IJEGEO

International Journal of Environment and Geoinformatics 10(4):146-156 (2023)

Review Article

From Emissions to Environmental Impact: Understanding the Carbon Footprint

Abuzer Çelekli[1,2*], Özgür Eren Zariç [1,2]

[1] Department of Biology, Faculty of Art and Science, Gaziantep University, Gaziantep, Türkiye
[2] Environmental Research Center (GÜÇAMER), Gaziantep University, Gaziantep, Türkiye

* Corresponding author: A. Çelekli
* E-mail: celekli.a@gmail.com

Received:30.10.2023
Accepted 17.12.2023

How to cite: Çelekli and Zariç (2023). From Emissions to Environmental Impact: Understanding the Carbon Footprint. *International Journal of Environment and Geoinformatics (IJEGEO)*, 10(4): 146-156. doi. 10.30897/ijegeo.1383311

Abstract

The atmosphere is being disturbed by an increase in the concentration of greenhouse gases, resulting in severe global warming and related effects. Each day, more comparable carbon dioxide is released into the atmosphere because of industrial processes, transportation, animal activities, lighting, cooking, heating, and illumination. The term "carbon footprint" refers to the number of greenhouse gases that a person, a nation, or an organization emits because of their activities. The methodologies for calculating carbon footprints are still being developed, but they are becoming a vital tool for managing greenhouse gases. This review article discusses the carbon footprint, measurement methods, and other important information. In the future, it is critical to keep developing and enhancing techniques for evaluating the environmental effect, including creating more thorough and consistent systems for computing carbon footprints. To develop a more comprehensive understanding of the environmental impact of human activities, it will also be crucial to consider environmental effects other than greenhouse gas emissions. These actions will ultimately be essential for reducing the impact of climate change and maintaining the health and well-being of our planet.

Keywords: Carbon Footprint, Climate Change, Environmental Sustainability, Greenhouse Gases, Global Warming

Introduction

The carbon footprint measures the greenhouse gas emissions associated with a product, organization, or activity (Wiedmann and Minx, 2008). It is used to assess the environmental impact of various products and processes and is an essential tool for managing greenhouse gas emissions (Pajula et al., 2017). As awareness of the effects of climate change increases, the term “carbon footprint” is becoming more widely used in commercial and industrial contexts (Ridanpää, 2022). However, there is an ongoing debate about the best methodologies for measuring carbon footprints, and the field is still evolving (Joensuu et al., 2022). All modern countries must make strategic policy decisions to pursue sustainable development (Lim, 2022). Sustainable development prioritizes the needs of the current generation without compromising the ability of future generations to meet their own needs (Opoku, 2022). Figure 1 shows the United Nations’ sustainable development goals (Sachs et al., 2022). It is a holistic approach considering economic, social, and environmental factors to create a more equitable and sustainable society (Scott and Rajabifard, 2017). Extreme weather and climate change are already warning signs of imbalances in natural systems caused by global warming, but they also pose challenges, such as human migration. (Çelekli et al., 2023a; Ripple et al., 2021). The effects of global warming are becoming more severe, and average temperature levels are being exceeded year after year (Sun et al., 2019). Ice is melting at unprecedented rates, and natural disasters are becoming more common and severe (Jackson, 2020). Carbon footprint analysis is a widely used method for quantifying the environmental impact of human activities (Chen et al., 2022).

Fig. 1. United Nations sustainable development goals (Sachs et al., 2022)

The concept of a "carbon footprint" was first introduced in the early 1990s as a way to measure the emissions of greenhouse gases (GHGs) associated with various activities, such as burning fossil fuels for transportation and electricity generation (Wiedmann and Minx, 2008). Since then, carbon footprint analysis has been used in various fields, including environmental science, sustainability, and corporate social responsibility (Yue et al., 2020). The main objective of this method is to Identify the significant sources of greenhouse gas emissions, also known as a carbon footprint, which is an essential aspect of sustainable development (Karwacka et al., 2020). Figure 2 shows the causes, consequences, and ways to reduce the carbon footprint. It allows organizations and individuals to understand their contribution to climate change and to take action to reduce or offset their emissions (Gössling and Humpe, 2020).

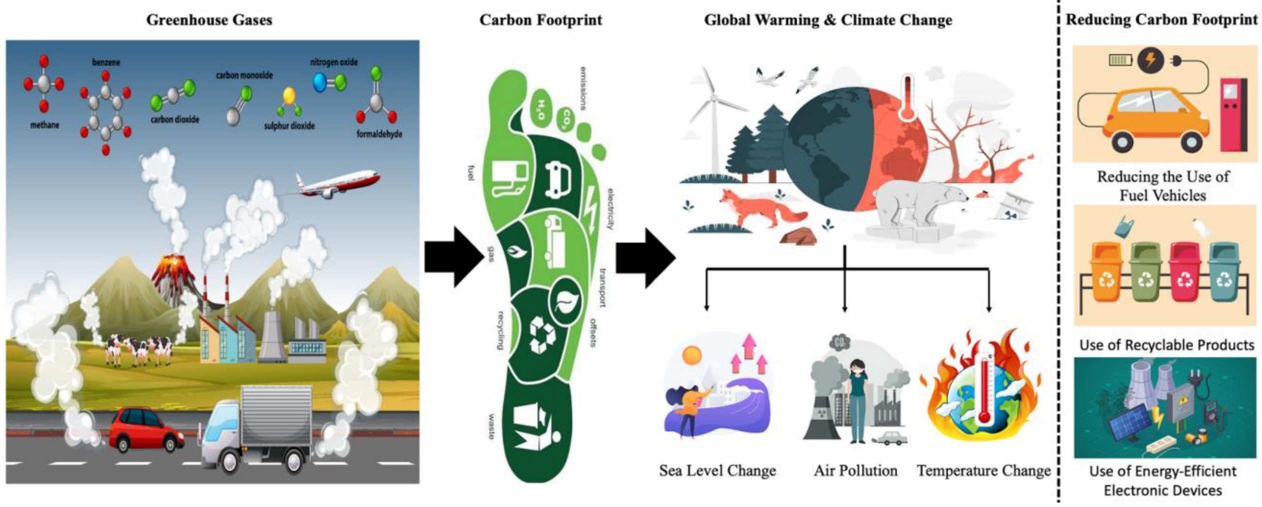

Fig. 2. Carbon footprint context path.

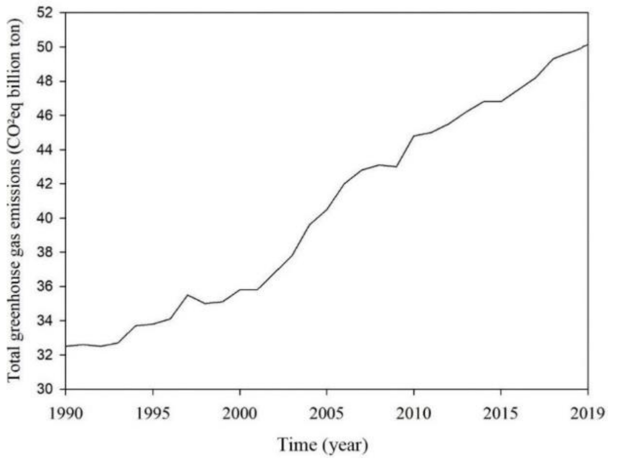

Fig. 3. Total greenhouse gas emissions in the world (Taylor, 2008)

