International Journal of Research in Engineering, Science and Management
Volume 9, Issue 4, April 2026
www.ijresm.com | E-ISSN: 2581-5792 | RESAIM Publishing | www.resaim.com

Rubberised Concrete as a Climate-Mitigation Strategy: Integrating AI Prediction and Atmospheric Dispersion Modelling to Assess Urban Air-Quality Impacts

Dominic Wambugu Mwaniki*
CE, FIEK, PMP, Consultant and Senior Infrastructure Engineer, Kenya Power and Lighting Company (KPLC), Nairobi, Kenya

Abstract*: Cement production is responsible for about 7-8% of global carbon dioxide (CO_2) emissions; while over 1-1.6 billion tyres come to the end of their life every year. This study examines the environmental aspects of using pulverised waste tyre rubber (PWTR) as part of a concrete mix. An integrated modelling framework between global estimation of the concrete demand, the tyre utilisation modelling, the carbon footprint modelling, the atmospheric dispersion modelling, and Support Vector Machine (SVM) prediction has been established. Results show that when small percentages of the cement and sand are replaced with PWTR the compressive strength is preserved at around 24 MPa with the CO_2 emissions reduced by about 9.59 kg CO_2 per m^3 of concrete. In the example of a 777.5 km infrastructure trench project, the results of this analysis estimate a recycling of about 5.3 million tyres, a saving of 4 353.76 metric tons of CO_2 and saving of 473.79 TJ of energy. Long-term simulations reveal cumulative global CO_2 savings under adoption scenarios resulting in measurable reductions in projected global temperature increase. These results show that rubberised concrete can play its role in the utilisation of waste tyres and mitigation of emissions in infrastructure construction.

***Keywords*: Rubberized concrete, air quality modelling, sustainable construction, machine learning, atmospheric dispersion, waste tyre recycling.**

1. Introduction

Concrete remains the most used construction material in the world, thanks to its high compressive strength, robustness and versatility of infrastructures development [8]-[11]. Cement production is extremely energy-intensive and a major source of greenhouse gases; cement production generates about 0.93 kg of carbon dioxide (CO_2) per kg of cement; therefore, cement production is a major contributor to environmental pollution [7].

The rapid growth of the global automobile industry has led to an unprecedented increase in end-of-life tyres (ELTs), creating a major waste management challenge worldwide, as indicated in Fig. 1. Recent estimates indicate that approximately 1–1.6 billion tyres reach the end of their service life each year, corresponding to nearly 17–30 million tonnes of waste rubber globally [4], [17]. The accumulation of these tyres has resulted in more than four billion tyres currently stockpiled or disposed of in landfills around the world [3].

Fig. 1. Photo gallery of World's biggest tire graveyard in Kuwait [1]

Improper disposal practices such as open burning and uncontrolled dumping release significant quantities of hazardous pollutants including particulate matter (PM), sulphur oxides (SO_x), nitrogen oxides (NO_x), and polycyclic aromatic hydrocarbons, which pose severe environmental and public health risks [4]. Studies indicate that nearly 75% of waste tyres are still disposed of in landfills in many regions, highlighting the urgent need for sustainable waste utilisation pathways [6].

Rubberised concrete utilizes a percentage of natural aggregates or cement with recycled rubber particles of old tyres. Empirical studies indicate that even modest percentages of substitution are capable of sustaining acceptable mechanical functionality as well as enhancing sustainability metrics. As experimentation reveals, replacement ratios of approximately 2-3% cement and 3-4% sand produce optimum compressive strengths of approximately 24 Mpa, and at the same time, improve durability and flexibility.

Despite some promising results in the realm of materials engineering, not much research has focused on how the use of

---

*Corresponding author: otienomoses42@gmail.com

rubberised concrete affects more global environmental factors such as urban air quality and carbon emissions. Consequently, a multidisciplinary approach combining materials engineering, atmospheric modelling and artificial intelligence is presented for the evaluation of environmental impacts of rubberised concrete adoption.

2. Theoretical Framework

Waste tyre management remains a major environmental concern worldwide. About 1 billion tyres reach end-of-life each year, and projects that by 2030 around 5 billion more tyres could be discarded annually, while only a small fraction is actually recycled [16]. Millions of tyres are still stockpiled, buried, or landfilled, intensifying pressure on waste systems [12].

