*14th Annual International Conference on Industrial Engineering and Operations Management Dubai United Arab Emirates (UAE), February 12-14, 2024*

Publisher: IEOM Society International, USA DOI: 10.46254/AN14.20240617
Published: February 12, 2024

# Zeolite as an Alternative Exhaust Filter

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## Abstract

The Earth, a complex and interconnected system, faces an imminent threat from climate change, exacerbated by escalating carbon emissions. The Philippines addressed air quality concerns with the Clean Air Act of 1999, emphasizing mobile sources like vehicles. This paper proposed a catalytic converter prototype incorporating zeolite to assess its efficiency in reducing carbon emissions. Employing an experimental approach, the study utilizes t-tests as a statistical tool to compare carbon emissions between vehicles with and without the zeolite-based catalytic converter and value analysis and value engineering to optimize the production process and reduce costs. Based on the obtained results, *"Z-Lite"* is a profitable alternative exhaust filter for diesel engines, showcasing its potential to reduce carbon emissions significantly. The statistical analysis, yielding a low p-value, supports the hypothesis that zeolite filters effectively reduce carbon emissions. With over 100 emission centers in the Philippines, the marketability of Z-Lite in Marikina City underscores its practicality in addressing environmental concerns and promoting sustainable practices in the transportation industry. The integration of value analysis and value engineering ensures that it is both environmentally friendly and affordable, making it a promising and sustainable choice for mitigating the environmental impact of diesel engine emissions.

## Keywords

Carbon Emission, Zeolite, Catalytic Converter, Diesel Engine, Z-Lite

## 1. Introduction

Earth is such a complex domain, as it persists in requiring different things to maintain its harmony. However, everything that people should ensure does have a significant impact on the environment. According to research undertaken by Weiskopf (2020), climate change poses a widespread and escalating worldwide menace to biodiversity and its ecosystems. As climate change constitutes a surging combination worldwide throughout the dominion, this particular phenomenon impacts individual species, influencing their interactions with other animals and habitats. Consequently, this spearheads modifications in the structure and functioning of ecosystems and the provision of products and services by natural systems to civilization (Díaz et al., 2019).

The amount of carbon emissions trapped in the atmosphere contributes to the worsening case of climate change in the domain. Several harmful effects on the environment, human and animal life, and the future of the populace, including melting the polar ice caps, rising sea levels, disruption of animal habitats, and extreme weather events, are also contained within this dilemma.

Since transport is one of the fastest growing sectors contributing to emissions, using catalytic converters on vehicles shows a practical approach to lessen the harmful pollutants. The researchers proposed further improving the catalytic converter's efficiency by incorporating it as a zeolite, creating an emission filter for automotive vehicles. The natural

zeolites forming the corresponding group of tectosilicate mineral subclass, due to their specific crystal-chemical characteristics providing unique ion exchange and molecular sieve properties, are known as effective adsorbents and catalysts.

The zeolites are highly rigid under dehydration and various aggressive surrounding actions. The zeolites' molecular sieving and other physio-chemical properties can be managed by thermal or chemical treatment. Such features provide the practical and comprehensive utilization of these materials in industry, agriculture, medicine, environmental protection, and other fields (Cobzaru, 2012). These properties make the zeolite an ideal choice for catalytic converters, as it can effectively reduce the emission of hazardous pollutants from automotive engines.

Holman (1999) states that power stations and road transport are two primary sources of classical air pollutants. However, the contribution of different sources varies between countries and within countries. Emissions from moving cars and smoke-belching are linked to air pollution, a growing worldwide concern, particularly in the Western Pacific and Southeast Asian regions. The Philippines established the Clean Air Act of 1999 to address the growing concern over the quality of the country's air, which included mobile sources like vehicles. According to the study conducted by Olabi et al. (2020), the overall emissions that the automotive industry produces each year are a complex problem that has recently affected the industry. This investigation concludes that these toxic emissions are generated by diesel engine cars.

Zeolite exhaust filters use mineral zeolite to remove PM from vehicle exhaust due to its porous nature, making it a main compound that traps PM particles on its surface. Zeolite exhaust filters are already used in various applications, including industrial settings and some vehicles (Stern, 2024). Nevertheless, zeolites have yet to be widely used in the Philippines.

