

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Quantifying Carbon Emissions and Sequestration Potential in Educational Infrastructure: A Case Study from Sindh, Pakistan

Dr. Jam Shahzaib Khan¹, Asim Perwaiz², Syed Kumail Abbas³, Syed Nadeem Haider Kazmi³, Muneer Ahmed⁴, Abid Ali⁵, Anees Ur Rehman Kakar⁶

¹Assistant Professor Quaid e Awam University of Engineering Science and Technology Nawabshah, Sindh Pakistan

²Institute of Environmental Engineering, People's Friendship University of Russia named after Patrice Lumumba

³Institute of Environmental Engineering People's Friendship University of Russia

⁴Department of Civil Engineering, Quaid-e-Awam University of Engineering Science and Technology NawabShah, Sindh

⁵Department of Civil Engineering. Alma mater: Quaid-e-Awam University of Engineering, Sciences and Technology, NawabShah.

⁶Department of Environmental Engineering, People's Friendship University of Russia named after Patrice Lumumba

Corresponding Email: 1032245394@pfur.ru

ABSTRACT

The construction industry is a major source of anthropogenic greenhouse gas emissions, primarily CO₂, released during the building stage from materials and operations. This research quantifies the embodied carbon emissions and the resulting sequestration potential for a specific infrastructure project in a developing region. The case study focuses on a two-storied educational building (41,491 ft² total floor area) located at Quaid e Awam University of Engineering Science & Technology, Nawabshah, Sindh. The study estimated emissions embodied in four structural materials: brick, cement, sand, and steel. Analysis indicated that the educational building emits 35.68 kg CO₂ per square foot through the construction materials required. To offset this environmental impact, a strategic carbon sequestration method was proposed, utilizing free space near the building's surroundings covered by vegetation (trees). The mitigation modeling showed that the rate of CO₂ sequestration is 0.006 kg per square foot. The total estimated annual CO₂ sequestered is 50.778 tons or 101,556 lb (assuming a 5-year-old plant). Based on this sequestration rate, the research concluded that approximately 30 years would be necessary to fully absorb the carbon emitted from the construction materials. The study highlights the environmental burden of traditional construction and underscores the necessity of calculating emissions and sequestration to combat climate change. It recommends adopting vegetation-based carbon reduction strategies and mandating the use of eco-friendly materials before planning any infrastructure, aligning with Sustainable Development Goals (SDGs).

Key Words: Carbon Emission, Carbon Sequestration, Educational Infrastructure,

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Construction Industry, Building Materials, Life Cycle Assessment (LCA)

Introduction:

The global challenge of climate change refers to long-term shifts in temperatures and weather patterns primarily driven by human activities, such as the burning of fossil fuels, which results in the production of heat-trapping gases (Hussain et al., 2019). To prevent dangerous anthropogenic interferences with the climate system, global negotiations have adopted a "guard rail" requiring the drastic and timely reduction of greenhouse gas emissions to limit the average global temperature rise to well below 2 °C compared to preindustrial levels. This ambitious target necessitates comprehensive strategies across all socio-metabolic sectors (Mustafa et al., 2022).

Infrastructures, representing the entirety of the built environment stocks, are fundamentally situated at the nexus of human development and climate change. While infrastructures are critical for satisfying human needs including shelter, energy, and transportation and promoting economic growth, they simultaneously cause anthropogenic greenhouse gas emissions throughout their entire life cycle (Yasin et al., 2024). These emissions occur not only during the direct use phase (which are well-known), but also indirectly during the production, manufacturing, and construction phases, often generated decades prior to service delivery. The construction and building industry is identified as one of seven major sectors that significantly contribute to the increase in greenhouse gas emissions, with buildings globally accounting for approximately 30% of all greenhouse gas emissions annually. Specifically, carbon dioxide (CO₂) is a primary greenhouse gas, and materials such as cement and steel are known to emit large quantities of CO₂ during their production (Ullah et al., 2020). Understanding the full implications of infrastructure development requires addressing the indirect or embodied emissions associated with the stocks of materials and products in use. As shown in Figure 1, developing nations face a disproportionately high emissions burden if they adopt Western infrastructure models using current technologies.

Online ISSN

3007-3197

Print ISSN

3007-3189

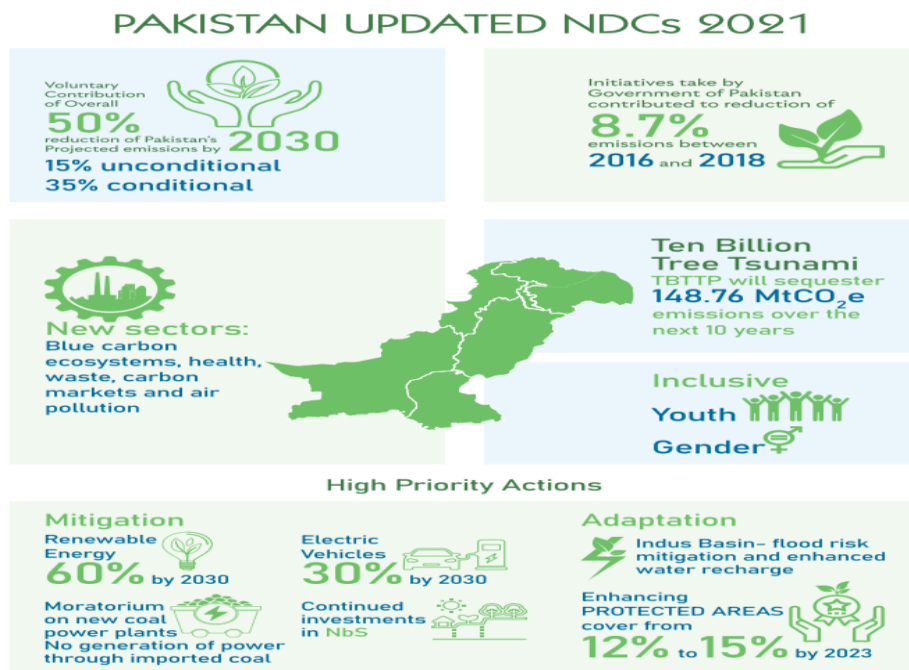
<http://amresearchreview.com/index.php/Journal/about>

Figure 1: Global comparison of per-capita carbon footprints and emissions budget for developing versus industrialized countries.

