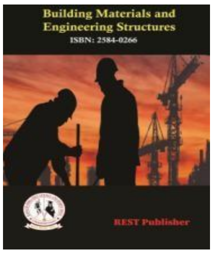
Building Materials and Engineering Structures
Vol: 3(3), September 2025
REST Publisher; ISSN: 2584-0266 (Online)
Website: https://restpublisher.com/journals/bmes/
DOI: http://doi.org/10.46632/bmes/3/3/4



Grinding High-Modulus Natural Silicate: Impacts on Embodied Energy in Geopolymer Cement Production Using WASPASS Method

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Abstract: *Introduction: The properties of geopolymer bricks are significantly affected by the raw material composition, the proportions of alkaline solutions and the level of sodium hydroxide concentration. Several experiments focused on increasing the strength, hardening and durability of bricks Contribute to the advancement of energy-efficient and environment-friendly solutions. Research highlights the potential of industrial concrete derived from plant-based materials and waste, which offers advantages over traditional cement, including reduced waste generation, lower CO2 emissions and improved thermal properties that improve energy efficiency in buildings. The construction industry's consumption of raw materials and its significant contribution to greenhouse gas emissions underline the need for sustainable practices. Also, using red mud, a by-product of aluminium refining in geopolymer production, not only reduces costs but also reduces environmental impact. Research significance: Switching from traditional Ordinary Portland Cement (OPC) to industrial concrete derived from plant-based materials and wastes offers many benefits, such as reduced environmental impact through lower CO2 emissions and reduced reliance on virgin resources. The construction industry, which uses a disproportionate number of raw materials and generates substantial waste, has benefited significantly from innovations in materials science. Geopolymer concrete, recognized for its long service life and excellent mechanical properties, is emerging as a promising alternative. Its resistance to chemical attacks and temperature fluctuations improves building performance and leads to better indoor air quality, energy efficiency and an overall improved quality of life. Methodology: Alternative: Eco Mix, Green Bind, Gaolie, Tarragon, Enviro Crete. Evaluation Preference: Energy Consumption (MJ/ton), CO2 Emissions (kg CO2/ton), Production Efficiency (%), Material Cost Savings (%). Result: The results indicate that Gaolie achieved the highest rank, while Green Bind had the lowest rank being attained. Conclusion: "The value of the dataset Energy Efficiency in Geopolymer Production, according to the Vespa's method, Gaolie achieves the highest ranking."*

Key words: *Geopolymer Bricks, CO2 Emissions, Geopolymer Concrete, Construction Waste, Thermal Properties, Moisture Resistance.*

