sensitive ecosystems such as coastal areas and coral reefs (Chen et al., 2023).

Secondary effects are the indirect consequences of primary changes. Examples include declines in agricultural production, disruptions to food supply chains, the degradation of terrestrial and marine ecosystems, infrastructure and energy system problems, and economic losses. Rising temperatures and changing rainfall patterns can lead to drought and water scarcity, which threatens both agriculture and human health. In addition, labor markets and economic output are negatively impacted, resulting in increased social stress and poverty, and decreased community resilience (Chen et al., 2023).

Tertiary effects emerge in the long term and have a profound impact on social and ecological systems. Examples of tertiary effects include chronic diseases, mental health problems, migration and social conflicts. Climate change threatens sustainability by leading to the depletion of natural resources and the degradation of ecosystems. These effects are more acute in poor and developing countries with limited adaptation capacity (Chen et al., 2023).

The urgency of climate change has increased its impact in environmental, economic and social areas, leading to various research and business approaches being developed. Studies have shown that companies have a responsibility to manage environmental risks and develop solutions in collaboration with stakeholders. Consequently, climate change emerges as a multi-layered problem that must be addressed in terms of both its environmental and social dimensions (Schena et al., 2025).

In summary, the direct and indirect effects of climate change are putting long-term pressure on ecosystems, human health and economic systems, thereby threatening social and environmental sustainability (Chen et al., 2023).

The strong link between climate change and sustainability compels us to take a closer look at the underlying causes of this problem. There is now a need for concrete, measurable concepts that reveal the environmental impact of individuals, institutions and societies. Given that sustainability is both a goal and a result of the decisions we make in our daily lives, it is important to understand how these impacts are formed. This understanding leads us directly to the concept of the carbon footprint. As it reveals the source and scale of greenhouse gas emissions, one of the main causes of climate change, the carbon footprint is a fundamental tool for determining the steps needed for a sustainable future (Debnath et al., 2023).

Therefore, the following section will go into detail about the carbon footprint, UI GreenMetric, QS Sustainability, and Impact Ranking

Systems in order to better understand the relationship between climate change and sustainability.

3. GREENHOUSE GAS MANAGEMENT

3.1. Carbon Footprint and Debates on Measurement

The concept of the carbon footprint lies at the heart of discussions about responsibility and reducing emissions in the fight against global climate change. In recent years, it has become widely used in the media, by public institutions and in the business world. However, the literature contains no agreed definition of what the concept measures, how it should be expressed, or its scope (Wiedmann & Minx, 2008; Williams et al., 2012).

The ecological footprint approach, which attempts to calculate the area of the Earth's surface needed to supply the resources and process the waste required for a particular population, organization, or activity, is where the term “carbon footprint” originates. According to a different definition, a carbon footprint is a measurement of the quantity of greenhouse gases released by human activity, usually expressed in terms of CO_2 emissions. Since its introduction, the term has been used to indicate the relationship between human activity and specific greenhouse gas emissions. However, there are various definitions in the literature. Some cover only CO_2 emissions, some cover all greenhouse gases, some cover direct and indirect emissions, and some cover only direct fuel and energy use. These differences make it difficult to clearly define the concept of a carbon footprint (Ramachandra & Mahapatra, 2016; Williams et al., 2012). Considering these definitional differences, this chapter takes a comprehensive approach, defining the carbon footprint as the total amount of greenhouse gas emissions, expressed in

CO_2 equivalents, that are associated with an activity, organization, or product. This definition includes both direct and indirect emissions across the entire life cycle. Although the concept of the carbon footprint remains ambiguous, its practical importance in assessing environmental impacts has increased significantly. Therefore, it is essential to understand how carbon footprint analysis contributes to environmental sustainability.

3.2. Carbon Footprint Analysis and Environmental Significance

An essential tool for determining the greenhouse gas emissions linked to a company, activity, or product as well as evaluating the environmental effects of different processes and products is a carbon footprint. In order to quantify emissions from the use of fossil fuels in processes like transportation and electricity production, the idea was first presented in the early 1990s. Since then, it has become widely used in many fields, including environmental science, sustainability, and corporate social responsibility. As awareness of the effects of climate change has grown, the concept of the carbon footprint has become increasingly important in commercial and industrial fields. However, discussions regarding measurement methods are ongoing, and this field is still evolving.

The primary purpose of carbon footprint analysis is to identify the main sources of greenhouse gas emissions, a key component of sustainable development, and to inform the development of strategies to reduce these emissions. Extreme weather events and climate change signal imbalances in natural systems caused by global warming, and they can also lead to serious social challenges, such as human migration. The effects of global warming are intensifying year on year: average temperatures are rising, glaciers are melting at unprecedented rates, and natural disasters are becoming more frequent and destructive. In this context, carbon footprint analysis is an important and widespread method of quantitatively revealing the environmental impacts of human activities. This enables individuals and institutions to understand their contribution to climate change and take measures to reduce or offset their emissions (Çelekli & Zariç, 2023).

These analyses are only as effective as the measurement methods used, which is why accurate measurement methods are so important.

3.3. Carbon Footprint in Practice

Following the Paris Agreement (COP21, 2015), which established legally binding targets to restrict global warming to below 2°C above pre-industrial levels, organizations and industries have begun to recognize the importance of accurately measuring and managing their greenhouse gas emissions. Calculating corporate carbon footprints to assess both direct and indirect emissions has become a crucial tool for developing effective mitigation strategies and understanding the ecological impact of activities (Kocabey Çiftçi & Özceylan, 2025).

In order to achieve a carbon-neutral future, all sectors must reduce their greenhouse gas emissions. The energy, industry, buildings, transportation and agriculture-forestry-other land use sectors are the main sources of global greenhouse gas emissions. The buildings sector accounts for around 37% of global CO_2 emissions and 36% of global energy consumption occurs during construction, use and demolition activities. Therefore, buildings and institutional activities play a key role in terms of greenhouse gas emissions (GABC, 2021; Lamb et al., 2021; Paredes-Canencio et al., 2024).

In this context, organizations and institutions should measure the direct and indirect greenhouse gas emissions of their activities. Key factors influencing an organization's carbon footprint include energy consumption, transportation, fuel use, and waste management. Calculating the corporate carbon footprint allows organizations to understand their environmental impact and develop effective strategies to reduce it (Kocabey Çiftçi & Özceylan, 2025; Zhang et al., 2024).

Universities, as complex institutions, contribute to both direct and indirect emissions due to their infrastructure and activities such as energy use, transportation, and waste management. They can reduce their emissions by establishing carbon accounting and reporting systems, implementing energy efficiency and sustainable campus practices, and promoting sustainable lifestyles to the community (Kocabey Çiftçi & Özceylan, 2025; Paredes-Canencio et al., 2024).

3.4. Carbon Footprint Indicators Used in International Sustainability Ranking Systems for Universities

Universities have diverse emission sources, including energy consumption, transportation, and academic activities. From a university perspective, this limitation becomes critical. With better information and the right incentives, organizations, including universities, would find it easier to secure the financing needed for decarbonization investments. Better metrics and data would also facilitate the evaluation of whether finance is aligned with climate goals (OECD, 2025).

The UI GreenMetric World University Rankings is an international ranking system, launched by the UI in 2010, which evaluates universities' sustainability performance worldwide. The ranking uses a variety of criteria to evaluate universities' environmental sustainability strategies and practices.

GreenMetric is designed to measure environmental commitments and encourage sustainable practices among universities. Campus carbon footprints are evaluated alongside other indicators; in particular, total campus carbon emissions per capita are used as an indicator. This ranking encourages universities to calculate and report their carbon footprints, and to develop policies to reduce them (UI GreenMetric, 2024).

Within the UI GreenMetric World University Rankings framework, the Energy and Climate Change (EC) area is the category with the highest weighting in terms of universities' environmental performance and campus-focused sustainability efforts. Accounting for 21% of the total score, this main category examines critical issues such as energy efficiency, renewable energy use, and greenhouse gas emission reduction. The following details regarding greenhouse gas emissions, energy consumption and reduction practices are relevant to your area of interest: Under Greenhouse Gas Emissions and Carbon Footprint, universities' programmes to reduce greenhouse gas emissions are assessed across three different scopes. Scope 1 (direct emissions) includes direct sources such as stationary combustion on campus (e.g. boilers and heaters), mobile combustion from institutional vehicles, and gases leaking from cooling systems (e.g. fugitive emissions). Scope 2 (Indirect Energy Emissions) covers emissions from electricity purchased and consumed by the university. Scope 3 (Other Indirect Emissions) covers indirect emissions from waste disposal, the water supply, staff and student commuting, and air travel. The university's total carbon footprint is calculated by multiplying the annual electricity consumption and transport data (cars and motorcycles) by specific coefficients and is expressed in metric tons per person. The following indicators are highlighted in the resources under the heading 'Energy Consumption and Efficiency-Focused Applications' to optimize campus-based energy usage: Within the scope of energy-efficient devices, the use of LED bulbs, Energy Star-certified computers, and environmentally friendly air conditioners is encouraged. The ratio of smart buildings equipped with energy and water-saving automation, occupancy sensors and data monitoring systems (BMS/BAS) to the total building area is examined under Smart Building Applications. In the section on renewable energy, the production of energy from sources such as solar, wind, biodiesel and geothermal is evaluated, as well as the ratio of this production to total consumption. The following criteria have been established under Carbon Reduction and Innovation Applications for the active role of universities in combating climate change: “Innovative Programs” evaluates original technological approaches and patented inventions developed by the university (e.g.

smart indoor health systems). ICT Use (EC.11) refers to the use of information and communication technologies in the planning, monitoring and evaluation of energy and climate change programmes, which is an important element emphasized in the 2025 guide. Under Impact-Focused Education, training and seminar programmes are expected to be organized for local, national, or international communities on climate change risks and adaptation. In summary, the campus' environmental performance is measured by energy savings, a comprehensive emissions inventory, the integration of smart management systems (ISMS) and the institution's own innovative solutions (UI GreenMetric, 2025).

The QS Sustainability Rankings are a system that measures and enables global comparison of universities' sustainability performance. It comprehensively assesses environmental impact, corporate governance, sustainability strategies and social responsibility projects. Core criteria include indicators such as greenhouse gas emissions, energy consumption, renewable energy production, carbon neutrality targets, environmental policy and transparent reporting. The rankings are significant for universities in terms of both academic prestige and global visibility. The rankings serve as a reference for students, academics, and investors, and guide institutions in developing their environmental and social responsibility policies.