For developing nations, infrastructure development presents an unprecedented challenge. Industrialized (Annex I) countries generally dispose of large infrastructure stocks, but a globalization of Western infrastructure stocks using current technologies would demand substantial resources from developing countries (Babar et al., 2025). The average per-capita carbon footprint of existing infrastructures in developing countries ($10 (\pm 1)$ t CO₂) is roughly five times smaller than that of industrialized countries ($53 (\pm 6)$ t CO₂). If developing countries were to expand their built environment stocks to the current level of industrialized countries using current technologies, it would require an emissions budget of close to 350 Gt CO₂ from primary materials production. This significant burden would consume between 35% and 60% of the remaining global carbon budget available until 2050 to keep the 2 °C target alive (Ahmed et al., 2011). Therefore, identifying and implementing effective strategies for reducing indirect emissions and achieving service levels with a lower carbon replacement value (CRVP) through options like leapfrogging is crucial.

Against this backdrop, emerging economies, including Pakistan, are increasingly focusing on mitigation strategies. Pakistan has committed to shifting towards 60% renewable energy, achieving 30% electric vehicles by 2030, and expanding nature-based solutions. Within the construction sector, one indispensable method to reduce the concentration of CO₂ in the atmosphere is carbon sequestration, defined as the act of taking in and storing carbon (Malik et al., 2025). This is most commonly achieved through the photosynthesis process in plants, which convert CO₂ into sugar and

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

oxygen, thereby removing it from the atmosphere. Owing to the negative impacts of large amounts of carbon being emitted by infrastructures, carbon sequestration plays a vital role in constructing eco-friendly projects. Global environmental watchdogs are proposing reforestation and preservation of existing biodiversity as key approaches for CO₂ reduction (Masood et al., 2025).

In the regional context of Sindh, Pakistan, while the importance of carbon sequestration is recognized, its application in the construction industry remains largely unpracticed. Calculating both carbon emissions and sequestration potential accurately is identified as a critical yet challenging task that can help prevent ecocide. To address the strong relationship between carbon emission and the deterioration of the global climate, localized assessment and implementation strategies are necessary (Haider et al., 2025). This research aims to quantify the carbon emissions and sequestration potential of educational infrastructure within this critical regional context. The primary objective is to evaluate and understand the calculation of carbon emissions attributable to infrastructure and subsequently calculate the carbon sequestration achievable through provided green areas (Zeeshan et al., 2022). Using a critical literature review and established calculation methodologies, this study estimates the carbon emissions associated with an educational building at the design stage in Quaid-e-Awam University of Engineering, Sciences & Technology (QUEST), Nawabshah, Sindh, Pakistan. By focusing specifically on the construction phase of the building's life cycle and the major structural materials (brick, cement, and steel), this work seeks to analyze and propose estimated carbon emission sequestration potential, offering valuable data to support the use of eco-friendly material selection and carbon reduction strategies in future infrastructure planning in line with Sustainable Development Goals (SDGs) (Herth et al., 2023). Figure 2 outlines the Sustainable Development Goals linked to reducing carbon emissions in construction and promoting sustainable practices.



Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Figure No: 2 Sustainable Development Goals (SDGs) relevant to carbon emission reduction and eco-friendly infrastructure.

As illustrated in Figure 3, the study aims to quantify carbon emissions and evaluate the sequestration potential of green spaces in educational buildings.



Figure No: 3 Research aim and objectives focusing on carbon emission quantification and sequestration in educational infrastructure.

Aim of Research

The aim of this research is to identify the carbon emission factors which affect the environment, to sequester carbon which causes severity affect to environment.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Objectives

To evaluate & understand calculation of carbon emission of the infrastructure using critical literature review.

To calculate carbon sequestration by green area provided.

To analyze and propose estimated carbon emission sequestration.

Literature review

Infrastructure, defined as the entirety of built environment stocks, is situated at the critical juncture of human development and climate change. While vital for economic growth and satisfying fundamental human needs such as shelter and transportation, infrastructure development simultaneously leads to anthropogenic greenhouse gas (GHG) emissions across the entire socio-metabolic system (Muller et al., 2013). These emissions occur throughout the infrastructure life cycle, including the construction phase (indirect emissions), the use phase (direct emissions), and the end-of-life phase. The long service lifetimes of infrastructures mean they significantly determine how a society's carbon emissions change over time. The construction and building industry is one of the seven major sectors that contribute substantially to rising GHG emissions. Globally, buildings account for approximately 30% of all annual GHG emissions. Carbon dioxide (CO₂) is a primary GHG, with materials such as cement and steel contributing significantly to CO₂ emissions during their production (Klein-Banai et al., 2013). It is recognized that essential socio-metabolic linkages between infrastructure and material-producing sectors are often omitted when models only consider infrastructure stocks as energy users, highlighting a gap in studies addressing emissions embodied in the stocks of materials and products in use. Figure 4 demonstrates the interconnected stages of the infrastructure life cycle contributing to embodied carbon emissions.