1. INTRODUCTION

The properties of geopolymer bricks can vary greatly depending on the composition of the raw material, the ratio of alkali solutions and the concentration of sodium hydroxide used. The research describes a set of tests to improve the factors affecting the strength, hardening, and durability of bricks. The results contribute to the development of energy-efficient, eco-friendly bricks. [1] In conclusion, industrial concrete, derived from plant-based materials and waste, has great potential. It offers many advantages compared to conventional cement and concrete such as reduced waste generation, dependence on Ordinary Portland Cement (OPC), and carbon dioxide emissions. It increases energy efficiency in buildings, reduces both upfront and ongoing costs, and raises the quality of life by providing superior thermal insulation and moisture resistance. [2] The construction industry involves many elements such as design, material selection, use of natural resources, and interactions with socioeconomic, regulatory, and administrative factors. It consumes rawer materials by weight compared to other industries. Also, the impending shortage of virgin aggregates will increase costs, while long-term trends in cement use in Europe remain unpredictable. The built environment is the primary contributor to greenhouse gas emissions related to energy consumption. Construction and demolition activities generate the most waste by weight in Europe, most of which is recyclable. Environmental considerations help reduce the impact of construction on raw material use, indoor air quality, and water and energy efficiency. [5] The embodied energy in the production of ordinary Portland cement (OPC) is mainly influenced by the technology used in the kiln processes. This analysis uses weighted average energy intensity from the International Energy Agency's Global Survey of Industrial Energy Efficiency, due to its comprehensive coverage and global importance. This may lead to a conservative estimate (with lower power) compared to other statistics, resulting in a similarly cautious comparison with BDG. [8] Red mud is a waste product from the Bayer process, which is used in the industrial production of aluminium. In this process, bauxite is dissolved in sodium hydroxide under elevated temperature and pressure, resulting in a red mud with a high pH due to residual sodium hydroxide. Using red mud in its wet form saves time and energy required for drying, and by increasing its natural alkalinity, less alkali activator is required, reducing the overall cost of geopolymer production. [9] However, data on new or improved energy efficiency and low carbon technologies is still under development. This paper collects information on these emerging technologies to provide engineers, researchers, investors, cement companies, policy makers and other stakeholders with convenient access to a complete and well-organized database on the subject. [12] Sodium hydroxide (Nao) is typically produced as a by-product of chlorine production through electrolysis, where electricity is applied to a salt solution. Without proper management, desalination can be inefficient in terms of energy use. Using diaphragm cells is a method to improve energy efficiency. In sodium hydroxide (Nao) production, the system scope typically includes material extraction, production, and transportation to the production facility. [15] However, its use as a lightweight construction material has gained significant popularity in recent decades, driven by increasing concerns about developing energy efficiency. Another technique to improve thermal insulation involves the use of fine aggregates, although this falls outside the scope of this review, which focuses primarily on the development of lightweight binders. [16] An environmental impact assessment was conducted to model the performance of new geopolymer materials for thermal energy storage and to compare them with existing literature, aiming to evaluate the production of 1 m^3 of material and its impact on the ecosystem. This method helped to identify technical and environmental constraints of materials intended for heat storage units. The Environmental Impact Assessment conforms to the principles of Life Cycle Assessment (LCA), using a cradle-gate approach with Environmental Product Declaration (EPD®) standards to facilitate possible future industrialization in Italy. [17] Geopolymer concrete is recognized as having a longer lifespan compared to traditional ordinary Portland cement (OPC) concrete, thanks to its stronger mechanical properties, greater resistance to chemical attacks, and improved temperature resistance. In the literature, geopolymer concrete is often compared to CEM I-type ordinary Portland cement (OPC) concrete. However, other types of concrete conforming to cement standards may also be considered traditional. [18] Grinding of high-modulus natural silicate (HMNS) contributes to the embodied energy of geopolymer cement. This ability is necessary to transform large HMNS aggregates into micrometre-sized particles. In this study, milling was carried out with a laboratory ball mill, which exhibits significantly different energy efficiency from actual manufacturing processes. Grinding of HMNS can also take place in a blast furnace slag grinding facility. Energy requirements vary based on the type of plant used and the desired fineness of production. [19] A suggested solution to solve this problem is the use of geopolymers. Geopolymer concrete (GPC) is a sophisticated, eco-friendly construction material It is generally prepared by activating the cementitious properties of solid alum inosilicate materials with alkali activators such as sodium silicate and sodium hydroxide at low curing temperatures. [20]

