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JLASC
Journal of Latin American Sciences and Culture

"JLASC fosters the Science Culture Construction, facilitates the exchange of knowledge, and promotes the sharing of information, all of which contribute to building a global community with a shared future for humanity."

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"JLASC is committed to global engagement. By popularizing science, we aim to advance societal development and enhance the well-being and quality of life for all people."

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Media and Information Literacy: Empowering Citizens in the Fight Against Climate Change

In today's technology-driven world, digitalization permeates all sectors of society, increasing theimportance of media and information literacy (MIL). Knowledge, skills and attitudes towards media and information have become essential tools for all citizens, who increasingly interact withmedia platforms, especially online. Developing MIL competencies is a lifelong process that can be supported by various stakeholders through formal, informal and non-formal initiatives.

MIL has gained ground globally, with numerous national and international efforts promoting its growth. As a foundation for scientific literacy, MIL equips individuals with fundamental skills tounderstand and evaluate media content, enabling them to actively engage on pressing global issues such as climate change. When combined with climate literacy, MIL can empower ordinary citizensto meaningfully contribute to environmental preservation efforts.

Climate literacy is part of scientific literacy and encompasses a set of competencies to understandthe causes, impacts, and mitigation strategies related to climate change. These competencies are often developed and applied through media, digital tools, and information channels, and are thus intertwined with media and information literacy. Without media and information literacy, citizensare susceptible to misinformation and unverified climate-related claims, which obstruct public acceptance of climate science and lead to inaction. Addressing climate change skepticism through media and information literacy can foster a more informed society that understands the importanceof climate science and engages in collective action

Media and technology companies play a critical role in educating citizens on climate issues, disseminating facts and dispelling misinformation. As media outlets communicate the urgency ofthe climate crisis, it is essential for citizens to understand how news content is produced, the intentions behind it and the sources of information. Journalists also benefit from media and information literacy, as it underpins accurate and evidence-based reporting on climate issues

Organizations such as UNESCO have been instrumental in promoting media and information literacy around the world, highlighting its role in achieving the Sustainable Development Goals (SDGs). Media and information literacy enables citizens and decision-makers to access reliable climate information, helping them make informed consumption decisions, reduce their carbon footprint and avoid decisions that could worsen the crisis. Media and information literate people are prepared to advocate for climate action, strengthening public trust in science.

- To promote media and information and climate literacy, we advocate for:
- Raising awareness about fact-checking in environmental reporting and the reliability of sources;
- Equipping citizens with resources to identify misinformation and responsibly disseminate information on climate issues;
- Fostering continuous learning about the latest news, research, and actionable climate strategies.

We aim to convene experts from diverse backgrounds to share knowledge on the maturity levels f media and information literacy globally, addressing unique challenges and informing future policy recommendations. By strengthening media and information literacy, we can empower citizens around the world to engage in a science-based approach to combat climate change.

Sincerely:

Andean Road Countries for Science and Technology

Building a Foundation for the Future: The Science Culture Building Initiative

The implementation of any meaningful initiative requires a careful, step-by-step approach, ensuring that each fundamental element is interconnected and useful. Science Culture Building (SCC) follows this model, fostering a culture that integrates scientific ideas, habits, and actions into institutions and society. This culture helps to disseminate knowledge, foster innovation, promote economic and technological progress, and address global challenges that science and technology can help solve.

Since 2018, the countries of the Andean Route for Science and Technology (ARCST) have been committed to advancing SCC, drawing on the support of universities, academic institutions, the public and private sectors, and various social groups. ARCST's mission is focused on expanding public engagement with green science, popularizing scientific knowledge, conserving biodiversity, supporting sustainable development, and encouraging international collaboration. While rooted in Latin America, the SCC's influence has catalyzed partnerships across Africa, Asia, and Europe, reinforcing science as a universal force for positive change.

We invite academics, researchers, students, and society at large to join the SCC initiative. By sharing our expertise and fostering green science, research and innovation, biodiversity conservation, and sustainable development, we can build a future where science and technology lead the way to a sustainable and prosperous world.

Andean Route Country for Science and Technology

The Science Culture Construction (SCC)

The construction of any significant endeavor requires a meticulous and systematic approach. A step-by-step process ensures that the foundational elements are correctly interconnected, establishing a solid and meaningful structure. In parallel, the Science Culture Construction embodies the acquisition of ideas, habits, and actions that permeate scientific and academic institutions, ultimately influencing society. This culture establishes pathways to disseminate knowledge, promote innovation, drive economic and technological development, and defend our world from threats that science and technology can mitigate.

Since 2018, the Andean Road Countries for Science and Technology (ARCST) have beendedicated to building the Science Culture Construction (SCC). Our efforts have garnered support from universities, academic institutions, the public and private sectors, and various social strata.

Our mission is to engage more people in Green Science, Science Popularization, Biodiversity Conservation, Green Development, innovation, technology development, and international collaboration. Though our work began in Latin America, the impact has opened opportunities for partnerships across Africa, Asia, and Europe. We invite you to join us in the Science Culture Construction. We welcome academicians,researchers, students, and society at large to exchange knowledge and promote Green Science, Research and Innovation, Science Popularization, Biodiversity Conservation, Green and Sustainable Development.

Together, let us forge a future where science and technology lead the way to a brighter, moresustainable world.

Sincerely,
Andean Road Countries for Science and Technology

AROST

Andean Road Countries
for Science & Technology
安第斯路国际科学技术组织

" A new blueprint for cooperation:
The SCIENCE CULTURE CONSTRUCTION (SCC)
fostering innovation and green development "

《合作新蓝图：
推动创新、绿色发展的科学文化建设》

The Journal of Latin American Sciences and Culture
promotes the

“Science Culture Construction”

A practical approach emerged to foster

“Media and Information Literacy (MIL)”

“Science Literacy”

&

“South - South Biodiversity Science Project (SSBSP)”
“Biodiversity Conservation and Green Development”

ÍNDICE

Editor’s note: Advancing science, technology, and climate literacy for a sustainable future

In this issue, we are pleased to present the first winning paper of the 2023 Science and Technology for a Sustainable Future (SFAST) international competition, “Reducing Greenhouse Gas Emissions by Improving Public Transportation” (Reducing Greenhouse Gas Emissions by Improving Public Transportation). Written by Jason Liao, it embodies rigorous analysis and an unwavering commitment to sustainable development. Through data-driven arguments, a global perspective, and an emphasis on equitable strategies, Liao’s work offers viable solutions to one of the world’s most pressing challenges: transportation emissions. His compelling calls to action and policy recommendations reflect a deep understanding of the technical and social dimensions of sustainable urban development, making him a well-deserved recipient of this prestigious recognition.

In addition to this exemplary work, we are also honored to publish the first technical report of the Intercontinental Conference on Science and Climate Education, held on August 13, 2024. This historic event brought together global opinion leaders to discuss perspectives on the advancement of science. research. and climate education in Latin America and the Caribbean. Key outcomes of the conference include plans to develop a Declaration on Science and Climate Literacy in Latin America and the Caribbean, initially developed in 2021. The revised Manifesto will reflect the knowledge gathered during the conference and address challenges and pressing issues related to promoting science and climate literacy in the context of a world increasingly affected by climate demands. The dialogues that took place enriched knowledge and, more importantly, laid the foundation for future collaborations aimed at fostering scientifically literate and environmentally conscious societies.

Looking ahead, this issue also addresses the dynamic area of building a green science culture. This theme, fundamental to a sustainable future, intersects with the transformative potential of digital tools and the fundamental role of enabling a sustainable digital transformation across all disciplines. Our comprehensive analysis of bioenergy highlights both the potential and challenges inherent in this renewable energy source, underscoring its importance in the broader context of a sustainable energy transition.

As always, we invite readers to contribute to this discussion by submitting their own research, news and innovations whose ideas continue to push the boundaries of knowledge and promote the changes needed for a sustainable future.

