Ethics and sustainability in technological innovation: A systematic review of its environmental impact

Ética y sostenibilidad en la innovación tecnológica: revisión sistemática sobre su impacto ambiental

Aldo Atausinchi Masias
https://orcid.org/0009-0001-9076-3065
aaatausinchima@ucvvirtual.edu.pe
Universidad César Vallejo
Lima-Peru

Dilmar Atausinchi Masias
https://orcid.org/0000-0002-3539-1289
40324772@caen.edu.pe
Centro de Altos Estudios Nacionales
Lima-Peru

Robert Julio Contreras Rivera
https://orcid.org/0000-0003-3188-3662
rjcontrerasr@ucvvirtual.edu.pe
Universidad César Vallejo
Lima-Peru

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Abstract

Technological innovation has driven significant advances in various fields, but it has also generated negative impacts on the environment, such as pollution and excessive consumption of natural resources. In this context, the need arises to address ethics in innovation in order to achieve a balance between technological progress and environmental sustainability. The objective of this research is to analyze the integration of ethical principles in the development of technological innovations and their environmental impact, promoting responsible practices that minimize ecological damage. A systematic, qualitative and descriptive review of the scientific literature was carried out, following the PRISMA protocol to ensure rigor and transparency. The search focused on articles in English and Spanish available in Scopus, published between 2023 and 2024, that addressed the relationship between scientific innovation, ethics and the environment. Strict inclusion and exclusion criteria were applied to select 28 relevant studies. The results show that, although technological innovation can have adverse effects on the environment, it also offers opportunities for the development of clean and sustainable technologies, such as renewable energies and advanced recycling systems. The studies highlight the importance of rigorous environmental policies, education and public awareness to foster an ethical and responsible culture. In conclusion, the research underlines that technological innovation and environmental care are not opposing objectives; with an

appropriate ethical approach, it is possible to achieve sustainable economic development that preserves the health of the planet.

Keywords: ethics, environmental impact, technological innovation.

Resumen

La innovación tecnológica ha impulsado avances significativos en diversos ámbitos, pero también ha generado impactos negativos en el medio ambiente, como la contaminación y el consumo excesivo de recursos naturales. En este contexto, surge la necesidad de abordar la ética en la innovación para lograr un equilibrio entre el progreso tecnológico y la sostenibilidad ambiental. El objetivo de esta investigación consiste en analizar la integración de principios éticos en el desarrollo de innovaciones tecnológicas y su impacto ambiental, promoviendo prácticas responsables que minimicen los daños ecológicos. Se realizó una revisión sistemática, de carácter cualitativo y descriptivo, de la literatura científica, siguiendo el protocolo PRISMA para garantizar el rigor y la transparencia. La búsqueda se centró en artículos en inglés y español disponibles en Scopus, publicados entre 2023 y 2024, que abordaran la relación entre innovación científica, ética y medio ambiente. Se aplicaron criterios estrictos de inclusión y exclusión para seleccionar 28 estudios relevantes. Los resultados evidencian que, aunque la innovación tecnológica puede tener efectos adversos sobre el medio ambiente, también ofrece oportunidades para el desarrollo de tecnologías limpias y sostenibles, como las energías renovables y los sistemas de reciclaje avanzados. Los estudios destacan la importancia de políticas ambientales rigurosas, la educación y la concienciación pública para fomentar una cultura ética y responsable. En conclusión, la investigación subraya que la innovación tecnológica y el cuidado ambiental no son objetivos opuestos; con un enfoque ético adecuado, es posible alcanzar un desarrollo económico sostenible que preserve la salud del planeta.

Palabras clave: ética, impacto ambiental, innovación tecnológica.

Introduction

The rapid evolution of technology has led to significant advancements in various areas of human life, from medicine to communication and transportation. However, this progress also poses serious ethical challenges, particularly regarding its impact on the environment. The ethics of technological innovation is a discipline that seeks to balance the benefits of technological development with the responsibility to minimize ecological harm. Reflecting on these issues is essential to ensure that technological progress does not compromise the sustainability of the planet. In this context, it is necessary to consider both the direct and indirect implications of technology on ecosystems and human communities, promoting an ethical approach that integrates innovation with environmental conservation.

As the global population and production scale continue to expand, total wealth grows exponentially, and the environment, which is fundamental to human survival, faces significant challenges (Peng et al., 2023). In response to the increasingly severe effects of global warming, many countries have agreed to promote the green transformation of their economies and societies.