2. MATERIALS AND METHOD

Zavadskas, Antucheviciene, and Rizvi Hagigah improved the Vespa's method by incorporating interval-valued intuitionistic fuzzy numbers and compared its results with other existing methods. Lashkar, Antuchevičienė, Delaware, and Kheirkhah integrated the Quantitative Strategic Planning Matrix (QSPM) with the visas method to develop a multi-criterion decision-making (MCDM) approach to developing outsourcing strategies. Vafeipur, Solana, Variance, Threat and Eshkaluk are using SWARA and WASPAS methods to evaluate solar power projects based on regional priorities. Meanwhile, Džiugaitė-Tumėnienė and Lapinskienė analysed various criteria of energy supply systems in low-energy houses using the WASPAS method. [1] The methodology presented in this paper shows a high level of accuracy in solving decision-making problems, supported by the research described in the Materials and Methods section. Along with employing accurate statistical and mathematical techniques for risk ranking, experienced experts identify potential risks in road construction projects and offer valuable insights for future research in the field. The rest of the paper is organized as follows: Section 'Was pass method' introduces the Was pass method. [2] As mentioned earlier, the classical WASPAS method uses a linear normalization procedure. However, when working with interval type-2 fuzzy sets (IT2FSs) that have zero elements in the result matrix, normalized IT2FSs for null criteria will yield infinite values. To address this, the proposed extended WASPAS method modifies the normalization process. Additionally, the WPM process is modified to avoid calculations involving complex numbers. In this approach, the calculation of criterion weights combines the weights assigned to the decision makers and the weights obtained from the entropy method. [3] This approach differs from the previously discussed multiple criteria decision making (MCDM) methods for project evaluation. In particular, an improved version of the WASPAS method, referred to as the OFN-WASPAS method, is introduced, and the paper outlines a methodology for selecting development projects using this proposed approach. [4] This study focused on a multi-criteria economic analysis of various machining processes, using the WASPAS method to select the most suitable machining process. Also, they rank and select the best healthcare outsourcing strategies using the Qualitative Strategic Planning Matrix (QSPM) and WASPAS methodology. [6] The integration of two optimization criteria, the weighted sum model (WSM) and the weighted product model (WPM), is known as the weighted total product evaluation (WASPASS) and is used to assess the suitability and effectiveness of an integrated method for selecting waste incineration plant construction sites. In this context, a new extension of the original WASPAS method, called WASPAS-SVNS, includes a single-valued neutrosophic ensemble. [8] The WASPAS methodology enables decision makers to evaluate alternatives using subjective and objective criteria. These characteristics distinguish the proposed solution method from other multi-criteria decision-making techniques and make it the preferred approach for this study. [10] This method combines the SCORE function, entropy measure, and the classical Was pass approach within the framework of fuzzy sets. A coherent procedure is proposed to determine the criterion weights using both the entropy measure and the score function. A new scoring function with desirable properties and multiple entropy measures is introduced into the FFSs framework. Additionally, an illustrative case study of sanitary waste (HCW) disposal site selection under FFSs is presented, demonstrating the practicality and effectiveness of the developed approach. [11] Additionally, a comparative analysis between the developed approach and various existing methods is conducted to validate the results. A sensitivity analysis involving various criterion weights and parameter values was performed to assess the stability of the HF-WASPAS approach. The findings indicate that HF-WASPAS is useful and highly compatible with current methods. [12] This section illustrates the effectiveness of the IVIF-WASPAS method through a case study focusing on reservoir flood control management. Given the enormous threat and widespread occurrence of flooding, this natural disaster poses a significant risk to society. Therefore, a flood control management policy is necessary to mitigate flood risk while ensuring that the reservoir water level is as low as possible at the end of the flood. [13] To rank these TSPs based on operational performance, a new integrated approach called the “Expanded WASPAS Methodology” has been developed. This method uses a decision-making process to solve a multi-criterion decision-making (MCDM) problem within the framework of interval fuzzy sets (IFSs). [14]

3. ANALYSIS AND DISCUSSION

TABLE 1. Energy Efficiency in Geopolymer Production

DATA SET				
	Energy Consumption (MJ/ton)	CO2 Emissions (kg CO2/ton)	Production Efficiency (%)	Material Cost Savings (%)
Eco Mix	1700	180	88	12
Green Bind	1600	175	90	15
Gaolie	1850	190	85	10
Tarragon	1750	185	87	14
Enviro Crete	1650	170	89	13

Energy consumption (MJ/ton) and CO2 emissions (kg CO2/ton) are non-benefit parameters, meaning lower values are more favorable. Green Bind has the lowest energy consumption (1600 MJ/ton) and CO2 emissions (175 kg CO2/ton), making it the most environmentally efficient option. Gaolie, on the other hand, consumes the most energy (1850 MJ/ton) and has the highest emissions (190 kg CO2/ton), making it the least efficient in these categories. Production efficiency (%) and material cost savings (%) are benefit parameters, where higher values are preferred. Green Bind also leads in production efficiency (90%) and material cost savings (15%), making it the most efficient method in terms of output and cost. Gaolie lags behind with the lowest production efficiency (85%) and cost savings (10%).