In the pursuit of a greener, more scientific world, we remain committed to publishing work that inspires, informs and mobilizes. We hope to continue to count on our readers and collaborators to participate in this collective effort.

Prof. Jasivia Gonzales Rocabado

Member of the Editorial Board JLASC

Nota del editor: Promoción de la ciencia, la tecnología y el conocimiento climático para un futuro sostenible

En este número, nos complace presentar el primer artículo ganador del concurso internacional Aplicaciones de ciencia y tecnología para un futuro sostenible (SFAST) de 2023 "Reducción de las emisiones de gases de efecto invernadero mediante la mejora del transporte público" (Reducción de las emisiones de gases de efecto invernadero mediante la mejora del transporte público). Escrito por Jason Liao y que incorpora un análisis riguroso y un compromiso inquebrantable con la sostenibilidad. A través de argumentos basados en datos, una perspectiva global y un énfasis en estrategias equitativas, el trabajo de Liao proporciona soluciones viables a uno de los desafíos más apremiantes del mundo: las emisiones del transporte. Sus convincentes llamados a la acción y recomendaciones de políticas reflejan una profunda comprensión de las dimensiones técnicas y sociales del desarrollo urbano sostenible, lo que lo hace bien merecido de este prestigioso reconocimiento.

Además de este trabajo ejemplar, tenemos el honor de publicar el primer informe técnico (white paper) de la Conferencia Intercontinental sobre Ciencia y Educación Climática el 13 de agosto de 2024. Este evento histórico reúne a líderes de opinión globales para discutir perspectivas sobre el avance científico. Investigación. Educación climática en América Latina y el Caribe. Los resultados clave de la conferencia incluyen planes para desarrollar una Declaración sobre alfabetización científica y climática en América Latina y el Caribe, desarrollada inicialmente en 2021. La declaración revisada reflejará el conocimiento recopilado durante la conferencia y abordará desafíos y cuestiones apremiantes relacionadas con la promoción de la ciencia y la alfabetización climática. La cultura en el contexto de un mundo cada vez más condicionado por las exigencias climáticas. El diálogo que tuvo lugar enriqueció el conocimiento y, lo que es más importante, sentó las bases para futuras colaboraciones destinadas a fomentar una sociedad científicamente alfabetizada y consciente del medio ambiente.

De cara al futuro, este número también aborda el campo dinámico de la construcción de una cultura científica verde. Este tema es fundamental para un futuro sostenible y se cruza con el potencial transformador de las herramientas digitales y el papel fundamental de permitir la transformación digital sostenible en todas las disciplinas. Nuestro análisis integral de la bioenergía destaca el potencial y los desafíos inherentes a esta fuente de energía renovable, subrayando su importancia dentro del contexto más amplio de una transición energética sostenible.

Como siempre, invitamos a los lectores a contribuir a esta discusión enviando sus propias investigaciones, noticias e innovaciones. Sus ideas continúan ampliando los límites del conocimiento y catalizando los cambios necesarios para un futuro sostenible.

En la búsqueda de un mundo más ecológico y científico, seguimos comprometidos con la publicación de trabajos que inspiren, informen y movilicen. Esperamos seguir confiando en nuestros lectores y colaboradores para participar en este esfuerzo colectivo.

Prof. Jasivia Gonzales Rocabado

Miembro del Editorial Board JLASC

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White Paper

Enhancing Science and Climate Literacy in Latin America and the Caribbean

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Abstract: The Intercontinental Meeting on Science Literacy 2024 brought together experts, educators, and policymakers to discuss the changing landscape of science and climate literacy in Latin America and the Caribbean. This document synthesizes the ideas shared at the conference and aims to serve as a resource to promote science literacy measures. Key topics include the impact of digital transformation on education, the integration of climate literacy into school curricula, the importance of cultural relevance, and the challenges of accessibility and misinformation. Opportunities to improve scientific literacy through collaborative networks, public engagement, and supportive policies are also highlighted. The white paper presents strategies to integrate digital tools, promote inclusion, and promote lifelong learning. These recommendations will be integrated into the ongoing development of the Declaration on Science and Climate Literacy, initially published in 2021 by the Andean Road Countries for Science and Technology and its collaborators.

Keywords: science literacy; science culture construction; annual meeting on science literacy

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1. Introduction

The 2024 Intercontinental Meeting on Scientific Literacy 2024 brought together leading experts, educators, and policymakers to address the changing landscape of scientific and climate literacy in Latin America and the Caribbean. The insights and responses shared by our esteemed speakers have been carefully compiled into this comprehensive white paper. This document is intended to serve as a valuable resource for current and future initiatives and will be integrated into the framework of the Latin American and Caribbean Declaration on Scientific and Climate Literacy. Our goal is to build on this declaration and ensure that it continues to evolve to address today's most pressing challenges and opportunities in scientific literacy.

2. The evolution of scientific culture

2.1. Digital transformation

The rapid digital transformation affecting the entire world is profoundly reshaping the way science is communicated, taught, and understood. Digital tools, including online platforms, social media, and virtual reality, offer new possibilities to engage diverse audiences in scientific debates. This entails transformative opportunities to expand access to scientific knowledge beyond the traditional classroom to a broader and more diverse audience. However, this also poses challenges, such as the need for digital literacy among teachers and students and the risk of a digital divide that could exacerbate existing inequalities. Effective use of digital tools requires specific strategies to ensure that they enhance, rather than hinder, scientific literacy efforts.

2.2. Climate change awareness

Climate literacy has become an integral part of scientific literacy, especially as the impacts of climate change become more apparent in the region. Society should be educated about the science behind climate change, its impacts, and the importance of adopting sustainable practices. This involves not only understanding scientific principles but also recognizing the socioeconomic and cultural dimensions of climate change. Curricula and public engagement initiatives should be developed to emphasize the urgency of climate action and provide practical advice for individuals and communities to reduce environmental impacts.

2.3. Cultural relevance

Science literacy efforts must be culturally relevant to resonate with diverse populations in Latin America and the Caribbean. The region is characterized by a rich diversity of languages, traditions, and knowledge systems, each of which can play a vital role in promoting a deeper understanding of science. Incorporating indigenous knowledge, local traditions, and culturally appropriate examples into science education can make scientific concepts more relevant and accessible. Furthermore, respecting these diverse perspectives and integrating them into science literacy initiatives can close the gap between modern understanding of science and traditional forms of knowledge, thereby enriching mainstream discourse.

3. Challenges faced by the science culture construction

3.1. Accessibility

One of the most significant challenges in promoting science and climate literacy is ensuring that scientific information is accessible to all individuals, regardless of their socioeconomic status, geographic location, or educational background. In many parts of Latin America and the Caribbean, access to quality education, internet connectivity, and scientific resources remains limited. This disparity can lead to a significant knowledge gap, where only a fraction of the population benefits from advancements in science and technology. Overcoming these barriers requires innovative solutions, such as mobile learning platforms, community-based education programs, and policies that prioritize equitable access to educational resources.

3.2. Misinformation

The proliferation of misinformation, particularly through social media and other online platforms, poses a significant threat to public understanding of science. Misinformation can undermine trust in scientific institutions, spread false narratives about critical issues like climate change, and lead to harmful behaviors. Combating misinformation requires a multifaceted approach that includes educating the public on how to critically evaluate sources of information, promoting media literacy, and ensuring that accurate and reliable scientific information is readily available. Additionally, fostering a culture of transparency and open communication within the scientific community is essential to building public trust.

3.3. Integration into Education Systems

Integrating science and climate literacy into formal education systems presents both opportunities and challenges. While there is widespread recognition of the importance of these topics, translating that recognition into actionable changes in curricula, teacher training, and assessment methods can be difficult. Education systems across the region vary widely in their capacity to incorporate new content and pedagogical approaches. Ensuring that science and climate literacy are prioritized in national education agendas, providing educators with the necessary training and resources, and developing assessments that accurately measure students' understanding of these topics are all critical steps in this process.