## 1.1 Problem Statement

Today, air pollution is an unavoidable factor. Air pollution is caused by substances in the form of particles or gases suspended in the air and negatively impacts the environment and living things in both direct and indirect ways. Zalakeviciute et al. (2020) stated that air pollution is a global environmental issue that worsens quickly, particularly in developing nations.

Faiz and Mundial (1990) state that although carbon dioxide builds up and contributes to the greenhouse effect, it has no direct adverse impact on public welfare or human health. In addition to nitrous oxides, methane, chlorofluorocarbons (CFCs), and ozone, other greenhouse gasses trap heat, both leading others to global warming and possible climatic changes. The following greenhouse gasses currently contribute to global warming in roughly the following amounts: carbon dioxide (49–55%), chlorofluorocarbons (14–25%), methane (12–18%), nitrous oxides and other gasses (13–19%).

This paper proposed enhancing automotive catalytic converters by incorporating zeolite as a filtering mechanism. The study aimed to design and develop a prototype catalytic converter with an integrated alternating butterfly valve and zeolite tailored for non-euro four diesel engines. The primary goal was to reduce carbon emissions and address critical questions, including comparing performance with existing catalytic converters, assessing significant differences, evaluating effectiveness through emission/kiloton meter testing, and identifying areas for improvement based on testing center feedback.

## 1.2 Objectives

This study examines and suggests approaches for mitigating carbon emissions within the transportation industry, particularly in cars powered by diesel engines. The aim is to address the issue of climate change and enhance air quality. Specific objectives of this study are to investigate and evaluate various strategies for mitigating carbon emissions in the transportation industry, focusing on diesel vehicles, to determine if the experimental catalytic converter designed to reduce carbon emissions from vehicles performs comparably to the extant catalytic converters widely used in the automotive industry; to evaluate its potential to reduce carbon emissions in kilotons; and to identify and address specific areas in the design and operation of the prototype zeolite-based catalytic converter that may require improvement based on the results and feedback obtained from the emission testing center.

### 1.3 Hypothesis

$H_0$: No significant difference in carbon emissions is observed between motor vehicles fitted with zeolite filters and those equipped with conventional catalytic converters.
$H_A$: Automotive vehicles equipped with zeolite filters exhibit a notable decrease in carbon emissions compared to conventional catalytic converters.

### 1.4 Scope and Limitations

This study focuses on the effectiveness of natural zeolite as a filter in the catalytic converter of automotive vehicles, specifically diesel engines. It was an experiment in Marikina City, and thoroughly investigated institutions with emission testing centers in Marikina City, which has over 100 emission centers in the Philippines, this study conducted emission testing and used observation sheets and checklists or scales to record significant differences in a diesel engine without natural zeolite on the catalytic converter and with natural zeolite on the catalytic converter equipped. The study will only cover automotive vehicles that use diesel engines and not tackle other car types.

## 2. Literature Review

Zeolite has been identified as a potential agent in mitigating the release of greenhouse gasses, particularly carbon dioxide, which is widely recognized as the principal contributor to global warming. Implementing more rigorous emission regulations presents a promising avenue for using zeolites as commercial catalysts (Li et al., 2022). Due to zeolites' inherent structural characteristics, it presents a viable avenue for addressing emission control concerns, enabling automobile engine manufacturers or companies to adopt a more comprehensive strategy for mitigating emissions. Zeolites can function as molecular sieves by utilizing small cages that selectively filter molecules according to their particle sizes. A loosely attached negative surface charge binds minerals – thus, they can substitute numerous undesirable substances with beneficial alternatives (Ristic, 2021).

A study by Arambala (2021) assessed the effectiveness of the smoke filter based on the emission test results. It concluded that the smoke filter is feasible and effective in reducing carbon monoxide and hydrocarbons caused by motor vehicle exhaust. The positive result of the study brings a promising prospect that zeolite can also filter emissions on massive engines and any other exhaust that produces more hydrocarbons. Even the present catalytic converter provides a considerable cut-off on the emission exhaust; it still has space to improve. One problem is that it only works at high temperatures - over 300°C/600°F (Woodford, 2022). This problem with catalytic converters could be more effective regarding cold emission. In a study conducted by Gao et al. (2019), it was found that the maximum concentrations of CO and unburned hydrocarbons emitted out of the exhaust engine during cold emissions ranged from 950 ppm to 8400 ppm and from 220 ppm to 28,000 ppm. It shows that engines emit massive carbon emissions at the start of the engine, and the present catalytic converter does not cover this period because it needs high heat for it to be able to catalyze.