Reducing carbon emissions is one of the key objectives of the green transformation across all countries (Shen & Yang, 2023). In this regard, green or high-efficiency technologies, such as sustainable design or advanced manufacturing, have proven to be essential for improving carbon reduction levels (Mu & Zhao, 2023). These technologies have also been linked to efforts to develop the digital economy and promote high-quality economic progress, aiming for a mutually beneficial relationship between energy and economic development. Meanwhile, the digital economy, as an emerging form of the economy, is characterized by its innovative capacity and its contribution to industrial synergies (Liu & Yang, 2023). This technological transformation allows for the convergence between sectors, fostering more sustainable and interconnected growth.

Furthermore, innovation is defined in the literature as the capacity to generate, apply, and experiment with novel ideas, processes, and structures aimed at industrial application (Vac et al., 2023). This capacity drives the transformation of ideas into products, processes, or services that create commercial value and can simultaneously be guided by a theocentric ethic of environmental management, providing a valuable framework for addressing core issues such as sustainability, conservation, or restoration of nature (DeWeese, 2023).

It is also noted that human development and modern lifestyles generate a significant amount of pollutants in wastewater, which are not always efficiently treated by current technologies, posing a significant environmental threat (Coccia & Bontempi, 2023).

Therefore, the objective of this research was to analyze and promote the integration of ethical principles in the development and implementation of technological innovations. This proposal seeks to minimize negative environmental impacts and foster a balance between technological progress and ecological conservation, ensuring long-term sustainability.

This study also underscores the importance of rigorous environmental policy as a corrective strategy against ecological challenges. Unlike previous research focused on environmental taxes or emissions, this study highlights the need to increase the use of renewable energy as an essential step to reduce CO_2 emissions resulting from fossil fuel use and to achieve sustainable economic growth (Tao et al., 2023).

On the other hand, the adoption of sustainability is understood as a dynamic process. Some companies integrate it strategically to gain competitive advantages, while others view it as a standard operational practice. Innovation in renewable energy technologies holds significant transformative potential, particularly in urban contexts, where higher levels of technological innovation and market capacity are concentrated (Zheng et al., 2023).

Similarly, it is argued that the implementation of cutting-edge green technologies can significantly enhance efficiency in the use of natural resources, thereby facilitating the establishment of a green growth model. Additionally, from a regulatory perspective, these innovations enable more effective monitoring of environmental compliance, allowing for the adoption of preventive or corrective measures against inadequate practices (Murshed, 2024).

Consequently, an obvious solution to combat climate change is the adoption of renewable energy sources, aligned with the goal of ensuring clean and affordable energy. Technological innovation, in this context, can have a dual impact on the environment, depending on its nature and the manner in which it is applied (Fang et al., 2024). Hence, the importance of designing and employing innovations that maximize ecological benefits while minimizing negative externalities.

Moreover, climate change represents one of the most urgent moral issues of our time, as its progression could generate profound and lasting consequences for human life by significantly altering natural ecosystems (Shriver, 2024). This scenario presents an unavoidable ethical challenge that requires comprehensive responses, supported both by science and by political will and social participation.

Among the most notable consequences are the accelerated loss of biodiversity, resource scarcity, and high air pollution levels. However, not all technological innovations adopted across various industries possess characteristics that simultaneously allow for energy savings and economic benefits, making them ineffective in countering the negative externalities associated with ecological degradation (Niu et al., 2024).

Thus, this research gains relevance and urgency by highlighting the need to reflect on and act regarding the impact of technologies on the environment. It is crucial to understand how we can address global environmental challenges through a strategic and intelligent use of technological innovation. Ultimately, the purpose of this study is to analyze how the potential of technologies can be channeled through an integrated and collaborative approach. This approach should articulate scientific research, investment in clean and sustainable technologies, and the design and implementation of effective public policies aimed at achieving a just and viable ecological transition in the long term.

Methodology

This research was conducted through a systematic literature review, following the guidelines of the PRISMA model (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), to ensure a rigorous, transparent, and reproducible process in identifying and selecting relevant studies on ethics, technological innovation, and its environmental impact.

For the search and analysis of scientific literature, stringent inclusion criteria were established to ensure the relevance and quality of the selected studies. Only articles explicitly addressing the relationship between scientific innovation and its environmental impact were considered. Another fundamental requirement was that the studies focused specifically on the effects of technological innovation on the natural environment. Additionally, only articles available in the Scopus database were included to ensure the provenance of validated academic sources. The publication timeframe was defined as spanning from 2003 to 2024 to include current and contextualized evidence.