3.4 Digital Tools

The development of educational materials that include mathematical techniques, infographics, images, videos, and interactive manuals, and also accompanied by gamification methods incorporating STEAM concepts enrich the process of literacy playfully and innovatively across a variety of topics, especially for younger populations. Computational models to simulate ecosystems and the effects of climate change on them can be integrated into educational applications to present three-dimensional interactive scenarios whose behavior teaches the consequences of climate change. By using principles of Augmented Reality and Virtual Reality, immersive experiences can be created, allowing users to explore habitats and see the impact of their actions in a virtual environment while interacting with the system to understand environmental concepts. Digital educational resources such as educational games, video games, and interactive workshops can be highly effective in promoting scientific literacy by addressing topics like the climate crisis and biodiversity. These gamified and playful formats not only facilitate the understanding of complex subjects but are also well-received by the population. The use of interactive and dynamic tools optimizes the learning process, making the content more accessible and engaging.

4. Opportunities for Advancing Science Literacy Collaborative Networks

The creation and strengthening of collaborative networks across Latin America and the Caribbean offer significant opportunities to advance science literacy. Such networks facilitate the sharing of resources, best practices, and research findings among countries with varying levels of development and expertise. The International Green Science Academy Network was highlighted as a successful model of regional collaboration, bringing together educational institutions, research centers, and policymakers to work towards common goals. Expanding these networks and fostering greater collaboration across borders can help to pool resources, amplify impact, and address shared challenges more effectively.

4.1. Public Engagement Initiatives

Public engagement is a cornerstone of science literacy, and there are numerous opportunities to increase public participation in science-related activities. Initiatives such as citizen science projects, science festivals, and online courses provide platforms for individuals to engage with scientific topics in meaningful ways. These initiatives not only increase public understanding of science but also foster a sense of ownership and empowerment, encouraging individuals to apply scientific knowledge in their daily lives. Additionally, public engagement initiatives can serve as a bridge between the scientific community and the general public, facilitating dialogue and mutual understanding.

4.2.Policy Support

Support from governments and policymakers is crucial for the success of science literacy initiatives. Policies that prioritize science education, fund public engagement efforts, and promote the integration of science and technology into everyday life are essential. Advocating for policies that address the unique needs of Latin America and the Caribbean, such as those that support bilingual education, protect indigenous knowledge, and promote sustainable development, can help to create an enabling environment for science literacy. Additionally, aligning science literacy initiatives with broader policy goals, such as economic development and environmental protection, can increase their impact and sustainability.

5. Integration with the Declaration of Science and Climate Literacy

Strengthening the Role of Education Education is at the heart of science and climate literacy, and strengthening its role is essential for the continued evolution of the Declaration of Science and Climate Literacy. This includes a focus on early childhood education, where foundational concepts of science and environmental stewardship can be introduced. Lifelong learning opportunities, such as adult education programs and continuing professional development, are also crucial for keeping the public informed about new scientific discoveries and emerging technologies. By embedding science literacy into all levels of education, we can ensure that individuals are equipped with the knowledge and skills they need to navigate an increasingly complex world.

5.1. Promoting Inclusivity

Inclusivity is a core principle of the Declaration, and it is vital to ensure that science literacy initiatives reach all segments of society, particularly marginalized and underserved communities. This includes addressing barriers related to language, disability, gender, and economic status. Tailoring science literacy programs to meet the needs of diverse populations can help to create a more equitable society where everyone has the opportunity to benefit from scientific advancements. Promoting inclusivity also involves actively engaging underrepresented groups in the scientific community, ensuring that their voices and perspectives are heard and valued.

5.2. Addressing Emerging Challenges

The Declaration of Science and Climate Literacy must be a living document that evolves to address emerging challenges. These challenges include the ethical implications of new technologies, such as artificial intelligence and biotechnology, as well as the ongoing global climate crisis. Adapting the declaration to reflect these challenges ensures that it remains relevant and effective in guiding science literacy efforts. Additionally, the declaration should provide a framework for anticipating future challenges and preparing society to respond to them in a proactive and informed manner.

6. Conclusion

The Intercontinental Meeting on Science Literacy 2024 has provided valuable insights and recommendations that will shape the future of science and climate literacy in Latin America and the Caribbean. This white paper serves as a roadmap for integrating these insights into the ongoing development of the Declaration of Science and Climate Literacy. By working together, we can build a more scientifically literate society that is better equipped to tackle the challenges of today and tomorrow.

Next Steps

- Integration into the Declaration: Work with the drafting committee to integrate the findings of this white paper into the updated Declaration of Science and Climate Literacy. This will involve a thorough review of the current declaration and the development of new strategies to address emerging challenges.
- Dissemination: Distribute the white paper to relevant stakeholders, including governments, educational institutions, NGOs, and the broader public. Effective dissemination is crucial for ensuring that the insights and recommendations outlined in this document are widely understood and implemented.
- Ongoing Collaboration: Continue to foster collaboration across the region to ensure the successful implementation of the recommendations outlined in this document. This includes building new partnerships, strengthening existing networks, and encouraging cross-sectoral dialogue and cooperation.

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References

Cabero, M. (2022). A practical approach emerged to foster media and information literacy (MIL) and science literacy: First annual meeting on science literacy 2021: A prerequisite for stimulating climate change engagement. *Journal of Latin American Sciences and Culture, 4*(Special Issue), 1–6. https://revistas.univalle.edu/index.php/jlsc/article/view/203

Cabero, M. (2023). A new blueprint of collaboration: The science culture construction fostering innovation and green development. *Jo*urnal of Latin American Sciences and Culture, 5(8), 99–109. https://doi.org/10.52428/27888991.v5i8.1075

China Biodiversity Conservation and Green Development Foundation (CBCGDF). (n.d.). CBCGDF partnership initiatives [Web page]. Retrieved from http://z.cbcgdf.org/nd.jsp?id=580

China Biodiversity Conservation and Green Development Foundation (CBCGDF). (n.d.). *International green development initiatives* [Web page]. Retrieved from http://z.cbcgdf.org/en/nd.jsp?id=1193&fromMid=3&groupId=72

Journal of Latin American Science and Culture. (2023, January 25). Science and climate literacy in Latin America and the Caribbean. *Journal of Latin American Science and Culture*. https://journalasc.org/2023/01/25/science_lac/

Journal of Latin American Science and Culture. (2021). Annual meeting on science and climate literacy. *Journal of Latin American Science and Culture*. https://journalasc.org/annual_meeting/

Journal of Latin American Science and Culture. (2022). The Science Culture Construction (SCC). *Journal of Latin American Science and Culture*. Retrieved from https://journalasc.org/blog/igsan/scc/

Pérez Canencio, J. G., Ojeda Solarte, M. L., Torres Herrera, A. A., & Giraldo Ceballos, A. E. (2022). Ecobarómetro digital: Midiendo la conciencia ambiental ciudadana en Colombia. *Journal of Latin American Sciences and Culture*, 4(6), 68–71. https://doi.org/10.52428/27888991.v4i6.362

World Organization for Science Literacy (WOSL). (2023). **Global vision: Science literacy initiatives** [Web page]. Retrieved from https://www.wosl.org.cn/en/NewsCenter/GlobalVision/art/2023/art_58cc7472b2124bb1ae0d6d314af93ef7.html

Construir una Cultura Científica Popularizando la Ciencia Verde: Retos y Oportunidades

Mary Luz Ojeda Solarte[1,*], José Gabriel Pérez Canencio[2], Christian Andrés Cuero Gamboa[3], Jorge Enrique Guevara Bejarano[4], Miguel Angel Pérez Ojeda[5]

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Resumen: Hacer frente al cambio climático representa un reto ambiental sin precedentes, sin embargo, la política climática a nivel mundial ofrece oportunidades importantes. Muchos de los efectos del cambio climático son ya evidentes y por eso es necesario actuar de forma inmediata, pero ¿cómo hacerlo?, ¿cómo crear una cultura del cuidado del planeta y de su biodiversidad?