Coz et al. (2015) assert that the Philippine Jeepney holds a prominent position as a widely utilized, easily accessible, and economically viable mode of public transportation inside the nation. The public utility jeepneys (PUJs) have emerged as notable symbols of Filipino ingenuity and inventiveness in contemporary times. It has also become the primary means of public transportation in the Philippines, with a substantial fleet of 220,114 registered units as of 2012. Given the growing prevalence of private vehicles and other forms of public transport, it is noteworthy that public utility jeepneys continue to be the nation's most cost-effective means of transit. Jeepney drivers in the Philippines choose diesel fuel to save vehicle maintenance and fuel use costs. The ongoing carbon dioxide emission into the atmosphere contributes to environmental degradation by inducing air pollution.

According to the findings of Magalhães et al. (2022), the efficacy of zeolite in removing contaminants is contingent upon the specific contaminant in question. Their investigation revealed that zeolite can achieve up to 96% removal efficiencies for heavy metals, 90% for phosphoric compounds, 96% for dyes, 80% for nitrogen compounds, and 89% for organic compounds. Based on the research conducted by Soudejani et al. (2019), the application of compost treated with zeolite has exhibited a notable reduction in the levels of total and bioavailable heavy metals (HMs), together with a decrease in the occurrence of antibiotic resistance genes. Applying zeolite has been observed to yield beneficial effects on compost quality by promoting maturity and reducing salt concentrations. Incorporating zeolite-amended compost led to a notable improvement in agricultural production, as evidenced by an increase in crop yield, higher water retention capacity, and the prevention of soil nutrient depletion.

Value engineering is a tool used by several industries to enhance operations, reduce manufacturing costs, and enhance the design of products and processes. Sison et al. (2018) suggested two ideas utilizing VA/VE and the Design of a Facility from the linked literature to optimize a wood manufacturing company's current processes. The study shows how ProModel Simulation, process VA/VE, and Design Layout may be applied to the current processes. The simulation's output leads to an 80% increase in production. Furthermore, Palisoc et al.'s (2019) study aims to enhance a media broadcasting company's remote production setup by considering trade-offs based on pertinent limitations including Material VA/VE, Product VA/VE, Process VA/VE, Ergonomics, Economic, and Productivity. Additionally, Navarro, M.M., Navarro, B.B. (2022), and Navarro et al. (2022) incorporate VA/VE in the semiconductor industry's fabrication and manufacturing process as well as the fabrication of stainless steel sheets.

## 3. Methods

In this study, the main objective is to examine and suggest approaches for mitigating carbon emissions within the transportation industry, particularly in cars powered by diesel engines. The study aims to address climate change and enhance air quality. This paper used observation, emission testing results, t-test, value analysis and engineering (VaVe), and time and motion study (TMS) as data collection methods. This study conducted two separate emission tests with different variables. First, this study tested the engine without a zeolite inside the catalytic converter to see the baseline result of the diesel engine. The second test would be testing the diesel engine with a zeolite inside the catalytic converter, which acts as an emission filter created by the researchers. The primary purpose was to lessen carbon emissions in diesel engines. The result of each test for each variable was recorded. The researchers conducted multiple tests to get the mean. The device was designed to lessen smoke emissions by changing the exhaust flow direction within each section.

Figure 1. Diesel Carbon Emission Without Z-Lite

Figure 2. Diesel Carbon Emission With Z-Lite

Figures 1 and 2 compare data gathered for the diesel carbon emission for the diesel engine equipped with Z-Lite and without the Z-Lite attached. Based on the carbon emission testing, a diesel engine equipped with Z-Lite emits less carbon than a diesel engine without Z-Lite attached.

