IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

Investigating the integration of sustainable principles in engineering designs and their impact on the environment and economy

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Abstract

This study examines how sustainable practices are incorporated into engineering designs and how they affect the economy and environment. The purpose of the study is to investigate how sustainable engineering practices affect these two important factors. The study investigates the possible advantages and difficulties of integrating sustainable practices into engineering practices by examining the integration of sustainable principles in engineering designs. The study technique entails a thorough evaluation of the body of literature, case studies, and offers insights into the state of sustainable engineering practices at the moment and their effects on the economy and environment. The Environmental, Social, and Governance (ESG) framework is also used in the study to evaluate the ethical and sustainability implications of engineering projects. In order to comprehend how ESG aspects, such as social repercussions, governance practices, and environmental concerns, affect the results of sustainable engineering, these factors are examined. The study emphasizes the value of doing life cycle analyses to examine the environmental effect of engineering designs over the course of their full life cycle, from the extraction of raw materials to disposal. The study highlights how crucial it is to include ESG factors, especially LCA, early in the design process to improve the environmental and financial results of engineering projects.

1. Introduction

One of the most important steps in resolving environmental issues and fostering a more sustainable future is the incorporation of sustainable ideas into engineering designs. This type of integration entails taking into account an engineering project's overall environmental, social, and economic implications. The environment may be significantly improved when sustainable practices are included into engineering designs. Sustainable designs assist to conserve resources and lessen the harmful consequences of engineering operations on ecosystems by minimizing the use of non-renewable resources, cutting down on energy usage, and minimizing waste output [1]. Engineering solutions that use sustainable principles may benefit the economy as well. Although introducing sustainable designs may require an initial expenditure, they frequently lead to long-term cost benefits. For instance, by minimizing energy usage, energy-efficient buildings cut operational expenses and subsequently utility prices [2]. Given the rising need for ecologically and socially responsible solutions, sustainable designs may also increase the worth and marketability of infrastructure projects. Sustainable engineering approaches can also help build an infrastructure that is more adaptive and robust. To maintain long-term sustainability and lower the risk of damage or interruption, infrastructure should be designed to account for climate change forecasts, such as rising sea levels or an increase in the frequency of extreme weather events. Engineering designs that use sustainable principles may promote innovation and promote economic prosperity. It opens up possibilities for the creation and use of novel materials, techniques, and technologies [3]. This may result in the development of jobs in industries like renewable energy, environmentally friendly buildings, and sustainable transportation. Societies may promote the transition to a more sustainable and resilient economy by coordinating engineering practices with sustainable aims.

Considering the purpose of reducing environmental effects and fostering a more resilient and sustainable future, it is essential to include sustainable concepts in engineering designs. Sustainable designs may help preserve resources, decrease emissions, improve resilience, and provide economic possibilities by taking the environment and economy into account throughout the whole life cycle of engineering projects [4]. The study explores the trade-offs and difficulties that may arise when incorporating sustainable practices into engineering projects. It looks at things like market acceptability, stakeholder participation, regulatory frameworks, and technical constraints. The study investigates the function of incentives and governmental interventions in advancing sustainable engineering practices. The study emphasizes how crucial it is to implement sustainable practices, consider ESG aspects, and carry out LCA to slow down environmental deterioration and ensure long-term economic sustainability. In order to encourage a more sustainable and environmentally sensitive approach to engineering practices, the study offers insights and recommendations for engineers, policymakers, and stakeholders to support incorporating sustainable concepts into engineering designs. This study emphasizes the value of incorporating sustainable practices, including ESG considerations, and performing life cycle assessments (LCA) in engineering designs to solve environmental problems, encourage social responsibility, and spur economic growth [5]. It examines environmentally friendly design methods such using renewable materials, waste reduction techniques, and energy-efficient systems. The study assesses the long-term financial gains, resource efficiency, and cost-effectiveness of sustainable engineering from an economic perspective. The research emphasizes the need of working together among engineers, decision-makers, and stakeholders to guarantee sustainable growth and have a good influence on the economy and the environment [6]. The key contributions of the investigation are as follows,