La biodiversidad es esencial para el funcionamiento de los ecosistemas y los beneficios que brindan a la humanidad. Su conservación es importante para la sostenibilidad y se ha convertido en una prioridad para asegurar un futuro equilibrado.

Este artículo aborda los desafíos en la educación y divulgación de la Ciencia Verde, al igual que su integración en los currículos educativos, la formación docente y la falta de recursos. Estos desafíos, junto con la necesidad de compromiso político, requieren una acción concertada por parte de gobiernos y academias. A pesar de las barreras, la alfabetización en Ciencia Verde presenta oportunidades en la academia, la investigación y la educación para sensibilizar y actuar.

Mediante un enfoque metodológico mixto que combina la Ciencia Ciudadana y la Investigación Acción Participativa (IAP), se busca empoderar a las comunidades y facilitar la transferencia bidireccional de saberes. Este enfoque promueve la participación activa de la ciudadanía en la investigación y la educación ambiental, ayudando a enfrentar los desafíos y aprovechar las oportunidades que la Ciencia Verde ofrece para un desarrollo humano equitativo.

Palabras clave: Ciencia Verde; cultura científica; biodiversidad; cambio climático; educación ambiental; ciencia ciudadana; desarrollo sostenible.

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1. Introducción

La biodiversidad es esencial para el correcto funcionamiento de los ecosistemas y los beneficios que estos brindan a la humanidad. Preservar la diversidad biológica es importante para garantizar la sostenibilidad y se ha convertido en una prioridad en la investigación para asegurar un futuro equilibrado y sostenible.

Las prácticas científicas y tecnológicas enfocadas en la sostenibilidad ambiental y la protección de la biodiversidad conocidas como Ciencia Verde, o "Green Science" incluyen prácticas interdisciplinarias como la conservación, ecología, biología de la conservación y políticas ambientales, entre otras. Popularizar la Ciencia Verde es esencial para alfabetizar a la ciudadanía en temas ambientales, aumentar la conciencia ambiental y empoderar a las personas para tomar decisiones sostenibles.

Grandes desafíos se presentan cuando se aborda el tema de la educación y divulgación de la Ciencia Verde, por eso en este artículo se presentan algunos de ellos, como la integración en currículos educativos, formación de docentes, el acceso a recursos educativos, el compromiso político y otros que hacen parte de responsabilidad de gobiernos y academias para mitigar los efectos adversos que se presentan si no se atiende con prontitud cada reto.

Así como la alfabetización en Ciencia Verde es una necesidad urgente debido a los desafíos ambientales actuales, también es una oportunidad para promover un desarrollo humano equitativo y sostenible para las generaciones presentes y futuras. Se destacan en este artículo oportunidades en dos áreas principales: la academia e investigación, y la educación para sensibilizar y actuar.

2. Materiales y métodos

Enfoque Metodológico

Para crear escenarios de popularización de la Ciencia Verde que enfrentan los grandes desafíos y el aprovechamiento de las oportunidades que se mencionan más adelante, se puede emplear un enfoque metodológico mixto que combine la **Ciencia Ciudadana** (Citizen Science) y el método de **Investigación Acción Participativa** (IAP) para la construcción colectiva de conocimiento y la transferencia bidireccional de saberes entre investigadores y diversas comunidades en todos los territorios. Este enfoque permite no solo la generación de datos científicos, sino también el empoderamiento de las comunidades participantes y la integración de sus conocimientos tradicionales y contextuales en la investigación.

Con la aplicación de la Ciencia Ciudadana que implica la participación activa de ciudadanos no especializados en procesos de investigación científica, se facilita la recopilación de datos a gran escala y se promueve la educación científica y la concienciación ambiental tal como lo expone (Bonney, y otros, 2009).

Materiales

El empleo de plataformas digitales y aplicaciones móviles para que la ciudadanía registre sus propios datos geo referenciados e información relacionada con prácticas de sostenibilidad que realicen en sus entornos locales es muy importante para mantener un registro detallado de estas acciones y posteriormente analizar e interpretar los datos que conlleven a investigaciones más profundas sobre aquellos aspectos que se puedan mejorar en beneficio de la biodiversidad local y regional.

Guías y protocolos de observación: Documentos detallados que explican cómo capturar, registrar y reportar observaciones de manera estandarizada tal como el protocolo GHG para el cálculo de la huella de carbono. (Institute, World Resources, 2011), son de gran utilidad para el proceso científico.

Material educativo: Folletos, videos y tutoriales de elaboración local para capacitar a los participantes en el uso de las herramientas y en la comprensión de los objetivos del estudio.

Métodos

Reclutamiento de participantes: A través de la programación de eventos en Universidades e Instituciones Educativas y comunidades, divulgados en redes sociales y la colaboración con instituciones del gobierno y ONGs se hace la convocatoria y posterior registro de participantes.

Capacitación: Se realiza con la aplicación de talleres prácticos con formatos digitales interactivos y charlas para sensibilizar a los participantes sobre temáticas de Ciencia Verde.

Identificación de Problemas y Prioridades: A través de talleres participativos, las comunidades identificaron las principales preocupaciones y áreas de interés relacionadas con la biodiversidad, la sostenibilidad y el cambio climático.

Planificación y Acción Conjunta: Se diseñan y ejecutan planes de acción específicos para cada comunidad, basados en las prioridades identificadas.

Evaluación y Reflexión: Se realizan evaluaciones periódicas mediante grupos focales y cuestionarios para valorar el impacto de las acciones implementadas y ajustar las estrategias según fuera necesario.

Retroalimentación Continua: Las comunidades reciben informes regulares sobre los hallazgos de la investigación y se promueve un diálogo continuo para integrar sus perspectivas y conocimientos en las siguientes fases del estudio.

Integración de Conocimientos y Transferencia de Saberes

Investigación, Acción Participativa (IAP): El método de IAP que se aplica en la implementación de los talleres y otros proyectos, se centra en la colaboración activa entre investigadores y miembros de la comunidad, fomentando un proceso cíclico de reflexión, acción y evaluación (Altrichter, Kemmis, McTaggart, & Skerritt, 2002). Este enfoque asegura que las investigaciones sean relevantes y beneficiosas para las comunidades involucradas.

3. Resultados.

3.1 Conceptos previos importantes

Varios conceptos importantes para la comprensión de los resultados se incluyen a continuación

3.1.1 Biodiversidad.

De acuerdo con National Geographic (National Geographic, 2024) la biodiversidad se refiere a la variedad de especies vivas en la tierra, incluidas plantas, animales, bacterias y hongos; es esencial para el funcionamiento de los ecosistemas y los servicios que estos proveen a los humanos, la conservación de esta biodiversidad es fundamental para la sostenibilidad. En un artículo publicado en la revista "Sustainability", (Niesenbaum, 2019) destaca la integración de la conservación de la biodiversidad con la sostenibilidad como un área de investigación prioritaria, subrayando la importancia de proteger los ecosistemas y sus servicios para asegurar un futuro sostenible.

3.1.2 Ciencia Verde, o "Green Science".

La Ciencia Verde se relaciona con varios conceptos clave en la conservación del medio ambiente, la biodiversidad y la sostenibilidad mencionados por (National Geographic, 2024); por lo general, se refiere a las prácticas científicas y tecnológicas que tienen un enfoque especial en la sostenibilidad ambiental, la protección de la biodiversidad y la minimización del impacto negativo en los ecosistemas. Esto incluye esfuerzos interdisciplinarios que abarcan la conservación, la ecología, la biología de la conservación y las políticas ambientales.