Recent research has explored the use of crumb or pulverized rubber as a partial replacement for sand and, in some cases, cement in concrete mixtures [10]. Mwaniki *et al.* [11] study reports an experimentally bounded design space of 0–7% cement replacement and 0–11% sand replacement, with compressive strengths spanning 10–25 MPa and flexural strengths spanning 1.5–3 MPa. It further shows that the predicted optimal mix achieved a compressive strength of 24.9960 MPa and a flexural strength of 3.0048 MPa, indicating that low-dose rubber substitution can preserve structural performance while advancing sustainability goals. Mwaniki [10] notes that 5% and 10% rubber replacement levels can maintain acceptable compressive strength, whereas 15% replacement causes marked declines, highlighting the importance of identifying an optimum threshold rather than maximizing rubber content indiscriminately.

Mwaniki [11] study shows that the model can predict concrete performance with practical accuracy, reporting a compressive-strength MAE of 1.6927 MPa and RMSE of 1.8395 MPa, while the flexural-strength model performs even better with MAE of 0.1284 MPa, MSE of 0.0184 MPa ^{2}, and RMSE of 0.1358 MPa. These results show that SVM regression is capable of capturing the nonlinear relationship between rubber replacement ratios and concrete performance, making it suitable for screening sustainable mix designs before full laboratory validation.

Rubberized concrete shows measurable environmental and economic benefits. Mwaniki *et al.* [9] study reports that the PWTR-modified trench concrete reduced cost from 5000 Ksh/m ^{3} to 4200 Ksh/m ^{3}, equivalent to a 16% cost saving, while maintaining compressive strength close to conventional concrete at 24 MPa versus 25 MPa. Cement production is also estimated to emits about 0.93 kg CO $_2$ per kg of cement, and estimates that the rubberized mix reduces emissions by 9.59 kg CO $_2$ per m ^{3} of concrete. For the modeled 777.5 km cable-trench project, Mwaniki *et al.* [10] estimate a total saving of 4,353.76 metric tons of CO $_2$, diversion of about 5.3 million waste tyres from landfill, and 473.79 TJ of energy savings. These findings strongly support the argument that rubberized concrete is not only a materials innovation but also a credible pathway for circular-economy practice, embodied-carbon reduction, and landfill diversion. What remains less developed in the current literature, is the explicit coupling of these materials decisions to urban air-quality outcomes and climate-mitigation trajectories, which is precisely the gap your paper is addressing.

3. Methodology

This study develops an integrated modelling framework that combines materials engineering, environmental modelling, and artificial intelligence to evaluate the sustainability potential of rubberised concrete in reducing carbon emissions and improving urban air quality. The framework integrates five interconnected modelling components: global concrete demand simulation, tyre waste utilisation modelling, carbon footprint reduction estimation, atmospheric dispersion modelling, and machine learning prediction using Support Vector Machines (SVM). The integration of these components enables a comprehensive assessment of the environmental implications associated with the adoption of pulverized waste tyre rubber (PWTR) in concrete production.

A. Global Concrete Demand Model

The first component estimates global concrete demand in order to quantify the potential scale at which rubberised concrete could influence carbon emissions. Global concrete consumption is largely driven by population growth, urbanisation, and infrastructure development [13].

Accordingly, global concrete demand can be expressed as,

$$C_{global} = P \times I \times \alpha \tag{1}$$

where P represents the global population, I denotes the infrastructure demand per capita, and α is the concrete consumption coefficient that captures material intensity within construction activities. This formulation provides an estimate of the total concrete production required to sustain global infrastructure development.

B. Tyre Utilisation Model

The second component quantifies the number of waste tyres that can be incorporated into concrete mixtures through the use of pulverized waste tyre rubber (PWTR). Waste tyres represent one of the fastest-growing solid waste streams globally, with billions of tyres reaching end-of-life each year [4]. The number of tyres utilised per cubic meter of rubberised concrete can be estimated as,

$$T = \frac{M_r}{M_t} \tag{2}$$

where M_r denotes the mass of recycled rubber incorporated per cubic meter of concrete and M_t represents the average mass of a single tyre. This relationship allows the estimation of the number of tyres recycled through concrete production and provides a quantitative measure of waste diversion from landfills.