- Utilizing secondary data sources such as real reference
- Applying Life Cycle Assessment (LCA) methodology to assess environmental impacts across different life cycle stages
- Applying ESG principles to guide the selection of materials, construction processes, and end-of-life management strategies
- Identifying strategies for effective integration of sustainable principles, including material selection, energy efficiency improvements, waste management, and circular economy practices

2. Literature Review

Litvinenko et al. [7] examines the effects of the monopolization and decreased supply of certain minerals and emphasizes the necessity for international legal standards to predict and implement environmental policies. The importance of professional expertise in resource extraction firms is acknowledged at the opening of the article, particularly in regard to ESG principles. It emphasizes that a company's capacity to adhere to ESG norms and foster stakeholder confidence is strongly impacted by the level of professional competence. A useful method for evaluating and enhancing the skills of resource extraction engineers is provided by the suggested system for identifying professional competences based on the "International Standards for Resource Extraction Engineers (ISREE)". This paper's emphasis on incorporating ESG principles and sustainable development objectives into the evaluation of professional abilities is one of its highlights. The fact that the authors took into account additional knowledge needs for topics like ethics, safety, the environment, and financial viability demonstrates their understanding of the complex nature of sustainable resource extraction. This strategy emphasizes the significance of ethical and sustainable business practices. In addition, the study provides a methodology and digital indicators for assessing the operations of publicly traded extractive businesses while taking into consideration ESG guidelines and sustainable development objectives. This work is notable because it deals with the issue of fostering trust among local communities impacted by resource extraction operations and the necessity for openness. The research gives useful insights towards encouraging sustainable practices and stakeholder involvement by offering a methodology for assessing the social and environmental effect of extractive enterprises.

` Chen et al. [9] seeks to strike a balance and offers a new classification scheme for GCP, breaking it down into three major components: safety and sustainability, and pollution and avoiding accidents. A systematic framework for evaluating GCP practices in the context of the circular economy is provided by this category. In order to shed light on the international movement of GCP in policies across several nations, the paper also suggests five methods for putting GCP implementation in the circular economy at the top of the priority list. The implementation of cross-departmental collaboration, the creation of greener manufacturing processes and products, the supply of integrated-chemical-management systems, the adoption of Green-chemistry-education initiatives, and the development of business models are some of these measures. The authors offer helpful advice for incorporating GCP into the idea of the circular economy and encouraging sustainable practices in diverse industries by defining these techniques. The report also examines the possible advantages and futures of the discipline components linked to the adoption of GCP. Although, there is no quantitative evidence or statistical analysis to back up the study's results and assertions, the study's findings would be more credible and solid if they were supported by empirical facts and quantitative information.

Van Eldik et al. [10] explains the increasing significance of sustainability in infrastructure projects and investigates how Environmental Impact Assessment (EIA) and Building Information Modeling (BIM) might be combined. The study identifies a number of shortcomings in the method currently used to combine EIA and BIM and suggests a framework for continuous and reciprocal data exchange between the two. The strength of the article is in identifying the current difficulties in conducting EIA during the design phase of infrastructure projects. The authors correctly point out that conventional EIA procedures used towards the conclusion of the design cycle can be expensive and time-consuming, making it challenging to integrate changes. These difficulties may be overcome through the integration of EIA with BIM, which enables continuous evaluation and instantaneous visualization of environmental consequences. The suggested framework tries to solve the drawbacks of the existing integration strategy. Improving interoperability and flexibility necessitates the creation of an explicit data structure and the capacity to include data from diverse sources. Designers are empowered to make informed decisions and monitor the development of the design in terms of its environmental effect thanks to the bidirectional data exchange feature, which enables them to see the findings of EIA in real-time. The creation and evaluation of a prototype on a case study serve to show the viability of the suggested framework in the article. The framework's functionality, usability, scalability, and contribution to sustainability consciousness were evaluated by professionals in a workshop, which strengthens the validity of the research. It is interesting that experts have given the tool high marks for easing EIA and integrating it into the decision-making process.