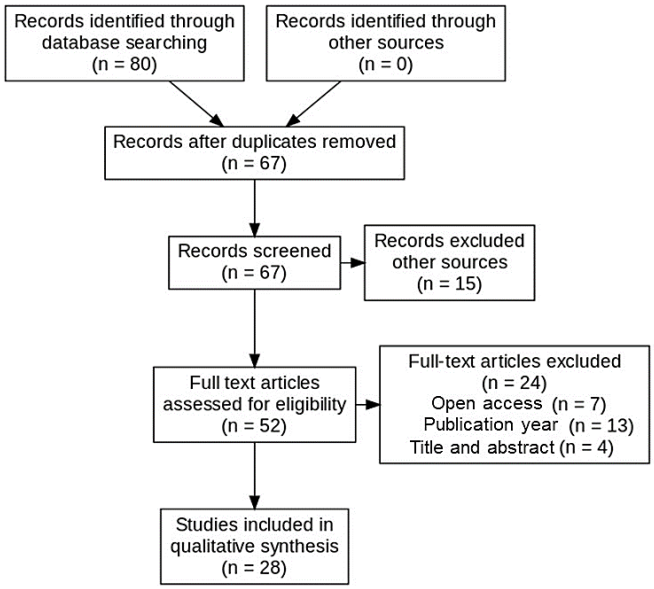
Regarding the exclusion criteria, various types of documents that did not meet the required empirical focus for this review were discarded. Essays, monographs, book chapters, letters to the editor, documentary studies, non-systematic reviews, books, and conference papers were removed from the sample, prioritizing only original scientific articles. Open-access texts that did not meet established editorial standards were also excluded.

Furthermore, studies that addressed technological innovation or its environmental effects without an explicit linkage to ethical analysis or contextualization were eliminated. Similarly, studies focusing solely on contemporary environmental issues, without reference to technological evolution, were excluded. Finally, all articles written in languages other than English or Spanish were omitted to maintain linguistic coherence in the analysis.

During the selection process, predetermined descriptors in Scopus were employed as the primary source of information, supplemented with additional records from other relevant sources to enrich the collected data and ensure comprehensive coverage. The descriptors and keywords encompassed the categories of technological innovation and the environment. The search string in Spanish was: ((("innovación tecnológica") OR ("technological innovation")) AND (("medio ambiente") OR ("environment"))), and in English: (("technological innovation") AND (("environment"))).

Figure 1

Identification of new studies through databases and records



The PRISMA diagram illustrates the systematic process of identifying, selecting, and evaluating studies used in a qualitative review. Initially, 80 records were identified through database searches, with no additional records found from other sources. After removing duplicates, 67 unique articles were retained for initial analysis. During the screening stage, the titles and abstracts of these 67 records were examined. As a result, 15 articles were excluded for not meeting the established thematic or methodological criteria. Subsequently, 52 articles were evaluated in full to determine their eligibility.

Of these, 24 articles were discarded after a complete reading due to the following reasons: 7 lacked open access, 13 were outside the defined temporal range according to the inclusion criteria (year of publication), and 4 did not provide sufficient information in the title and abstract to be considered relevant. Finally, 28 studies were included in the qualitative synthesis, representing the empirical basis of the systematic review. This process ensures a high level of methodological rigor, transparency, and reliability in the selection of literature, aligned with international standards for systematic reviews.

Results and discussion

To provide a more structured view of the evidence gathered, Table 1 has been prepared, summarizing the main studies included in the systematic review. This table allows for the identification of the most relevant characteristics of each publication, such as the author, year, country of origin, and the methodological approach adopted. In this way, it facilitates comparisons between studies and reinforces the understanding of the current landscape regarding the connection between technological innovation, ethics, and environmental sustainability.

The information presented serves as the empirical foundation upon which the results are discussed and subsequent reflections of the study are based.