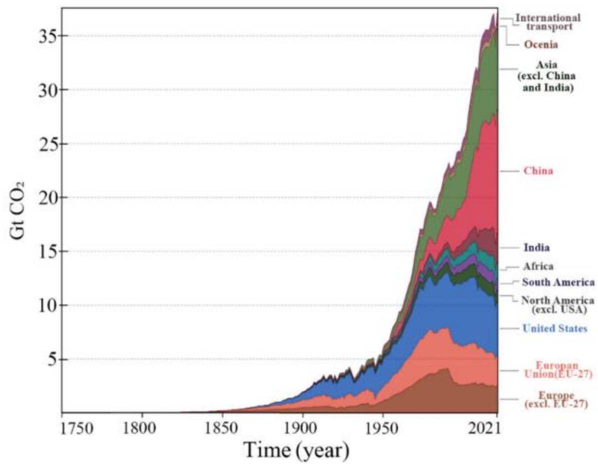

Fig. 4. Annual CO_2 emissions by world region (Our World in Data, 2022)

A carbon footprint is a tool used to identify the sources of emissions associated with a product, service, or activity and to develop strategies to decrease or make up for them to align with the sustainable development goal (Olabi et al., 2022).

Greenhouse Gases

Excessive emissions of greenhouse gases, particularly carbon dioxide and methane, are significant contributors to air pollution and the planet's warming (Yoro and Daramola, 2020; Adıgüzel, 2023). The burning of fossil fuels for energy and power generation is the primary source of these emissions, which cause the Earth's atmosphere to trap more heat, leading to the phenomenon known as the "greenhouse effect" and causing a range of environmental problems such as global warming, sea-level rise, changes in precipitation, and more frequent extreme weather events (Jeffry et al., 2021). As the human population grows, so will the energy demand (Bose, 2010). Nowadays, the majority of energy demand is met by the combustion of fossil fuels, which emits massive amounts of greenhouse gases (Stepanov and Makarov, 2022). Rapidly rising global CO_2 concentrations risk unpredictable climatic changes and sea-level rises, threatening marine and human life (Dermawan et al., 2022). The atmosphere's capacity to retain heat, known as the "greenhouse effect," contributes to this threat (Bonan, 2008; Rabie and Franck, 2018). Human-induced emissions of greenhouse gases like methane, ozone, and CFCs exacerbate this effect (Rodhe, 1990). Figure 3 depicts global greenhouse gas emissions, measured in

CO_2eq (Taylor, 2008). Such escalations intensify the greenhouse process, leading to global warming and climate change issues (Ali Mozaffari, 2022). Figure 4 displays annual CO_2 emissions by region (Our World in Data, 2022).

Global Warming

The greenhouse effect is the gradual increase in the Earth's atmosphere of gases, primarily carbon dioxide and methane, that trap heat from the sun and cause the planet's temperature to rise over time (Banday et al., 2022). This phenomenon is caused by human activities, particularly the burning of fossil fuels for energy and power generation, which has accelerated since the Industrial Revolution (Ülker et al., 2018; Rehman et al., 2022). This buildup of greenhouse gases in the atmosphere leads to climate change and various environmental problems (Bose, 2010). The release of greenhouse gases and pollutants into the atmosphere is primarily caused by anthropogenic factors such as excessive population growth, urbanization, rising living standards, industrial production, etc. (Çelekli al., 2023b; Singh et al., 2020). Excessive consumption of fossil fuels like coal, natural gas, and oil, as well as changes in land cover, such as deforestation and land use, are also significant contributors (K. Wang et al., 2022). These activities release large amounts of harmful gases and particles into the atmosphere, leading to global warming and other environmental problems (Landsea, 2005). Figure 5 shows anomalies in temperature over land and the ocean (GISS Data and Images, n.d.). Annual (thin lines) and five-year lowess smooth (thick lines) temperature anomalies (vs. 1951–1980) averaged over the Earth's land area, and sea surface temperature anomalies (vs. 1951–1980) averaged over the section of the ocean that is free of ice at all times (open ocean).

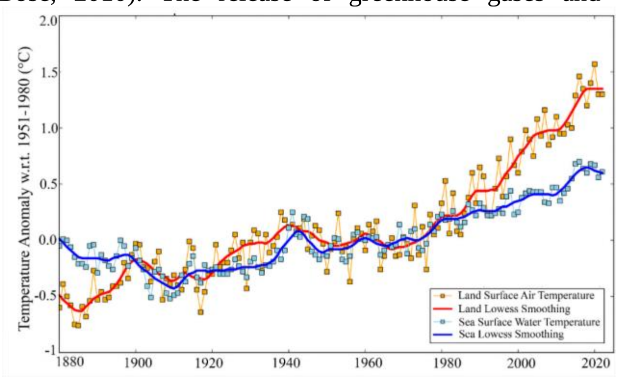

Fig. 5. Anomalies in temperature over land and the ocean (NASA, 2023.)

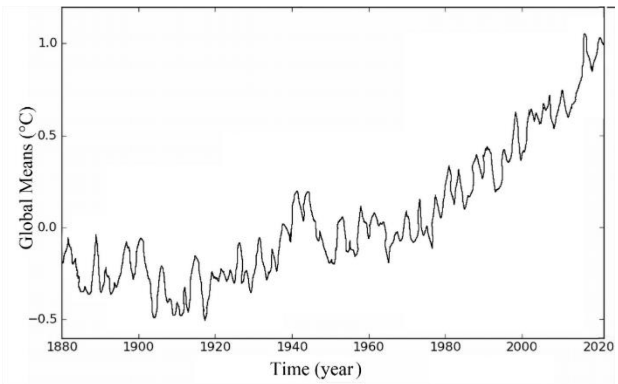

Fig. 6. 12-month global means 1951-2022 (NASA, 2023

Global warming is a significant problem that threatens the overall structure of the ecosystems that sustain life on Earth, causes the extinction of thousands of plant and animal species, has an impact on human life, and contributes to an increase in other meteorological disasters such as excessive heat, fires, drought, acidification, and aridification (Rather et al., 2022). Figure 6 shows the 12-month global mean (GISS Data and Images, n.d.). The change in temperature changes between 1880-2020 in Celsius compared to the average difference between 1951-1980 is shown with lines. The temperature tends to increase, and it causes global warming.

Climate Change

Climate change, which is also referred to as “global warming,” is a change in the Earth's climate due to an increase of gases, such as carbon dioxide and methane, in the atmosphere that traps heat, leading to a warming of the planet (Çelekli and Zariç, 2023b; Kweku et al., 2018). Climate change is also changing sea levels (Mimura, 2013). Figure 7 depicts how sea level change is calculated about the sea level average between 1993 and 2021(Lindsey, 2021). In recent decades, the average global sea level change has increased from a few centimeters per century throughout recent millennia to a few tens of centimeters each century (Hawkes, 2013). Due to the melting of land ice and the thermal expansion of ocean water, this tenfold increase in the rate of rise can be linked to climate change (Hawkes, 2013). Global mean sea level will keep rising as long as the current warming trend is anticipated to last (Houghton, 2005). Regarding the global average, land ice loss (due to glacier melting and ice sheet mass loss) and changes in terrestrial water storage are the three main factors contributing to rising sea levels (Cazenave and Moreira, 2022). The oceans' thermal expansion between 1993 and 2018 was responsible for 42% of the rise in sea level (Cazenave et al., 2018). Melting temperature glaciers, 21%; Greenland, 15%; and Antarctica has an 8% contribution (Quiquet and Dumas, 2021). Climate change causes abnormal temperature changes (Malhi et al., 2021).