3. Problem statement

The present state of acquaintance regarding the integration of sustainable principles in engineering designs and its impact on the environment and economy is limited. There is a need to investigate and analyze the direct linkages between sustainable principles, engineering design decisions, environmental outcomes, and economic performance. While there is a growing recognition of the need for sustainable engineering practices, there remains a lack of comprehensive understanding of the direct implications and quantifiable outcomes of integrating sustainable principles in engineering designs [11]. This research gap hinders the effective implementation of sustainable practices and decision-making processes in engineering projects.

4. Life cycle assessment for the impact on the environment and economy

By integrating LCA into the design process, engineers can better understand the potential environmental impacts of their designs, make informed decisions, and identify areas for improvement. This integration supports the integration of sustainable principles in engineering designs, ultimately leading to environmentally conscious and economically viable solutions.

Material Quantities (A_1-A_3):

Knowledge of the substance amounts utilized in actual construction endeavors is available from real references case structures and professional construction documents. They serve as valuable sources of data for understanding typical material requirements in engineering designs.

Material Database: *Ecoinvent, GaBi*:

Ecoinvent and GaBi are well-known material databases that provide comprehensive data on the environmental impacts of different materials. These databases contain information on factors such as resource consumption, energy use, and emissions associated with various materials throughout their life cycles.

Environmental Product Declaration *(EPD)*:

EPDs are standardized documents that provide transparent and verified information about the environmental performance of products, including building materials. EPDs include data on factors such as carbon footprint, energy consumption, and resource use. They serve as valuable sources of information for assessing the environmental impacts of materials and products.

Average European Transport Distance:

Statistics on the typical distances of transportation for each type of material that's used in engineering plans are provided by this additional information resource. It helps estimate the environmental impacts associated with the transportation of materials from their source to the construction site.

Table 1: **Life cycle assessment for engineer design**

Area of Analysis	**Data Sources and Assumptions**
Material-quantities (A_1–A_3)	Data inventories utilizing documents for technological structures and real-world references cases sites Material database: *Ecoinvent, GaBi* Environmental-Product-Declaration is a source of ecological statistics. If it's practicable, average geographical data from Europe. If not, a local contractor was chosen.
Building-material transport-distances (A_4)	The typical European transportation distance for every kind of commodity
Construction and installation-process (A_5)	The calculating method of the basic scenarios served as the basis for an average of emissions during the building phase
Material-service-lifetime (B_4–B_5)	As per the Environmental Product Declaration
Building use phase energy-consumption (B6)	The calculation of energy usage using actual measured data from several shops. Calculations of emissions from grid power were made using the European energy mix.
End-of-Life-Stage (C_1–C_4)	based on a case study the calculator provides
Total-lifetime TLT	40 years

Average Emissions for Construction Process:

The calculating tool's basic assumption serves as the basis for the standard emission for the building phase. This secondary data source provides information on typical emissions associated with construction activities, enabling the assessment of environmental impacts during the construction phase.

Environmental Data for Building Use Phase:

Real measured data from different stores is used to determine the energy consumption during the use phase of buildings. The European energy composition is used to compute grid power emissions, which is a secondary data source providing information on the composition of the energy supply and associated emissions.

Scenario for End-of-Life Stage:

The end-of-life stage is based on a scenario provided in the calculation tool. This secondary data source outlines the typical pathways for waste management, recycling, and disposal practices, which are crucial for understanding the environmental impacts associated with the end-of-life phase of engineering designs.

These data sources and assumptions provide a basis for conducting a life cycle assessment for the integration of sustainable principles in engineering designs. It is important to use relevant and reliable data sources, adapt them to the specific context of the designs being studied, and consider any regional or local variations that may impact the environmental and economic performance [12].