No.	Author, Year	Country	Approach
1	(Peng et al., 2023)	USA	Quantitative
2	(Li & Hai, 2023)	China	Mixed
3	(Shen & Yang, 2023)	China	Mixed
4	(Mu & Zhao, 2023)	China	Mixed
5	(Liu & Yang, 2023)	China	Mixed
6	(DeWeese, 2023)	USA	Quantitative
7	(Coccia & Bontempi, 2023)	USA	Mixed
8	(Witkowski et al., 2023)	USA	Quantitative
9	(Tao et al., 2023)	USA	Quantitative
10	(Kong et al., 2023)	China	Quantitative
11	(Zheng et al., 2023)	China	Quantitative
12	(Murshed, 2024)	Bangladesh	Quantitative
13	(Fang et al., 2024)	USA	Quantitative
14	(Shriver, 2024)	USA	Quantitative
15	(Niu et al., 2024)	USA	Quantitative
16	(Almeida et al., 2022)	Brazil	Quantitative
17	(Richards et al., 2024)	New Zealand	Quantitative
18	(Kopnina, 2012)	China	Quantitative
19	(Casañ et al., 2020)	France	Quantitative
20	(Pettersen & Boks, 2008)	Norway	Mixed
21	(Mir & Chang, 2024)	USA	Mixed
22	(Badea et al., 2024)	China	Quantitative
23	(Neményi et al., 2022)	China	Quantitative
24	(Robbins & van Wynsberghe, 2022).	Germany	Mixed
25	(Sandbrook, 2015)	UK	Quantitative
26	(Moore et al., 2020)	UK	Quantitative
27	(Ribeiro-Rodrigues & Bortoleto, 2024)	Brazil	Mixed
28	(Wu et al. 2024)	China	Quantitative

The authors highlighted the potential benefits of the technological innovation approach and its impact on the environment, which has significantly contributed to improving the article. For instance, Peng et al. (2023) address the significant environmental risks associated with economic and demographic growth, emphasizing the importance of tackling these challenges to ensure sustainability and the continuity of human life. Li & Hai (2023) also analyze the negative impact of rapid economic development on the environment, stressing the excessive use of natural resources, which has exceeded the environment's recovery capacity, generating harmful effects. Shen & Yang (2023) explore the environmental issues arising from technological innovations and the intensive exploitation of natural resources, resulting in pollution and resource depletion, thereby driving the need to promote green transformation and reduce carbon emissions globally.

In this regard, Mu & Zhao (2023) and Liu & Yang (2023) also address these environmental challenges, emphasizing the importance of green transformation and the development of the digital economy to achieve sustainable economic progress. On the other hand, DeWeese (2023) proposes a theocentric ethic of environmental management that emphasizes valuing nature and addresses key issues of environmental ethics, such as preservation, conservation, and sustainability. Additionally, Coccia & Bontempi (2023) investigate how human development and contemporary lifestyles generate pollutants that impact wastewater, highlighting the importance of addressing these issues comprehensively.

Moreover, it is noted that many water treatment technologies fail to effectively identify and reduce these substances. Witkowski et al. (2023) discuss the integration of ethical principles into technological innovations to minimize their environmental impact and promote sustainability, seeking to balance technological progress with ecological conservation. Conversely, Tao et al. (2023) highlight the importance of implementing environmental policies and promoting the use of renewable energies to reduce CO_2 emissions and foster sustainable economic growth. Kong et al. (2023) explore how companies perceive and adopt sustainability, with some viewing it as a competitive advantage, while others integrate it as a standard part of their operations, complying with regulations and basic expectations.

Similarly, Zheng et al. (2023) discuss the significant impact that innovation in renewable energy technologies can have, particularly in urban environments that favor their development. Murshed (2024) investigates how technological innovation can generate a positive impact on both the environment and society, empowering individuals toward a more sustainable and equitable future. Fang et al. (2024) stress the importance of adopting renewable energies to mitigate climate change, emphasizing how the management and application of technological innovation can significantly influence the environment.

Additionally, Shriver (2024) emphasizes the ethical and moral importance of climate change in contemporary society, highlighting its capacity to alter natural ecosystems and profoundly affect human life from a moral perspective. Likewise, Niu et al. (2024) underscore the critical challenges that China faces regarding environmental management and urban development, emphasizing the urgency of implementing effective policies and actions to address these crises. Ribeiro-Rodrigues & Bortoleto (2024) advocate for the application of environmental psychology knowledge to motivate changes in human behavior toward more sustainable and environmentally protective practices.

Furthermore, Kopnina (2012) highlights the rising level of global environmental concern, as reflected in international surveys. This increase in awareness suggests a greater recognition and attention to the environmental impacts of human activities, underscoring the urgent need to address these issues to ensure sustainable and balanced development on a global scale. Casañ et al. (2020) advocate for the integration of ethical and social considerations in the training of engineers and scientists in the field of information and communication technologies to ensure that technological progress is responsible and beneficial for society as a whole.