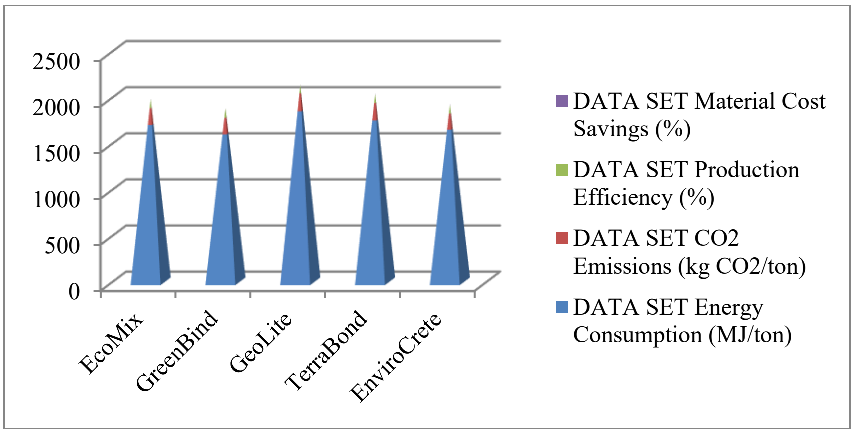

FIGURE 1. Energy Efficiency in Geopolymer Production

The CO2 emissions component, shown in red, is also relatively consistent across the alternatives, with **Green** Bind and EnviroCrete producing the least CO2, and Gaolie and Tarragon generating slightly more emissions. Eco Mix stands somewhere in the middle. The green portion of the bars, representing production efficiency, shows that Green Bind and Gaolie have higher production efficiencies, while Eco Mix **and** EnviroCrete follow closely behind. Gaolie, though consuming the most energy, balances that with high efficiency. Finally, material **cost savings**, indicated in purple, shows that Green Bind offers the highest savings, followed by Tarragon and EnviroCrete**,** while **Gaolie** and Eco Mix have slightly lower cost savings. Gaolie and Green Bind emerge as strong contenders with a balance of high efficiency and relatively controlled emissions, while Eco Mix and Tarragon offer decent cost savings but slightly higher energy consumption.

TABLE 2. Performance value

Performance value			
0.918919	0.947368	1	0.833333
0.864865	0.921053	0.9	0.666667
1	1	1	1
0.945946	0.973684	1	0.714286
0.891892	0.894737	1	0.769231

The first alternative shows strong performance in most areas, particularly in production efficiency, where it scores the maximum value of 1. However, its material cost savings (0.833) lag slightly behind, indicating room for improvement in cost efficiency. The second alternative demonstrates lower performance in material cost savings (0.667) and production efficiency (0.9), suggesting it is less competitive compared to the other alternatives. Its performance in CO2 emissions (0.921) and energy consumption (0.865) is also slightly behind the leading alternatives. The third alternative performs exceptionally well, with perfect scores of 1 across all parameters, indicating it is the best option overall, excelling in energy consumption, emissions, efficiency, and cost savings. The fourth alternative performs strongly in most areas, particularly in production efficiency (1) and CO2 emissions (0.974), but its material cost savings (0.714) are weaker.

TABLE 3. Weight

Weight			
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25

By assigning equal weight, the decision-making process assumes that all parameters are equally important for assessing the energy efficiency in geopolymer production. For instance, energy consumption and CO2 emissions (both non-benefit parameters) hold the same importance as production efficiency and material cost savings (both benefit parameters). This balance ensures a fair and unbiased assessment, where a strong performance in one category does not disproportionately influence the ranking.

TABLE 4. Weighted normalized decision matrix

Weighted normalized decision matrix			
0.22973	0.23684	0.24148	0.20833
0.21622	0.23026	0.23611	0.16667
0.25000	0.25000	0.25000	0.25000
0.23649	0.24342	0.24425	0.17857
0.22297	0.22368	0.23876	0.19231

The third alternative stands out with values of 0.25 across all parameters, indicating perfect performance and balance in energy consumption, CO2 emissions, production efficiency, and material cost savings. This suggests that this alternative performs equally well across all factors, making it the most optimal choice based on the equal weighting scheme. The first alternative also performs relatively well, with slightly lower values in the material cost savings parameter (0.208), suggesting that while it excels in other areas, its cost savings are somewhat less competitive. The second alternative has weaker performance, especially in material cost savings (0.167), indicating that its overall score is negatively impacted by its inefficiency in this area.

TABLE 5. Preference Score

Preference Score	
Eco Mix	0.91638
Green Bind	0.84926
Gaolie	1.00000
Tarragon	0.90273
EnviroCrete	0.87773

Gaolie stands out with a perfect preference score of 1.000, meaning it performs optimally across all evaluation parameters—energy consumption, CO2 emissions, production efficiency, and material cost savings. This suggests Gaolie is the most efficient and balanced option, excelling in both environmental sustainability and economic benefits**.** Eco Mix has a strong preference score of 0.916, indicating it is competitive but slightly underperforms in some areas compared to Gaolie. Similarly, Tarragon, with a score of 0.903**,** follows closely, reflecting good overall performance but with some room for improvement, likely in material cost savings or efficiency. EnviroCrete scores 0.878, indicating moderate performance. It is effective but less competitive than Eco Mix or Tarragon, possibly due to weaker results in one or more parameters. Green Bind, with the lowest score of 0.849**,** lags behind the other alternatives, indicating it may have issues in areas like energy consumption or cost savings that reduce its overall efficiency.