4.1 ESG in engineering designs and their impact on the environment and economy

Environmental, Social, and Governance refers to a set of criteria or principles used to assess and evaluate the sustainability and ethical practices of a business or organization. In the context of investigating the integration of sustainable principles in engineering designs and their impact on the environment and economy, ESG principles provide a framework for considering the broader environmental, social, and governance aspects associated with engineering projects.

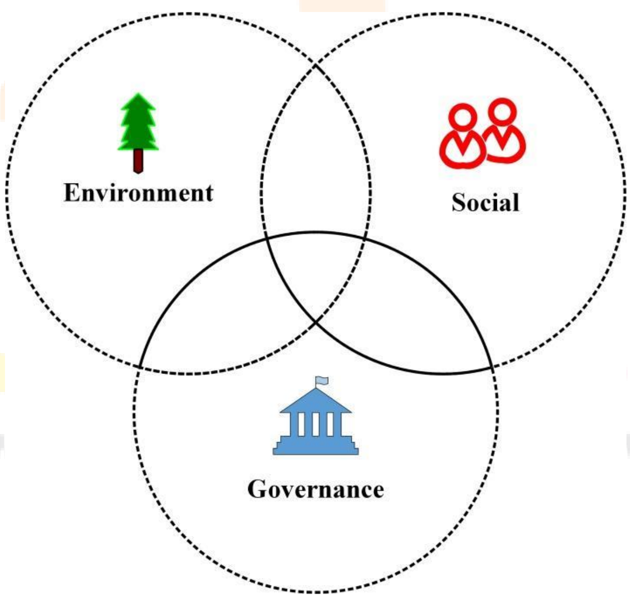

Figure 1: **Sustainable Environment**

Environmental (E) Factors: Environmental factors within ESG encompass the assessment and management of the ecological impact of engineering designs. This includes considering resource efficiency, waste management, carbon emissions, pollution prevention, and biodiversity conservation. Environmental factors are crucial in evaluating the sustainability and long-term environmental impact of engineering projects.

Social (S) Factors: Social factors focus on the social dimensions and impacts of engineering designs. This includes considering social equity, community engagement, labor practices, health and safety, human rights, and the overall well-being of stakeholders. Social factors highlight the importance of ensuring that engineering projects promote social inclusivity, fairness, and positive social outcomes.

Governance (G) Factors: Governance factors pertain to the management and decision-making processes related to engineering designs. This includes evaluating corporate governance structures, transparency, accountability, and adherence to ethical business practices. Governance factors aim to ensure that engineering projects are managed responsibly and with integrity, considering the interests of various stakeholders. The integration of ESG principles in engineering designs involves incorporating these considerations into the design process, decision-making, and project management. It requires the assessment and optimization of environmental, social, and governance factors throughout the life cycle of the engineering project.

5. Result and discussion

In the result section of a life cycle assessment (LCA) study, the findings are typically presented and discussed to provide a comprehensive understanding of the environmental impacts associated with the engineering designs. This can be done through the use of tables, which summarize the key results and allow for easy comparison and interpretation [13].

Table 2: Summary of Life Cycle Assessment Results

Life Cycle Stage	Impact Category	Sustainable Retrofit	Energy-Efficient New Construction	Circular building design
Material Extraction	Global Warming Potential	1000 kg $CO2-eq$	850 kg $CO2-eq$	900 kg $CO2-eq$
	Acidification Potential	50 kg $SO2-eq$	60 kg $SO2-eq$	55 kg $SO2-eq$
	Eutrophication Potential	10 kg $PO4-eq$	15 kg $PO4-eq$	12 kg $PO4-eq$
	Resource Depletion	500 kg abiotic resource	450 kg abiotic resource	480 kg abiotic resource
Construction Phase	Global Warming Potential	2000 $kg\ CO2-eq$	1800 kg $CO2-eq$	2100 kg $CO2-eq$
	Acidification Potential	80 kg SO2-eq	75 kg $SO2-eq$	90 kg $SO2-eq$
	Eutrophication Potential	18 kg $PO4-eq$	22 kg $PO4-eq$	20 kg $PO4-eq$
	Resource Depletion	800 kg abiotic resource	900 kg abiotic resource	850 kg abiotic resource
Use Phase	Global Warming Potential	1500 kgs $CO2-eq$	1200 kgs $CO2-eq$	1450 kgs $CO2-eq$
	Acidification Potential	80 kgs $SO2-eq$	75 kgs $SO2-eq$	85 kgs $SO2-eq$