C. Carbon Footprint Model

The environmental benefits of rubberised concrete are primarily associated with the reduction of cement consumption. Cement production is responsible for approximately 7–8% of global carbon dioxide emissions due to the energy-intensive clinker manufacturing process [5]. The reduction in carbon emissions resulting from cement replacement can therefore be estimated using,

$$CO_2 = (E_c \times W_c) - (E_r \times W_r) \tag{3}$$

where E_c represents the emission factor associated with cement production, E_r denotes the emission factor for recycled rubber processing, W_c is the mass of cement replaced in the concrete mix, and W_r represents the mass of recycled rubber incorporated into the mixture. This formulation quantifies the net reduction in CO_2 emissions achieved through the substitution of cement with recycled tyre rubber.

D. Atmospheric Dispersion Model

To evaluate the potential air-quality benefits associated with reduced tyre burning and lower industrial emissions, the Gaussian plume dispersion model is used to simulate pollutant transport in the atmosphere [15]. The Gaussian plume model is widely used in environmental engineering to estimate the spatial distribution of pollutants emitted from point sources under steady-state conditions [14]. The pollutant concentration at a location (x, y, z) is calculated as,

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z U} e^{-\frac{y^2}{2\sigma_y^2}} \left[e^{-\frac{(z-H)^2}{2\sigma_z^2}} + e^{-\frac{(z+H)^2}{2\sigma_z^2}} \right] \tag{4}$$

where Q denotes the emission rate of the pollutant source, U represents the wind velocity, σ_y and σ_z are the horizontal and vertical dispersion coefficients respectively, and H is the effective stack height of the emission source. This model enables the estimation of pollutant concentration fields under different emission scenarios.

E. Machine Learning Prediction Model

In addition to environmental modelling, artificial intelligence techniques are incorporated to predict the mechanical performance of rubberised concrete. Support Vector Machines (SVM) are employed due to their strong predictive capabilities in nonlinear regression problems and their successful application in concrete strength prediction studies [2]. The SVM model is trained using experimental datasets that include rubber replacement ratios, mix design parameters, and curing conditions in order to predict compressive strength and identify optimal mixture proportions. By integrating machine learning with environmental modelling, the proposed framework provides a holistic approach for evaluating both structural performance and environmental sustainability of rubberised concrete.

4. Simulation Scenario

The modelling scenario evaluates the environmental impact of using rubberized concrete in large-scale infrastructure projects.

Table 1

Global concrete and tyre waste scenario

Parameter	Value
Global concrete demand	30 billion tons/year
Annual waste tyres	1 billion tyres
Rubber per m ^{3}	25.37 kg
Tyres reused per m ^{3}	

A. Environmental Impact Analysis

Table 2

Comparison of conventional and rubberized concrete

Property	Conventional	Rubberized
Compressive Strength (MPa)	25	24
Flexural Strength (MPa)	3.5	2.9
CO_2 emissions (kg/m ^{3})	325.5	315.9
Cost per m ^{3}	5000	4200

Table 3

Environmental benefits for large infrastructure project

Impact Category	Per m ^{3}	Total Impact
CO_2 Reduction	9.59 kg	4353.76 tons
Tyres Recycled	11.67	5.3 million
Energy Savings	1043.96 MJ	473.79 TJ

B. Global Climate Mitigation Projection

Beyond project-scale environmental benefits, the adoption of rubberised concrete has the potential to generate measurable climate mitigation impacts at the global scale. To evaluate this effect, a long-term simulation was developed to estimate annual and cumulative carbon dioxide (CO_2) savings resulting from the partial replacement of cement with recycled tyre rubber in concrete production.