TABLE 6. WASPAS Coefficient

WASPAS Coefficient	
Eco Mix	0.91566
Green Bind	0.84540
Gaolie	1.00000
Tarragon	0.89906
EnviroCrete	0.87638

Gaolie achieves the highest WASPAS coefficient of 1.000**,** indicating that it performs optimally across all evaluation parameters—energy consumption, CO2 emissions, production efficiency, and material cost savings. This perfect score positions Gaolie as the most efficient and balanced alternative for sustainable geopolymer production. Eco Mix**,** with a WASPAS coefficient of 0.91566, is a strong competitor, performing well in most areas but falling slightly short of Elite's perfect balance. Similarly, Tarragon follows closely with a coefficient of 0.89906, indicating solid performance, though likely weaker in one or more parameters, such as material cost savings or energy consumption. EnviroCrete has a moderate WASPAS coefficient of 0.87638**,** reflecting reasonable performance but with some limitations, possibly in cost efficiency or emissions control. Green Bind**,** with the lowest coefficient of 0.84540, lags behind the other alternatives, suggesting that while it may perform well in certain areas, it is less competitive in overall efficiency and environmental impact.

Table 7. Rank

RANK	
Eco Mix	2
Green Bind	5
Gaolie	1
Tarragon	3
EnviroCrete	4

Gaolie holds the top spot with a rank of **1,** confirming that it is the most efficient and balanced alternative across all evaluation parameters, including energy consumption, CO2 emissions, production efficiency, and material cost savings. Its consistent performance across both environmental and economic factors makes it the best choice for sustainable geopolymer production**.** Eco Mix ranks **2**, indicating that it is a strong competitor, performing well in most criteria but slightly less optimal than Gaolie. It may have marginally lower performance in areas like material cost savings or CO2 emissions but remains highly competitive. Tarragon takes the 3rd position, reflecting solid performance across the board, though not as strong as Eco Mix or Gaolie. It likely excels in certain areas like production efficiency while falling behind slightly in others, such as energy consumption or environmental impact. EnviroCrete**,** with a rank of 4, performs reasonably well but is less competitive compared to the top three alternatives. Green Bind**,** ranked 5**,** is the weakest performer, suggesting that it may struggle with higher energy consumption, lower production efficiency, or cost savings compared to the others.

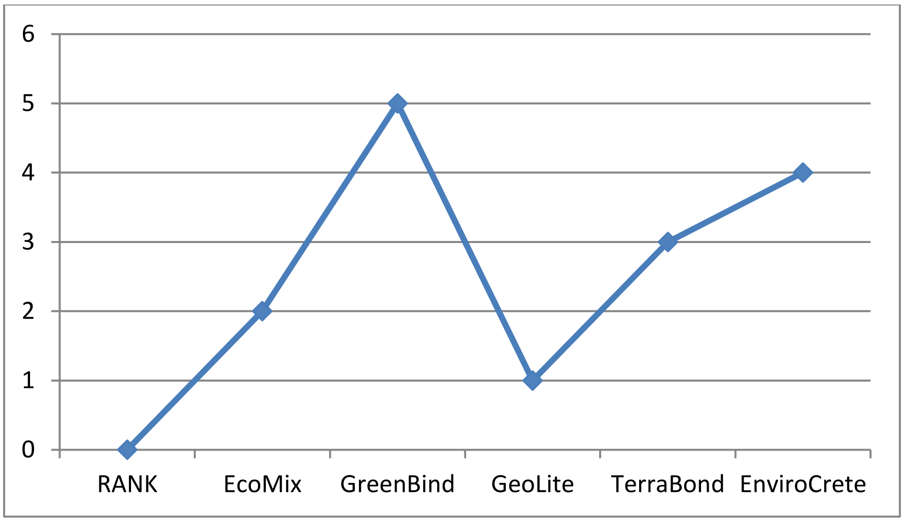

FIGURE 2. RANK

Gaolie clearly stands out with the lowest rank of **1**, showing that it is the most efficient alternative in terms of energy consumption, CO2 emissions, production efficiency, and material cost savings. This strong performance is reflected by the sharp drop in the graph at Elite's position**.** Eco Mix ranks **2**, suggesting solid overall performance, though slightly behind Gaolie. The graph shows a gradual rise after Eco Mix, indicating that the next alternative, Green Bind, is the weakest performer. With a rank of **5,** Green Bind's performance is the least favorable in the set, possibly due to higher energy consumption or lower cost savings. After Gaolie, the graph begins to rise again, with Tarragon ranked **3**, reflecting a mid-range performance. EnviroCrete, ranked 4**,** performs better than Green Bind but worse than Tarragon and Eco Mix. In summary, the graph visualizes that **Gaolie** is the top performer, while Green Bind is the least efficient**.** Eco Mix**,** Tarragon, and nviroCrete perform moderately, with Tarragon slightly outperforming EnviroCrete.