Greenhouse gas emissions are assessed under the 'Environmental Impact' component. This assessment includes the following indicators:

- Carbon footprint per student/staff member, which measures carbon emissions per student and staff member
- Scope 1 & 2 emissions reporting, which covers the reporting of direct and energy-related indirect emissions
- Net-zero/emissions reduction targets, which include carbon neutrality and emission reduction targets
- Environmental sustainability strategy, which demonstrates corporate sustainability and climate strategies
- External sustainability reporting, which ensures transparency and public reporting (QS Quacquarelli Symonds, 2024).

The Times Higher Education **(THE)** Impact Rankings are focused on the SDGs. Greenhouse gas emissions are assessed directly under SDG 13. In this context, universities are recognized for their efforts to address climate-related risks, reduce greenhouse gas emissions and increase adaptation capacity. They also stand out for their research and applications in affordable and clean energy under SDG 7, demonstrating their commitment to developing sustainable energy services, increasing energy efficiency, and investing in energy infrastructure. Relevant indicators include corporate carbon reduction policies, measurement and reporting of emissions, use of low-carbon and renewable energy, climate change education and research, and social awareness and stakeholder engagement. The focus is on climate action, policy development, education and social impact rather than emission quantities.

THE Impact Rankings are of great importance to universities. They increase institutions' global visibility and enhance their prestige in the areas of sustainability and social responsibility. They also influence the preferences of students and academics. Furthermore, these rankings help universities to develop their policies and strategies and attract financial support and investor interest. While the results of the THE Impact Rankings do not impose direct sanctions, poor performance can affect an institution's reputation and provide valuable data for strategic decision-making (Times Higher Education, n.d.).

3.5. Sources Used in the Preparation and Calculation of the Greenhouse Gas Inventory

The aim of carbon footprint calculations is to determine the contribution of human activities to climate change and set emission reduction targets fairly. Furthermore, carbon footprint calculations can take indirect impacts throughout the life cycle into account by converting all greenhouse gas emissions into CO_2 equivalents. These calculations can be based on various sources and standards. For example, the IPCC guidelines, the GHG Protocol and the ISO 14064 series provide guidance on carbon footprint calculations (Wiedmann & Minx, 2008; Williams et al., 2012).

The basic steps for calculating a carbon footprint are as follows (Williams et al., 2012):

1) Identify and categories all possible emission sources for the activity or system being calculated.

2) Deciding which sources to include in the calculation.
3) Choosing the best technique to convert each emission source's quantifiable activity into CO_2 equivalents.
4) Collecting the necessary data and calculating total emissions as CO_2 equivalents.
5) Documenting the method used and ensuring comparability with future calculations.

These steps establish a certain degree of standardization in the preparation of a carbon footprint inventory. However, several fundamental debates persist regarding the scope of the carbon footprint concept and the units of measurement used. For instance, it remains unclear whether only carbon-containing gases should be included, or whether other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O) should also be considered. Similarly, there is ongoing discussion as to whether emissions originating from non-fossil sources should be considered, and whether indirect emissions along the supply chain (Scope 3 emissions) should be included in the assessment. Furthermore, another key debate concerns whether the carbon footprint should merely represent the number of emissions as a “pressure indicator,” or whether it should also reflect global warming potential (GWP) as an “impact indicator.” Although these issues have long been discussed in the literature on ecological economics and life cycle assessment, their application to the carbon footprint concept remains unclear (Çelekli & Zariç, 2023).

These debates have led to the development of standardized methodologies that aim to improve the comparability and transparency of carbon footprint calculations.

Commonly used sources for carbon footprint calculation are the IPCC National Greenhouse Gas Inventory Guide and Greenhouse Gas Protocol (GHG Protocol) and the ISO 14064-1:2018 standard. The GHG Protocol defines the scope and reporting framework, ISO 14064-1, 14064-2 and 14064-3 define the scope of the calculations and ensure the reliability of the calculations by verifying them, while IPCC Tier 1, Tier 2 and Tier 3 provide greenhouse gas emission calculations (Figure 1) (IPCC, 2006b; ISO 14064-1, 2018; WRI&WBCSD, 2004).

Figure 1. The role of the GHG Protocol, the ISO 14064 standard and the IPCC guidelines in greenhouse gas inventories.

3.5.1. Greenhouse Gas Protocol (GHG Protocol) Methodology

The Greenhouse Gas Protocol (GHG Protocol) is the most widely accepted framework globally for calculating and reporting corporate carbon footprints. The theoretical basis of this approach is grounded in the IPCC National Greenhouse Gas Inventory Guidelines and standards developed by the WRI (World Resources Institute) and WBCSD (World Business Council for Sustainable Development). However, depending on sectoral characteristics, operational complexities, and stakeholder demands, the depth of analyses and the methods used may vary (Ersoy Mirici & Berberoğlu, 2022).

The GHG Protocol (2004) classifies organizational emissions into three main scopes according to responsibility and control (Harangozo & Szigeti, 2017):

Scope 1 (Direct Greenhouse Gas Emissions): Refers to emissions from sources owned or directly controlled by the organization. Examples of this category include fuel consumption by trucks in the organization's own vehicle fleet or natural gas heating systems within the facility.

Scope 2 (Energy-Related Indirect Emissions): Covers emissions generated during the production of electricity, heat, steam or cooling energy consumed by the organization and purchased externally. Although the GHG Protocol focuses primarily on electricity, all forms of externally procured energy are assessed within this scope.

Scope 3 (Other Indirect Emissions): This section, which is an optional (voluntary) category under the Protocol, covers all other indirect emissions generated throughout the organization's value chain. It covers the upstream (raw material extraction, supplier activities) and downstream (product use, waste management) processes of the product life cycle, offering the broadest scope of analysis.

This segmentation of the greenhouse gas inventory enables organizations to analyze their emission sources more accurately, improve risk management, and report their sustainability targets transparently (Harangozo & Szigeti, 2017; WRI&WBCSD, 2004).

3.5.2. ISO 14064 Greenhouse Gas Management Standards Series

To ensure international recognition and methodological consistency in corporate inventory studies and emission reporting, the ISO 14064 series, developed by the International Organization for Standardization (ISO), is accepted as the primary reference (Ersoy Mirici & Berberoğlu, 2022). This series provides a systematic framework for greenhouse gas management and consists of three main parts, each offering applied guidance in specific areas:

ISO 14064-1:2018: Specifies requirements at the organization level for the design, development, management, and reporting of GHG inventories. This part establishes the fundamental procedures for monitoring emissions and removals, serving as the basis for verification. It essentially consists of six categories (ISO 14064-1, 2018).

ISO 14064-2:2019: Focuses on GHG projects or project-based activities specifically designed to reduce emissions or enhance removals. It provides measurement and reporting criteria for evaluating project-based improvements and constitutes the basis for the validation and verification of such projects (ISO 14064-2, 2019).

ISO 14064-3:2019: Provides principles, requirements, and guidance for third parties conducting the verification and validation of GHG assertions. This standard manages a process designed to ensure that a company's or project's GHG declarations are complete, accurate, consistent, transparent, and free from material discrepancies (ISO 14064-3, 2019).

Approaches to calculating greenhouse gas emissions are fundamentally based on the IPCC National Greenhouse Gas Inventory Guidelines and Greenhouse Gas Protocols; however, various methods may be adopted by different institutions and organizations in detailed applications (Ersoy Mirici & Berberoğlu, 2022; IPCC, 2006b; WRI&WBCSD, 2004). Greenhouse gas inventory studies conducted at the institutional and organizational level are mostly based on standards published by the ISO (ISO, 2018). The combined application of the three parts of the ISO 14064 series enables organizations to monitor their greenhouse gas performance in a systematic and transparent manner and provides a comprehensive greenhouse gas management framework that supports the achievement of sustainability goals (Figure 2) (ISO 14064-1, 2018; ISO 14064-2, 2019; ISO 14064-3, 2019).

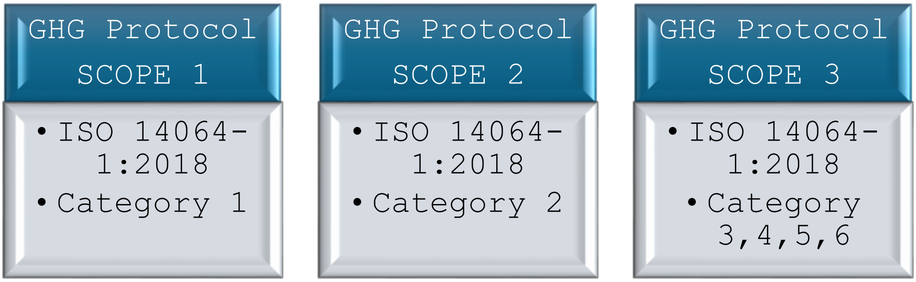

Figure 2. GHG Protocol and ISO 14064-1:2018 scope- category summary.

3.5.3. IPCC Tier Methodology

The IPCC Tier Methodology is predominantly used as the carbon footprint calculation method. The IPCC methodology consists of Tier 1, Tier 2, and Tier 3 approaches (IPCC, 2006a). According to the IPCC 2006 Guidelines, the choice of calculation method directly dictates the selection of the carbon emission factor. The Tier 1 approach is a simplified and globally applicable methodology that relies on the use of generalized, default emission factors. Under this approach, a country's or organization's total fuel consumption is multiplied by international standard emission factors to estimate CO_2 emissions. Since Tier 1 assumes that emission factors do not depend on the specific location of the activity, the combustion technology, or the existing control measures, it inherently carries a certain level of uncertainty. Despite these limitations, it serves as an essential and rapid assessment tool, particularly for regions or entities where detailed, site-specific data is limited (IPCC, 2006b; Turanlı, 2015).