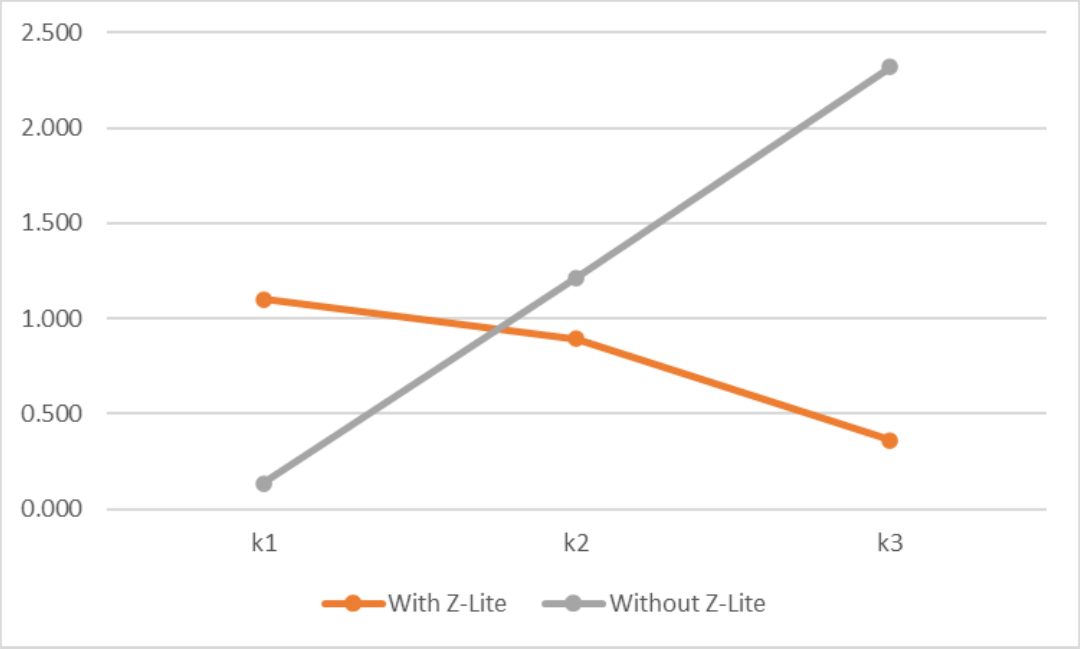


Figure 3. Carbon Emissions in Kilotons Results for the Diesel Engine with and without Z-Lite

Figure 3 compares data gathered for the carbon emission in kilotons for diesel engines equipped with and without a Z-Lite device. Based on the test results, Z-Lite performs the best in reducing carbon emissions, being significantly lowest compared with no device attached in emission testing. The emission standard result is based on the year model of the test vehicle (1/1/1900 to 12/31/2017, with a 2.5 kiloton passing rate).

**Estimation for Difference**

| Difference | Pooled StDev | 95% CI for Difference |
|---|---|---|
| 0.439 | 0.818 | (-1.415, 2.293) |

**Test**

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

| T-Value | DF | P-Value |
|---|---|---|
| 0.66 | 4 | 0.547 |

| ↓ | C1 | C2 | C3 |
|---|---|---|---|
| | With Z-Lite | Without Z-Lite | |
| 1 | 1.100 | 0.136 | |
| 2 | 0.893 | 1.215 | |
| 3 | 0.359 | 2.319 | |

Figure 4. T-test Result Using Minitab

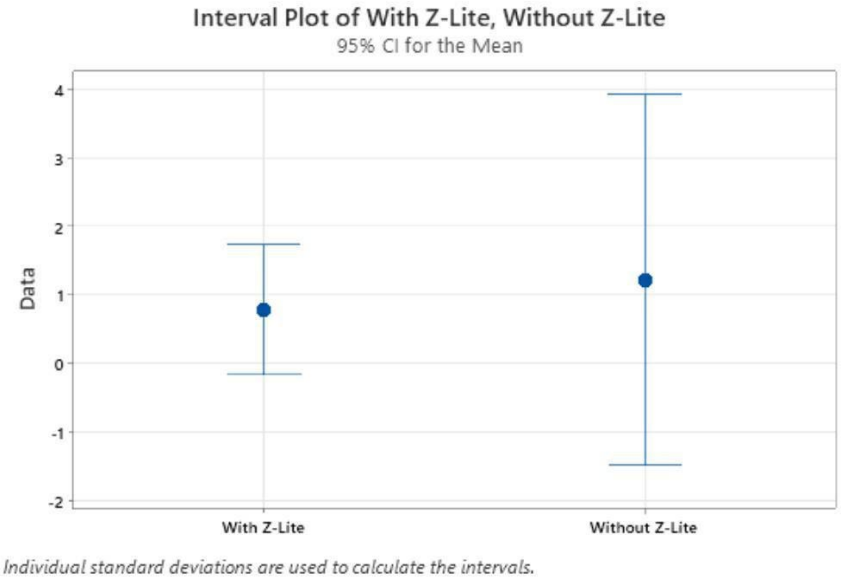


Figure 5. Interval Plot of With and Without Z-Lite

Figures 4 and 5 show the obtained through Minitab, comparing carbon emissions between motor vehicles equipped with and without zeolite filters. The statistical analysis yields a T-value of 0.66, a Degree of Freedom of 4, and a P-value of 0.547.