4. CONCLUSION

Industrial concrete produced from plant-based materials and waste offers a significant opportunity to reduce the environmental impact of construction. Compared to traditional Ordinary Portland Cement (OPC), geopolymer concrete offers numerous advantages, including lower CO2 emissions, reduced waste generation, and a decreased reliance on non-renewable resources. These properties not only help mitigate climate change but also enhance energy efficiency in buildings, ultimately leading to lower operational costs and improved quality of life through better thermal properties and moisture resistance. The construction industry, responsible for substantial raw material consumption and greenhouse gas emissions, faces mounting challenges, including future shortages of virgin aggregates. By adopting geopolymer technology, we can transition toward a more sustainable model that prioritizes resource efficiency and waste minimization. The incorporation of by-products such as red mud demonstrates the feasibility of utilizing waste materials, which further decreases the embodied energy associated with geopolymer production. Moreover, this research underscores the need for emerging energy-efficient technologies within the cement industry, aiming to compile and present relevant data to stakeholders such as engineers, policymakers, and investors. This is particularly important as the market continues to evolve, and stakeholders seek reliable information on sustainable practices. The potential of geopolymer concrete extends beyond its immediate environmental benefits; it offers a pathway to a circular economy in construction. By integrating life cycle assessments and environmental impact analyses, we can better understand the implications of material choices on ecosystems and resource conservation. In conclusion, this study not only highlights the advantages of geopolymer bricks over traditional materials but also advocates for a broader adoption of sustainable practices in the construction industry. By leveraging the unique properties of geopolymers and reducing dependence on conventional cement, we can pave the way for a more sustainable and resilient built environment. The research findings provide a strong foundation for future investigations and advancements in geopolymer technology, ultimately fostering a greener and more efficient construction sector.