The model assumes that global concrete production currently exceeds 30 billion tonnes per year and continues to grow at a modest annual rate. If a fraction of this production adopts rubberised concrete technology, significant CO_2 savings can be achieved due to the reduced cement content in the mixture. The annual CO_2 savings are estimated using:

$$E_{annual} = C_{global} \times A \times S \tag{5}$$

where C_{global} = global concrete production (tonnes/year), A = adoption fraction of rubberised concrete, S = CO_2 savings per unit of concrete. The cumulative emissions savings over time are obtained by integrating the annual savings from the base year to the target year:

$$E_{cum}(t) = \sum_{i=2025}^{t} E_{annual,i} \tag{6}$$

where $E_{cum}(t)$ represents the cumulative avoided emissions measured in gigatonnes of CO_2 ($GtCO_2$).

C. Climate Response Estimation

To translate avoided emissions into potential climate benefits, a simplified temperature response model was used. Climate science research indicates that global mean temperature change is approximately proportional to cumulative CO_2 emissions. This relationship can be represented as:

$$\Delta T = \alpha \times E_{cum} \tag{7}$$

where ΔT = avoided global warming (°C), E_{cum} = cumulative avoided emissions ($GtCO_2$), α = climate response parameter. A commonly used approximation in climate modelling literature assumes:

$$\alpha = 0.45\ ^\circ C \text{ per } 1000\ \mathrm{GtCO_2} \tag{8}$$

This implies that preventing 1000 gigatonnes of CO_2 emissions would reduce global warming by approximately 0.45 °C within a simplified climate response framework.

D. Scenario Analysis

To explore the long-term climate implications of rubberised concrete, multiple adoption scenarios were simulated from 2025 to 2100:

1. Low adoption scenario (5% of global concrete production),
2. Moderate adoption scenario (15%),
3. High adoption scenario (30%).

For each scenario, the simulation produced: annual global CO_2 savings, cumulative avoided emissions, estimated avoided global temperature increase. The results illustrate that even modest adoption rates can produce substantial cumulative emissions reductions over multiple decades. As infrastructure construction continues to expand globally, sustainable materials such as rubberised concrete could therefore contribute meaningfully to climate mitigation strategies while simultaneously improving waste tyre management and urban air quality.

5. Discussion

The simulation results provide a quantitative extension of the material, economic, and environmental analyses presented in the preceding sections. In particular, the figures translate the optimized PWTR concrete mix into project-scale and global-scale indicators related to tyre reuse, air quality, carbon savings, and long-term climate response. This supports the main objective of the paper, connecting a feasible rubberised concrete mix design with broader environmental performance outcomes [9]-[11].

A. Relationship Between the Simulations and the Mix-Design Results

The environmental simulations are based on the assumption that the selected PWTR mix remains mechanically acceptable for the intended infrastructure application. This assumption is consistent with the experimental and SVM-based results in [10, 11], where low replacement levels of cement and sand with PWTR produced compressive strength values in the range required for the trench application. The simulation framework therefore does not treat rubber substitution as an abstract environmental scenario; instead, it builds on a mix proportion that has already been shown to be technically plausible. The projected environmental benefits are only meaningful if the material remains suitable for use. The prior cost-benefit and mechanical analyses indicated that PWTR-modified concrete can reduce material cost while maintaining compressive strength close to that of conventional concrete [9]. The graphical results extend this finding by showing how these mix-level changes may affect larger systems when applied at project and adoption-scenario scales.

B. Global Waste Tyre Reuse Potential

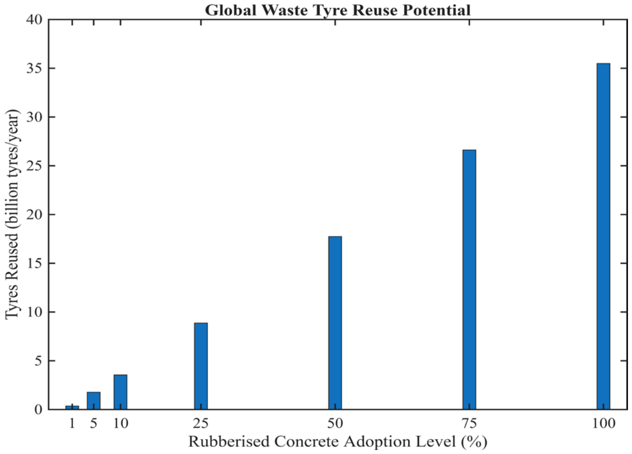

Fig. 2. Global waste tyre reuse potential under different adoption levels of rubberised concrete

Fig. 2 shows the projected number of waste tyres that could be incorporated into concrete under different adoption levels of rubberised concrete. The trend is approximately linear because tyre reuse is directly proportional to both the rubber content per cubic meter and the assumed fraction of concrete production using the modified mix. As expected, low adoption levels produce moderate reuse volumes, while higher adoption levels produce substantially larger reuse potential.