The Tier 2 approach, which provides a higher level of detail than Tier 1, requires the use of country-specific emission factors for each source category and fuel type. These factors offer greater precision as they are based on localized parameters such as fuel quality, combustion technology, equipment age, maintenance standards, operating conditions, and control technologies. Because the emission factors are tailored to specific national or regional circumstances, the variability in data is minimized, resulting in more accurate CO_2 emission figures. Consequently, the Tier 2 methodology significantly reduces calculation uncertainty and plays a vital role in conducting robust, sector-based emission analyses (IPCC, 2006b; Turanlı, 2015). As the most sophisticated and detailed methodology, Tier 3 incorporates technology as a primary variable in the calculation of emission factors. In this context, "technology" refers to the specific combustion processes, fuel properties, and other technical factors that directly influence emission outcomes. Unlike simpler methods, Tier 3 utilizes comprehensive modeling and facility-specific data, accounting for intricate parameters such as technological efficiency, transport distances, and payload quantities. Consequently, while it is the most complex method to implement due to high data requirements, it provides the highest level of accuracy. Furthermore, Tier 3 serves as an advanced tool that supports long-term emission reduction strategies and strategic policymaking through high-fidelity data (IPCC, 2006b; Turanlı, 2015). The definitions of comparison criteria according to the IPCC, GHG Protocol, and ISO 14064 standard are explained in the Table 1 below.

Table 1. Comparison criteria for IPCC Guidlines, GHG Protocol and ISO 14064 standart series.

Comparison Criterion	IPCC Guidelines (Tier 1–2–3)	GHG Protocol	ISO 14064 Standard Series
Primary role	Calculation methodology for National Inventories	Reporting and accounting framework for Organizations	International standard for Verification and reporting
Main purpose	To provide methods for estimating national emissions	To define how corporate emissions are classified (Scope 1-2-3)	To provide a verifiable framework for GHG declarations
Focus	Emission factors and calculation methods	Scope 1–2–3, organizational boundaries	Verification, certification, transparency
Scope / Category Approach	Sector-based (Energy, Waste)	Scope 1, 2, and 3	Categories 1 to 6 (Compatible with the GHG Protocol)
Emission factors	IPCC default (Tier 1) or country-specific (Tier 2–3)	IPCC/national/sector-based sources	IPCC/national/documented sources
Calculation accuracy	Varies by Tier (Tier 3 is highest)	High (if data quality is high)	High (Emphasizes uncertainty management))
Verification requirement	No	No	Yes (ISO 14064-3)
Suitability for corporate reporting	Medium	High	Very high
Suitability for universities and public institutions	Entry level	Standard practice	Advanced / verified

Corporate carbon footprint calculations are conducted in accordance with the methods defined in the ISO 14064-1 series of guidelines and specifications, following the calculation scopes outlined in the GHG Protocol, and by making use of the data collection, calculation, reporting frameworks, as well as reference emission factors and tables provided in the IPCC guidelines. Once the environmental impacts have been understood through carbon footprint analyses, the resulting data can be applied across various fields and effectively used in the development of corporate strategies.

4. ESTABLISHING A GREENHOUSE GAS INVENTORY ON UNIVERSITY CAMPUSES

4.1. Developing a Standard Greenhouse Gas Inventory for Universities

Measuring and lowering greenhouse gas emissions has become an essential duty for all institutions in accordance with sustainable development goals and climate change mitigation. Universities are expected to produce knowledge and serve as role models for sustainable practices in society due to their missions in education, research, and social contribution. Universities have a large environmental impact due to their extensive use of resources and activities.

Carbon footprint studies conducted in higher education institutions (HEIs) contribute to increasing environmental awareness, particularly among the student population, and enable this effect to spread to wider sections of society. Accordingly, the number of higher education institutions calculating their carbon footprint is increasing; these institutions can improve their operational efficiency while reducing their environmental impact (Valls-Val & Bovea, 2021).

Sustainability-based ranking and evaluation systems are increasingly putting institutional pressure on universities by focusing on indicators such as carbon emissions, energy consumption, and waste management (Findler et al., 2019). In parallel, carbon neutrality targets set by countries and regions require higher education institutions to develop policies aligned with these targets and actively contribute to the process

(Findler et al., 2019; IPCC, 2006b; Valls-Val & Bovea, 2021). Furthermore, funding organisations are increasingly prioritising sustainability criteria in their grant and support programmes, placing universities with strong and measurable sustainability practices in a more advantageous position (Lozano et al., 2015).

Students, parents, graduates, and local communities, among a wide range of stakeholders, expect universities to take a leadership role in sustainability; institutions that fail to adequately fulfil their environmental responsibilities may face serious reputational risks (Filimonau et al., 2021).

All these global dynamics clearly demonstrate that academia must address the reduction of carbon emissions and sustainability initiatives as both a moral obligation and a strategic necessity in the face of the multidimensional challenges posed by climate change.

Although various international standards and guidelines have been developed to ensure transparency in the reporting of greenhouse gas emissions, there is still no comprehensive measurement, reporting and verification approach specific to higher education institutions that is globally accepted and allows for inter-institutional comparison. This deficiency leads to significant differences in universities' carbon footprint calculations and makes it difficult to compare the results obtained. In this context, it has become critically important for universities to be able to determine their carbon footprints in a reliable, consistent and comparable manner. However, the variation in the methods used in practice from institution to institution clearly highlights the need to develop a common and standardised carbon footprint calculation methodology for higher education institutions (Valls-Val & Bovea, 2021).

4.2. Determining the Organizational Boundaries

4.2.1. Fundamental Consolidation Methods

Determining organizational boundaries is one of the basic steps in carbon footprint calculations, according to ISO 14064-1 (2018) and WRI & WBCSD (2004) sources. The organizational boundary specifies which of an organization's affiliates, subsidiaries, or units will be taken into account when calculating greenhouse gas emissions. The extent, precision, and inter-organizational comparability of carbon footprint calculations are directly impacted by the proper definition of this boundary.

The Equity Approach and the Control Approach are the two primary methods for establishing organizational boundaries, according to sources (ISO 14064-1, (2018); WRI&WBCSD, 2004).

Equity Share Approach: This method involves the organization accounting for greenhouse gas emissions from the relevant operation in proportion to its ownership or economic interest in that operation. Because it represents the organization's degree of involvement in the risks and rewards of the operation, this approach is in line with commercial reality (WRI&WBCSD, 2004).

Control Approach: According to WRI and WBCSD (2004), the organization's inventory contains 100% of emissions from operations under its control, but excludes emissions from operations over which it has an ownership interest but no control. Two criteria can be used to apply the control approach.

- Financial Control: If an organization has the power to control an operation's financial and operational policies for financial gain, it is said to have financial control. In general, this criterion is in line with full consolidation financial accounting standards (WRI&WBCSD, 2004).
- Operational Control: According to WRI&WBCSD (2004) and WRI (2015), an organization has operational control if it or one of its subsidiaries has complete authority to implement and enforce business policies in the relevant operation. When a facility has an operating license, it usually means that the organization has operational control (WRI&WBCSD, 2004).

Organizational boundaries can be precisely defined thanks to the control approach, especially in organizations with intricate organizational structures.

The reliability of carbon accounting depends on accurately defining organizational boundaries, according to studies in the literature. For instance, research on industrial facilities demonstrates that incorporating all of a company's production units within the organizational boundary guarantees that emissions are evaluated holistically (Çolak & Atılgan Türkmen, 2023). In a similar vein, research on carbon footprints across various industries demonstrates that inter-organizational comparability is improved by precisely defining organizational boundaries.

In terms of national and international carbon accounting and carbon trading practices, establishing organizational boundaries in carbon footprint calculations is also crucial. The units that are included within the organizational boundaries directly affect the accuracy and dependability of carbon accounting. As a result, when determining their carbon footprint, organizations need to clearly, consistently, and globally compliantly define their organizational boundaries (Gürbüz et al., 2019).

Establishing organizational boundaries is crucial in determining the extent of carbon footprint calculations in institutions like universities that have multiple units, campuses, and related structures. Universities typically use an operational control approach to define organizational boundaries in order to report greenhouse gas emissions through the faculties, research centers, administrative buildings, and other affiliated units they own or directly manage. By clearly defining the areas in which universities have direct control and responsibility, this method improves the accuracy and comparability of the data collected and permits a more transparent evaluation of their sustainability performance. In order to accomplish sustainability goals and fight climate change, it is therefore thought that all institutions, especially universities, must accurately and consistently determine organizational boundaries.

4.3. Selection of the Base Year and Calculation Period

Selecting the base year and defining the calculation period accurately are critical for ensuring reliable and comparable carbon footprint calculations.

The significance, traceability, and efficacy of sustainability strategies are significantly impacted by the choice of base year and calculation period in carbon footprint calculations. The year that an organization's or activity's carbon footprint is first determined or referenced is usually known as the base year (ISO 14064-1, 2018). The precise time during which the carbon footprint measurement is carried out is referred to as the calculation period. Setting goals for the future and making historical comparisons are both made possible by accurately defining these two ideas.

The significance of choosing the base year and calculation period is emphasized by the standards and procedures used in carbon footprint calculations. For instance, in carbon footprint calculations, the GHG Protocol and ISO 14064 standards mandate that the base year and the calculation period be clearly defined (ISO 14064-1, 2018; Tosun & Tunç Dede, 2024). These guidelines were created to guarantee the transparency, consistency, and comparability of carbon footprint calculations. It is possible to monitor changes in energy consumption and carbon emissions over time by choosing an annual calculation period.

In corporate carbon footprint calculations, the base year is typically chosen to be one in which the organization's operations have not changed significantly, the data is available, and the data is trustworthy. The base year emissions must be recalculated whenever the company's structure undergoes major changes, such as mergers, acquisitions, or divestitures. This guarantees a consistent comparison across years.

4.5. Data Collection and Quality Control Processes

Based on its origin and uniqueness, the data used to create a greenhouse gas inventory is separated into two primary categories: primary and secondary data. For the inventory to be accurate, transparent, and dependable, gathering this data is essential.

4.5.1. Primary Data

Gathered directly from particular activities within an organization's own value chain is referred to as primary data. At the location of the activities, this data is measured or computed. Meter readings, purchase records, invoices, engineering models, and direct monitoring (such as continuous emission monitoring systems, or CEMS) are used to gather primary activity data. This information could be more general corporate-level information or "site-specific" information gathered from the field or facility. Product-level data, process-level data, facility-level data, business unit-level data, and corporate-level data are ranked from highest to lowest in the GHG Protocol's uniqueness hierarchy.

Specifically for Scope 3, product-based inventory data or life cycle data may be requested from suppliers via surveys or questionnaires.