Figure No: 4 Conceptual framework of embodied carbon emissions within the infrastructure life cycle.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

A foundational step toward understanding the full implications of infrastructure development and emissions abatement is the quantification of these indirect or embodied emissions. Due to the historical nature of infrastructure development, the allocation of a carbon footprint to mixed-age stocks is non-trivial. This research employs the concept of Carbon Replacement Value (CRV), specifically CRVP2008, which reflects the estimated greenhouse gas emissions released if the existing stock were replaced using current standard technologies based on primary production (Kavehei et al., 2018). In 2008, the CRVP was estimated using three key materials steel, cement, and aluminum which collectively accounted for nearly half of industrial emissions: 25% from steel, 19% from cement, and 3% from aluminum, contributing 17% of total energy- and process-related CO₂ emissions. As presented in Figure 5, industrialized countries exhibit a per-capita infrastructure carbon footprint nearly five times greater than developing nations.

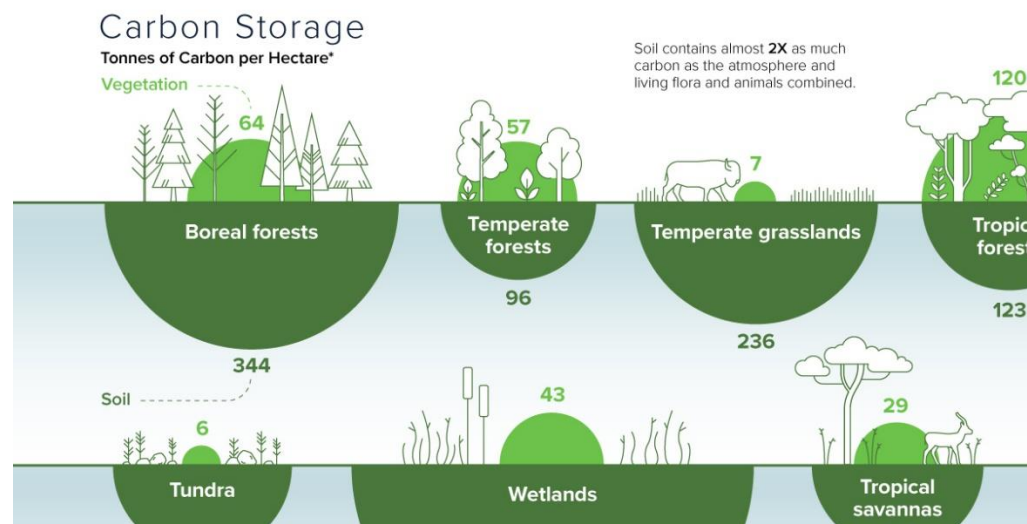


Figure 5: Global infrastructure carbon footprint and disparities between industrialized and developing countries.

Global assessment of infrastructure stocks reveals a significant disparity between industrialized and developing countries. The estimated carbon footprint of the existing global infrastructure stock in 2008 was 122 Gt CO₂ (Horan et al., 2019). However, the average per-capita carbon footprint of infrastructures in industrialized (Annex I) countries (53 t CO₂) was found to be approximately five times greater than that of developing (non-Annex I) countries (10 t CO₂). If developing countries were to expand their built environment stocks to the current levels of industrialized countries using existing technologies, this expansion would require an emissions budget of approximately 350 Gt CO₂ from primary materials production (Gharibi et al., 2024). This amount represents a massive burden, consuming between 35% and 60% of the remaining global carbon budget available until 2050 to keep the 2 °C warming limit alive, thus calling into question how the 2 °C target can be reconciled with the principle of equity regarding infrastructure services.

Given these constraints, strategies for reducing the CRVP of future infrastructures are essential. Such strategies can be decomposed into two main approaches: (i) reducing

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

the emission intensity of materials (F/M), and (ii) reducing the material stock per service unit (M/S). Efforts to reduce emission intensity through energy efficiency improvements are often limited (e.g., approximately 12% for aluminum, 13% for cement, and 24% for steel) (Yañez et al., 2019). More substantial reductions often require carbon capture and storage (CCS) or widespread use of less carbon-intensive energy, the latter of which is restricted by costs or land commitments. Therefore, decoupling material use from services (M/S) becomes a particularly important strategy. This can involve weight reduction at the product level (e.g., light weighting in buildings) or optimization at the urban system level. Evidence suggests that higher urban density tends to correlate with lower per-capita network length for services like water, wastewater, and road networks, indicating potentially smaller per-capita stocks and lower CRVPs (Valls-Val et al., 2021). The need to build up infrastructure stocks provides developing countries with opportunities for leapfrogging achieving high standards of living with a lower CRVP through innovative production technologies and urban planning.

Complementing emission reduction efforts is carbon sequestration, defined as the act of taking in and storing carbon to reduce atmospheric CO₂ concentration (Jain et al., 2017). This process is vital for constructing eco-friendly projects, given the negative impacts of large carbon emissions from infrastructures. The most common natural method of sequestration is photosynthesis in plants, which converts CO₂ into oxygen and sugar, removing it from the atmosphere. Global watchdogs advocate for reforestation and preservation of existing biodiversity as key approaches for CO₂ reduction. Within the construction sector, calculating both carbon emission and sequestration is a challenging but necessary task to prevent ecocide. Previous research on residential buildings has demonstrated that replacing primary components like cement and mortar with materials such as fly-ash can result in a significant decrease (around 45%) in total embodied CO₂ (Rani et al., 2025). Furthermore, studies focusing on carbon sequestration detail the methodological approach for calculation, including determining the total green weight of vegetation, dry weight, carbon content (typically 50% of entire volume), and converting carbon weight to CO₂ sequestered using the ratio of 3.667.