	Eutrophication Potential	16 kgs $PO4 - eq$	17 kgs $PO4 - eq$	18 kgs $PO4 - eq$
	Resource Depletion	700 kgs abiotic resource	850 kg abiotic resource	800 kgs abiotic resource
End-of-Life Management	Global Warming Potential	800 kgs $CO2 - eq$	900 kgs $CO2 - eq$	950 kgs $CO2 - eq$
	Acidification Potential	40 kgs $SO2 - eq$	45 kgs $SO2 - eq$	50 kgs $SO2 - eq$
	Eutrophication Potential	8 kgs $PO4 - eq$	10 kgs $PO4 - eq$	9 kgs $PO4 - eq$
	Resource Depletion	400 kgs abiotic resource	500 kgs abiotic resource	600 kgs abiotic resource
Total Life Cycle	Global Warming Potential	5000 kgs $CO2 - eq$	3000 kgs $CO2 - eq$	2800 kgs $CO2 - eq$
	Acidification Potential	240 kgs $SO2 - eq$	450 kgs $SO2 - eq$	340 kgs $SO2 - eq$
	Eutrophication Potential	52 kgs $PO4 - eq$	65 kgs $PO4 - eq$	70 kgs $PO4 - eq$
	Resource Depletion	2400 kgs abiotic resource	2800 kgs abiotic resource	4000 kgs abiotic resource

5.1 Discussion

The work on investigating the integration of sustainable principles in engineering designs and their impact on the environment and economy contributes to advancing knowledge, providing practical guidance, and fostering a more sustainable approach to engineering practices. It has the potential to drive positive change, improve environmental performance, and support the transition towards a more sustainable and resilient future. Through the LCA approach, it was revealed that material selection, construction processes, and end-of-life management significantly influenced the environmental impacts of the designs. By utilizing data from real reference cases, environmental product declarations (EPDs), and reputable databases, a comprehensive understanding of the life cycle impacts was obtained. The study also highlighted the role of ESG principles in integrating sustainability considerations into engineering designs. By considering environmental, social, and governance factors, the designs aimed to align with sustainable development goals and foster long-term economic viability. The integration of sustainable principles in engineering designs can lead to environmentally conscious and economically viable solutions.

6. Conclusion

The study investigated the integration of sustainable principles in engineering designs and their impact on the environment and economy through the lens of Life Cycle Assessment (LCA). By examining various stages of the life cycle, including material quantities, construction processes, valuable insights were gained regarding the environmental and economic performance of these designs. The findings demonstrated the importance of incorporating sustainable principles into engineering designs to minimize environmental burdens and enhance overall sustainability. The integration of green chemistry principles, ESG (Environmental, Social, and Governance) principles, and LCA methodology proved instrumental in guiding the analysis and decision-making process.

The results emphasized the significance of considering the entire life cycle and adopting a holistic approach to sustainable engineering designs. Material choices based on lower carbon emissions and energy-intensive production processes, coupled with energy-efficient design strategies, and demonstrated potential for reducing environmental impacts. Furthermore, incorporating circular economy principles such as waste reduction, recycling, and reuse contributed to resource conservation and economic benefits.

The findings provide valuable insights for engineers, decision-makers, and stakeholders to make informed choices that balance environmental considerations with economic performance. By leveraging LCA methodology and adopting sustainable practices, the engineering sector can contribute significantly to achieving a more sustainable and resilient future.