REFERENCES

[1]. Ganesh, A. Chithambar, M. Muthukannan, S. Aakassh, and B. Subramanaian. "Energy efficient production of geopolymer bricks using industrial waste." In IOP Conference Series: Materials Science and Engineering, vol. 872, no. 1, p. 012154. IOP Publishing, 2020.
[2]. Ahmad, Muhammad Riaz, Bing Chen, M. Aminul Haque, and Sajjad Yousefi Oderji. "Multiproperty characterization of cleaner and energy-efficient vegetal concrete based on one-part geopolymer binder." Journal of Cleaner Production 253 (2020): 119916.
[3]. Rakesh Mittapally. "Assessing Normality in Healthcare Expenditure Data: A Shapiro-Wilk Test Approach In P"thons." International Journal of Computer Science and Data Engineering 2, no. 4 (2025): 1-8.
[4]. Komnitsas, Konstantinos A. "Potential of geopolymer technology towards green buildings and sustainable cities." Procedia Engineering 21 (2011): 1023-1032.
[5]. Jamieson, Evan, Benjamin McLellan, Arie Van Riessen, and Hamid Nikraz. "Comparison of embodied energies of Ordinary Portland Cement with Bayer-derived geopolymer products." Journal of Cleaner Production 99 (2015): 112-118.
[6]. Sunitha, R., and D. Supreeth. "E-Learning Accessibility: Barriers and solutions for inclusive online education." Journal of Informatics Education and Research 4, no. 3 (2024).
[7]. Divya Soundarapandian, "Algorithmic Framework for Retail Media Optimization and Consumer Engagement Enhancement", Journal of Business Intelligence and Data Analytics, 1(3), 2024, 1-7.
[8]. Cong, Peiliang, and Yaqian Cheng. "Advances in geopolymer materials: A comprehensive review." Journal of Traffic and Transportation Engineering (English Edition) 8, no. 3 (2021): 283-314.
[9]. Hasanbeigi, Ali, Lynn Price, and Elina Lin. "Emerging energy-efficiency and CO2 emission-reduction technologies for cement and concrete production: A technical review." Renewable and Sustainable Energy Reviews 16, no. 8 (2012): 6220-6238.
[10]. Sandanayake, Malindu, Chamila Gunasekara, David Law, Guomin Zhang, and Sujeeva Setunge. "Greenhouse gas emissions of different fly ash based geopolymer concretes in building construction." Journal of cleaner production 204 (2018): 399-408.
[11]. Zhang, Zuhua, John L. Provis, Andrew Reid, and Hao Wang. "Geopolymer foam concrete: An emerging material for sustainable construction." Construction and Building Materials 56 (2014): 113-127.
[12]. Frattini, Domenico, Alessio Occhicone, Claudio Ferone, and Raffaele Cioffi. "Fibre-reinforced geopolymer concretes for sensible heat thermal energy storage: Simulations and environmental impact." Materials 14, no. 2 (2021): 414.
[13]. Rakesh Mittapally, "Data-Driven Prediction of Mechanical Properties in 3D-Printed Composites Using Hybrid Machine Learning Models." Journal of Data Science and Information Technology 2, no. 2 (2025): 1-16.
[14]. Rintala, Annastiina, Jouni Havukainen, and Mariam Abdulkareem. "Estimating the cost-competitiveness of recycling-based geopolymer concretes." Recycling 6, no. 3 (2021): 46.
[15]. Zhang, Zuhau, Yingcan Zhu, Tao Yang, Liangfeng Li, Huajun Zhu, and Hao Wang. "Conversion of local industrial wastes into greener cement through geopolymer technology: A case study of high-magnesium nickel slag." Journal of cleaner production 141 (2017): 463-471.
[16]. Shahmansouri, Amir Ali, Habib Akbarzadeh Bengar, and Saeed Ghanbari. "Compressive strength prediction of eco-efficient GGBS-based geopolymer concrete using GEP method." Journal of Building Engineering 31 (2020): 101326.
[17]. Vimala Saravanan, M. Ramachandran, Arunambigai Rames, Anusuya Mohan, "Electrical Evolution in Modern Aircraft: Advancements and Challenges" Building Materials and Engineering Structures, 3(2), June 2025, 15-27.
[18]. Divya Soundarapandian, "Reliability Analysis of Data Science Workflow Components Using SPSS A Correlation-Based Study", International Journal of Computer Science and Data Engineering, International Journal of Computer Science and Data Engineering, 1(2), 2024, 1-7.
[19]. [6]. Amala VijayaSelvi Rajan, Nasser Nassiri, Vishwesh Akre, Rejitha Ravikumar, Amal Nabeel, Maryam Buti, and Fatima Salah. "Virtual reality gaming addiction." 2018 Fifth HCT Information Technology Trends (ITT) (2018): 358-363.
[20]. Mardani, Abbas, Mehrbakhsh Nilashi, Norhayati Zakuan, Nanthakumar Loganathan, Somayeh Soheilirad, Muhamad Zameri Mat Saman, and Othman Ibrahim. "A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments." Applied soft computing 57 (2017): 265-292.
[21]. Balamuralikrishna, T., N. Raghavendrasai, and M. Satya Sukumar. "Mitigating online fraud by ant phishing model with URL & image-based webpage matching." International Journal of Scientific & Engineering Research 3, no. 3 (2012): 1-6.
[22]. Badalpur, Mohammadreza, and Ehsan Nurbakhsh. "An application of WASPAS method in risk qualitative analysis: a case study of a road construction project in Iran." International Journal of Construction Management 21, no. 9 (2021): 910-918.
[23]. SUNITHA, R., and BM LINGARAJA. "A COMPREHENSIVE STUDY ON STRATEGIC MARKETING APPROACHES TO CATALYSE ELECTRIC VEHICLE ADOPTION IN INDIA." INSTITUTE OF MANAGEMENT STUDIES, DAVANGERE UNIVERSITY, Shivagangothri, Davangere, Karnataka-577007 (2025).

[24]. Ghorabaee, Mehdi Keshavarz, Edmundas Kazimieras Zavadskas, Maghsoud Amiri, and Ahmad Esmaeili. "Multi-criteria evaluation of green suppliers using an extended WASPAS method with interval type-2 fuzzy sets." Journal of Cleaner Production 137 (2016): 213-229.

[25]. Rudnik, Katarzyna, Grzegorz Bocewicz, Aneta Kucińska-Landwójtowicz, and Izabela D. Czabak-Górska. "Ordered fuzzy WASPAS method for selection of improvement projects." Expert Systems with Applications 169 (2021): 114471.

[26]. Tirumala Rao Gundala, "Performance Optimization in Large-Scale Database Migration A MultiAlgorithm Assessment", Journal of Business Intelligence and Data Analytics, 1(3), 2024, 1-6.