End-of-life tyre generation remains high globally, and existing disposal pathways continue to place pressure on landfill systems and environmental controls. The simulation indicates that concrete production may provide a practical reuse pathway for part of this waste stream, particularly where large infrastructure demand already exists. In this context, the figure supports the circular-economy motivation of the study by quantifying the scale at which the construction sector may absorb waste rubber.

C. Air-Quality Interpretation of Tyre Reuse

Fig. 3 presents the simulated $PM_{2.5}$ concentration profile for two simplified scenarios: tyre burning and tyre reuse in concrete. Under the tyre-burning case, the modeled concentration is highest near the source and decreases with downwind distance, which is consistent with the Gaussian plume formulation used in the study. Under the reuse case, the additional source term associated with burning is removed, and the resulting concentration contribution is correspondingly negligible in the present simulation. The simulation extends that discussion by showing the air-quality implication of avoiding that route through reuse in concrete. Although the plume model is simplified and does not represent all meteorological conditions, it is sufficient to illustrate the direction of effect: reuse of tyres in concrete is associated with lower modeled PM $_{2.5}$ contribution than open burning.

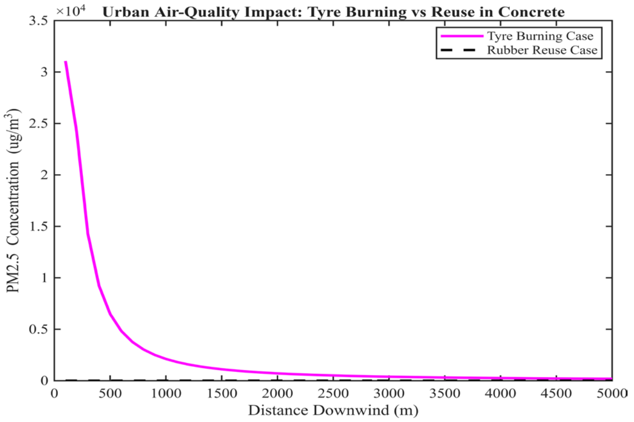

Fig. 3. Simulated PM $_{2.5}$ concentrations for tyre burning and rubber reuse scenarios using the Gaussian plume model

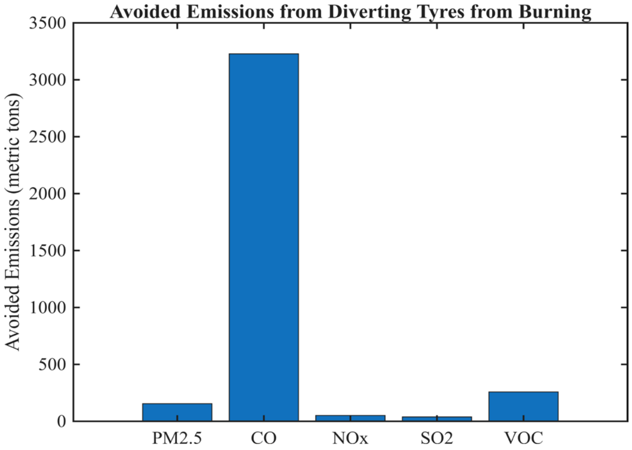

Fig. 4. Avoided emissions from diverting waste tyres from burning to reuse in concrete

A related result is shown in Fig. 4, where the avoided emissions associated with tyre diversion are summarized across several pollutant categories. The absolute values depend on the emission factors adopted in the scenario model; however, the figure is useful in comparative terms because it indicates that tyre reuse may reduce the need for disposal by burning and therefore reduce the associated pollutant burden. This is aligned with the environmental-control perspective of the paper and provides a basis for linking construction materials research with air-quality management.