The term "carbon footprint" has its roots in the concept of an "ecological footprint," which Wackernagel and Rees first proposed in 1996 (Yilanci et al., 2022). The term "ecological footprint" describes the biologically productive land and water needed to support a specific human population in world hectares (Ansari, 2022). The total amount of greenhouse gases released into the atmosphere due to an individual's or organization's activity is known as their "carbon footprint." (Wiedmann and Minx, 2008). These emissions are commonly quantified in carbon dioxide equivalents (CO_2eq) and can come from various sources, including transportation, power generation, industrial activities, and deforestation (Matthews et al., 2008). Nature maintains the balance of greenhouse gases in the atmosphere (Fuglestvedt et al., 2018). The carbon footprint calculation determines how much biocapacity we require (Lin et al., 2015). Under normal circumstances, the per capita biocapacity is projected to be greater than the per capita ecological footprint (Galli et al., 2012). Global CO_2 emissions for a year are shown in Figure 8 (Our World in Data, 2022). The carbon footprint per person is roughly 3.72 to 22.54 tons (H. Wang et al., 2012). China, America, and India have the highest carbon footprints, whereas many other countries, like Turkey, Italy, Germany, and Spain, require greater biocapacity (Fan et al., 2016). Figure 9 shows the total annual global emissions of fossil CO_2 by sector, given in Gt CO_2/yr (Crippa et al., 2019). Energy

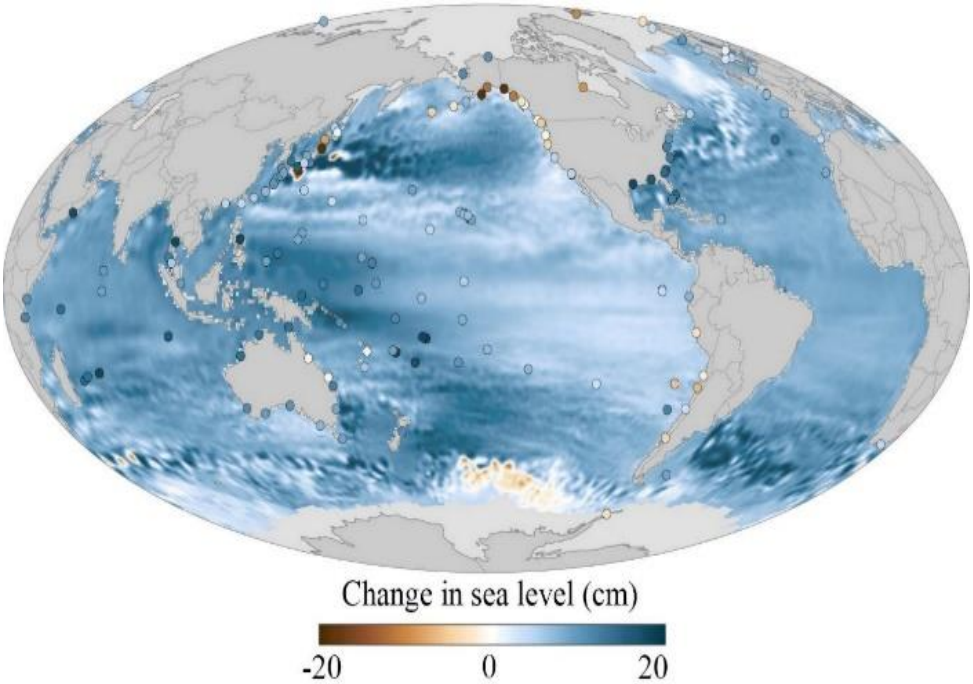

Fig. 7. Sea level change (1993-2021) (Lindsey, 2021)

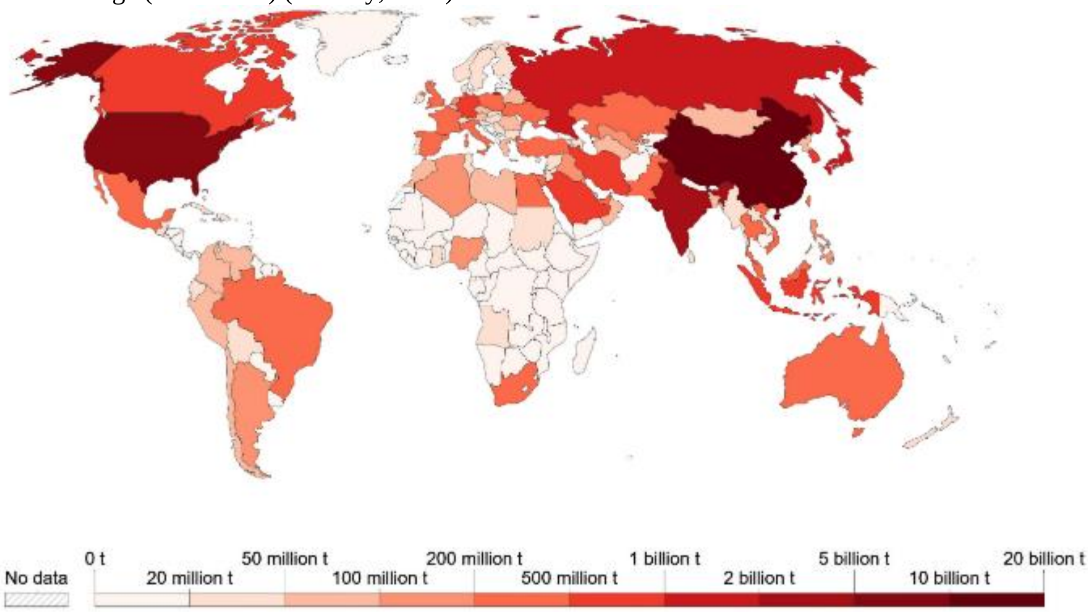

Fig. 8. Annual CO_2 emission (Our World in Data, 2022)

Carbon Footprint

consumption accounts for 73.2% of carbon dioxide emissions, with industry using 24.2% and transportation using 16.2%, respectively (Londoño-Pulgarin et al., 2021). In conclusion, the concept of the carbon footprint, rooted in the ecological footprint framework, serves as a pivotal metric for assessing the environmental impact of human activities. The disparities in per capita biocapacity and ecological footprint underscore the need for concerted global efforts to address environmental challenges. The regional discrepancies in carbon footprints shed light on the varying degrees of responsibility countries bear, necessitating collaborative strategies for a sustainable and ecologically balanced future.

Carbon Footprint Calculation

The number of greenhouse gases (GHGs) released into the atmosphere due to human activity may be calculated using a carbon footprint (Min et al., 2022). These activities can include transportation, electricity use, heating and cooling buildings, industrial processes, and deforestation (Labaran et al., 2022). Commonly, the calculation is given in carbon dioxide equivalent (CO_2e) units, which account for the various GHGs' varying warming potentials (Pandey et al., 2011). It's essential to consider every phase of a product or service's life cycle when evaluating its carbon footprint, from the source of raw materials to its disposal (Pattara et al., 2012). This method, also referred to as a "cradle-to-grave" study or life cycle assessment (LCA), offers a thorough understanding of a product's environmental effects, including GHG emissions, air pollution, water use, energy consumption, and more (Thoma et al., 2013). Technically referred to as "GHG accounting," LCA also goes by "environmental LCA" and calculates the number of GHGs released into the atmosphere or incorporated into a product at each step of its life cycle. Standards and guidelines are available to assist with this process (Çelekli and Zariç, 2023a; Kulak et al., 2013).