In the context of Pakistan, carbon sequestration is an important concept, yet its practice in the construction industry within Sindh remains largely unpracticed (Keyhani et al., 2023). Recognizing the strong relationship between carbon emission and global climate deterioration, this study builds upon established methodologies previously utilized in similar regional research on infrastructure (Sudhakar et al., 2025). The current work focuses on quantifying the carbon emissions associated with the construction phase of an educational building, specifically targeting major structural materials brick, cement, and steel at the design stage in Quaid-e-Awam University of Engineering, Sciences & Technology (QUEST), Nawabshah, Sindh, Pakistan. By providing a localized case study, this research contributes to the necessary evaluation and understanding of both carbon emission calculation and the potential for carbon sequestration via green areas surrounding infrastructure (Perwaiz et al., 2025).

METHODOLOGY

In this piece of work, carbon emissions and carbon sequestration in an educational building are estimated. The study of life cycle CO₂ emissions and sequestration has been done considering a project site in Nawabshah Sindh, Pakistan and anatomizing only the construction phases of the life cycle of building. The research article is elucidated using four methods. Figure 6 illustrates the research methodology used to estimate both carbon emissions and sequestration potential for the educational building project.

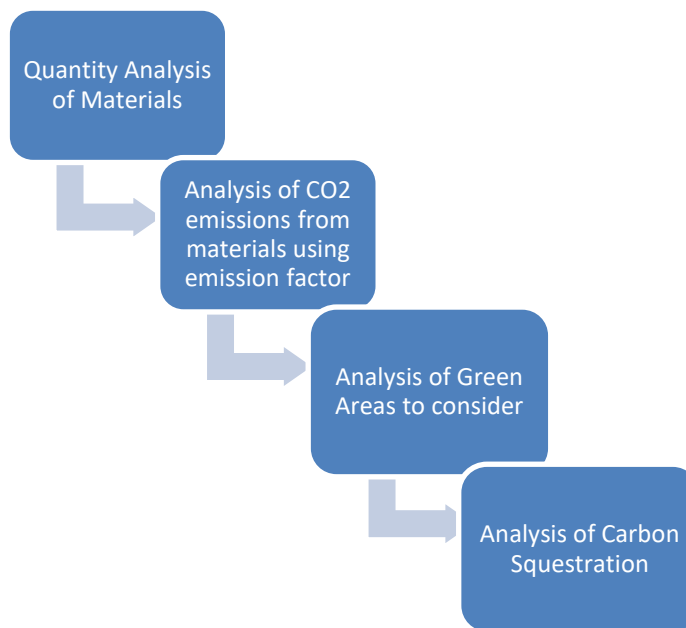


Figure 6: Methodological flowchart for quantifying carbon emissions and sequestration potential in the case study.

To make the study easier, only the superstructure of the building is deemed. As depicted in Figure 7, the educational building's floor plan formed the basis for calculating material quantities and corresponding carbon emissions.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