D. Annual and Cumulative CO_2 Savings

Fig. 5 shows the estimated annual global CO $_2$ savings under the baseline adoption scenario. The increasing trend is driven by two assumptions in the model: first, that the share of rubberised concrete grows over time up to the specified adoption level, and second, that total concrete demand also grows gradually. Because cement substitution is the primary source of CO $_2$ reduction in the present framework, the annual savings scale with the total volume of adopted concrete.

The mix-level savings per cubic meter are relatively modest, but when applied across large concrete volumes they become more significant. Fig 5 therefore serves as a bridge between the per-unit environmental metrics in the methodology and the wider adoption scenarios discussed in the motivation for the study.

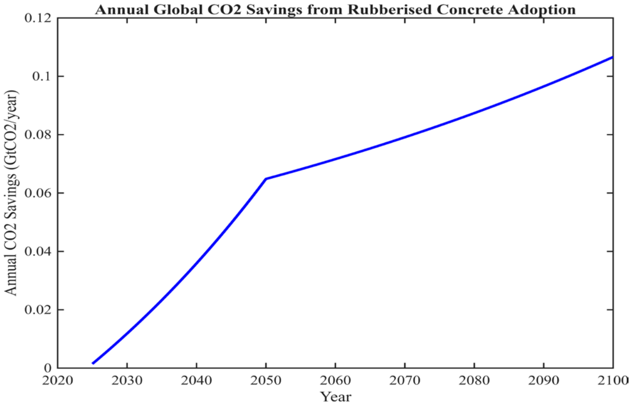

Fig. 5. Annual global CO $_2$ savings from rubberised concrete adoption

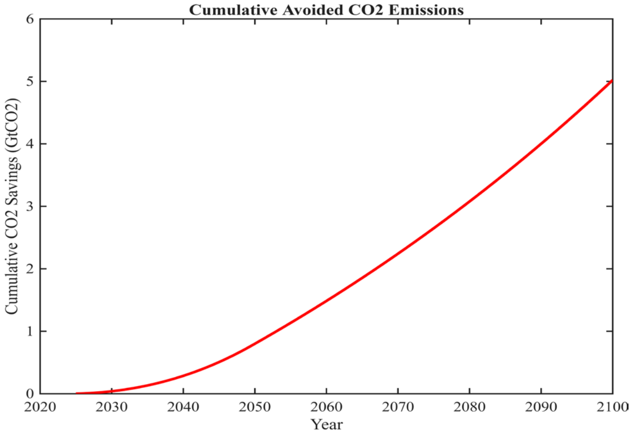

Fig. 6. Cumulative avoided CO $_2$ emissions under the baseline adoption scenario

Fig. 6 shows the cumulative avoided CO $_2$ emissions over time. This figure is particularly relevant because cumulative emissions are commonly used as an indicator for long-term climate response. The monotonic increase in the curve is expected, since annual savings are added year by year. From a policy perspective, the figure indicates that the long-term value of PWTR adoption is better understood over a multi-decade period than from a single-year comparison alone.

E. Estimated Climate Effect

Fig. 7 converts cumulative CO $_2$ savings into an estimated avoided temperature rise using the simplified TCRE-based relationship described in the methodology. The resulting values are small in magnitude under the present assumptions. This is not unexpected, given that the intervention considered here affects only a fraction of the emissions associated with one construction material stream. The result should therefore be interpreted as an incremental contribution rather than as a standalone solution to climate change.

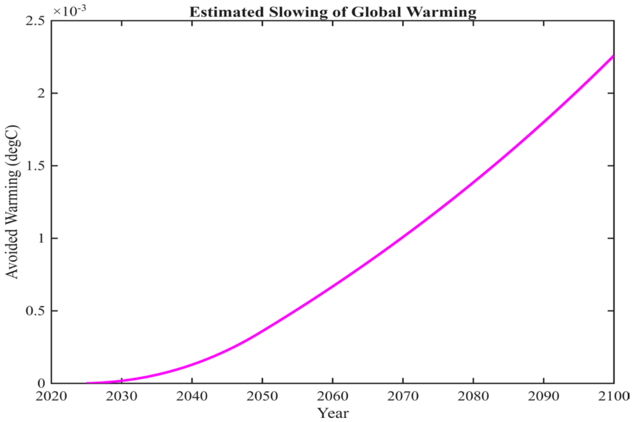

Fig. 7. Estimated slowing of global warming under the baseline adoption trajectory

Even so, the Fig. 7 provides a direct link between a materials-engineering intervention and a climate-response indicator. This is consistent with the broader aim of the study, which is to assess PWTR concrete not only in terms of structural and cost performance, but also in terms of its potential role in environmental mitigation.