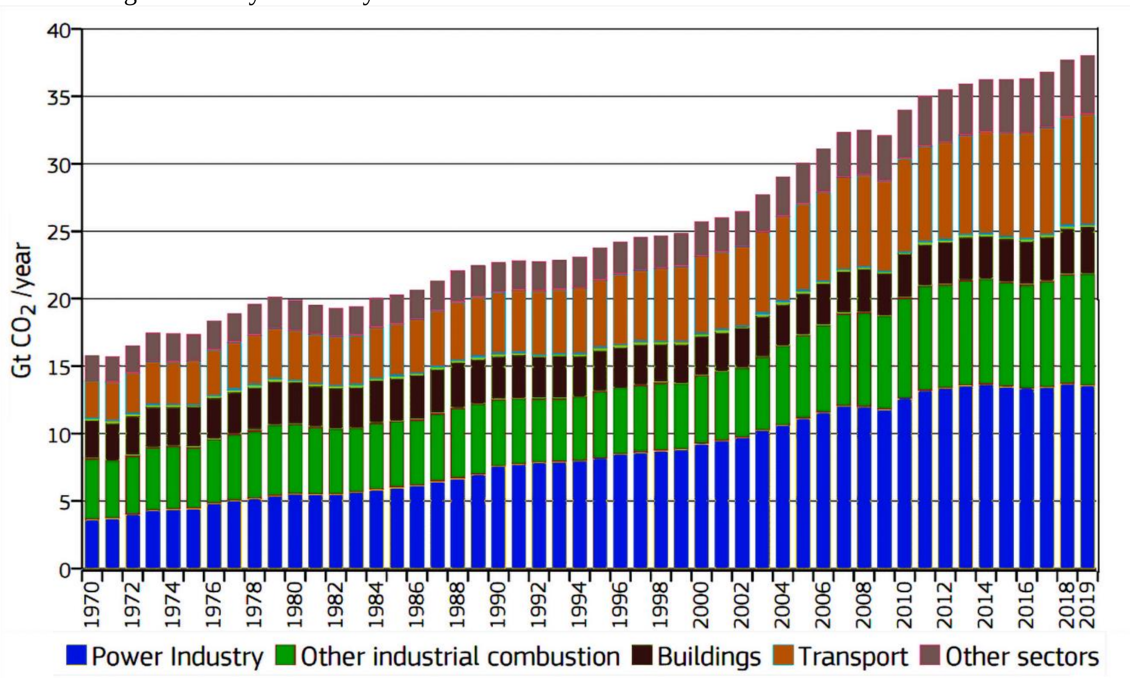

Fig. 9. Total yearly worldwide emissions of fossil CO2 (Gt CO2/yr) by sectors (Crippa et al., 2019)

The calculation of carbon footprints involves a multifaceted process that requires tailored approaches for different contexts, ranging from individual activities to broader industrial and agricultural practices. Various studies have been developed to estimate carbon footprints, each with its unique focus and methodology. For instance, Qafisheh et al. (2017) applied an Environmental Extended Input Output model to evaluate the carbon footprint of the Norwegian University of Technology and Science, demonstrating the application of advanced modeling techniques in assessing carbon footprints. Hertwich et al. (2022) highlighted the significance of electricity mixes in influencing the carbon footprints of electric vehicles, emphasizing the importance of considering regional variability and future trends in carbon footprints. Asube and Sinadjan (2021) conducted a study to evaluate online carbon footprint calculators, aiming to identify essential inputs and user engagement features. This underscores the importance of user-friendly tools to calculate accurately carbon footprint. Mohan et al. (2022) conducted a case study to analyze the carbon footprint of conventional rice cultivation, highlighting the application of carbon footprint assessments in the agricultural sector. Leach et al. (2017) emphasized the need for integrated tools to calculate and reduce institution carbon and nitrogen footprints, highlighting the importance of comprehensive approaches to address environmental impacts. Furthermore, Zhao et al. (2011) conducted an assessment and analysis of metropolitan carbon footprints, providing valuable insights into the factors contributing to carbon footprints and proposing policy recommendations for reducing them. These studies and models demonstrate the diverse applications of carbon footprint calculations, ranging from academic research to practical assessments in various sectors. The methodologies and findings from these studies contribute to the broader understanding of carbon footprints and provide valuable insights for policymakers, researchers, and practitioners seeking to mitigate environmental impacts. In conclusion, the concept of a carbon footprint extends beyond a simple calculation, encompassing a comprehensive analysis of human-induced GHG emissions across various activities. By employing approaches such as LCAs and according to set standards, one may get a more precise comprehension of the environmental consequences of products and services.

Kyoto Protocol

The Kyoto Protocol, adopted as part of the United Nations Framework Convention on Climate Change (UNFCCC) in 1997, is an international agreement aimed at reducing emissions of greenhouse gases and slowing the pace of climate change (Hepburn, 2007). 190 countries signed the treaty, which went into force in 2005 (Owen and Hanley, 2004). The Protocol establishes legally bound carbon reduction goals for developed nations, also known as Annex 1 nations, such as Germany, the United States of America, Italy, and Austria. (Hovi et al., 2003). These targets are intended to be met through various means, including carbon trading and using carbon sinks (Hepburn, 2007). Additionally, the pact established the Clean Development Mechanism, which enables wealthy nations to finance carbon-reduction initiatives in poor countries to offset their emissions (Popp, 2011). The Protocol was amended in 2012 to establish a second commitment period from 2013 to 2020 (Bäckstrand and Elgström, 2013).

Paris Agreement

The Paris Agreement was ratified as an international treaty by the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 to slow global warming and strengthen nations' capacity to deal with its consequences (Horowitz, 2016). The pact seeks to pursue efforts to limit global warming to 1.5 degrees Celsius over pre-industrial levels and to keep it far below 2 degrees Celsius (Horowitz, 2016). Countries must submit Nationally Determined Contributions (NDCs) under the Paris Agreement outlining their strategies for reducing greenhouse gas emissions (Delbeke et al., 2019). These NDCs are not legally binding, but countries are expected to report on their progress frequently and revise them over time to reflect their rising ambition (Savaresi, 2016). The Paris Agreement also encourages nations to cooperate in developing and transferring technology and establishes a financial mechanism to support developing nations' mitigation and adaptation efforts (Vinet and Zhedanov, 2011). On November 4, 2016, the Paris Agreement became official (Horowitz, 2016).

Reducing Carbon Footprint

Reducing one's carbon footprint entails reducing the number of greenhouse gases released into the atmosphere (Bond and Sun, 2005). This can be accomplished by utilizing renewable energy sources, energy-efficient equipment and minimizing meat and dairy product intake (Elahi et al., 2019). Individuals can also reduce their carbon footprint by taking public transit, walking or biking instead of driving, and recycling (Jackson, 2020). Overall, lowering one's carbon footprint can aid in slowing climate change and protecting the environment (Hansen et al., 2013). Waste management has the potential to significantly reduce greenhouse gas emissions (Mamais et al., 2015). Landfills mainly produce methane, a potent greenhouse gas, when organic waste decomposes (Lee et al., 2017). Methane can also be made during garbage incineration (Mboowa et al., 2017). On the other hand, recycling and composting can minimize the garbage sent to landfills and reduce methane emissions (Kristanto and Koven, 2019). Furthermore, manufacturing materials for recycling and composting might have a smaller carbon footprint than producing new materials (Diacono et al., 2019). Overall, more sustainable waste management techniques can aid in reducing greenhouse gas emissions (Mannina et al., 2016). Figure 9 indicates gas emissions from waste management (Eurostat, 2011).