4.5.2. Secondary Data

Secondary data, which is usually average or generalized data, is information gathered from sources outside the reporting company's value chain. This includes government statistics, industry averages, IEA (International Energy Agency) databases, scholarly literature reviews, and commercial life cycle assessment (LCA) databases. An essential secondary data source for converting economic expenditure data into emissions is Environmentally Extended Input-Output (EEIO) models. The average emissions released for every $1 million spent are estimated using this method. It is referred to as secondary data and entails substituting unavailable data with data from a comparable activity (scaled as needed).

4.5.3. Strategy for Gathering Data and Setting Priorities

To improve productivity and control expenses, organizations should use these methods when gathering data:

Accuracy and Preference: Because it lowers uncertainty, ISO 14064-1 and the GHG Protocol advise giving primary (field-specific) data top priority. Secondary data is typically used for sources with low emission significance or when gathering primary data is not feasible.

Hybrid Approach: Businesses usually use both approaches, filling in the gaps with secondary (average) data and using primary data when available.

Continuous Improvement: In high-emission ("hot spot") categories, businesses are expected to gradually switch from secondary data to higher-quality primary data (GHG Scope 3, 2013; ISO 14064-1, 2018; Sotos, 2015).

The quality of data collection procedures and the quality control methods used in these procedures directly affect the accuracy and dependability of carbon footprint calculations (ISO 14064-1, 2018). Therefore, to accurately determine environmental impacts and boost the efficacy of sustainability policies, it is crucial to carry out data collection and quality control procedures in carbon footprint assessments in a methodical and transparent manner. Calculations of carbon footprints may become uncertain and less reliable if data collection procedures are not carried out methodically.

Carbon footprint measurement, includes all processes from production to consumption and disposal, is usually done using the LCA methodology. The dependability of the results is directly impacted by the quality of the data used in carbon footprint calculations. Unsystematic data collection procedures have been found to cause uncertainty in the carbon and water footprint calculations of numerous organizations. A data quality indicator (DQI) management system has been proposed to address this problem, and it has been stated that the collected data must be assessed in terms of time, geography, reliability, integrity, and technological differences. Additionally, it has been highlighted that the DQI approach makes it possible to calculate carbon and water footprints simultaneously and accurately (Kuo et al., 2015). When deciding on tactics to enhance environmental performance, these quality control methods are a crucial point of reference.

At the corporate level, determining the sources of emissions, guaranteeing the transparency of data collection procedures, and putting quality control systems in place are essential to assisting businesses in reaching their sustainability objectives. Particularly in the fields of agriculture, industry, energy, and services, the quality of data used in carbon footprint calculations can differ greatly. For instance, the complexity of production processes and the existence of multiple emission sources in the industrial sector further increase the significance of data collection and quality control procedures in carbon footprint calculations. Accurate data collection procedures are crucial in the energy sector when calculating carbon footprints, especially when evaluating renewable energy sources (Levasseur et al., 2021).

The scientific validity of carbon footprint studies is currently directly impacted by the methods, criteria, and computation techniques employed.

Accurately estimating the environmental effects of communal living areas like cities, campuses, and offices depends on the caliber of data collection procedures used in carbon footprint computations. For instance, a university campus's carbon footprint necessitates thorough data collection procedures to thoroughly examine the life cycle assessment and sources of greenhouse gas emissions, i.e., to pinpoint the primary emission sources like steam production, electricity generation, and automobile transportation. Regarding the dependability of the outcomes, the precision and breadth of data collection procedures are crucial (Clabeaux et al., 2020).

To sum up, accurately determine environmental impacts, improve the efficacy of sustainability policies, and lower uncertainties, data collection and quality control procedures in carbon footprint analyses must be carried out in a methodical, transparent, and standards-compliant manner.

4.6. Operational Boundaries: Scope of Emissions

Once operational boundaries are defined, emissions are classified as direct and indirect based on their sources and grouped under three "Scopes".

The Greenhouse Gas Protocol and the ISO 14064 Standard series use two different terms to express operational boundaries: scope and category. Fundamentally, both words are used for the same purpose. The scope-category relationship between the two sources is presented in Figure 1. When evaluated from the perspective of the GHG Protocol, emissions are categorized as direct and indirect based on their sources and grouped under three "Scopes" after operational boundaries are established (WRI&WBCSD, 2004).

4.6.1. Scope 1: Direct Emissions

Definition: Scope 1 emissions refer to greenhouse gas releases directly originating from sources owned or controlled by an organization. This scope primarily includes four main sources: stationary combustion (fuel use in equipment such as boilers, furnaces, and turbines), mobile combustion (the organization's fleet of vehicles, ships, and aircraft), process emissions (emissions from physical or chemical processes such as chemical production or cement manufacturing), and fugitive emissions (refrigerant leaks, equipment leaks, or methane leaks from mines). Calculations cover gases such as CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3. CO_2 emissions from biomass combustion are not included in the Scope 1 total (Sotos, 2015; WRI&WBCSD, 2004).

Calculation of Scope 1 Emissions: Scope 1 emissions are typically calculated by multiplying activity data with the appropriate emission factors. According to the Tier approach, as also discussed in Section 3.5.3, this process follows a three-tier system based on data quality and level of detail: Tier 1 uses national energy statistics and default emission factors; Tier 2 applies country-specific or fuel-specific emission factors; and Tier 3 provides the most detailed calculations using facility-level direct measurements or technology-based complex models (Gómez et al., 2006; WRI & WBCSD, 2004).

In practice, activity data such as fuel consumption from stationary combustion, mobile combustion, process emissions, and fugitive emissions are collected from invoices, meters, or supplier records and expressed in physical units (m^3, litres, tons). To ensure calculation accuracy, these units are converted into energy units using fuel-specific density values and Net Calorific Values (NCV), obtained from suppliers, national statistics, or internationally recognised sources such as IPCC and IEA. Oxidation factors are generally assumed to be 1, though unburned carbon can be included in more precise calculations. Biogenic carbon from biomass or biofuels is excluded from the Scope 1 total and reported separately. This approach ensures that Scope 1 calculations are both accurate and consistent across different data quality levels (Garg et al., 2006; Gómez et al., 2006; WRI&WBCSD, 2004). Explanations regarding potential emission sources, source streams and activity data falling under Scope 1/Category 1 are presented in Table 2.

Table 2. Category 1 direct emissions examples.

Categories		Emission Source	Source flow	Activity data (relevant document/record)
Category 1	1.1 Direct emissions from stationary combustion sources	Boiler, generator, diesel fire pump, rotfire fire extinguishing device, oven	Natural gas, LPG, diesel	Invoices, inventory changes, fuel purchases, fuel receipts
	1.2 Direct emissions from mobile combustion	Company passenger vehicles, excavator, tractor, forklift, lawn mower	Diesel, LPG, gasoline	Fuel receipts
	1.3 Direct emissions from industrial processes	Melting furnace	Limestone, lime, anthracite, soda ash, kaolin	Weighbridge tickets, weighbridge log sheets, bunker weighbridge records
	1.4 Direct leakage/seepage emissions from GHG emissions in anthropogenic systems	Chillers, air conditioners, VRF systems, refrigerators, halocarbon fire extinguishers, carbon dioxide fire extinguishers, circuit breakers, water coolers, machine panel air conditioners, compressor dryers, cold rooms, server room fire extinguishers	R407C, R32, R410A, R600, 236FA, CO_2, SF_6, R134A, R407C, FM200	Service forms, product label information, refrigeration unit inventory document

Challenges in Calculation: Several challenges exist in determining Scope 1 emissions. Some sources may be hidden—for example, an aviation company must account for fuel used in engine tests. Data accessibility and quality can be a constraint, particularly for tracking fugitive emissions. Structural changes such as mergers, acquisitions, or divestments require recalculation of base year data to maintain consistency. Additionally, the precision of measurement equipment, assumptions in models, and expert estimates contribute to parameter uncertainty (WRI&WBCSD, 2004).

Importance of Scope 1 Emissions: Accurately assessing Scope 1 emissions allows an organization to understand its climate-related risks and anticipate potential carbon costs. This information is crucial for identifying efficiency opportunities in energy use and production processes, guiding the transition to low-carbon technologies, and reducing operational costs. A reliable and transparent data foundation supports compliance with legal requirements and participation in carbon markets, while also meeting stakeholder and investor expectations, thereby strengthening corporate reputation. Since Scope 1 emissions are primarily fuel-based, arising from activities such as heating and transport, evaluating the potential to replace fossil fuel–dependent processes with renewable energy sources is critical for strategic planning and effective emissions reduction (Garg et al., 2006; Gómez et al., 2006; WRI&WBCSD, 2004). Accurately and comprehensively identifying emission sources within this scope is particularly effective for emission reduction in energy-intensive sectors, such as the textile industry (Şahin, 2025).

Requirement for Separation by Gas Type: A publicly available SG report should detail emission data not only in total tonnes but also by gas type. Companies should report data for the following six main greenhouse gases separately in both metric tonnes and tonnes of CO_2 equivalent (CO_2e): CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 (ISO 14064-1, 2018; WRI&WBCSD, 2004).

4.6.2. Scope 2: Energy Indirect Emissions

Definition and Boundaries of Scope 2 Emissions: Scope 2 greenhouse gas emissions represent indirect emissions that result from an organization's operations but are not directly under its control. This category covers emissions produced during the generation of purchased or acquired energy types such as electricity, steam, heating, and cooling (WRI & WBCSD, 2004).

The primary reason Scope 2 emissions are categorized as "indirect" is that the emission of greenhouse gases takes place at third-party facilities (such as a thermal power plant) rather than the reporting company's own sites. However, the reporting organization's energy consumption patterns are directly responsible for the occurrence of these emissions. This distinction enables a business to evaluate its impact across its entire value chain as well as within its own operational boundaries (WRI & WBCSD, 2004, Scope 2 Guidance).

Boundary Setting and Technical Losses: The boundaries of Scope 2 are strictly defined. Technical losses—specifically transmission and distribution (T&D) losses—that occur while purchased electricity travels from the power plant to the company's facilities are not included in Scope 2. According to the GHG Protocol, emissions resulting from these losses are reported under the "Scope 3: Fuel and Energy-Related Activities" category. This classification enhances the accuracy of corporate inventories by ensuring that emissions are appropriately separated at the source and by preventing double counting (WRI & WBCSD, 2004).