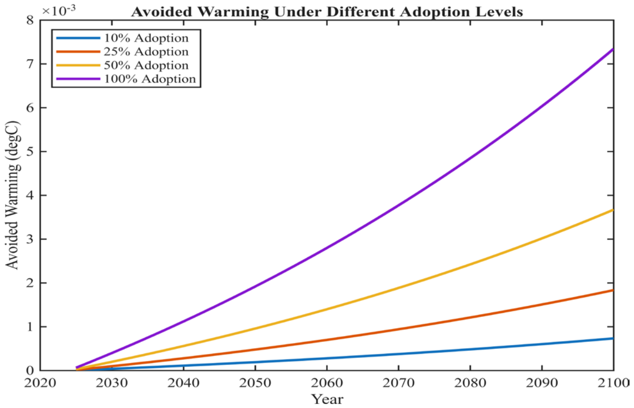

Fig. 8. Avoided warming under different global adoption levels of rubberised concrete

Fig. 8 extends this result by comparing avoided warming under several adoption levels. The separation among the curves indicates that the estimated climate effect is sensitive to the degree of deployment. Under higher adoption assumptions, the cumulative benefit increases correspondingly. This provides a useful scenario-based interpretation for decision makers: the environmental value of the material depends not only on mix performance, but also on the scale and persistence of implementation.

F. Environmental Implications

The experimental results establish that PWTR can be incorporated into concrete at low replacement levels with acceptable mechanical performance. The SVM model provides an efficient way to estimate mix performance and identify suitable replacement ratios. The cost and environmental calculations then quantify savings at project scale. The graphical simulations extend those results to broader scenarios involving tyre reuse capacity, avoided emissions, air-quality response, cumulative carbon savings, and indicative climate benefit.

This progression is consistent with the multidisciplinary scope. The work begins with concrete technology and materials optimization, then moves into environmental accounting, and finally into scenario-based air-quality and climate interpretation. In this sense, the graphical results are the part of the analysis that links the engineering results to environmental controls, urban air quality, and artificial intelligence-assisted decision support.

6. Conclusion

Concrete production is essential for global infrastructure development, but its environmental footprint is significant due to the high carbon intensity of cement manufacturing. At the same time, the increasing number of end-of-life tyres has created persistent waste management challenges worldwide. This study investigated the integration of pulverized waste tyre rubber (PWTR) in concrete mixtures as a potential approach for improving sustainability within the construction sector while addressing waste tyre disposal concerns.

The accumulation of waste tyres and the carbon emissions associated with cement production represent two major environmental challenges. Large quantities of tyres are disposed of through landfilling or uncontrolled burning, which can release pollutants such as particulate matter, nitrogen oxides, and sulphur oxides into the atmosphere. In parallel, cement production contributes approximately 7–8% of global CO_2 emissions. Despite previous research demonstrating the feasibility of rubberised concrete, limited studies have examined the combined implications for urban air quality, waste diversion, and long-term climate mitigation.

The results of the experimental analysis and simulation modelling indicate that small replacement ratios of cement and sand with PWTR can maintain acceptable mechanical performance while providing measurable environmental benefits. The optimized mix predicted using the Support Vector Machine (SVM) model achieved compressive strengths close to 24 MPa, which is comparable to conventional trench concrete. The environmental analysis showed reductions in cement consumption, corresponding decreases in CO_2 emissions, and diversion of waste tyres from landfill disposal.

Scenario simulations further demonstrated that rubberised concrete adoption could reduce emissions associated with tyre burning and lower particulate matter concentrations in atmospheric dispersion modelling. At the project scale, the analysis estimated substantial tyre reuse and energy savings, while global adoption scenarios suggested cumulative carbon emission reductions over time.