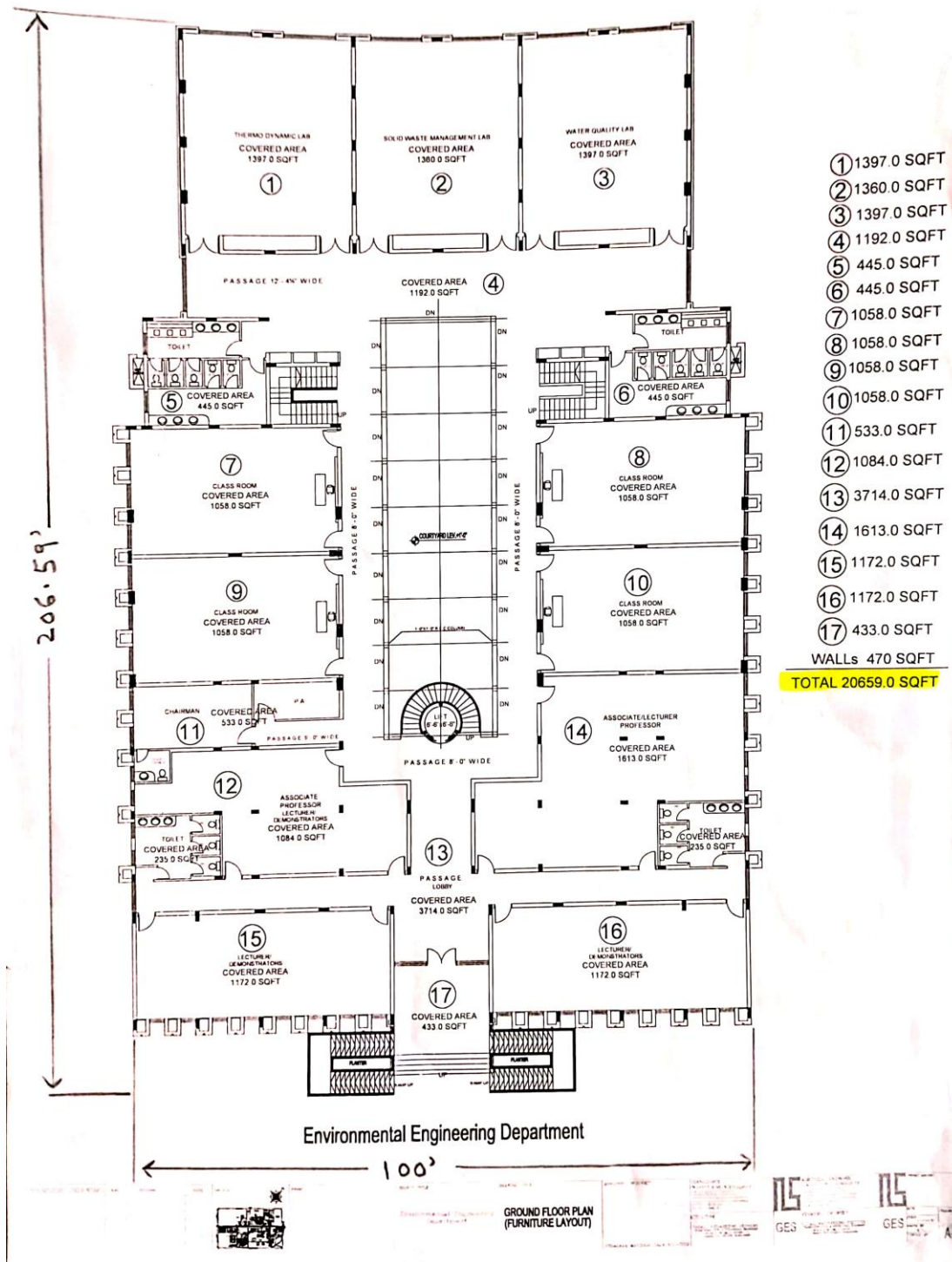


Figure 7: Architectural floor plan of the two-story educational building analyzed in the study.

The structure is proposed to be made of structural elements such as columns and beams,

with a typical storey height of 12 feet. The major structural material for columns and beams, floors, roof slabs is concrete, with a compressive strength of 4 ksi and 3 ksi, respectively, and yield strength of 60 ksi. The slabs have a thickness of 6 inches. The design procedures of building have been followed according to Building Code of Pakistan (BCP-2021). An estimation of reinforcing quantity is indispensable for total carbon emissions. The steel bars have rounded shape. The estimated amounts of reinforcement and their sizes used in the construction work are shown in Table 2. The proportions of concrete for the beams, footing and slab are 1:2:4 and for column is 1:1.5:3. The estimated different materials quantity is listed in Table 1.

Table 1: Estimated Quantities of Construction Materials Used in the Educational Building

Name of the Materials	Unit	Quantity
Steel	Kg	190162.3234
	Ft ³	855.59
Cement	Bag	8605
	Ft ³	10549.73
Sand	Ft ³	23638.9533
Brick	Nos.	545804
	Ft ³	38206.28

The CO₂ emissions for three of the most commonly used building materials, namely cement, steel and brick, have been estimated. The more the strength of concrete, the more will be the emissions. The CO₂ emission factor is given in below table 2. Different materials' emission factors are multiplied by their unit weight or density.

Table 2: Modified CO₂ Emission Factors for Building Materials

Name of the materials	Emission factor (CO ₂ kg/t) (source: ref: 13)	Material reference density (kg/ft ³)	Emission factor (changed) (kg/ft ³)
Steel	2.208	222.285	490.806
Cement	1.5	40.776	61.164
Brick	0.2	54.368	10.874

Green Portion Area of the Building

This project adhered to the BCP. For the sequestration of the carbon emissions of the

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

building materials, green portion area should include 9% of its length and 7% of its width. Calculation of green area is given in table 3 below.

Table 3: Calculation of Green Area for Carbon Sequestration

Length of building	Width of building	9% of length	7% of width	Calculated Green area
206.59 ft	100 ft	18.5 ft	7 ft	4909 ft ²

Table 4: Summary of Tree Characteristics and Total Weight for Carbon Sequestration

Type	Diameter (in)	Height (ft)	No. of tree	Weight (lb)
Ground	7	12	50	7350

The diameter and height of the tree are deemed for determination (Table 4). The amount of carbon sequestration is determined by the tree's growth and the density of the wood. It is at peak in the early phases of tree development .

CO₂ Sequestration for Building

Owing to the limited green space around the building, a minimal value was used to determine the carbon sequestration by plants. The procedure that follows is being considered to determine the carbon sequestration by trees is indicated in Table 5.

Table 5: Procedure and References for Calculating Carbon Sequestration by Trees

Content	Calculation process	References
1. Calculation of the tree's overall (green) mass	$W = 0.25 D^2 H$ (where, $D < 11$) $W = 0.15 D^2 H$ (where, $D \geq 11$) Here, W= The tree's weight above ground in pounds; D= The trunk's diameter in inches; H= The tree's height in feet.	(National Academies of Sciences, 2019)
2. Calculation of the tree's dry weight	The weight of the tree by 72.5 % percent to get the dry weight.	(Serra-Maluquer et al., 2021)
3. Calculation of the carbon content of the tree	The typical carbon content of a tree is around 50 percent of its entire volume.	(Karmakar et al., 2021)

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

4. Calculation of amount of CO ₂ sequestered by the tree	CO ₂ to C ratio is 3.667. Multiply the weight of carbon in the tree by 3.667 to get the weight of carbon dioxide stored in the tree.	(Ktenioudk et al., 2021)
---	---	--------------------------

RESULTS

After analyzing all the major materials that contribute to carbon emissions significantly, the carbon emissions of concerned materials were calculated and are shown in Table 6.

Table 6: Calculated CO₂ Emissions from Major Construction Materials

Name of the materials	CO ₂ Emission factor (kg/ft ³)	Quantity (ft ³)	CO ₂ emission (ton)
Steel	222.285	855.59	419.92
Cement	40.776	10549.73	645.26
Brick	54.368	38206.28	415.45
Total emission			1480.63

Total floor area is 41491 ft². So, CO₂ emission of a building is 0.0356 ton or 35.68 kg

Total Emission							
Material	Emission Factor	density	Changed	Quantity		Emission	Changed EF*Quantity
	kg/t	kg/ft ³	kg/ft ³				
Steel	2.208	222.285	490.806	855.59		419.9	
Cement	1.5	40.776	61.164	10549.73		645.3	
Brick	0.2	54.368	10.874	38206.28		415.5	
					Total Emission	1480.6	

per sq. ft. Total CO₂ sequestered in the tree per year is 101556 lb, or 50.778 ton (considering 5 years old plant). So, the rate of CO₂ sequestration of a building is 12.23 lb or 0.006 kg per sq. ft.