Calculation Methodology- Dual Reporting: The GHG Protocol requires a "Dual Reporting" methodology for Scope 2 emissions instead of a single calculation method. This strategic choice allows a company to simultaneously reflect the reality of the electrical grid in which it operates and the benefits of its specific energy procurement decisions:

- **Location-Based Method:** This approach reflects the average emission intensity of the electricity grids where energy consumption takes place. It typically utilizes grid average emission factors, which represent the average of all generation sources (fossil fuels, nuclear, renewables, etc.) within a specific national or regional grid. This method depends on geographic location and does not account for a company's specific green energy contracts.

- **Market-Based Method:** This approach accounts for the deliberate choices businesses make when purchasing electricity.

Calculations are based on "contract-based instruments" available in the energy market, such as renewable energy certificates (e.g., I-RECs) or choosing a low-carbon supplier. This allows a business to directly demonstrate the impact of its renewable energy investments within its Scope 2 data.

At least one-third of the world's greenhouse gas emissions originate from the production of heat and electricity. This figure places Scope 2 management at the heart of the global fight against climate change. For many organizations, particularly in energy-intensive industries, these indirect emissions can constitute the majority of their total carbon footprint.

Accurate measurement and the dual reporting approach provide businesses with more than just regulatory compliance; they offer strategic advantages such as cost savings, risk management, and reputational enhancement. Ultimately, the data provided in such reports serves as a roadmap for companies to successfully meet both their long-term strategic business objectives and their environmental obligations. Broader policy-oriented studies emphasize that energy efficiency improvements and integrated sectoral strategies play a critical role in reducing carbon emissions and supporting institutional climate action efforts (Tırınk et al., 2025). The source flow and activity data descriptions for Scope 2 indirect energy types are shown in Table 3.

Table 3. Category 2 direct emissions details.

Categories		Emission Source	Source flow	Activity data (relevant document/ record)
Category 2	2.1 Indirect emissions from imported electricity	All equipment that causes electricity consumption	Electricity	Invoices
	2.2 Indirect emissions from imported energy other than electricity	Compressed air, hot water, steam	Compressed air systems, heating systems	Bills, hot water calorimeters, steam meters

4.6.3. Scope 3: Other Indirect Emissions

Definition: Scope 3 emissions are all indirect greenhouse gas emissions resulting from sources not owned or controlled by the reporting company but occurring across the company's value chain, both upstream and downstream, as a consequence of its activities. Scope 3 represents all other indirect emissions outside the company's ownership and spans the full value chain, from raw material extraction to product transport, customer use, and end-of-life disposal (GHG Scope 3, 2013; Sotos, 2015; WRI&WBCSD, 2004).

Categories of Scope 3 Emissions: The GHG Protocol defines 15 mutually exclusive categories to systematically measure Scope 3 emissions. These categories are grouped into upstream and downstream headings. Upstream categories include purchased goods and services, capital goods, fuel- and energy-related activities excluding Scope 1 and 2, upstream transportation and distribution, operational waste, business travel, employee commuting, and leased assets. Downstream categories include downstream transportation of sold products, processing of sold products, use and end-of-life management of sold products, downstream leased assets, franchises, and investments (GHG Scope 3, 2013). The source flow and activity data descriptions for Category 3-6 indirect energy types are s in Table 4.

Table 4. Indirect emissions examples for Category 3-6.

Categories		**Emissions Source**	**Source flow**	**Activity data (relevant document/ record)**
Category 3	3.1 Indirect emissions from the transportation and distribution of input materials	Road, Sea, Air	Road Truck (ton/km or km), Cargo Ship, Cargo Aircraft Truck, Panel Van Vehicles	km Information, Google Maps
	3.2 Indirect emissions from the transportation and distribution of output materials	Highway	Warehousing, transport of outputs, distribution logistics, shipping, retail delivery	km information, google maps
	3.3 Indirect emissions from employees' commuting to and from work	Work vehicles, tram, bus, passenger vehicles	Minibus, tram, bus, passenger vehicles	km information, employee number distribution
	3.4 Indirect emissions from visitors' and customers' transportation to the facility	Tram,bus, passenger vehicles	Tram, bus, passenger vehicles	km information
	3.5 Indirect emissions from business travel	Air travel, hotel, road travel	Long-short haul, business-economy class,country-based accommodation	Person/km information, person/day accommodation information

Category 4	4.1 Indirect emissions from purchased products	All purchased products	Plastic, wood, metal, paper, cardboard, electronics, electrical, construction materials	Weight information, purchase records, invoices
	4.2 Indirect emissions from capital assets	Building, knitting machine, forklift, construction equipment, cnc machine, oven, boiler, etc. (equipment with remaining depreciation period)	Construction materials wood, metal, paper, cardboard, electronics, electrical, plastic	Weight information, purchase records, invoices
	4.3 Indirect emissions from the disposal of solid and liquid waste	Glass waste, household waste, plastic waste, hazardous waste, paper waste	Glass waste, household waste, plastic waste, hazardous waste, paper waste	Weight information
	4.4 Indirect emissions from the use of assets not owned by the business	Crane rental, forklift rental	Fuel consumption	km information, working hours
	4.5 Indirect emissions from the use of other services	Maintenance, cleaning, consulting, freight forwarding	Transportation, heating, electricity	Consumption quantities
Category 5	5.1 Indirect emissions arising from the use phase of the product	Product usage	Electricity	Consumption quantity
	5.2 Indirect emissions resulting from the use of capital assets	Production machinery, boilers, generators, HVAC systems, vehicles &	Electricity, fuel	Electricity consumption, fuel use, equipment operating hours

	owned by the facility	material handling equipment, IT equipment, compressors, pumps		
	5.3 Indirect emissions from waste management after the product has become waste	Fiberglass, fabric, pipe-profile, chair-sofa, computer, electronic waste, carpet	Glass waste, plastic waste, hazardous waste, paper waste, metal waste	Plastic, metal, paper, glass, % recycled, landfilled, incinerated, composted
	5.4 Indirect emissions from investments	Equity, debt, project finance	Investment, financing services	Loans, bonds, funds
Category 6	6. Indirect emissions from other sources	Leased assets, franchises, investments	Manufacture of equipment, machinery, buildings	Number, mass, or value of assets

Calculation Methods: Data collection for Scope 3 emissions is divided into primary and secondary data depending on availability. The main calculation approaches include;

- supplier-specific, where direct product-level emissions data is obtained from suppliers;
- hybrid, which uses primary supplier data where available and sector averages where data is missing;
- average-data, which multiplies the mass or unit of purchased products by secondary emission factors from literature or databases;
- spend-based, which calculates emissions based on economic value using environmentally EEIO models.

Data representativeness across technology, geography, and time should be assessed, and the accuracy and confidence level of the inventory should be reported (GHG Scope 3, 2013; WRI&WBCSD, 2004).

Challenges: Determining Scope 3 emissions involves several challenges. Collecting high-quality data from value chain partners, particularly downstream, is often costly and time-consuming. Multi-tiered supply chains make it difficult to define boundaries accurately and allocate emissions correctly. Additionally, predicting emissions over the life cycle of sold products requires numerous assumptions and scenario analyses, increasing estimation complexity (GHG Scope 3, 2013; WRI&WBCSD, 2004). In this scope, determining greenhouse gas emissions originating specifically from microbial processes is challenging. Integrating metagenomic data into biogeochemical models enhances the accuracy of greenhouse gas flux predictions by tracking processes such as methane production and nitrification (Böke Özkoç et al., 2025).

Importance: Scope 3 emissions are important for companies to understand because they help identify carbon risks in the value chain, such as potential cost increases from carbon taxes. Understanding emissions allows companies to determine “hot spots” and implement interventions to reduce actual environmental impacts. Meeting transparency expectations from investors and consumers enhances corporate reputation and provides competitive advantages. Additionally, analyzing Scope 3 emissions can reveal energy and material inefficiencies in the value chain, enabling operational improvements and potential cost savings (GHG Scope 3, 2013; Sotos, 2015; WRI&WBCSD, 2004).

4.7. Greenhouse Gas Emissions Calculation on College Campuses

The net calorific values of fuels that are likely to be found in the university inventory, examples of GWPs for gases produced by the combustion of these fuels, and fluids that are likely to be found in refrigeration systems in the university inventory are all included in this section, along with calculation formulas for some basic emission sources, emission factors to be used in the calculations, and information on where these emission factors can be obtained. This section will also include national emission factors for Scope 2 emissions, such as transmission-distribution losses and electricity generation. Below are definitions for some of the terms used in the computation.

Net Calorific Value - NCV: Commonly known as the Lower Heating Value (LHV), this parameter represents a measure of the *useful* thermal energy released as a result of the complete combustion of a fuel. In the preparation of greenhouse gas inventories, the LHV is used as a fundamental component to convert activity data expressed in physical units (such as tonnes or cubic meters) into energy units (e.g., terajoules – TJ). It is typically expressed in units of TJ/Gg. (Garg et al.; WRI&WBCSD, 2004).

Global Warming Potential (GWP) is a measure of how much heat a specific greenhouse gas traps in the atmosphere compared to carbon dioxide (CO_2). In most applications, the 100-year time horizon (GWP100) is used as the reference. The GWP values of the most commonly used greenhouse gases in the calculation and reporting of greenhouse gas emissions are regularly updated by the IPCC (Garg et al.; WRI&WBCSD, 2004).

Emission Factor: A parameter indicating the quantity of greenhouse gas emissions released per unit of activity data(ISO-14064-1).

4.7.1. Calculation of GHG Protocol Scope 1 - ISO 14064 Category 1 Emissions (Direct)

In Section 4.6.1, the Scope 1 emission sources specific to university operations were explained in detail, and the emission sources to be included in this category were presented in Table 2. This section describes the calculation methodology for the emission values derived from Scope 1 sources in terms of CO_2e. Stationary combustion is the primary component of this scope and results from the combustion of fuels in stationary equipment located within the organizational boundaries, such as boilers, furnaces, burners, turbines, heaters, incinerators, and generators. Mobile combustion is the second component of this scope. Emissions originating from the fuel consumption of organization-owned vehicles—for example, diesel or gasoline consumption of shuttle buses and gasoline consumption of institutional passenger cars—are calculated within this scope. Other components encountered in universities under Scope 1 are direct emissions resulting from the leakage or fugitive emissions of greenhouse gases in anthropogenic systems. The IPCC Tier 1 Method, which is widely accepted and requires less specific data than higher tiers, is the basis for the computations. The tables below show the values for the NCV, Emission Factors, and GWP that will be utilized in the computations. The bibliography also includes the sources for the tables that contain this information. It is necessary to read the pertinent data in the tables and incorporate it into the computation in accordance with the greenhouse gas inventory component.