Pettersen & Boks (2008) emphasize the importance of addressing these ethical challenges equitably and proactively, thoroughly considering the potential negative impacts and ethical dilemmas associated with the technologies used in sustainable industrial design, in order to find solutions that minimize risks and maximize benefits for society and the environment.

Almeida et al. (2022) highlight how environmental ethics has evolved from being an academic topic to becoming an urgent ethical and social imperative, motivated by increasing public awareness and the need to address global environmental issues in an ethical and sustainable manner. Mir & Chang (2024) note that the increase in electronic waste is due to a combination of lower prices and a more limited lifespan of electronic products, contributing to the rising amount of e-waste generated worldwide.

On the other hand, Badea et al. (2024) highlight the advantages and disadvantages of using electric arc furnaces in steel production, emphasizing the environmental issues associated with this method and the need to address these challenges to improve the sustainability of the steel industry. Neményi et al. (2022) underscore the environmental challenges linked to current agricultural practices, especially regarding fertilizer and chemical management, highlighting the need for more efficient and sustainable solutions in modern agriculture.

Similarly, Robbins & van Wynsberghe (2022) investigate the importance of integrating ethical, social, and environmental considerations at all stages of the life cycle of Artificial Intelligence (AI) to promote technology that is not only innovative but also sustainable and equitable. Sandbrook (2015) illustrates how artificial intelligence is being creatively and practically used in environmental conservation, employing drones to enhance resource management and restoration practices. Moore et al. (2020) highlight the transformative potential of artificial intelligence in the mining industry, both to address economic challenges and to foster more sustainable and environmentally friendly practices.

Additionally, Richards et al. (2024) emphasize the importance of incorporating natural solutions into environmental mitigation and conservation strategies, advocating for global collaboration and resource mobilization to effectively and sustainably address current environmental challenges. Likewise, Wu et al. (2024) stress the importance of balancing economic development with environmental protection and conservation, ensuring that industries can operate responsibly and contribute positively to global sustainability.

Finally, the results of the review have significant implications for practices and policies related to the ethics of technological innovation and its influence on the environment. The findings that highlight the potential ethical benefits of technological innovation suggest that policymakers and industry leaders might consider promoting innovative practices that are environmentally responsible. This approach could encourage the adoption of technologies that minimize negative environmental impacts and promote sustainability. Furthermore, comparative research could be conducted to analyze how different approaches to technological innovation impact the environment across various geographical and cultural contexts. This would allow for the identification of optimal ethical strategies and their adaptation to the specific needs of each community. However, it is essential to address the mentioned limitations and continue researching to gain a more comprehensive and balanced understanding of the ethical impact of technological innovation on the environmental context.

Furthermore, technological innovation has facilitated personalized learning experiences, allowing individuals to progress at their own pace and focus on their specific needs. This personalized approach has fostered a deeper understanding of the ethical concepts related to technology and has increased the sense of responsibility regarding the environmental impact of their actions. Similarly, the adoption of technological models has prepared individuals for the digital age by enhancing their technological competence and ethical decision-making skills. Through exposure to sustainable technologies, they have engaged in real-world contexts and integrated ethical considerations into their technological practices. These immersive experiences have contributed to a more holistic understanding of the ethical implications of technological innovation on the environment and society as a whole.

Conclusions

Technological innovation, while essential for progress and economic development, poses significant challenges to the environment. The implementation of new technologies often leads to increased extraction of natural resources, greenhouse gas emissions, and waste generation, contributing to environmental degradation and climate change. However, the solution to this problem does not lie in halting technological advancement but in redirecting it towards more sustainable practices.

To address these challenges, it is crucial to promote research and development of green technologies that minimize environmental impact. This includes the development of renewable energies, advanced recycling systems, and energy-efficient technologies. Additionally, it is necessary to implement policies and regulations that promote the adoption of sustainable practices across all industries. Incentivizing companies to reduce their ecological footprint through subsidies, environmental taxes, and certifications can accelerate the transition to a more sustainable economy.

Another important solution is education and public awareness regarding the significance of sustainability. By increasing awareness of the environmental impact of our technological and consumption decisions, a culture of ecological responsibility can be fostered at both individual and collective levels.

In summary, technological innovation and environmental care should not be viewed as incompatible goals. By promoting sustainable technologies, implementing appropriate policies, and providing environmental education, it is possible to achieve a balance that allows for economic development without compromising the health of the planet.

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