3.1.3 Popularización de la Ciencia Verde.

Mediante la divulgación masiva de las prácticas científicas y tecnológicas con enfoque especial en la sostenibilidad ambiental, se atiende la urgente necesidad de alfabetizar a la ciudadanía en temas relativos al cuidado del ambiente y la protección de la biodiversidad. Es importante que todos los estratos sociales tengan la misma oportunidad de alfabetizarse en estos temas porque a todos compete la tarea de cuidar el planeta, aumentar la conciencia ambiental y empoderar a las personas para tomar decisiones informadas que promuevan prácticas sostenibles fomentando un compromiso colectivo que minimice el impacto ambiental.

3.1.4 La alfabetización.

En temas de Ciencia Verde no solo trata la adquisición de conocimientos, sino también inspirar acciones concretas que contribuyan a la protección y restauración del medio ambiente. Esto incluye desde prácticas cotidianas en el hogar hasta la participación activa en políticas y movimientos ambientales a nivel comunitario y global.

El momento actual requiere de un compromiso renovado con la Ciencia Verde y la educación ambiental a nivel global. A los líderes mundiales que impulsan las acciones verdes les corresponde la responsabilidad compartida de abordar los desafíos urgentes que enfrenta el planeta y empoderar a todas las personas a través del conocimiento y la acción promoviendo la conservación de la biodiversidad, la mitigación del cambio climático y la transición hacia economías más verdes y resilientes

3.2. Retos actuales en la educación y Popularización de la Ciencia Verde.

A pesar de su importancia, la educación y popularización de la Ciencia Verde enfrenta numerosos desafíos. La integración de estos temas en los currículos educativos es aún desigual y a menudo depende de los recursos disponibles, la formación de los docentes y el compromiso político.

La UNESCO y la ONU han identificado la necesidad urgente de superar estas barreras para lograr una educación ambiental inclusiva y efectiva en todo el mundo (Glavic, 2020). La falta de recursos educativos de calidad, la variabilidad en la implementación de políticas ambientales y la necesidad de adaptar los contenidos a contextos locales son algunos de los principales obstáculos que deben abordarse para promover una comprensión y un compromiso más profundos con la sostenibilidad.

A continuación, se enuncian algunos de los retos:

3.2.1. Integración de la Ciencia Verde en los Currículos Educativos.

Uno de los desafíos más importantes es integrar los temas de Ciencia Verde en los currículos educativos a nivel global. La UNESCO ha subrayado la importancia de incluir la educación ambiental y la alfabetización científica en los planes de estudio desde la educación primaria hasta la universitaria. No obstante, numerosos sistemas educativos aún no han aplicado completamente estas sugerencias debido a la falta de recursos, capacitación para los docentes y materiales apropiados (Glavic, 2020).

3.2.2. Formación y Capacitación de Docentes.

Otro reto es la capacitación de los docentes para impartir temas de Ciencia Verde. Los profesores necesitan una formación especializada y constante para mantenerse actualizados con los avances en ciencia y tecnología vinculados a la sostenibilidad y al medio ambiente. Sin una preparación adecuada, los docentes podrían sentirse inseguros o carecer de la información necesaria para tratar estos temas en sus clases. (Glavic, 2020)

3.2.3. Acceso y Distribución de Recursos Educativos.

La falta de acceso equitativo a recursos educativos de calidad es un problema persistente. En muchos países en desarrollo, las escuelas carecen de libros, materiales didácticos y acceso a tecnologías que faciliten la enseñanza de la Ciencia Verde. La ONU ha señalado que las disparidades en la distribución de recursos educativos impiden el logro de una alfabetización científica global efectiva (Manos Antoninis, 2020)

3.2.4. Conciencia y Compromiso Político.

En el ámbito político, poner en marcha políticas que apoyen la educación en Ciencia Verde necesita un compromiso firme y continuo. A pesar de que hay muchos acuerdos internacionales que impulsan la educación ambiental, la implementación de estas políticas varía mucho de un país a otro. La falta de voluntad política y el escaso financiamiento para programas educativos sobre sostenibilidad son obstáculos clave.

3.2.5. Relevancia y Aplicabilidad Local.

Para que la educación en Ciencia Verde sea efectiva, los contenidos deben ser relevantes y aplicables a los contextos locales de los estudiantes. Esto implica adaptar los currículos para abordar los problemas ambientales específicos de cada región. Sin embargo, desarrollar y mantener programas educativos personalizados puede ser complicado y costoso.

3.2.6. Compromiso de la Comunidad y Participación.

La educación en Ciencia Verde no debería restringirse únicamente al entorno escolar. Es fundamental que la comunidad participe activamente para promover una comprensión y un compromiso más amplio con la sostenibilidad. No obstante, involucrar a las comunidades locales y desarrollar programas de educación ambiental que sean accesibles y atractivos para todos los sectores de la sociedad representa un desafío significativo. (Lewis, Scheneegans, & Straza, 2021)

3.2.7. Brechas culturales

Uno de los grandes desafíos en la educación sobre Ciencia Verde es superar las brechas culturales que existen en comunidades que resisten la protección del medio ambiente o que no reconocen el cambio climático como una responsabilidad colectiva. Estas brechas culturales pueden surgir de diferencias en valores, tradiciones y creencias que influyen en cómo se perciben y aceptan las cuestiones ambientales. En muchos casos, estas comunidades pueden tener prácticas y conocimientos tradicionales que entran en conflicto con las perspectivas modernas sobre sostenibilidad y cambio climático. Superar estas barreras requiere un enfoque sensible y adaptado a las realidades culturales locales, promoviendo un diálogo respetuoso y la integración de enfoques científicos con el conocimiento y las prácticas tradicionales.

3.3 Oportunidades

Alfabetizar al mundo en temas de Ciencia Verde no solo es una necesidad urgente frente a los desafíos ambientales actuales, sino también una oportunidad para promover un desarrollo humano más equitativo y sostenible para las generaciones presentes y futuras. A continuación, se enuncian algunas oportunidades desde dos puntos de vista: la academia e investigación y la educación para sensibilizar y actuar.

3.3.1 Desde la academia y la investigación

- **Investigación y Desarrollo:** Un escenario apropiado para generar conocimiento en este campo es la Academia y los Grupos de Investigación desde los cuales se puede incentivar la producción científica relacionada con la Ciencia Verde. Es preciso fomentar el desarrollo de proyectos interdisciplinarios e interinstitucionales que exploren nuevas tecnologías, políticas efectivas y prácticas innovadoras que contribuyan a un futuro más sostenible. La investigación y el desarrollo no solo debe centrarse en soluciones técnicas, sino también en entender las interacciones complejas entre la sociedad, la cultura, la economía y el medio ambiente.

- **Alfabetización y Divulgación**: Una vez que se generen los productos es importante divulgar los resultados en los medios de difusión masiva en formato audiovisual o artículos, notas científicas o libros para asegurar que el nuevo conocimiento en Ciencia Verde sea accesible para todos. El desarrollo tecnológico y la innovación facilitan las tareas de trasladar el conocimiento a las comunidades tanto científicas como no científicas si se desarrollan estrategias efectivas de divulgación que lleguen a todos los sectores de la sociedad, utilizando medios diversos y adaptando los mensajes a diferentes contextos culturales y sociales.

Es claro que empleando los métodos apropiados para alfabetizar y empoderar a los ciudadanos se les permitirá tomar decisiones informadas y participar activamente en la protección del planeta.

- **Colaboración y Compromiso Global**: La colaboración activa entre gobiernos, instituciones académicas, organizaciones no gubernamentales y el sector privado para investigar, desarrollar y compartir conocimientos al igual que mejores prácticas y recursos será siempre fundamental para construir una red global de conocimiento y acción que impulse políticas efectivas y soluciones concretas para los problemas ambientales que enfrentamos a diario. Para lograrlo es importante convocar a todos los actores sociales a participar de prácticas de intercambio, diálogo, análisis, reflexión y negociación que promueven la comprensión e intervención de sus contextos para llevar la Ciencia Verde a todos los sectores de una sociedad sin fronteras.