Direct emissions from stationary and mobile combustion sources

According to the methodologies summarized in Section 3.5 and the information provided in Section 4.6, stationary and mobile combustion emissions are calculated using Equation 1. The units of the variables constituting the formula must be verified, and necessary unit conversion factors should be applied. To calculate the amount of emissions resulting from the combustion of fuels, the emission factors for CO_2, CH_4 ve N_2O used in the emission equation are obtained by using the default emission factors provided in the IPCC stationary combustion and mobile combustion documents. Example values for specific fuels are presented in Table 5 (Gómez et al., 2006; Waldron et al., 2006).

Table 5. Emission factor of some fuels.

Emission Type	Unit	Emission Factor			Reference
		CO_2	CH_4	N_2O	
Natural Gas (Stationary Combustion)	kg/TJ	56100	1	0.1	(Gómez et al., 2006)
Gas Diesel Oil (Stationary Combustion)	kg/TJ	74100	3	0.6	(Gómez et al., 2006)
Gas Diesel Oil (Mobil Combustion)	kg/TJ	74100	3.9	3.9	(Waldron et al., 2006)
LPG (Stationary Combustion)	kg/TJ	63100	1	0.1	(Gómez et al., 2006)
Motor Gasoline (Mobil Combustion)	kg/TJ	69300	25	8	(Waldron et al., 2006)

The net calorific values for fuels were obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Example net calorific values for certain fuels are presented in Table 6 (Garg et al., 2006). Also GWP of some greenhouse gases are demonstrated in Table 7.

Table 6. Net Calorific Value of some fuels.

Fuel Type	**Unit**	**Net Calorific Value**	**Reference**
Natural Gas	TJ/Gg	48	(Garg et al., 2006)
Gas Diesel Oil	TJ/Gg	43	
Gasoline	TJ/Gg	44.3	
LPG(Liquefied Petroleum Gases)	TJ/Gg	47.3	
Coal(Lignite)	TJ/Gg	11.9	

Table 7. GWP of some greenhouse gases.

Name	**Chemical Formula**	**GWP -100 (AR6) (100-year time horizon)**	**Reference**
Carbon dioxide	CO_2	1	(Smith et al., 2021)
Methane	CH_4	27.9	
Nitrous oxide	N_2O	273	
Sulfur Hexafluoride	SF_6	24300	
Refrigerant Name			
HFC-134a	CH_2FCF_3	1530	
HFC-32	CH_2F_2	771	
HFC-125	C_2HF_5	3740	

Since CH_4 and N_2O emissions are also generated alongside CO_2 during the combustion of fuels in both stationary and mobile combustion categories, the GWP values of these gases must be utilized to include them in the calculation.

$$E_{tCO_2}e = (AD \times D \times NCV \times EF \times OF \times GWP) \quad (1)$$

AD (Activity Data): The amount of fuel consumed in stationary or mobile combustion sources (liters or m^3).

D ($Density$): The weight per unit volume of the fuel (kg/m^3, kg/Nm^3 etc.).

NCV (Net Calorific Value): The energy content of the fuel (tJ/Gg or $kcal/m^3$).

EF (Emission Factor): The emission coefficient in kg per Terajoule (kg/TJ), ($kgCO_2/TJ$), ($kgCH_4/TJ$), (kg N_2O /TJ).

OF (Oxidation Factor): The ratio of fuel that is completely oxidized (usually assumed to be 1 for Tier 1).

GWP (Global Warming Potential): The coefficient used to compare the radiative forcing of different gases to CO_2.

In Equation 1, used for calculating emissions from stationary and mobile combustion, if the GWP is not included, emissions originating from CH_4 and N_2O can be calculated as CO_2 equivalents using Equation 2. The total emission is equal to the sum of the emissions of all gases released during combustion in terms of CO_2 equivalent. The total emission calculation is shown in Equation 2 below.

$$Total\ Emissions = \left(E_{CO_2} \times 1\right) + \left(E_{CH_4} \times GWP_{CH_4}\right) + \left(E_{N_2O} \times GWP_{N_2O}\right) \quad (2)$$

Direct emissions resulting from the leakage or fugitive emissions of greenhouse gases in anthropogenic systems (Category 1.4 - ISO 14064-1)

Fugitive gas emissions originating from cooling systems, as specified in the categories of the ISO 14064-1:2018 standard, are calculated according to Equation 3. The activity data to be used here is obtained from systems containing gases with greenhouse effects, such as air conditioners, central cooling systems, and fire extinguishers. When calculating the amount of activity data, the amount of leaked gas in the system must be taken into account. The amount of fugitive gas can be calculated using the refrigerant gas recharge amount performed in annual periods due to emissions or by using the leak rate. If the refrigerant gas consists of a gas mixture, the GWP must be calculated according to the weight ratios of these gases. The emission calculation equation, established under the assumption that the fugitive gas is R410a and consists of a 50/50 mixture of R-32 and R-125 gases, is presented in Equation 3.

$$E_{tCO_2e} = (AD_{R410_a} \times LR_{\%} \times (0.5 \times GWP(R-32) + (0.5 \times GWP(R-125)) \quad (3)$$

E_{tCO_2e}: Total R410a gas emissions carbon dioxide equivalent.

AD_{R410_a} (Activity Data): Total R410a refrigerant charge in the system (kg).

$LR_{\%}$: (Leakage Rate / Annual Leakage Fraction): The percentage of the total capacity that leaks per year (e.g., 10% = 0.10).

$GWP(R-32)$: Global Warming Potential (GWP100) of Gas CH_2F_2 .

$GWP(R-125)$: Global Warming Potential (GWP100) of Gas C_2HF_5 .

(The percentage of the total R410a gas charged to the system – emissions occur at around 1% annually) (Ashford & Harnisch, 2006).

4.7.2. Calculation of GHG Protocol Scope 2 - ISO 14064 Category 2 Emissions (Energy Indirect)

In Section 4.6.2, the Scope 2 emission sources specific to university operations were explained in detail, and the emission sources to be included in this category were presented in Table 3. This section describes the calculation methodology for the emission values resulting from Scope 2 sources in terms of CO_2e. In this category, indirect greenhouse gas emissions originating from the energy imported by the organization are calculated. Indirect emissions originating from imported electricity are the primary component of this scope. After determining the electricity consumption amount in kWh-MWh units, the organization can calculate the emissions resulting from purchased electricity by using emission factors obtained in ton CO_2e /MWh units. Here, electricity generated from renewable energy sources is included in the calculation as market-based electricity; the organization can declare how much of its electricity consumption is provided from renewable energy by performing dual reporting as specified in Section 4.6.2. Indirect emissions originating from imported energy are the second component of this scope. The indirect emissions related to the production of energy (steam, heating, cooling, and compressed air) imported by the organization via a physical network (excluding consumed electricity) are calculated in this class.

Indirect emissions from imported electricity

If the greenhouse gas emission factor resulting from purchased grid electricity consumption in Scope 2 can be obtained from national sources, a more accurate regional-based emission value can be derived using this data. In order to calculate the emission intensity of the grid electricity, the emission factor for Turkey, as published by the EEA in its country-specific electricity generation emission intensity values, is presented in Table 8 (Republic of Türkiye Ministry of Energy and Natural Resources, 2024).

Table 8. Grid emission factor for electricity generation in Türkiye.

Factor Type	**Year**	**Value (tCO_2/MWh)**	**Value (tCO_2e/MWh)**	**Reference**
Grid Emission Factors for Electricity Generation in Turkey	2022	0.438	0.442	(Republic of Türkiye Ministry of Energy and Natural Resources, 2024)
Grid-connected Consumption Point Emission Factor	2022	0.474	0.478	

Greenhouse gas emissions originating from electricity consumption are calculated according to Equation 4.

$$E_{tCO_2e} = (AD \times EF) \quad (4)$$

E_{tCO_2e}: Total Location-Based GHG Emissions from Electricity Consumption

AD = Activity Data (Electricity consumption (location-based) kWh, MWh etc.)

EF= Grid Emission Factor (kg CO_2e /MWh)

No emissions are generated as a result of electricity consumption itself. The emissions declared here are those originating from the production of electricity. This is explained in detail in Section 4.6.2.

In the calculation of emissions originating from electricity transmission and distribution losses, the value obtained by subtracting the 'Turkey Grid Electricity Generation Emission Factor' from the 'Distribution Line-Connected Consumption Point Emission Factor' provided in Table 7 is used as the emission factor.

According to the data in Table 8, this value for Turkey is;

$$EF = 0.478 - 0.442 = 0.036 \ (tCO_2e/MWh)$$

is calculated as [value]. These emissions, originating from transmission and distribution losses that occur until electricity reaches the point of consumption from the point of production, are calculated and reported within Scope 3.

4.7.3. Calculation of GHG Protocol Scope 3 - ISO 14064 Categories 3, 4, 5, and 6 Emissions (Other Indirect)

In Section 4.6.3, the Scope 3 emission sources specific to university operations were explained in detail, and the emission sources to be included in this category were presented in Table 4. This section describes the calculation methodology for the emission values resulting from Scope 3 sources in terms of CO_2e. In these categories, other indirect greenhouse gas emissions originating from sources that are related to the organization's activities but are not owned or directly controlled by the organization are calculated. After determining the activity data (kg, ton, liter, km, kWh, etc.) in various sub-categories such as purchased goods and services, capital goods, fuel and energy-related activities (such as transmission and distribution losses outside of Scope 1 and 2), and waste management, the organization can calculate its total emissions in terms of ton CO_2e by using the relevant emission factors. These categories are generally divided into two main groups based on the value chain: Upstream Activities, which are all activities that occur before products or services reach the company—including supply chain processes such as raw material extraction, material production, and transportation to your company—and Downstream Activities, which consist of all activities that occur after products or services leave the company, including steps such as the customer's use of the product, its distribution, and its disposal at the end of the product's life.

Scope 3 calculations are based on data obtained from suppliers or LCA data derived from secondary databases. Furthermore, indirect emissions related to energy but outside of Scope 2, such as technical losses in the transmission and distribution lines of purchased energy and the extraction and transportation of fuels, are also calculated in this class. Emissions originating from the organization’s leased assets, business travel, and employee commuting constitute other significant components under this broad category.