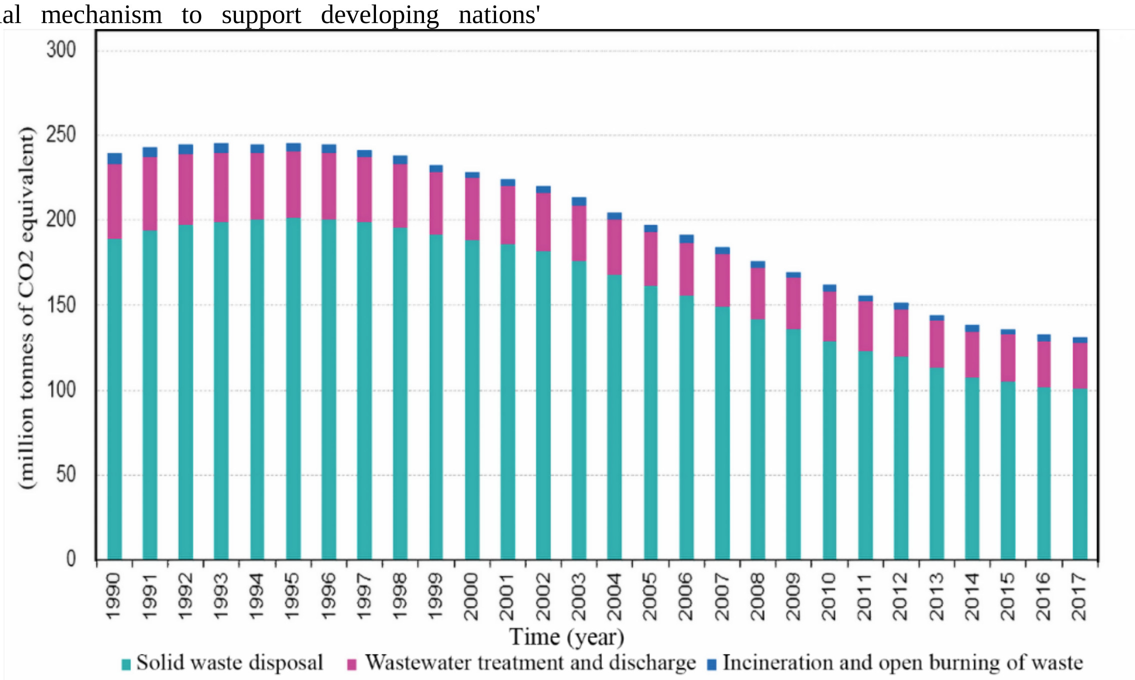

Fig. 10. Gas emissions from waste management (Eurostat, 2011).

Reducing the Use of Fuel Vehicles

Motor vehicles greatly influence the environment in terms of carbon emissions since they run on fossil fuels. A typical automobile emits 4.6 metric tons of CO_2 yearly (Zacharof et al., 2016). Reduced consumption can significantly reduce the number of greenhouse gases discharged into the environment (Satterthwaite, 2008)

Use of Energy-Efficient Electronic Devices

When comparing energy consumption, Class A refrigerators use significantly less energy than Class G refrigerators (Mills and Schleich, 2010). On average, Class A refrigerators consume 449 kWh per year, while Class G refrigerators consume over 1020 kWh annually (Mansouri et al., 1996). Choosing appliances and household goods with a high energy efficiency rating is recommended to minimize the environmental impact (Jeong and Kim, 2015).

Use of recyclable products

Emphasizing recycling is one of the most practical ways to reduce your carbon footprint. By separating paper, glass, and plastic waste and storing them in different areas, we can significantly contribute to the environment's protection (Al-Maaded et al., 2012). Especially in clothing shopping, focusing on recycled products is also important from a sustainability perspective (Diddi et al., 2019). Because each kilogram of new textile product produced results in the release of 2 kilograms of carbon dioxide into the environment (Quadrelli et al., 2011), recycling and promoting a circular economy can be considered effective ways to minimize the environmental impacts caused by the waste and consumption of resources (Di Maio and Rem, 2015). By choosing recycled materials and products, the amount of waste is reduced, and the energy consumption and greenhouse gas emissions caused by the production of new materials are minimized (Corsten et al., 2013).

Conclusion

Assessing the environmental impact of human activities is essential to understanding and mitigating their effects on the planet. One popular way of quantifying this impact is through the concept of carbon footprint, which measures the total greenhouse gas emissions caused by an individual, organization, or product. In recent years, there has been increasing awareness of the importance of reducing carbon footprints as part of the effort to combat climate change. As a result, many governments and businesses have adopted carbon reduction targets and are implementing strategies to reduce their carbon emissions. However, there are some limitations to the carbon footprint concept, including the fact that it needs to consider other types of environmental impacts, such as water usage, land use, and pollution. Additionally, there needs to be a standardized methodology for calculating carbon footprints, which can lead to inconsistencies in the data. In the future, it is critical to keep developing and enhancing techniques for evaluating the environmental effect, including creating more thorough and consistent systems for computing carbon footprints. To develop a more comprehensive understanding of the environmental impact of human activities, it will also be crucial to consider environmental effects other than greenhouse gas emissions. These actions will ultimately be essential for reducing the impact of climate change and maintaining the health and well-being of our planet.

Acknowledgments

Authors thank Gaziantep University, Environmental Research Center (GÜÇAMER).

References

Adigüzel, F. (2023). Effects of Green Spaces on Microclimate in Sustainable Urban Planning. *International Journal of Environment and Geoinformatics*, 10(3), 124-131. https://doi.org/10.30897/ijegeo.1342287

Ali Mozaffari, G. (2022). Climate Change and Its Consequences in Agriculture. *The Nature, Causes, Effects and Mitigation of Climate Change on the Environment*, 83. https://doi.org/10.5772/intechopen.101444

Ansari, M. A. (2022). Re-visiting the Environmental Kuznets curve for ASEAN: A comparison between ecological footprint and carbon dioxide emissions. *Renewable and Sustainable Energy Reviews*, 168, 112867. https://doi.org/10.1016/j.rser.2022.112867

Asube, L. C. S., R. L. Sinadjan. 2021. "Estimations of Carbon Footprint from Electricity Consumption during Covid-19 Lockdown and Pre-Lockdown in Butuan City." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* 46(4/W6-2021):49–56. doi: 10.5194/isprs-Archives-XLVI-4-W6-2021-49-2021.

Bäckstrand, K., Elgström, O. (2013). The EU's role in climate change negotiations: From leader to "leadiator." *Journal of European Public Policy*, 20(10), 1369–1386. https://doi.org/10.1080/13501763.2013.781781

Banday, T., Nissa, S. S., Shanaz, S., Tramboo, S. R. (2022). 16 Climate Impact on Change Poultry and Production Its. *Environmental Studies and Climate Change*, 257.