Table 7: Summary of Total CO₂ Emissions and Sequestration in the Educational Building

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Parameters	Amount (lb)
Total green weight (roots included)	8432.44
Total dry weight	6113.5
Total carbon weight	138474
Total CO2 sequestered in the tree	507784.15

Table 8: Summary of Tree-Based Carbon Sequestration and Annual Sequestration Rate

Sequestration		
	No; of trees	50
	Tree's dia (inches)	7
	Tree's height (ft)	12
	Tree Weight (lb) $W = 0.25(d*d)*H$	7350
	Total weight including roots	8432
	Total Dry Weight (72.5% of total weight)	6113.2
	Total Carbon Weight(50% of entire volume)	138474
	volume of trees $(3.14/4*d*d*h)$	276948
	Total CO2 Sequestered $3.667*carbon\ weight\ (lb)$	507784.2
	CO2 Sequestered per year (lb)	101556.8
	Rate of Sequestration (lb per sq.ft)	12.24
	Total floor area (ft ²)	41491

The following graph shows the correlation between carbon emission and carbon sequestration of the building.

Number of Year

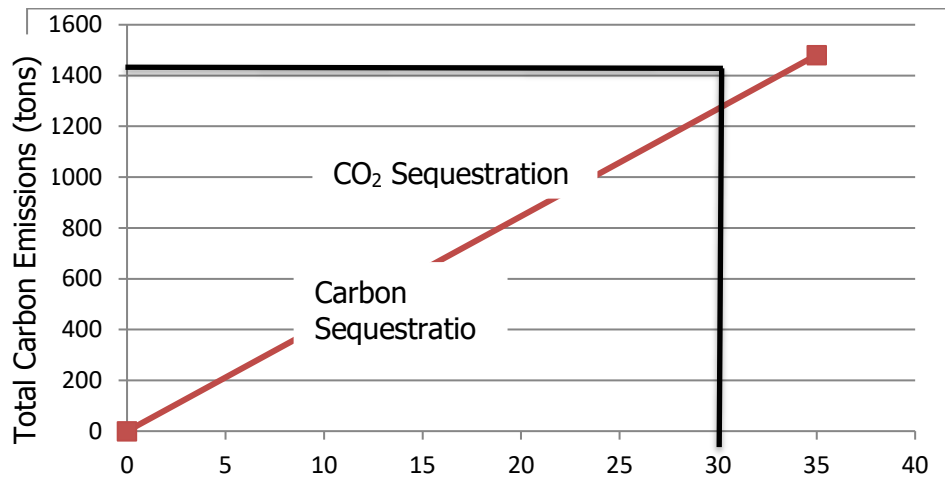
Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>



Graph 1:

With this green area, carbon sequestration will require 30 years to sequester the emitted amount of carbon.

Discussion:

The findings of this case study quantify the carbon footprint associated with constructing educational infrastructure in the regional context of Sindh, Pakistan, revealing both the substantial environmental burden of traditional construction materials and the limitations of current localized mitigation efforts. The estimated total carbon emissions for the two-story educational building analyzed reached 1480.6 tons of CO₂, translating to a burden of 35.68 kg CO₂ per square foot. The calculation focused on the upstream production of major structural materials steel, cement, and brick (Ivanova et al., 2020). Cement was the largest contributor to these embodied emissions (645.26 tons), followed by steel (419.92 tons) and brick (415.45 tons). This aligns with global research noting that the construction and building industry is a major sector contributing to the rise in greenhouse gas emissions and that the largest source of emissions in the construction life cycle occurs during the upstream phase in the material manufacturing industry, particularly from materials like cement and steel (Alelweet et al., 2025).

The necessity of calculating indirect or embodied emissions is fundamental, especially for developing countries, to estimate future emissions accurately. The concept of the Carbon Replacement Value (CRVP), which measures the emissions required to replace existing infrastructure stocks using current technologies based on primary production, provides a critical benchmark for interpreting these results (Wu et al., 2025). Compared to industrialized countries, developing countries have a per-capita carbon footprint roughly five times smaller (10 t CO₂ vs. 53 t CO₂). However, if developing countries were to expand their built environment stocks to match current Western levels using present technologies, an enormous emissions budget of approximately 350 Gt CO₂ would be required from primary materials production. This significant burden would consume between 35% and 60% of the remaining global carbon budget allocated to

maintain the 2 °C limit until 2050, bringing into sharp focus the challenge of reconciling the 2 °C target with the principle of equity regarding infrastructure services (Dhakal et al., 2010).

To address the localized emissions identified, the research evaluated carbon sequestration, an indispensable method for reducing atmospheric CO₂ concentration, achieved most commonly through reforestation. The study's proposed mitigation strategy, based on the green area calculation (4909 ft²) and 50 trees planted, resulted in a sequestration rate of 0.006 kg CO₂ per square foot. The total sequestration was estimated at 50.778 tons per year. Although this demonstrates a positive mitigation effect, the correlation analysis showed that at this rate, it would take approximately 30 years for the vegetation to absorb the embodied carbon emissions generated during the construction materials' production (Hignite et al., 2009). The minimal sequestration value observed is attributed to the limited green space around the building. This highlights the gap in practical application within regions like Sindh, where carbon sequestration in the construction industry remains largely unpracticed. The findings underscore the urgency of adopting the recommendation made by global environmental watchdogs to utilize reforestation and preservation of existing biodiversity as a key approach for CO₂ reduction (Clabeaux et al., 2020).