The null hypothesis (H0) posits no significant difference in carbon emissions between vehicles with zeolite filters and those with conventional catalytic converters. Conversely, the alternative hypothesis (HA) suggests that cars with zeolite filters exhibit a notable decrease in carbon emissions compared to those with traditional catalytic converters.

The obtained P-value of 0.547 is more significant than the chosen significance level, resulting in rejecting the null hypothesis in support of the alternative perspective. Hence, the study concludes that there is a substantial difference in carbon emissions between vehicles with and without Z-Lite, supporting the idea that zeolite filters reduce carbon emissions.

Table 1. Components and Costs of Z-Lite

| **Components** | **Costs (PHP)** |
|---|---|
| Zeolite Rocks | 100 |
| 4” 1.5 mm Stainless Tube | 225 |
| 2.5” 1.2 mm Stainless Tube | 58 |
| Stainless Sheet | 18.26 |
| Perforated | 8.26 |
| Total: | **409.52** |

Table 2. Components and Costs of Traditional Catalytic Converter

| Components | Costs (PHP) |
|---|---|
| Catalyst | 1,606.11 |
| Substrate | 2,608 |
| Heat Shield | 5,546 |
| Oxygen Sensor | 3,658 |
| Exhaust Manifold | 6,465.96 |
| Total: | **19,884.07** |

Tables 1 and 2 show the components and costs of the proposed and traditional catalytic converter. The study reveals that the proposed catalytic converter is more affordable than the conventional one.

Table 3. Comparative Value Analysis and Value Engineering for Z-Lite and Traditional Catalytic Converter

| Description | Value | Reasoning |
|---|---|---|
| Zeolite Rocks | Low | Zeolite rocks contribute to cleaner combustion by effectively filtering and catalyzing impurities. They are in line with emission control regulations and reasonably priced. |
| Catalyst | High | The catalyst, frequently made of valuable metals, is essential for changing dangerous pollutants into less harmful ones. It is more costly, but it is vital to lowering emissions. |
| Stainless Tubes | Medium | It guarantees the filter's longevity and structural integrity, which improves exhaust gas flow efficiency. |
| Substrate | High | The substrate offers a robust framework for the catalyst to allow for sufficient surface area for contact between exhaust gasses and the catalyst |
| Stainless Sheet | Low | Its assistance with effective catalysis and filtering enhances the Z-Lite filter’s total efficacy. |
| Heat Shield | High | Its nearby components form excessive heat to maintain an ideal operating temperature during catalytic processes. |

| | | |
|---|---|---|
| Perforated | Low | It improves gas flow and interaction with zeolite to improve filtration and catalysis in the Z-Lite filter. |
| Oxygen Sensor | High | Its real-time data enables the engine control unit to modify the air-fuel mixture for the best catalytic converter performance. |
| Overall Cost of Z-Lite | Potentially Cost-Effective | The modular design of the Z-Lite filter makes it possible to replace individual parts, which could lower maintenance costs. |
| Overall Cost of Traditional Catalytic Converter | Higher Overall Cost | The conventional approach has a track record of success, but adding costly metals to the catalyst raises the overall cost. |
| Environmental Impact of Z-Lite | Positive | It complies with environmental regulations and helps to promote cleaner combustion by lowering carbon emissions. |
| Environmental Impact of Traditional Catalytic Converter | Positive | Although the extraction and processing of precious metals may have an impact on the environment, it was effective in transforming harmful contaminants. |
| Durability of Z-Lite | High | Stainless steel parts contribute to durability and corrosion resistance. |
| Durability of Traditional Catalytic Converter | High | The substrate and other parts contribute to its durability. |
| Efficiency of Z-Lite | High | It is created for efficient filtration and catalysis, contributing to a cleaner combustion procedure. |
| Efficiency of Traditional Catalytic Converter | High | Efficient in converting pollutants, with catalyst being a key component. |
| Adaptability of Z-Lite | High | Modular design may make the replacement of individual components more accessible adaptation possible. |
| Adaptability of Traditional Catalytic Converter | Moderate | While more complex replacements could be needed for integrated designs, the conventional converter is still extensively used. |