[27]. Tuş, Ayşegül, and Esra Aytaç Adalı. "The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem." Opsearch 56 (2019): 528-538.

[28]. Kazimieras Zavadskas, Edmundas, Romualdas Baušys, and Marius Lazauskas. "Sustainable assessment of alternative sites for the construction of a waste incineration plant by applying WASPAS method with single-valued neutrosophic set." Sustainability 7, no. 12 (2015): 15923-15936.

[29]. Anusuya Mohan, Soniya Sriram, Vimala Saravanan, M. Ramachandran, "Modeling Distribution Automation System Components Using IEC 61850 Using ARAS Method" REST Journal on Advances in Mechanical Engineering, 4(3), 2025, 1-12.

[30]. Kandula, Nagababu. "Innovative Fabrication of Advanced Robots Using the Waspas Method a New Era in Robotics Engineering." IJRMLT 1 (2025): 1-13.

[31]. Yücenur, G. Nilay, and Ahmet Ipekçi. "SWARA/WASPAS methods for a marine current energy plant location selection problem." Renewable Energy 163 (2021): 1287-1298.

[32]. Karthik Perikala, "Architecting Retail-Scale Vector Store Systems for Agentic Generative AI", International Journal of Computer Engineering and Technology (IJCET), 17(1), 2026, 1-14. DOI: 10.34218/IJCET_17_01_001

[33]. Mishra, Arunodaya Raj, and Pratibha Rani. "Multi-criteria healthcare waste disposal location selection based on Fermatean fuzzy WASPAS method." Complex & Intelligent Systems 7, no. 5 (2021): 2469-2484.

[34]. Mishra, Arunodaya Raj, Pratibha Rani, Kamal Raj Pardasani, and Abbas Mardani. "A novel hesitant fuzzy WASPAS method for assessment of green supplier problem based on exponential information measures." Journal of Cleaner Production 238 (2019): 117901.

[35]. Tirumala Rao Gundala "Oracle OIPA Cloud Migration Analysis: Machine Learning Models for Predicting Resource Utilization and Success Outcomes." International Journal of Artificial intelligence and Machine Learning 2, no. 3 (2024): 1-8.

[36]. Kandula, Nagababu. "Gray Relational Analysis of Tuberculosis Drug Interactions A Multi-Parameter Evaluation of Treatment Efficacy." Journal of Computer Science Applications and Information Technology 8 (2), (2023), 1-10.

[37]. Mishra, Arunodaya Raj, and Pratibha Rani. "Interval-valued intuitionistic fuzzy WASPAS method: application in reservoir flood control management policy." Group Decision and Negotiation 27 (2018): 1047-1078.

[38]. Mishra, Arunodaya Raj, Rahul Kumar Singh, and Deepak Motwani. "Multi-criteria assessment of cellular mobile telephone service providers using intuitionistic fuzzy WASPAS method with similarity measures." Granular Computing 4 (2019): 511-529.

[39]. Sunitha, R. "Financial Institution's Role in Supply Chain Risk Management: Strengthening Resilience and Mitigating Financial Risks." REST Journal on Emerging Trends in Modelling and Manufacturing 10, no. 2 (2024): 1-7.

[40]. Vikas, B., Satya Sukumar Makkapati, Srinivasa Rao Bogireddy, K. S. Balamurugan, and M. Deepa. "Advancements in lung cancer diagnosis: A comprehensive study on the role of PCA, LDA, and t-SNE in deep learning frameworks." In 2024 Asian Conference on Communication and Networks (ASIANComNet), pp. 1-7. IEEE, 2024.

[41]. Karthik Perikala, "A Modular Benchmarking Framework for Evaluating LLM-Based Agent Applications", International Journal of Research in Computer Applications and Information Technology (IJRCAIT), 9(1), 2026, 1-14. DOI: https://doi.org/10.34218/IJRCAIT_09_01_001

[42]. Sunitha, R. "A Study On Knowledge Base and Skill Development in Financial Accounting Using The SPSS Method." Journal on Innovations in Teaching and Learning, 3(2), June 2024, 1-12

[43]. AlMheiri, Nawal Harib, Amala VijayaSelvi Rajan, and Vishwesh Akre. "Framework for Open-Source Software implementation in the Government Sector of Dubai." In 2018 Fifth HCT Information Technology Trends (ITT), pp. 71-76. IEEE, 2018.