Therefore, achieving a high standard of infrastructure service while maintaining climate goals necessitates strategies beyond relying solely on sequestration from limited green spaces. Mitigation options must focus on reducing the Carbon Replacement Value (CRVP) by reducing the emission intensity of materials (F/M) or reducing the material stock per service unit (M/S). Developing countries have the opportunity for leapfrogging to achieve high standards of living with a lower CRVP through innovative production technologies and urban design (Rotz et al., 2018). The literature supports that replacing high-emission materials, such as cement and mortar, with alternatives like fly-ash or blast furnace slag, can lead to substantial reductions (around 45%) in total embodied CO₂. This material efficiency approach, coupled with strategic urban planning that reduces material demand per service unit (M/S) through design choices such as higher urban density, offers a path forward. The results of this study directly support the recommendation to use eco-friendly materials to combat greenhouse gas emissions before planning any infrastructure, aligning infrastructure development in regions like Sindh with broader Sustainable Development Goals (SDGs) (Singh et al., 2023).

Conclusion:

Based on the comprehensive analysis of embodied emissions and sequestration potential within the case study of educational infrastructure in Sindh, Pakistan, the following conclusions are drawn: The construction phase of the educational building generates a substantial carbon emission burden, primarily driven by the use of conventional high-emission materials. The estimated total carbon emissions for the two-story educational building analysed reached 1480.6 tons of CO₂. This translates to a significant environmental impact of 35.68 kg CO₂ per square foot of the building area. Cement, steel, and brick were the primary sources of these embodied emissions. Specifically, cement accounted for the largest share of emissions (645.26 tons),

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

followed by steel (419.92 tons) and brick (415.45 tons). This finding reinforces the global understanding that the construction and building industry is a major contributor to greenhouse gas emissions, particularly during the upstream production of materials such as cement and steel. The reliance on limited green space surrounding the building, utilizing 50 trees across an estimated green area of 4909 ft², yields a minimal rate of carbon sequestration. The sequestration rate of the building is calculated at 0.006 kg CO₂ per square foot, with a total sequestration capacity of 50.778 tons per year. At the identified rate of sequestration, the analysis concludes that it would require approximately 30 years for the vegetation to absorb the embodied carbon emissions generated by the construction materials. This gap emphasizes that current practices involving limited green areas are insufficient to offset the immediate and substantial indirect emissions of infrastructure development. In the broader context, the challenge faced in Sindh, Pakistan, mirrors the global dilemma of reconciling infrastructure development with ambitious climate change mitigation targets. While industrialized (Annex I) countries hold a significantly larger per-capita infrastructure carbon footprint (53 t CO₂) compared to developing (non-Annex I) countries (10 t CO₂), the current trajectory for developing countries seeking to match Western service levels using existing technologies would consume between 35% and 60% of the remaining global carbon budget available until 2050 to keep the 2 °C guard rail intact. Therefore, the study strongly suggests that future infrastructure planning in regions like Sindh must incorporate proactive mitigation strategies focused on reducing the Carbon Replacement Value (CRV) rather than solely relying on post-construction sequestration. This includes adopting alternative, eco-friendly materials to fight greenhouse gas emissions before planning any infrastructure, thereby embracing the opportunity for leapfrogging achieving high service standards with a lower CRVP. Such strategic interventions are crucial for aligning development in Pakistan with broader Sustainable Development Goals (SDGs) and ensuring a fair and effective participation in the post-Kyoto climate change policy architecture.

References

- Ahmed, V., Malik, A. A. K., Ramay, S., Munawwar, Z., & Pervaiz, A. (2011). National economic and environmental development study: the case of Pakistan.
- Alleweert, O. (2025). Carbon Footprint Assessment Initiative and Trees Role in Reducing Emissions. *Advances in Environmental and Engineering Research*, 6(1), 1-5.
- Babar, A. H. K., Ali, Y., & Gohar, A. (2025, February). Economic and environmental impact of green infrastructures on developing economies: Pakistan a case in point. In *Natural Resources Forum* (Vol. 49, No. 1, pp. 776-799). Oxford, UK: Blackwell Publishing Ltd.
- Clabeaux, R., Carbajales-Dale, M., Ladner, D., & Walker, T. (2020). Assessing the carbon footprint of a university campus using a life cycle assessment approach. *Journal of Cleaner Production*, 273, 122600.
- Dhakal, S. (2010). GHG emissions from urbanization and opportunities for urban carbon mitigation. *Current Opinion in Environmental Sustainability*, 2(4), 277-283.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