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, 320(5882), 1444–1449. https://doi.org/10.1126/science.1155121

Bond, T. C., Sun, K. (2005). Can reducing black carbon emissions counteract global warming? *In Environmental Science and Technology* (Vol. 39, Issue 16, pp. 5921–5926). ACS Publications. https://doi.org/10.1021/es0480421

Bose, B. K. (2010). Global warming: Energy, environmental pollution, and the impact of power electronics. *IEEE Industrial Electronics Magazine*, 4(1), 6–17. https://doi.org/10.1109/MIE.2010.935860

Cazenave, A., Moreira, L. (2022). Contemporary sea-level changes from global to local scales: A review. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 478(2261), 20220049. https://doi.org/10.1098/rspa.2022.0049

Cazenave, A., Palanisamy, H., Ablain, M. (2018). Contemporary sea level changes from satellite altimetry: What have we learned? What are the new challenges? *Advances in Space Research*, 62(7), 1639–1653. https://doi.org/10.1016/j.asr.2018.07.017

Çelekli, A., Yaygır, S., Zariç, Ö. E. (2023a). A review of climate change-induced migration. Acta Biologica Turcica, 36(2), A3:1-11. https://doi.org/10.5281/zenodo.8190755

Çelekli, A., Yeşildağ, İ., Yaygır, S., Zariç, Ö. E. (2023b). Effects of urbanization on bioclimatic comfort conditions. Acta Biologica Turcica, 36(4), S2:1-10. https://doi.org/10.5281/zenodo.8224327

Çelekli, A., Zariç, Ö. E. (2023a). Assessing the environmental impact of functional foods. *6th International Eurasian Conference on Biological and Chemical Sciences*, 103. https://doi.org/10.5281/zenodo.10021465

Çelekli, A., Zariç, Ö. E. (2023b). Hydrobiology and ecology in the context of climate change: the future of aquatic ecosystems. *6th International Eurasian Conference on Biological and Chemical Sciences*, 539–545. https://doi.org/10.5281/zenodo.10021473

Chen, L., Msigwa, G., Yang, M., Osman, A. I., Fawzy, S., Rooney, D. W., Yap, P. S. (2022). Strategies to achieve a carbon neutral society: a review. *Environmental Chemistry Letters*, 20(4), 2277–2310. https://doi.org/10.1007/s10311-022-01435-8

Corsten, M., Worrell, E., Rouw, M., Van Duin, A. (2013). The potential contribution of sustainable waste management to energy use and greenhouse gas emission reduction in the Netherlands. Resources, *Conservation and Recycling*, 77, 13–21.

Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J. G. ., Vignati, E. (2019). Fossil CO2 and GHG emissions of all world countries. *Publication Office of the European Union*: Luxemburg, October, 251. https://doi.org/10.2760/143674

Delbeke, J., Runge-Metzger, A., Slingenberg, Y., Werksman, J. (2019). The paris agreement. *In Towards a Climate-Neutral Europe: Curbing the Trend* (pp. 24–45). Routledge. https://doi.org/10.4324/9789276082569-2

Dermawan, D., Wang, Y. F., You, S. J., Jiang, J. J., Hsieh, Y. K. (2022). Impact of climatic and non-climatic stressors on ocean life and human health: A review. *Science of the Total Environment*, 821, 153387. https://doi.org/10.1016/j.scitotenv.2022.153387

Di Maio, F., Rem, P. C. (2015). A Robust Indicator for Promoting Circular Economy through Recycling. *Journal of Environmental Protection*, 06(10), 1095–1104. https://doi.org/10.4236/jep.2015.610096

Diacono, M., Persiani, A., Testani, E., Montemurro, F., Ciaccia, C. (2019). Recycling agricultural wastes and by-products in organic farming: Biofertilizer production, yield performance and carbon footprint analysis. *Sustainability (Switzerland)*, 11(14), 3824. https://doi.org/10.3390/su11143824

Diddi, S., Yan, R. N., Bloodhart, B., Bajtelsmit, V., McShane, K. (2019). Exploring young adult consumers' sustainable clothing consumption intention-behavior gap: A Behavioral Reasoning Theory perspective. *Sustainable Production and Consumption*, 18, 200–209. https://doi.org/10.1016/j.spc.2019.02.009

Elahi, E., Weijun, C., Jha, S. K., Zhang, H. (2019). Estimation of realistic renewable and non-renewable energy use targets for livestock production systems utilising an artificial neural network method: A step towards livestock sustainability. *Energy*, 183, 191–204. https://doi.org/10.1016/j.energy.2019.06.084

Eurostat. (2011). Eurostat: Climate change - driving forces. Web Page of Eurostat. http://epp.eurostat.ec.europa.eu

Fan, J. L., Hou, Y. B., Wang, Q., Wang, C., Wei, Y. M. (2016). Exploring the characteristics of production-based and consumption-based carbon emissions of major economies: A multiple-dimension comparison. *Applied Energy*, 184, 790–799.

Fuglestvedt, J., Rogelj, J., Millar, R. J., Allen, M., Boucher, O., Cain, M., Forster, P. M., Kriegler, E., Shindell, D. (2018). Implications of possible interpretations of'greenhouse gas balance' in the Paris Agreement. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 376(2119), 20160445. https://doi.org/10.1098/rsta.2016.0445

Galli, A., Kitzes, J., Niccolucci, V., Wackernagel, M., Wada, Y., Marchettini, N. (2012). Assessing the global environmental consequences of economic growth through the Ecological Footprint: A focus on China and India. *Ecological Indicators*, 17, 99–107. https://doi.org/10.1016/j.ecolind.2011.04.022

Gössling, S., Humpe, A. (2020). The global scale, distribution and growth of aviation: Implications for climate change. *Global Environmental Change*, 65, 102194. https://doi.org/10.1016/j.gloenvcha.2020.102194

Hansen, J., Kharecha, P., Sato, M., Masson-Delmotte, V., Ackerman, F., Beerling, D. J., Hearty, P. J., Hoegh-Guldberg, O., Hsu, S. L., Parmesan, C., Rockstrom, J., Rohling, E. J., Sachs, J., Smith, P., Steffen, K., Van Susteren, L., Von Schuckmann, K., Zachos, J. C. (2013). Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature. *PLoS ONE*, 8(12), e81648. https://doi.org/10.1371/journal.pone.0081648

Hawkes, P. J. (2013). Sea level change. *In Encyclopedia of Earth Sciences Series*. PM Cambridge University Press. https://doi.org/10.1007/978-1-4020-4399-4_309

Hepburn, C. (2007). Carbon trading: A review of the kyoto mechanisms. *Annual Review of Environment and Resources*, 32(1), 375–393. https://doi.org/10.1146/annurev.energy.32.053006.141203

Hertwich, Edgar, Ziyang Wu, Paul Wolfram, Can Wang, Xin Sun, Fu Sun. (2022). Regional Variability and Future Trends in Carbon Footprints of Electric Vehicles in China Based on THEMIS Model. *Proceedings of the 16th International Conference on Environmental Science and Technology* 16. doi: 10.30955/gnc2019.00479.

Horowitz, C. A. (2016). Paris Agreement. *International Legal Materials*, 55(4), 740–755. https://doi.org/10.1017/s0020782900004253

Houghton, J. (2005). Global warming. *Reports on Progress in Physics*, 68(6), 1343–1403. https://doi.org/10.1088/0034-4885/68/6/R02

Hovi, J., Skodvin, T., Andresen, S. (2003). The Persistence of the Kyoto Protocol: Why Other Annex I Countries Move on Without the United States.