The findings of this study indicate that rubberised concrete represents a technically feasible and environmentally beneficial material alternative for selected infrastructure applications. By integrating materials engineering, artificial intelligence prediction, and environmental modelling, the study demonstrates that sustainable construction materials can contribute to waste management, emissions reduction, and improved environmental performance. Although the projected climate benefits are modest under the assumptions used in the model, the results show that incremental improvements within large industrial sectors such as concrete production may contribute to broader climate mitigation efforts when implemented at scale.

The results suggest several policy and research directions. First, regulatory frameworks and construction standards could support the adoption of recycled materials in concrete production where structural performance requirements are satisfied. Second, waste management policies may encourage the diversion of end-of-life tyres toward construction material applications rather than landfill disposal or open burning.

Future research should focus on long-term durability studies of rubberised concrete, large-scale field implementation, and improved environmental modelling that incorporates real atmospheric data and lifecycle assessment approaches. Additional research integrating real-time air quality monitoring and advanced machine learning techniques may further enhance predictive capability and support decision-making for sustainable infrastructure development.

References

[1] Anadolu Agency, "Environmental disaster: World's biggest tire graveyard in Kuwait," Aug. 2021.

[2] J.-S. Chou and A.-D. Pham, "Enhanced artificial intelligence for ensemble approach to predicting high performance concrete compressive strength," *Construction and Building Materials*, vol. 49, pp. 554–563, 2014.

[3] J. Hailstone, "What happens when tyres reach the end of the road?," 2022.

[4] M. Hashamfirooz *et al.*, "Environmental and health impacts of waste tyres: A systematic review," *Heliyon*, vol. 11, p. e2890, 2025.

[5] International Energy Agency, "Cement," 2023.

[6] D. Kumar, A. Singh *et al.*, "Comparative analysis of waste tyre treatment technologies," *Renewable and Sustainable Energy Reviews*, vol. 189, p. 114071, 2025.

[7] Kunak, "Impact of cement on the environment," 2021.

[8] B. A. Manu, "Innovative construction materials: Advancing sustainability, durability, efficiency, and cost-effectiveness in modern infrastructure," *International Journal of Research Publication and Reviews*, vol. 5, no. 12, pp. 4987–4999, 2024.

[9] D. W. Mwaniki, F. S. Isaac, and T. Mungathia, "Cost-benefit analysis of pulverized waste-tyre rubber in construction of pre-cast concrete power cable trenches," *International Journal of Recent Research in Civil and Mechanical Engineering*, vol. 12, no. 1, pp. 1–10, 2025.

[10] D. W. Mwaniki, T. Mungathia, and I. F. Sanewu, "Sustainable solutions for concrete power cable trenches: Evaluating pulverized rubber tire waste as a partial aggregate replacement," *Open Journal of Civil Engineering*, vol. 15, no. 1, pp. 40–55, 2025.

[11] D. W. Mwaniki, I. F. Sanewu, and T. Mungathia, "A mathematical model for predicting performance of pulverized waste rubber tire as a partial replacement for aggregate," *International Journal of Scientific and Engineering Science*, vol. 9, no. 4, pp. 63–68, 2025.

[12] N. Nkosi, T. Nhubu, and N. H. Mthombeni, "An inventory analysis of waste tyre generation and management in South Africa," *Waste Management*, vol. 194, pp. 353–365, 2025.

[13] K. Scrivener, V. John, and E. Gartner, "Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry," *Cement and Concrete Research*, vol. 114, pp. 2–26, 2018.

[14] J. H. Seinfeld and S. N. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. Hoboken, NJ: Wiley, 2016.

[15] H. Snoun, M. Krichen, and H. Chérif, "A comprehensive review of Gaussian atmospheric dispersion models," *Euro-Mediterranean Journal for Environmental Integration*, vol. 8, no. 1, pp. 219–242, 2023.

[16] I. Uvarova *et al.*, "End-of-life tyre recycling: Circular business models in Latvia," *Engineering for Rural Development*, vol. 19, pp. 1680–1691, 2020.

[17] N. H. Zerin, M. Rahman *et al.*, "End-of-life tyre conversion to energy: A review on pyrolysis technologies," *Science of the Total Environment*, vol. 871, p. 162109, 2023.