4.7.3.1. Indirect emissions from employees commuting to and from work

The ISO 14064-1, 2018 standard classifies transportation-related indirect emissions under Category 3. Particularly in the service industry, technology firms, or academic institutions, emissions from activities like employee commuting, business travel, and visitor transportation can account for a sizable amount of the organization's overall carbon footprint.

It is required that the vehicles included in the calculation here are not owned by the organization. In this case, the company needs to gather information based on its transportation choices. Both fuel-based and mileage-based data can be used to calculate emissions in this category. When the precise amount of fuel consumed by employees (in liters or kilograms) is known, the fuel-based method is employed. When information is gathered from employee service invoices and the company's official vehicles, this approach typically yields the most accurate results. Emissions are computed in terms of carbon dioxide equivalents using the mobile combustion emission equation (Equation 1).

E_{tCO_2e}: Upstream emissions from transportation

AD (Activity Data): The amount of fuel consumed for employee commuting (liters or m^3).

EF (Emission Factor): The emission coefficient in kg per Terajoule (kg/TJ), ($kgCO_2/TJ$), ($kgCH_4/TJ$), ($kg\ N_2O\ /TJ$).

This also makes use of the mobile combustion emission factors listed in Table 5.

In the kilometer-based calculation method, indirect emissions from transportation are calculated by multiplying the average distance traveled by employees and guests to reach the organization by the emission factors provided in the UK Government (2024) source, based on the fuel type and segment of the vehicles. For instance, assuming an employee travels 1,000 km with a 'medium diesel' vehicle, this 1,000 km value is multiplied by the relevant 'medium car: diesel' emission factor of 0.17474 kg CO_2e/km found in the emission table of the UK Government (2024) source. Equation 4 should be utilized for the calculation. The emissions calculated in this category should be reported as indirect emissions.

E_{tCO_2e}: Upstream emissions from transportation

AD =Distance Traveled (km)

EF= Emission Factor ($kgCO_2e$ /km)

4.7.3.2. Indirect emissions from purchased products

Indirect emissions from purchased fuels

Emissions arising during stages such as the extraction, production, and transportation of purchased fuels are calculated at this stage. The product-related emissions of all fuels included in Scope 1 must also be calculated.

Indirect emissions originating from the production of diesel are referred to in the literature as Well-to-Tank (WTT) emissions. These emissions cover the 'life story' of the fuel before it enters the vehicle's tank. Direct combustion emission factors and WTT emission factors are distinct from one another. WTT fuel emission factors are retrieved from the 'WTT-Fuel' tab in the source provided by the UK Government (2024). In regions where there is a legal obligation to mix a certain proportion of biodiesel into diesel, the emission factor for 'Diesel (average biofuel blend)' is used. This value is 733.644,6 kg CO_2e/ton. Depending on the type of fuel, WTT emission factors are retrieved from the relevant table in the same source, multiplied by the activity data, and the emissions are calculated in terms of CO_2 equivalent; Equation 4 should be utilized for the calculation.

E_{tCO_2e}: Upstream emissions from fuel production (WTT)

AD = The amount of fuel consumed in stationary or mobile combustion sources (ton, liters, m^3).

EF= Emission Factor (kgCO_2e/ton)

This calculation of emissions shows us how much of the fuel's emissions happened prior to purchase.

Indirect emissions from purchased paper

Emissions originating from the production of paper purchased by the organization are also calculated within this scope. In the calculation of indirect emissions originating from paper production, the 'Paper and board: paper material production' emission factor for Paper in the 'Material Use' tab of the source (UK Government, 2024) should be used. This value is 1339.31834 kg CO_2e/ton. Using Equation 4, the emissions originating from the production of the purchased paper are calculated in terms of CO_2 equivalent.

4.7.3.3. Indirect emissions from the disposal of solid and liquid waste

Emissions originating from the waste generated by the organization are also calculated within this scope using Equation 4.

E_{tCO_2e}: Downstream emissions from plastic waste generated in operations.

AD = The amount of plastic waste (ton, kg).

EF= Emission Factor (kgCO_2e/ton).

In the calculation of indirect emissions originating from waste plastics, the “Plastics: average plastics Closed Loop” emission factor for Plastic in the “Waste disposal” tab of the source (UK Government, 2024) should be used. This value is 6.41061 kg CO_2e/ton. Since sufficient data regarding waste recycling could not be obtained, the emission factors in the source provide the same values for many categories.

The emission sources calculated within Scope 3 - Categories 3, 4, 5 and 6 are quite numerous; therefore, sample calculation methodologies and emission factor sources for some categories are provided in this book.

To calculate other emissions included in the organization's inventory within Scope 1, Scope 2, and Scope 3, the resources summarized in Section 3.5 should be used, and the emission factors should be selected in accordance with the latest scientific updates and international standards. While it is not possible to evaluate every single potential emission source individually within the scope of this section due to the vast diversity of organizational activities, the fundamental calculation methodologies and reference sources have been clearly established. By following the provided equations and referencing the verified emission factor databases, organizations can ensure that all relevant indirect and direct activities are accurately quantified, maintaining the integrity and transparency of their greenhouse gas inventory.

4.8. Carbon Footprint Reporting

The process of preparing a GHG inventory report or carbon footprint report is a critical step for an organisation to manage its climate change-related risks and ensure transparency (Sotos, 2015; WRI&WBCSD, 2004). At the core of the reporting process are five key principles that ensure the reliability of data: relevance, completeness, consistency, transparency and accuracy.

Relevance: It must be ensured that the greenhouse gas inventory accurately reflects the organisation's emissions and serves the decision-making needs of both internal and external users (Sotos, 2015; WRI&WBCSD, 2004). When selecting inventory boundaries, not only the legal form of the organisation but also the economic reality and substance of its business relationships should be taken into account (WRI&WBCSD, 2004).

Completeness: All greenhouse gas emission sources and activities within the selected inventory boundary must be accounted for and reported (Sotos, 2015). If certain resources are excluded from the inventory, this must be documented transparently and justified (Sotos, 2015; WRI&WBCSD, 2004).

Consistency: Consistent methodologies should be used to enable meaningful comparisons of emissions performance over time. Any changes made to inventory boundaries, data used or methods employed must be documented transparently and the reasons for these changes must be provided. (WRI&WBCSD, 2004).

Transparency: All relevant matters in the inventory process should be addressed in a realistic and consistent manner based on a clear audit trail. The report should contain clear references to the calculation methodologies used, data sources and assumptions made so that a third party can reach the same conclusion (Sotos, 2015; WRI&WBCSD, 2004).

Accuracy: When determining the quantity of greenhouse gas emissions, it must be ensured that the data does not systematically overstate or understate the actual emissions. Uncertainties in the data should be reduced as far as practicable, and the accuracy of the report should be sufficient to enable users to make decisions with reasonable confidence (Sotos, 2015; WRI&WBCSD, 2004).

When applying these principles, companies may sometimes have to strike a balance (trade-off); for example, less accurate data may need to be used in order to achieve the most complete inventory. In such cases, a balance should be maintained in line with the organisation's business objectives (Sotos, 2015; WRI&WBCSD, 2004).

The basis of the greenhouse gas inventory is to clearly define the boundaries of the organisation. This process consists of two main stages: organisational boundaries and operational boundaries, both of which must be transparently explained in the reports (ISO 14064-1, 2018; WRI&WBCSD, 2004).

As mention in Section 4.2, organizational boundaries define which operations are included in a company’s greenhouse gas inventory and how emissions are consolidated. These boundaries are commonly set using the Equity Share, Financial Control, or Operational Control approaches, and the selected approach must be clearly stated and applied consistently throughout the inventory (ISO 14064-1, 2018; WRI & WBCSD, 2004).

As mention in Section 4.6, Once organisational boundaries are defined, emissions are classified into Scope 1 (direct emissions from owned or controlled sources), Scope 2 (indirect emissions from purchased energy, reported using location-based and market-based methods), and Scope 3 (other indirect value-chain emissions across up to 15 categories). Public reporting should summarise organisational and operational boundaries, the consolidation approach, relevant Scope 3 categories, any justified exclusions, and the criteria for identifying significant indirect emissions (GHG Scope 3, 2013; ISO 14064-1, 2018; Sotos, 2015; WRI & WBCSD, 2004).

Certain emission data are not included in the standard scope totals but should be disclosed in the report for transparency purposes:

Biogenic Emissions: Direct CO_2 emissions from the combustion of biomass or biofuels should not be included in Scope 1, 2 or 3 totals; instead, they should be reported as a separate memo item ‘outside the scopes’ (Sotos, 2015; WRI&WBCSD, 2004). However, CH_4 and N_2O emissions from biogenic sources are included in the relevant scope (Sotos, 2015).

Offsets and Credits: Purchased offsets or SG credits should not be deducted from the gross emissions totals of the inventory. These commercial transactions should be presented in the optional information section of the report, completely independent of the physical inventory data (WRI&WBCSD, 2004).

As mention in Section 4.3, to ensure consistent tracking of greenhouse gas emissions over time, organisations must define a base year with reliable data, clearly stating the rationale, methodology, and base year emissions, and report emissions for all subsequent years. A recalculation policy should be applied when significant structural or methodological changes occur, based on a defined significance threshold, while excluding normal organic growth or contraction; Scope 2 base years should include both location- and market-based data, and Scope 3 targets should also rely on transparent base year information (ISO 14064-1, 2018; Sotos, 2015; WRI & WBCSD, 2004).

As mention in Section 4.6 and 4.7, organisations must clearly specify the methodologies used to calculate greenhouse gas emissions to ensure transparency and comparability over time. Emissions are generally calculated by combining activity data with emission factors, with different approaches applied across Scope 1 (fuel- and distance-based calculations), Scope 2 (location-based and market-based electricity factors), and Scope 3 (value-chain estimates using primary, supplier, or average data), each affecting accuracy and uncertainty (Garg et al., 2006; GHG Scope 3, 2013; Gómez et al., 2006; Sotos, 2015; Waldron et al., 2006; WRI & WBCSD, 2004).

ISO 14064-1 and the GHG Protocol require organisations to assess greenhouse gas inventory uncertainties qualitatively and, where feasible, quantitatively, ensuring emissions are not systematically over-or underestimated. Uncertainty analyses should be conducted at the emission category level, typically reported with a 95% confidence interval, and sensitivity analysis is recommended for future-oriented estimates such as Scope 3 use-of-sold-products emissions; where quantification is not possible, justified qualitative explanations should be provided (ISO 14064-1, 2018; WRI & WBCSD, 2004).