- **Las colaboraciones internacionales** juegan un papel fundamental en el avance de la alfabetización científica, ya que permiten compartir conocimientos, recursos y experiencias entre diferentes países y culturas. Estas colaboraciones facilitan el acceso a la información y a las últimas investigaciones en diversas áreas de la ciencia, fomentando así el desarrollo de habilidades críticas y analíticas en las personas.

3.3.2 Desde la educación.

- **Crear una conciencia ambiental global:** La alfabetización en Ciencia Verde fortalece la oportunidad de aumentar la conciencia sobre los desafíos ambientales globales, como el cambio climático, la pérdida de biodiversidad, la contaminación y la escasez de recursos. Esto permite que las personas comprendan mejor cómo sus acciones individuales y colectivas impactan en el medio ambiente

- **Aumentar la capacidad de acción informada**: Con conocimientos en Ciencia Verde, las personas pueden tomar decisiones informadas y adoptar prácticas sostenibles en su vida diaria. Esto incluye desde decisiones de consumo y la revisión de los hábitos energéticos hasta participación en iniciativas comunitarias y en la formulación de políticas públicas ambientales.

- **Promover prácticas sostenibles:** La alfabetización en Ciencia Verde promueve el desarrollo y la adopción de prácticas sostenibles en diversos sectores, como la agricultura, la industria, la energía, el transporte, el gobierno. Estas prácticas son esenciales para mitigar los impactos ambientales negativos y avanzar hacia un desarrollo más equitativo y respetuoso con el medio ambiente.

- **Fomentar la innovación y tecnología verde**: Fomentar la alfabetización en Ciencia Verde impulsa la investigación y la innovación en tecnologías limpias y soluciones ambientales. Esto puede conducir a avances significativos en áreas como la energía renovable, la gestión de residuos, el cuidado de la especies animal y vegetal, la conservación del agua, la agricultura sostenible y la adopción de buenas prácticas tecnológicas verdes – Green It.

- **Fortalecer la resiliencia ante Cambios Globales**: En un mundo cada vez más afectado por fenómenos climáticos extremos y otros impactos ambientales, la alfabetización en Ciencia Verde fortalece la capacidad de las comunidades para adaptarse y responder de manera efectiva a estos cambios, reduciendo así su vulnerabilidad.

- **Ampliar la responsabilidad Compartida:** La protección del medio ambiente es responsabilidad de todos los individuos, comunidades, gobiernos y empresas. La alfabetización en Ciencia Verde promueve una comprensión común de esta responsabilidad compartida y fomenta la colaboración global para abordar los problemas ambientales de manera coordinada y efectiva.

4. Discusión

El análisis de los resultados obtenidos a través de la implementación de metodologías mixtas, como la Ciencia Ciudadana y la Investigación Acción Participativa (IAP), permite identificar tanto desafíos como oportunidades clave en la integración de la Ciencia Verde en la educación para la sostenibilidad.

En línea con lo señalado por (Gonzalez Gaudiano & Meira Cartea, 2020) , la falta de adaptación curricular y de formación docente en estos temas limita la capacidad de las instituciones educativas para formar estudiantes con una conciencia ambiental sólida. Sin embargo, como lo evidencia el trabajo de (Pérez & González, 2023), las tecnologías emergentes y las plataformas digitales ofrecen nuevas vías para involucrar a la ciudadanía en la conservación de la biodiversidad, abriendo oportunidades para que la educación se desplace hacia enfoques más participativos y prácticos.

Un aspecto crítico que emerge es la necesidad de apoyo institucional y político para la inclusión de la Ciencia Verde en los currículos. Tal como lo muestra (Ruano, 2023) , los marcos normativos actuales no siempre facilitan la implementación de programas educativos sostenibles, y los recursos destinados a la capacitación de docentes en temas de biodiversidad y sostenibilidad son escasos. Sin embargo, la colaboración entre gobiernos, instituciones académicas y actores locales, como se propone en el libro de (Aikens, Mckenzie, & Vaughter, 2018) , puede generar soluciones innovadoras que logren una mayor efectividad en la enseñanza y sensibilización sobre la crisis climática.

Asimismo, se debe destacar el papel de la educación ambiental en la creación de espacios de resistencia frente a la mercantilización de los recursos naturales, como el agua y la biodiversidad. Las comunidades indígenas, afrodescendientes y otros grupos locales juegan un rol fundamental en la articulación de saberes tradicionales con la ciencia contemporánea. Esto resuena con las propuestas de (UNESCO, 2021) sobre la importancia de integrar saberes ancestrales en la formulación de políticas educativas más inclusivas y representativas de la diversidad cultural y ecológica.

5. Conclusiones

La integración de la Ciencia Verde en los sistemas educativos no solo es posible, sino necesaria, para enfrentar los desafíos globales relacionados con la biodiversidad y la crisis climática.

A través de metodologías participativas como la Ciencia Ciudadana y la IAP, se logra un mayor compromiso de los estudiantes, los profesores, los investigadores y la ciudadanía en temas de sostenibilidad ambiental, facilitando el desarrollo de una conciencia crítica frente a los problemas ambientales contemporáneos.

Se resalta la urgente necesidad de una mayor inversión en la capacitación de los docentes y en la creación de materiales didácticos que aborden de manera efectiva la protección del medio ambiente y la biodiversidad.

Además, se hace imprescindible una mayor articulación entre actores políticos, académicos y la sociedad para superar las barreras estructurales que impiden la implementación de programas educativos centrados en la sostenibilidad.

La integración de saberes ancestrales y locales en los currículos de Ciencia Verde no solo es una cuestión de justicia social, sino también una estrategia efectiva para promover un enfoque más holístico de la educación ambiental.

Este enfoque permite enfrentar la crisis climática desde una perspectiva más inclusiva y contextualizada, aprovechando el conocimiento acumulado por las comunidades locales en la gestión de sus territorios y recursos naturales.

Referencias:

Aikens, K., Mckenzie, M., & Vaughter, P. (2018). Investigación sobre políticas de educación ambiental y para la sostenibilidad. Londres: Taylor and Francis Group.

Altrichter, H., Kemmis, S., McTaggart, R., & Skerritt, Z. (2002). The concept of action research. The learning organization.

Bonney, R., Ballard, H., Jordan, R., MacCallie, H., Shirk, J., Phillips, T., & Candie C, W. (2009). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report. Institute of education science. Obtenido de Center for Advancement of In.

Glavic, P. (2020). Identificación de cuestiones clave de la educación para el desarrollo sostenible. Sustainability, 12-16.

Gonzalez Gaudiano, E., & Meira Cartea, P. (2020). Educación para el cambio climático: ¿Educar sobre el clima o para el cambio? Perfiles educativos.

Institute, World Resources. (2011). Greenhouse Gas Protocol. GHG Protocol Scope 2 Guidance.

Lewis, J., Scheneegans, S., & Straza, T. (2021). UNESCO, Science report:The race against time for smarter development . Unesco.

Manos Antoninis, D. A. (2020). Todo significa todo: Introducción al Informe de Seguimiento de la Educación en el Mundo 2020 sobre inclusión. Prospects, 103 - 109.

National Geographic. (21 de 06 de 2024). Biodiversity. Obtenido de https://education.nationalgeographic.org/resource/biodiversity

Niesenbaum, R. A. (2019). The integration of conservation, biodiversity, and sustainability. Sustainability, 11-17.

Pérez , R., & González, A. (2023). Ciencia ciudadana, estrategias de conservación de la biodiversidad y biomonitoreos de los organismos genéticamente modificados (OGM´s). Sociedades Rurales, Producción y Medio Ambiente.

Ruano, L. (2023). El diálogo político birregional verde UE-CELAC. Funadación Carolina.

UNESCO. (2016). El mandato y la mision de la UNESCO en resúmen. Obtenido de https://www.unesco.org/es/brief

UNESCO. (2021). Reimaginando juntos nuestro futuro : Un nuevo contrato social para la educación. París: Unesco.