Global Environmental Politics, 3(4), 1–23. https://doi.org/10.1162/152638003322757907

Jackson, D. J. (2020). Addressing the challenges of reducing greenhouse gas emissions in the construction industry: a multi-perspective approach. https://doi.org/10.7488/ERA/269

Jeffry, L., Ong, M. Y., Nomanbhay, S., Mofijur, M., Mubashir, M., Show, P. L. (2021). Greenhouse gases utilization: A review. *Fuel*, 301. https://doi.org/10.1016/j.fuel.2021.121017

Jeong, G., Kim, Y. (2015). The effects of energy efficiency and environmental labels on appliance choice in South Korea. *Energy Efficiency*, 8(3), 559–576. https://doi.org/10.1007/s12053-014-9307-1

Joensuu, T., Leino, R., Heinonen, J., Saari, A. (2022). Developing Buildings' Life Cycle Assessment in Circular Economy-Comparing methods for assessing carbon footprint of reusable components. *Sustainable Cities and Society*, 77, 103499. https://doi.org/10.1016/j.scs.2021.103499

Karwacka, M., Ciurzyńska, A., Lenart, A., Janowicz, M. (2020). Sustainable Development in the Agri-Food Sector in Terms of the Carbon Footprint: A Review. *Sustainability (Switzerland)*, 12(16), 6463.

Kristanto, G. A., Koven, W. (2019). Estimating greenhouse gas emissions from municipal solid waste management in Depok, Indonesia. *City and Environment Interactions*, 4, 100027. https://doi.org/10.1016/j.cacint.2020.100027

Kulak, M., Graves, A., Chatterton, J. (2013). Reducing greenhouse gas emissions with urban agriculture: A Life Cycle Assessment perspective. *Landscape and Urban Planning*, 111(1), 68–78. https://doi.org/10.1016/j.landurbplan.2012.11.007

Kweku, D., Bismark, O., Maxwell, A., Desmond, K., Danso, K., Oti-Mensah, E., Quachie, A., Adormaa, B. (2018). Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research and Reports*, 17(6), 1–9.

Labaran, Y. H., Mathur, V. S., Muhammad, S. U., Musa, A. A. (2022). Carbon footprint management: A review of construction industry. *Cleaner Engineering and Technology*, 9.

Landsea, C. W. (2005). Hurricanes and global warming. *Nature*, 438(7071), E11–E12. https://doi.org/10.1038/nature04477

Leach, Allison M., James N. Galloway, Elizabeth A. Castner, Jennifer Andrews, Neil Leary, John D. Aber. (2017). An Integrated Tool for Calculating and Reducing Institution Carbon and Nitrogen Footprints. *Sustainability the Journal of Record*. doi: 10.1089/sus.2017.29092.aml.

Lee, U., Han, J., Wang, M. (2017). Evaluation of landfill gas emissions from municipal solid waste landfills for the life-cycle analysis of waste-to-energy pathways. *Journal of Cleaner Production*, 166, 335–342. https://doi.org/10.1016/j.jclepro.2017.08.016

Lim, W. M. (2022). The Sustainability Pyramid: A Hierarchical Approach to Greater Sustainability and the United Nations Sustainable Development Goals With Implications for Marketing Theory, Practice, and Public Policy. *Australasian Marketing Journal*, 30(2), 142–150.

Lin, D., Wackernagel, M., Galli, A., Kelly, R. (2015). Ecological Footprint: Informative and evolving - A response to van den Bergh and Grazi (2014). *Ecological Indicators*, 58, 464–468.

Lindsey, R. (2021). Climate Change: Global Sea Level | NOAA Climate

Londoño-Pulgarin, D., Cardona-Montoya, G., Restrepo, J. C., Muñoz-Leiva, F. (2021). Fossil or bioenergy? Global fuel market trends. *Renewable and Sustainable Energy Reviews*, 143, 110905.

Madi, N. K., Kahraman, R., Hodzic, A., Ozerkan, N. G. (2012). An Overview of Solid Waste Management and Plastic Recycling in Qatar. *Journal of Polymers and the Environment*, 20(1), 186–194. https://doi.org/10.1007/s10924-011-0332-2

Malhi, G. S., Kaur, M., Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability (Switzerland)*, 13(3), 1–21. https://doi.org/10.3390/su13031318

Mamais, D., Noutsopoulos, C., Dimopoulou, A., Stasinakis, A., Lekkas, T. D. (2015). Wastewater treatment process impact on energy savings and greenhouse gas emissions. *Water Science and Technology*, 71(2), 303–308. https://doi.org/10.2166/wst.2014.521

Mannina, G., Ekama, G., Caniani, D., Cosenza, A., Esposito, G., Gori, R., Garrido-Baserba, M., Rosso, D., Olsson, G. (2016). Greenhouse gases from wastewater treatment - A review of modelling tools. *Science of the Total Environment*, 551–552, 254–270. https://doi.org/10.1016/j.scitotenv.2016.01.163

Mansouri, I., Newborough, M., Probert, D. (1996). Energy consumption in uk households: Impact of domestic electrical appliances. *Applied Energy*, 54(3 SPEC. ISS.), 211–285. https://doi.org/10.1016/0306-2619(96)00001-3

Matthews, H. S., Hendrickson, C. T., Weber, C. L. (2008). The importance of carbon footprint estimation boundaries. In *Environmental Science and Technology* (Vol. 42, Issue 16, pp. 5839–5842). ACS Publications. https://doi.org/10.1021/es703112w

Mboowa, D., Quereshi, S., Bhattacharjee, C., Tonny, K., Dutta, S. (2017). Qualitative determination of energy potential and methane generation from municipal solid waste (MSW) in Dhanbad (India). *Energy*, 123, 386–391. https://doi.org/10.1016/j.energy.2017.02.009

Mills, B., Schleich, J. (2010). What's driving energy efficient appliance label awareness and purchase propensity? *Energy Policy*, 38(2), 814–825. https://doi.org/10.1016/j.enpol.2009.10.028

Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. *Proceedings of the Japan Academy Series B: Physical and Biological Sciences*, 89(7), 281–301. https://doi.org/10.2183/pjab.89.281

Min, J., Yan, G., Abed, A. M., Elattar, S., Amine Khadimallah, M., Jan, A., Elhosiny Ali, H. (2022). The effect of carbon dioxide emissions on the building energy efficiency. *Fuel*, 326, 124842. https://doi.org/10.1016/j.fuel.2022.124842

Mohan, S. Megha, A. Vidhyavathi, S. Padmarani, and P. Balaji. (2022). Carbon Footprints and Conventional

Rice Cultivation; A Case Study in Thanjavur District. *Asian Journal of Agricultural Extension, Economics & Sociology* 233–43. doi: 10.9734/ajaees/2022/v40i1031066.

NASA. (2023). Nasa. Retrieved January 17, 2023, from http://data.giss.nasa.gov/

Olabi, A. G., Obaideen, K., Elsaid, K., Wilberforce, T., Sayed, E. T., Maghrabie, H. M., Abdelkareem, M. A. (2022). Assessment of the pre-combustion carbon capture contribution into sustainable development goals SDGs using novel indicators. *Renewable and Sustainable Energy Reviews*, 153, 111710. https://doi.org/10.1016/j.rser.2021.111710

Opoku, A. (2022). Construction industry and the Sustainable Development Goals (SDGs). *In Research Companion to Construction Economics* (pp. 199–214). Edward Elgar Publishing.

Our World in Data. (2022). Greenhouse gas emissions - *Our World in Data*.

Owen, A. D., Hanley, N. (2004). *The economics of climate change. In The Economics of Climate Change* (pp. 1–297). Routledge.