In the following section, their carbon footprints and the unique challenges and opportunities in reducing greenhouse gas emissions will be highlighted.

4.9. Studies on the Preparation of Greenhouse Gas Inventories Conducted at Universities

Several international case studies demonstrate how higher education institutions apply greenhouse gas accounting methodologies under the GHG Protocol, while highlighting the relative importance of different emission scopes. At the University of Oulu, Kiehle et al. (2023) conducted a comprehensive carbon footprint assessment for 2019 using a hybrid methodology that combines LCA and EEIO. In this study, LCA was mainly applied to Scope 1 and Scope 2 emissions and selected Scope 3 categories with available activity data, while EEIO was used for procurement-related Scope 3 categories based on financial expenditure. The results show that district heating is the dominant emission source, accounting for approximately 40% of total emissions, followed by procurement and transportation. A key conclusion of the study is that insufficient data availability and fragmented data collection systems represent the main barriers to accurate institutional carbon footprinting, leading to recommendations for improved data management and sustainable procurement practices (Kiehle et al., 2023).

A similar emphasis on comprehensive Scope 3 coverage is found in the study by Larsen et al. (2013) on the Norwegian University of Science and Technology (NTNU). This research primarily employed an EEIO modeling approach, supplemented with hybridized data for Scope 1 and Scope 2 emissions, to capture the full supply chain impacts of university activities. The use of standardized financial accounting data enabled a complete overview of emissions and avoided common system boundary cut-off errors associated with bottom-up LCAs. The findings indicate that construction activities, energy use, and equipment purchases are major contributors, with laboratory-intensive departments such as engineering and medicine exhibiting significantly higher emissions per student. The study highlights the usefulness of EEIO methods for cost- and time-efficient annual updates and for developing department-specific mitigation strategies (Larsen et al., 2013).

Other case studies reveal that Scope 3 emissions often dominate the total carbon footprint of universities. At the University of Technology of Pereira in Colombia, Varón-Hoyos et al. (2021) calculated the 2017 corporate carbon footprint and found that Scope 3 emissions account for approximately 97% of total emissions, largely driven by daily commuting of students and staff. Student mobility alone contributes nearly three-quarters of total emissions, while construction activities represent the second-largest source. Scope 1 emissions remain minimal due to the absence of on-campus energy generation, and Scope 2 emissions are low because Colombia’s electricity mix is largely based on hydropower (Varón-Hoyos et al., 2021).

More recently, Rus et al. (2025) analyzed the carbon footprint of Cluj-Napoca Technical University using the GHG Protocol and One Click LCA software for 2022–2023. The study identifies natural gas consumption for heating as the primary emission source, reflecting the university’s cold climate conditions, followed by purchased electricity and Scope 3 emissions related to waste, procurement, and travel. While energy efficiency measures and a cleaner national electricity mix have reduced Scope 2 emissions over time, the results emphasize that Scope 3 categories remain critical for achieving climate-neutral campus targets (Rus et al., 2025).

4.10. Reducing the Carbon Footprint in Universities

Universities have a significant responsibility for establishing a sustainability mindset and fostering an environmentally conscious society. They are not just educational and research institutions; they also set an example by promoting sustainable practices (Kiehle et al., 2023; Moldovan et al., 2025; Valls-Val & Bovea, 2022). Also, student transportation, particularly the use of single-occupancy vehicles, contributes significantly to a university's carbon footprint. Therefore, it is crucial to understand the behavioural and economic factors that influence transport choices in order to develop sustainable campus policies (Roknaldin et al., 2025). Survey studies and findings obtained within the framework of strategic planning reveal that concrete, feasible steps can be taken to reduce the carbon footprint of university campuses (Guvenc et al., 2023; Saguansub et al., 2025). These steps provide a more comprehensive approach to addressing greenhouse gas emissions, taking into account Scope 1, Scope 2 and Scope 3 classifications.

Direct emissions assessed under Scope 1 originate from activities that are under the university's own control. Therefore, improving the energy efficiency of campus buildings is a priority. Making existing structures more environmentally sensitive, reducing heat loss through insulation and promoting energy-efficient designs can all help to limit direct energy consumption. However, the planned regulation of land use and an increase in permanent green spaces will contribute to carbon dioxide sequestration and have a positive effect on the campus ecosystem. Afforestation efforts are a key part of this process. Regular monitoring of Scope 1 emissions at the faculty level helps measure the impact of insulation, energy efficiency, and building management measures with concrete data (Moldovan et al., 2025; Tırınk & Aykaç Özen, 2023). The implementation of structural measures to reduce Scope 1 emissions can be demonstrated through applications such as building insulation, landscaping and tree planting at Yıldız Technical University (Guvenc et al., 2023).

Scope 2 emissions arise from the use of externally sourced energy by universities. In this context, systematically monitoring and managing energy use is crucial. The fact that electricity consumption was the main source of emissions at the Davutpaşa Campus in 2020 highlights the importance of investing in energy efficiency and renewable energy in order to reduce Scope 2 emissions (Guvenc et al., 2023). Also, Technical University of Cluj-Napoca and Dokuz Eylül University data shows that natural gas consumption accounts for a large share of the carbon footprint (Kokulu & Özyürek, 2024; Rus et al., 2025). One effective method for universities to reduce their energy-related carbon emissions is to shift towards renewable sources such as solar energy. Furthermore, implementing a monitoring system that allows for regular tracking of energy consumption data enables the identification of inefficiencies in resource use and facilitates necessary improvements. These practices reduce indirect emissions by decreasing dependence on purchased energy.

Scope 3 covers indirect emissions that are not under the university's direct control, but which are closely related to campus life. Waste and water management are particularly important in this area. The basis of sustainable waste management is reducing resource consumption, encouraging reuse and promoting recycling practices. The electronic document management system, waste separation infrastructure and rainwater harvesting system at Yıldız Technical University demonstrate the importance of managerial and behavioural measures in reducing Scope 3 emissions (Guvenc et al., 2023). Separating waste at source, reducing single-use plastics and encouraging responsible consumption habits can help universities to achieve their zero-waste goals. Meanwhile, effective wastewater treatment and water management practices enable the more efficient use of water resources.

Using carbon-neutral certified companies for campus food services and in the supply chain helps to reduce Scope 3 emissions. Providing low-carbon, sustainable menus is a tangible step towards reducing the university's carbon footprint, given that a significant proportion of global greenhouse gas emissions originate from food production. Sabancı University (SU, 2025) therefore states that it closely monitors its food services through strict procedures and quality control measures, ensuring the use of safe and sustainable food across campus via its cafeterias and catering operations. In line with their net-zero supply chain goals, some universities are increasing their procurement from carbon-neutral certified companies. Assessing Scope 3 emissions is especially important for understanding indirect impacts, such as those from the supply chain (Battistini et al., 2022; SU, 2025).

In this context, the behaviour of students and university staff is crucial. Factors that can contribute to reducing greenhouse gas emissions across the campus include choosing eco-friendly products in daily life, reducing paper and energy consumption, adopting low-carbon transport options and promoting more sustainable eating habits. It has been observed that students' transport preferences are influenced by both environmental awareness and practical factors such as safety, cost, time and comfort. Research shows that, while financial incentives are effective, behavioral nudges that target intrinsic motivation can also contribute significantly to changing transport habits (Roknaldin et al., 2025). The shift to online education in 2020 led to a reduction in transport-related emissions of around 50%. This emphasises the importance of behavioral approaches in reducing Scope 3 emissions from transport (Guvenc et al., 2023; Roknaldin et al., 2025).

Additionally, the role of universities in research, education and social interaction should be reinforced (Duzdar & Yıldız, 2025). Calculating a carbon footprint provides universities with a foundation on which to continuously update their reduction strategies and define their own paths towards carbon neutrality (Cano et al., 2023; Herth & Blok, 2023; Samara et al., 2022). Supporting sustainability-focused research, integrating environmental and climate change issues into course content and organizing awareness-raising events will contribute to establishing environmental awareness in the long term. Education and campaigns raising awareness of global climate change and sustainable campuses can encourage environmentally friendly behavior among students and staff. Collaborating with local communities extends the impact of universities' sustainability efforts beyond campus boundaries.

Consequently, universities can significantly reduce their carbon footprint by addressing Scope 1 emissions through building and land management, Scope 2 emissions through converting energy sources, and Scope 3 emissions through behavioral and managerial practices. Using tools developed to measure the carbon footprint of universities, alongside future improvements, will support decision-making processes and set an example for other institutions. Data-driven analyses implemented at the faculty level will accelerate universities' progress toward sustainability goals and serve as a model for other academic institutions.

CONCLUSION AND EVALUATION

The necessity of addressing sustainability in university through an institutional approach within a thorough framework focused on greenhouse gas management systems and carbon footprint calculation methodology has been discussed in this book. Universities are now multifaceted living spaces where sustainable development goals are tested, developed, and demonstrated to society in addition to being locations for education and research. In this regard, the methodical assessment and control of greenhouse gas emissions at university is regarded as a strategic governance instrument that goes beyond environmental accountability.

The importance of developing an integrated greenhouse gas inventory that incorporates Scope 1, Scope 2, and Scope 3 emissions in compliance with international standards is emphasized by the carbon footprint calculation techniques discussed in the book. Emission sources at universities are made visible through the analysis of emissions from energy use, transportation, waste and water management, and supply chain operations. This allows priority reduction areas to be determined using scientific data. This strategy makes it possible to manage sustainability initiatives through quantifiable and trackable performance indicators by preventing them from staying only at the reporting level.

In the future, digitalization, AI-powered monitoring systems, integration of renewable energy, and circular economy applications are anticipated to bolster sustainability and carbon management initiatives in universities. Campuses will have a great chance to meet net-zero carbon targets thanks to these developments, which will help them establish themselves as key players in national and international sustainability initiatives.

The necessity of addressing carbon footprint calculation and greenhouse gas management systems in university in a manner that is integrated with performance management, strategic planning, and sustainable development goals is emphasized in the book's conclusion. It is expected that the topics covered, and methodological framework will assist universities in taking proactive steps to reduce their environmental impact and develop university models that will serve as role models for society in a sustainable future.

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