Review Article

Enabling a Sustainable Digital Transformation

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Abstract: This paper explores the critical intersections between digital transformation and sustainable development, proposing an integrated framework for achieving sustainable digital transformation that combines technological advancement with environmental management. The study begins by defining sustainable digital transformation as an integrated approach that takes into account environmental, economic, and social perspectives. The environmental impacts of digital technologies, including the generation of e-waste, energy consumption, and resource depletion, are examined while identifying opportunities for digital solutions to address environmental challenges. Key strategies to drive sustainable digital transformation are discussed, such as developing energy-efficient technologies, implementing circular economy principles, and promoting green IT practices. The paper also discusses the role of policy frameworks, corporate social responsibility, and multi-stakeholder collaboration in promoting sustainable practices in digital industries. The paper illustrates successful examples of sustainable digital transformation through case studies from various industries, including the use of artificial intelligence to optimize energy consumption, blockchain to increase procurement chain transparency, and the use of the Internet of Things (IoT) to improve resource efficiency. Agriculture and manufacturing. The study concludes with a call to action for policymakers, business leaders, and researchers to prioritize sustainability in digital transformation initiatives, emphasizing the need for a holistic approach to ensure that the digital future is not only technologically advanced but also ecologically sustainable. This paper contributes to the current debate on sustainable development by providing practical insights and promoting collaborative efforts towards a sustainable digital era.

Keywords: sustainability; digital transformation; environmental impact

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1. Enabling Sustainable Digital Transformation

Sustainable digital transformation is the process of integrating digital technologies in ways that minimize environmental harm while promoting economic and social sustainability. This approach emphasizes the intentional design, deployment, and use of digital tools and systems to reduce carbon footprints, increase resource efficiency, and support the Sustainable Development Goals (SDGs). As the world becomes increasingly connected through digital technologies, these advances must be integrated with broader environmental vision and long-term sustainability goals (Berkhout & Hertin, 2004). In doing so, sustainable digital transformation can contribute to a balanced and inclusive digital future that meets the needs of current and future generations.

The impact of digital on the environment is multifaceted, bringing both challenges and opportunities. On the one hand, digital solutions can significantly increase efficiency and reduce waste in everything from energy to transportation. For example, the use of smart grids, cloud computing, and digital platforms can significantly reduce resource consumption and greenhouse gas emissions (European Commission, 2020). However, on the other hand, the production, use, and disposal of digital devices lead to e-waste, energy consumption, and resource depletion. The rapid updating of electronic devices and the increasing demand for data storage and processing power have exacerbated these environmental problems, highlighting the need for a more sustainable approach to digital transformation (Berkhout & Hertin, 2004).

Achieving sustainable digital transformation requires a holistic approach that balances the benefits of digital innovation with its potential environmental costs. This includes designing digital products and systems with sustainability in mind, for example by using energy-saving technologies, promoting a circular economy, and encouraging responsible consumption of digital resources. The European Commission (2020) highlights the importance of adopting eco-design principles and promoting digital literacy to help consumers and businesses make more sustainable choices. In addition, governments and organizations need to implement policies and incentives that support the development and adoption of green digital technologies, ensuring that sustainability is at the heart of digital transformation strategies.

A key aspect of sustainable digital transformation is reducing the carbon footprint of digital industries. Data centers are an integral part of the functioning of the digital economy. They represent one of the largest consumers of electricity in the world and contribute significantly to carbon emissions (International Energy Agency, 2021). To address this issue, efforts are underway to switch to renewable energy sources, improve energy efficiency, and develop innovative cooling technologies to reduce the environmental impact of data centers. In addition, the concept of "green computing" is gaining ground, encouraging the design and use of computers and other digital devices in a way that minimizes their environmental footprint (Berkhout and Hertin, 2004).

Another important aspect of sustainable digital transformation is e-waste management. The disposal of electronic devices is a growing environmental problem, with millions of tonnes of e-waste generated worldwide each year. Sustainable practices in the digital sphere involve not only reducing the amount of e-waste but also ensuring its proper recycling and disposal. This includes promoting the use of recycled materials in the production of new devices, extending the lifespan of digital products, and establishing efficient e-waste management systems (European Commission, 2020). By addressing the e-waste challenge, sustainable digital transformation can help mitigate the negative environmental impacts associated with the digital economy. Sustainable digital transformation is a complex and multifaceted process that requires a careful balance between technological innovation and environmental responsibility. It involves integrating digital technologies to minimize environmental damage while promoting sustainable economic and social development.

By adopting sustainable practices such as reducing energy consumption, managing e-waste, and designing green digital systems, we can ensure that digital transformation contributes to a more sustainable and equitable future. Successfully implementing a sustainable digital transformation will depend on the collective efforts of governments, businesses, and individuals to prioritize sustainable development in the digital age (Berkhout and Hertin, 2004; European Commission, 2020; International Energy Agency, 2021).

2. Environmental Impacts of Digital Technologies

The environmental footprint of digital technologies is a growing concern in the modern world, as these technologies continue to permeate all aspects of life. While digital innovations have undoubtedly brought numerous benefits, such as increased efficiency, improved communication, and enhanced access to information, they also have significant environmental impacts. These impacts are particularly evident in three key areas: e-waste generation, energy consumption, and resource depletion. Addressing these challenges is crucial to ensuring that the digital transformation is sustainable and does not exacerbate existing environmental issues.

E-waste generation is one of the most pressing environmental challenges associated with digital technologies. The rapid pace of technological advancement and the short lifecycle of digital devices resulted in the generation of massive amounts of electronic waste, or e-waste. According to Forti, Balde, Kuehr, and Bel (2020), global e-waste reached a staggering 53.6 million metric tons in 2019, and this number is expected to continue rising. E-waste contains hazardous materials, such as lead, mercury, and cadmium, which can leach into the environment if not properly managed. Improper disposal of e-waste can lead to soil and water contamination, posing serious risks to both the environment and human health.

The management of e-waste is further complicated by the fact that only a small fraction of it is properly recycled. Forti et al. (2020) estimate that less than 20% of global e-waste is formally recycled, with the remainder often ending up in landfills or being processed in informal recycling facilities that lack the necessary safeguards to protect workers and the environment. The improper handling of e-waste not only leads to the release of toxic substances but also results in the loss of valuable materials, such as gold, silver, and copper, which could be recovered and reused. Addressing the e-waste problem requires concerted efforts to improve recycling rates, promote the design of longer-lasting products, and reduce the use of hazardous materials in electronic devices.

Energy consumption is another major environmental concern associated with digital technologies. The infrastructure that supports the digital economy, including data centers, servers, and cloud computing, consumes vast amounts of energy. Jones (2018) highlights that data centers alone account for approximately 1% of global electricity consumption, a figure that is expected to rise as the demand for digital services continues to grow. The energy required to power this infrastructure is often sourced from fossil fuels, contributing to higher greenhouse gas emissions and exacerbating climate change. As digital technologies become more pervasive, the need to reduce their energy consumption and transition to renewable energy sources becomes increasingly urgent.

In addition to energy consumption, the efficiency of digital infrastructure is a key factor in its environmental impact. While advances in technology have led to more energy-efficient data centers and devices, the overall increase in digital activity often offsets these gains. This phenomenon, known as the rebound effect, occurs when improvements in energy efficiency lead to increased usage, ultimately resulting in higher total energy consumption (Jones, 2018). To mitigate this effect, it is essential to adopt strategies that encourage responsible energy use, such as implementing energy-saving measures in data centers, optimizing software to reduce resource demand, and promoting digital literacy among consumers to reduce unnecessary usage.

Resource depletion is another significant environmental impact of digital technologies, particularly in the production of digital devices. The manufacture of smartphones, laptops, and other electronic devices requires substantial amounts of rare earth metals and other non-renewable resources. Graedel and Reck (2016) noted that the extraction and processing of these materials were associated with environmental degradation, including habitat destruction, soil and water pollution, and the generation of large amounts of waste. Furthermore, the increasing demand for digital devices is placing additional pressure on already limited natural resources, raising concerns about the long-term sustainability of current production practices.