- Gharibi, S., & Shayesteh, K. (2024). Quantifying and mapping the supply-demand for carbon sequestration by urban green infrastructures: Evidence from Hamadan Urban Area, Iran. *Environment, Development and Sustainability*, 1-23.
- Haider, S., Masood, M. U., Awan, A. A., Khan, R. Z. N., & Rashid, M. (2025). Adaptation, and Sustainable Development in Sindh, Pakistan. *Remote Sensing and GIS Application in Forest Conservation Planning*, 391.
- Herth, A., & Blok, K. (2023). Quantifying universities' direct and indirect carbon emissions—the case of Delft University of Technology. *International Journal of Sustainability in Higher Education*, 24(9), 21-52.
- Hignite, K. (2009). *The Educational Facilities Professional's Practical Guide to Reducing the Campus Carbon Footprint*. APPA: Association of Higher Education Facilities Officers. 1643 Prince Street, Alexandria, VA 22314-2818.
- Horan, W., Shawe, R., Moles, R., & O'Regan, B. (2019). Development and evaluation of a method to estimate the potential of decarbonisation technologies deployment at higher education campuses. *Sustainable Cities and Society*, 47, 101464.
- Hussain, M., Butt, A. R., Uzma, F., Ahmed, R., Islam, T., & Yousaf, B. (2019). A comprehensive review of sectorial contribution towards greenhouse gas emissions and progress in carbon capture and storage in Pakistan. *Greenhouse Gases: Science and Technology*, 9(4), 617-636.
- Ivanova, D., Barrett, J., Wiedenhofer, D., Macura, B., Callaghan, M., & Creutzig, F. (2020). Quantifying the potential for climate change mitigation of consumption options. *Environmental Research Letters*, 15(9), 093001.
- Jain, S., Agarwal, A., Jani, V., Singhal, S., Sharma, P., & Jalan, R. (2017). Assessment of carbon neutrality and sustainability in educational campuses (CaNSEC): A general framework. *Ecological Indicators*, 76, 131-143.
- Karmakar, D., Deb, K., & Padhy, P. K. (2021). Ecophysiological responses of tree species due to air pollution for biomonitoring of environmental health in urban area. *Urban Climate*, 35, 100741.
- Kavehei, E., Jenkins, G. A., Adame, M. F., & Lemckert, C. (2018). Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure. *Renewable and Sustainable Energy Reviews*, 94, 1179-1191.
- Keyhani, M., Bahadori-Jahromi, A., Mylona, A., Janbey, A., Godfrey, P. B., & Taşeli, B. (2023). Measuring and Mitigating Embodied Carbon in Educational buildings: A case study in the UK. *Engineering Future Sustainability*, 1(2).
- Klein-Banai, C., & Theis, T. L. (2013). Quantitative analysis of factors affecting greenhouse gas emissions at institutions of higher education. *Journal of Cleaner Production*, 48, 29-38.
- Ktenioudaki, A., O'Donnell, C. P., Emond, J. P., & do Nascimento Nunes, M. C. (2021). Blueberry supply chain: Critical steps impacting fruit quality and application of a boosted regression tree model to predict weight loss. *Postharvest Biology and Technology*, 179, 111590.
- Malik, A., & Raza, U. (2025). Engineering Design for Carbon Capture and Storage (CCS) Systems: A Multidisciplinary Perspective from Pakistan. *Software Engineering and Artificial Intelligence Systems*, 1(02), 65-76.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

- Masood, M., He, C., Shah, S. A., & Rehman, S. A. U. (2024). Land use change impacts over the Indus delta: A case study of Sindh province, Pakistan. *Land*, 13(7), 1080.
- Muller, D. B., Liu, G., Løvik, A. N., Modaresi, R., Pauliuk, S., Steinhoff, F. S., & Brattebø, H. (2013). Carbon emissions of infrastructure development. *Environmental Science & Technology*, 47(20), 11739-11746.
- Mustafa, A., Kazmi, M., Khan, H. R., Qazi, S. A., & Lodi, S. H. (2022). Towards a carbon neutral and sustainable campus: Case study of NED University of Engineering and Technology. *Sustainability*, 14(2), 794.
- National Academies of Sciences, Medicine, Division on Earth, Ocean Studies Board, Board on Chemical Sciences, Board on Earth Sciences, & Reliable Sequestration. (2019). Negative emissions technologies and reliable sequestration: A research agenda.
- Perwaiz, A., Ali, M., Abbas, S. K., Kakar, A. U. R., & Zardari, A. (2025). Numerical Analysis of slope stability and Settlement of local road Embankment Constructed with clay and Municipal Solid Waste. *Annual Methodological Archive Research Review*, 3(10), 463-480.
- Rani, M., Acharya, P., & Vyas, B. (2025). Assessing per capita carbon footprint in university campus: methodology and strategy implications for emissions reduction. *Sādhanā*, 50(4), 237.
- Rotz, C. A. (2018). Modeling greenhouse gas emissions from dairy farms. *Journal of Dairy Science*, 101(7), 6675-6690.
- Serra-Maluquer, X., Granda, E., Camarero, J. J., Vilà-Cabrera, A., Jump, A. S., Sánchez-Salguero, R., & Gazol, A. (2021). Impacts of recurrent dry and wet years alter long-term tree growth trajectories. *Journal of Ecology*, 109(3), 1561-1574.
- Singh, A. K., Singh, J. S., Singh, H., & Mishra, R. K. (2023). Quantifying carbon Stock and tree species diversity of green infrastructure of Varanasi, India. *INTERNATIONAL JOURNAL OF PLANT AND ENVIRONMENT*, 9(01), 15-23.
- Sudhakar, H. (2025). Sustainability education: cultivating environmental awareness and action through campus carbon sequestration studies. *International Journal of Sustainability in Higher Education*.
- Ullah, I., Islam-ud-Din, Habiba, U., Noreen, U., & Hussain, M. (2020). Carbon footprint as an environmental sustainability indicator for a higher education institution. *International Journal of Global Warming*, 20(4), 277-298.
- Valls-Val, K., & Bovea, M. D. (2021). Carbon footprint in Higher Education Institutions: a literature review and prospects for future research. *Clean technologies and environmental policy*, 23(9), 2523-2542.
- Wu, J. (2025). Cities that breathe: Quantifying carbon emission reductions through forest city designation. *Forest Policy and Economics*, 178, 103541.
- Yañez, P., Sinha, A., & Vásquez, M. (2019). Carbon footprint estimation in a university campus: Evaluation and insights. *Sustainability*, 12(1), 181.
- Yasin, G., Shoaib, M., Nawaz, M. F., Aziz, S., Azhar, M. F., Imtiaz, M. T., & Gul, S. (2024). Assessing the role of public institutions in carbon sequestration through woody vegetation under arid conditions: a case study of Bahauddin Zakriya University, Multan, Pakistan. *Pak. J. Bot*, 56(5), 1831-1840.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

Zeeshan, M., & Iqbal, N. (2022). Sustainable Solutions to Climate Challenges: The Role of Innovation in Pakistan. *Journal of Energy and Environmental Policy Options*, 5(2), 39-45.