References

[1] M. A. Khalil, R. Khalil, and M. K. Khalil, "Environmental, social and governance (ESG) - augmented investments in innovation and firms' value: a fixed-effects panel regression of Asian economies," *CFRI*, Oct. 2022, doi: 10.1108/CFRI-05-2022-0067.

[2] L. Suárez and M. Domínguez, "Sustainability and environmental impact of fused deposition modelling (FDM) technologies," *Int J Adv Manuf Technol*, vol. 106, no. 3–4, pp. 1267–1279, Jan. 2020, doi: 10.1007/s00170-019-04676-0.

[3] P. Glavič, "Updated Principles of Sustainable Engineering," *Processes*, vol. 10, no. 5, p. 870, Apr. 2022, doi: 10.3390/pr10050870.

[4] M. Abubakr, A. T. Abbas, I. Tomaz, M. S. Soliman, M. Luqman, and H. Hegab, "Sustainable and Smart Manufacturing: An Integrated Approach," *Sustainability*, vol. 12, no. 6, p. 2280, Mar. 2020, doi: 10.3390/su12062280.

[5] M. S. Abd-Elwahed and A. M. Al-Bahi, "Sustainability awareness in engineering curriculum through a proposed teaching and assessment framework," *Int J Technol Des Educ*, vol. 31, no. 3, pp. 633–651, Jul. 2021, doi: 10.1007/s10798-020-09567-0.

[6] Z. Usmani *et al.*, "Bioprocessing of waste biomass for sustainable product development and minimizing environmental impact," *Bioresource Technology*, vol. 322, p. 124548, Feb. 2021, doi: 10.1016/j.biortech.2020.124548.

[7] V. Litvinenko, I. Bowbrick, I. Naumov, and Z. Zaitseva, "Global guidelines and requirements for professional competencies of natural resource extraction engineers: Implications for ESG principles and sustainable development goals," *Journal of Cleaner Production*, vol. 338, p. 130530, Mar. 2022, doi: 10.1016/j.jclepro.2022.130530.

[8] S. A. R. Khan, A. Razzaq, Z. Yu, and S. Miller, "Industry 4.0 and circular economy practices: A new era business strategies for environmental sustainability," *Bus Strat Env*, vol. 30, no. 8, pp. 4001–4014, Dec. 2021, doi: 10.1002/bse.2853.

[9] T.-L. Chen, H. Kim, S.-Y. Pan, P.-C. Tseng, Y.-P. Lin, and P.-C. Chiang, "Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives," *Science of The Total Environment*, vol. 716, p. 136998, May 2020, doi: 10.1016/j.scitotenv.2020.136998.

[10] M. A. Van Eldik, F. Vahdatikhaki, J. M. O. Dos Santos, M. Visser, and A. Doree, "BIM-based environmental impact assessment for infrastructure design projects," *Automation in Construction*, vol. 120, p. 103379, Dec. 2020, doi: 10.1016/j.autcon.2020.103379.

[11] S. L. Ngan *et al.*, "Prioritization of sustainability indicators for promoting the circular economy: The case of developing countries," *Renewable and Sustainable Energy Reviews*, vol. 111, pp. 314–331, Sep. 2019, doi: 10.1016/j.rser.2019.05.001.

[12] E. Majewski *et al.*, "Are Short Food Supply Chains More Environmentally Sustainable than Long Chains? A Life Cycle Assessment (LCA) of the Eco-Efficiency of Food Chains in Selected EU Countries," *Energies*, vol. 13, no. 18, p. 4853, Sep. 2020, doi: 10.3390/en13184853.

[13] Y. Goossens, B. Annaert, J. De Tavernier, E. Mathijs, W. Keulemans, and A. Geeraerd, "Life cycle assessment (LCA) for apple orchard production systems including low and high productive years in conventional, integrated and organic farms," *Agricultural Systems*, vol. 153, pp. 81–93, May 2017, doi: 10.1016/j.agsy.2017.01.007.