Pajula, T., Behm, K., Vatanen, S., Saarivuori, E. (2017). Managing the life cycle to reduce environmental impacts. *Dynamics of Long-Life Assets: From Technology Adaptation to Upgrading the Business Model*, 93–113.

Pandey, D., Agrawal, M., Pandey, J. S. (2011). Carbon footprint: Current methods of estimation. *Environmental Monitoring and Assessment*, 178(1–4), 135–160.

Pattara, C., Raggi, A., Cichelli, A. (2012). Life cycle assessment and carbon footprint in the wine supply-chain. *Environmental Management*, 49(6), 1247–1258. https://doi.org/10.1007/s00267-012-9844-3

Popp, D. (2011). International technology transfer, climate change, and the clean development mechanism. *Review of Environmental Economics and Policy*, 5(1), 131–152.

Qafisheh, Nida, Makhtar Sarr, Umm Amara Hussain, Shikha Awadh. (2017). Carbon Footprint of ADU Students: Reasons and Solutions. *Environment and Pollution* 6(1):27. doi: 10.5539/ep.v6n1p27

Quadrelli, E. A., Centi, G., Duplan, J. L., Perathoner, S. (2011). Carbon dioxide recycling: Emerging large-scale technologies with industrial potential. *ChemSusChem*, 4(9), 1194–1215. https://doi.org/10.1002/cssc.201100473

Quiquet, A., Dumas, C. (2021). The GRISLI-LSCE contribution to the Ice Sheet Model Intercomparison Project for phase 6 of the Coupled Model Intercomparison Project (ISMIP6) - Part 1: Projections of the Greenland ice sheet evolution by the end of the 21st century. *Cryosphere*, 15(2), 1015–1030. https://doi.org/10.5194/tc-15-1015-2021

Rabie, M., Franck, C. M. (2018). Assessment of Eco-friendly Gases for Electrical Insulation to Replace the Most Potent Industrial Greenhouse Gas SF6. *Environmental Science and Technology*, 52(2), 369–380. https://doi.org/10.1021/acs.est.7b03465

Rather, Z. A., Ahmad, R., Dar, T. U. H., Khuroo, A. A. (2022). Ensemble modelling enables identification of suitable sites for habitat restoration of threatened biodiversity under climate change: A case study of Himalayan Trillium. *Ecological Engineering*, 176, 106534.

Rehman, A., Radulescu, M., Cismas, L. M., Alvarado, R., Secara, C. G., Tolea, C. (2022). Urbanization, Economic Development, and Environmental Degradation: Investigating the Role of Renewable Energy Use. *Sustainability (Switzerland)*, 14(15), 9337. https://doi.org/10.3390/su14159337

Ridanpää, J. (2022). 'Carbon footprint nationalism': re-conceptualizing Finnish nationalism and national pride through climate change discourse. *National Identities*, 24(4), 429–446. https://doi.org/10.1080/14608944.2021.1937974

Ripple, W. J., Wolf, C., Newsome, T. M., Gregg, J. W., Lenton, T. M., Palomo, I., Eikelboom, J. A. J., Law, B. E., Huq, S., Duffy, P. B., Rockström, J. (2021). World scientists' warning of a climate emergency 2021. In *BioScience* (Vol. 71, Issue 9, pp. 894–898). Oxford University Press.

Rodhe, H. (1990). A comparison of the contribution of various gases to the greenhouse effect. *Science*, 248(4960), 1217–1219.

Sachs, J., Kroll, C., Lafortune, G., Fuller, G., Woelm, F. (2022). Sustainable Development Report 2022. In *Sustainable Development Report 2022*. Cambridge University Press.

Satterthwaite, D. (2008). Cities' contribution to global warming: Notes on the allocation of greenhouse gas emissions. *Environment and Urbanization*, 20(2), 539–549. https://doi.org/10.1177/0956247808096127

Savaresi, A. (2016). The Paris agreement: A new beginning? *Journal of Energy and Natural Resources Law*, 34(1), 16–26. https://doi.org/10.1080/02646811.2016.1133983

Scott, G., Rajabifard, A. (2017). Sustainable development and geospatial information: a strategic framework for integrating a global policy agenda into national geospatial capabilities. *Geo-Spatial Information Science*, 20(2), 59–76.

Singh, N., Singh, S., Mall, R. K. (2020). Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus. In *Urban Ecology: Emerging Patterns and Social-Ecological Systems* (pp. 317–334). Elsevier. https://doi.org/10.1016/B978-0-12-820730-7.00017-3

Stepanov, I. A., Makarov, I. A. (2022). Greenhouse gas emissions regulation in fossil fuels exporting countries: opportunities and challenges for Russia. *Post-Communist Economies*, 34(7), 916–943.

Sun, Q., Miao, C., Hanel, M., Borthwick, A. G. L., Duan, Q., Ji, D., Li, H. (2019). Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environment International*, pp. 128, 125–136.

Taylor, P. (2008). Climate Watch 08. *Ecos*. Data

Thoma, G., Popp, J., Nutter, D., Shonnard, D., Ulrich, R., Matlock, M., Kim, D. S., Neiderman, Z., Kemper, N., East, C., Adom, F. (2013). Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. International Dairy Journal, 31(1), S3–S14.

Ülker, D., Ergüven, O., Gazioğlu, C. (2018). Socio-economic impacts in a Changing Climate: Case Study Syria. *International Journal of Environment and Geoinformatics,* 5(1), 84-93. https://doi.org/10.30897/ijegeo.406273

Vinet, L., Zhedanov, A. (2011). A "missing" family of classical orthogonal polynomials. *Journal of Physics A: Mathematical and Theoretical*, 44(8), 9–25. https://doi.org/10.1088/1751-8113/44/8/085201

Wang, H., Zhang, R., Liu, M., Bi, J. (2012). The carbon emissions of Chinese cities. *Atmospheric Chemistry and Physics*, 12(14), 6197–6206. https://doi.org/10.5194/acp-12-6197-2012

Wang, K., Li, X., Lyu, X., Dang, D., Dou, H., Li, M., Liu, S., Cao, W. (2022). Optimizing the Land Use and Land Cover Pattern to Increase Its Contribution to Carbon Neutrality. *Remote Sensing*, 14(19), 4751. https://doi.org/10.3390/rs14194751

Wiedmann, T., Minx, J. (2008). A definition of 'carbon footprint.' *Ecological Economics Research Trends*, 1(2008), 1–11.

Yılanci, V., Gorus, M. S., Solarin, S. A. (2022). Convergence in per capita carbon footprint and ecological footprint for G7 countries: Evidence from panel Fourier threshold unit root test. *Energy and Environment*, 33(3), 527–545.

Yoro, K. O., Daramola, M. O. (2020). CO2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture: Methods, Technologies and Applications* (pp. 3–28). Elsevier.

Yue, T., Liu, H., Long, R., Chen, H., Gan, X., Liu, J. (2020). Research trends and hotspots related to global carbon footprint based on bibliometric analysis: 2007–2018. *Environmental Science and Pollution Research*, 27(15), 17671–17691.

Zacharof, N., Tietge, U., Franco, V., Mock, P. (2016). Type approval and real-world CO2 and NOx emissions from EU light commercial vehicles. *Energy Policy*, 97, 540–548.

Zhao, Rongqin, Xianjin Huang, Taiyang Zhong, Jiawen Peng. (2011). Carbon Footprint of Different Industrial Spaces Based on Energy Consumption in China. *Journal of Geographical Sciences*. doi: 10.1007/s11442-011-0845-6.