A comparison of value analysis and value engineering of the current and proposed catalytic converter is shown in Table 3, along with its reasoning. The study reveals that by utilizing value engineering and analysis, "Z-Lite" demonstrates a substantial foundation for maximizing its exhaust filter's design, functionality, and cost. Through these approaches, the proponents want to present a reasonably priced remedy that not only efficiently lowers carbon emissions from diesel engines but also has a beneficial effect on the environment and the economy. Z-Lite is a viable option for long-term and significant diesel engine pollution management because of its modular design, low cost, and emphasis on excellent filtration and catalysis.

## 4. Conclusions

This study discovered Z-Lite to be a viable alternative exhaust filter for diesel engines, potentially significantly lowering carbon emissions and improving air quality. When included, Z-Lite efficiently filters out hazardous pollutants, reducing the adverse environmental effects of diesel engines. It highlights Z-Lite's potential as a valuable remedy for mitigating ecological issues related to diesel engine exhaust, enhancing overall air quality. It has also been revealed that zeolite is an adequate alternative exhaust filter for lowering carbon emissions from diesel engines. Its marketability in Marikina City emphasizes its applicability and utility in resolving environmental challenges and promoting sustainable habits, as evidenced by the more than 100 emission centers in the Philippines.

## References

Cobzaru, C, Modified zeolites: Modification of natural zeolites for catalytic applications, In BENTHAM SCIENCE PUBLISHERS eBooks (pp. 185–213), 2012, https://doi.org/10.2174/978160805261511201010185

Faiz, A., and Mundial, B, Automotive air pollution, Banco Mundial, 1990

Li, J., Meng, X., and Xiao, F, Zeolites for control of NOx emissions: Opportunities and challenges, Chem Catalysis, 2(2), 2022, https://www.sciencedirect.com/science/article/pii/S2667109321003286

Magalhães, L. F., Silva, G. R., and Peres, A. E. C, Zeolite Application in Wastewater Treatment. Adsorption Science and Technology, 2022, Article ID 4544104, 26 pages, 2022, https://doi.org/10.1155/2022/4544104

Navarro, M., and B. Navarro B., A Multi-Criteria VA/VE Design Case Study for fabricating Stainless Steel Equipment 304 and 430, Proceedings of the 1st Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, December 21, 2022, https://doi.org/10.46254/AU01.20220458.

Navarro, M., M. Bangayan J., and B. Navarro B., VA/VE in optimizing the process of Semiconductor Industry in the Philippines, Proceedings of the 1st Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, December 21, 2022, https://doi.org/10.46254/AU01.20220459.

Palisoc, A.A, Semifrania,G.O, Kurata, Y.B and Navarro M.M., Design Optimization of Equipment Controls Setup and Workstation Tables for the Remote Production Taping of a Media Broadcasting Company, Proceedings of the International Conference on Industrial Engineering and Operations Management Bangkok, Thailand, March 5-7, 2019.

Sison, J.P.,Jalac,P.I., Dinglasan J.M.,Navarro,M.,Palisoc, A., and Torres, M.J., Process Value Analysis for Wood-Based Furniture Company in the Philippines using VA/VE Approach , Proceedings of the International Conference on Industrial Engineering and Operations Management Bandung, Indonesia, March 6-8, 2018

Zalakeviciute, R., Vasquez, R., Bayas, D., Buenano, A., Mejia, D., Zegarra, R., Diaz, V., and Lamb, B, Drastic improvements in air quality in Ecuador during the COVID-19 outbreak, *Aerosol and Air Quality Research 20(8): 1783–1792*, 2022

## Biographies

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**Maricar M. Navarro** has the prestigious title of ASEAN Engineer (AE) and is a Professional Industrial Engineer (PIE) recognized by the Philippine Institute of Industrial Engineers (PIIE). She is currently an Associate Professor and a Professor in the Graduate School Program at Technological Institute of the Philippines. Her areas of expertise are optimization of production processes, facility layout design, warehouse operations, and service delivery. Her area of interest is in financial optimization and decision-making in operations research, and she holds both a master's and a Ph.D. in Industrial Engineering from Mapua University. As a committed member and Professional Industrial Engineer, Dr. Navarro actively contributes to the Philippine Institute of Industrial Engineers (PIIE).