The environmental costs of resource depletion extend beyond the immediate impacts of mining and material extraction. The reliance on non-renewable resources in digital device production also raises issues of resource scarcity and geopolitical tension. As the availability of certain rare earth metals decreases, competition for these resources is likely to intensify, potentially leading to conflicts and further environmental degradation (Graedel & Reck, 2016). To address these challenges, it is crucial to explore alternative materials, improve the efficiency of resource use, and develop recycling technologies that can recover valuable materials from end-of-life devices.

The cumulative environmental impact of digital technologies highlights the need for a more sustainable approach to their development and use. While digital technologies offer numerous benefits, their environmental costs cannot be ignored. To achieve sustainable digital transformation, it is essential to address the environmental impacts of e-waste generation, energy consumption, and resource depletion. This requires a combination of technological innovation, policy intervention, and consumer awareness to ensure that the digital revolution contributes to a more sustainable and equitable future.

The environmental impacts of digital technologies are significant and multifaceted. Addressing these challenges is critical to ensuring that the benefits of digital transformation do not come at the expense of the environment. By promoting the responsible design, use, and disposal of digital technologies, we can minimize their environmental footprint and support the transition to a more sustainable digital economy. This will require the collective efforts of governments, businesses, and individuals to implement sustainable practices and prioritize environmental action in the digital age.

3. Strategies for Sustainable Digital Transformation

Achieving sustainable digital transformation requires a holistic approach that encompasses energy-efficient technologies, circular economy principles, and green IT practices. As digital technologies become increasingly integrated into all aspects of modern life, their impact on the environment is correspondingly increasing. To mitigate these impacts and ensure a sustainable future, strategies that minimize energy consumption, reduce waste, and improve resource efficiency must be implemented. These strategies are essential to balancing the benefits of digital innovation with the need to protect the environment.

Energy-efficient technologies are at the forefront of sustainable digital transformation. The development and implementation of energy-efficient hardware and software can significantly reduce the environmental footprint of digital technologies. For example, low-power processors are designed to perform complex calculations with minimal power consumption, which is critical for devices that operate continuously, such as servers and mobile devices (Koomey, 2011). In addition, energy-efficient algorithms optimize the performance of software applications, reducing the required computing power and power consumption. These innovations play a vital role in mitigating the environmental impact of the growing demand for digital services.

Optimized data centers are another important component of energy-efficient technologies. Data centers, which house large amounts of data and form the backbone of digital services, are known for their high energy consumption. However, the energy requirements of these facilities can be significantly reduced through the use of advanced cooling systems, energy-efficient server designs, and optimized data management practices. Koomey (2011) notes that improvements in data center energy efficiency have already led to significant reductions in energy consumption, suggesting that there is potential for further growth as technology continues to evolve. Implementing these energy-saving technologies is essential to minimizing the carbon footprint of digital infrastructure.

Circular economy principles offer another path to a sustainable digital transformation. The circular economy is a business model that focuses on designing products for their useful life, promoting repair and reuse, and facilitating recycling. In the context of the technology industry, this means creating digital devices that are durable, easily repairable, and recyclable at the end of their life cycle (Ellen MacArthur Foundation, 2013). By adopting circular economy principles, the tech industry can reduce the amount of electronic waste generated and save valuable resources, such as rare earth metals and other non-renewable materials. This approach not only benefits the environment but also creates economic opportunities by developing new business models focused on product life cycle management.

Product longevity is a key aspect of the circular economy in the tech industry. Designing products to last longer reduces how often consumers replace their devices, which reduces the overall demand for new products and associated resource mining. Additionally, by making products easier to repair, manufacturers can extend their useful life, reducing electronic waste and conserving resources. The Ellen MacArthur Foundation (2013) highlights that adopting such practices can yield significant environmental benefits while providing consumers with more cost-effective options for maintaining their digital devices. Encouraging repair and reuse is essential to ending the product lifecycle and achieving a truly circular economy.

Recycling is another important component of the circular economy in the tech industry. When digital devices reach the end of their useful life, recycling can recover valuable materials such as metals and plastics that can be used to manufacture new products. This reduces the need for raw material extraction, which is often associated with significant environmental degradation. Promoting recycling within the tech industry consumption and environmental impact (Murugesan, 2008).

Cloud computing further enhances energy efficiency by optimizing the use of shared resources across a network, allowing for more efficient use of computing power and storage. Sustainable data center management is another key aspect of green IT practices. As previously mentioned, data centers are major consumers of energy, and their environmental impact can be significant. However, by implementing sustainable management practices, such as using renewable energy sources, optimizing cooling systems, and employing energy-efficient hardware, data centers can reduce their environmental footprint. Murugesan (2008) emphasizes that green IT practices not only benefit the environment but also provide economic advantages by reducing operational costs. Adopting these practices is essential for ensuring that the digital transformation contributes to sustainability goals rather than undermining them.

The strategies for sustainable digital transformation involve a combination of energy-efficient technologies, circular economy principles, and green IT practices. By implementing these strategies, the tech industry can minimize its environmental impact while continuing to drive innovation and economic growth. The transition to a sustainable digital economy requires the collective efforts of policymakers, businesses, and consumers to prioritize environmental sustainability in the design, deployment, and use of digital technologies. Through these efforts, it is possible to achieve a digital transformation that not only enhances our lives but also protects the planet for future generations.

4. The Role of Policy Frameworks and Corporate Responsibility

Policy frameworks play a critical role in fostering sustainable digital transformation. Governments can incentivize sustainable practices through regulations, standards, and financial support for green innovations. Corporate social responsibility (CSR) initiatives also drive sustainability, with companies adopting environmentally friendly practices to meet stakeholder expectations and regulatory requirements (Huber, Kirchler, & Sponhauer, 2017). Multi-Stakeholder Collaborations Policy frameworks are crucial in fostering sustainable digital transformation by setting the rules and incentives that guide both public and private sector actions. Governments play a pivotal role in this process by developing regulations, standards, and financial mechanisms that promote the adoption of environmentally friendly technologies and practices. For instance, governments can introduce policies that mandate the reduction of carbon emissions in the tech industry or provide tax incentives for companies that invest in green technologies (Huber, Kirchler, & Sponhauer, 2017). These policies help create a favorable environment for sustainable digital transformation by ensuring that sustainability considerations are embedded in the digital innovation process from the outset.

Regulatory frameworks are an essential component of these policy efforts. By establishing clear guidelines and standards for sustainable practices, governments can ensure that companies adhere to environmentally responsible behaviors. These frameworks might include regulations on energy efficiency, e-waste management, and the sustainable sourcing of materials used in digital devices. Such regulations not only protect the environment but also level the playing field, ensuring that all companies are held to the same standards, thereby preventing a "race to the bottom" where environmental concerns are sacrificed for competitive advantage (Huber, Kirchler, & Sponhauer, 2017). Effective regulatory frameworks are thus a cornerstone of sustainable digital transformation, guiding companies toward more sustainable practices. Financial support for green innovations is another critical aspect of policy frameworks. Governments can provide grants, subsidies, or low-interest loans to companies that are developing or deploying sustainable technologies. This financial support can help overcome the initial cost barriers associated with green innovation, making it more accessible to a wider range of companies.

By incentivizing the adoption of sustainable technologies, governments can accelerate the transition to a more sustainable digital economy. For example, subsidies for renewable energy technologies can make them more competitive with fossil fuels, encouraging their adoption across the tech industry (Huber, Kirchler, & Sponhauer, 2017). Such financial incentives are vital for driving the widespread adoption of sustainable practices in the digital sector.

Corporate social responsibility (CSR) initiatives also play a significant role in driving sustainable digital transformation. Companies are increasingly recognizing that they have a responsibility not only to their shareholders but also to the broader society and the environment. As a result, many are adopting CSR strategies that focus on reducing their environmental footprint, improving resource efficiency, and supporting sustainable development goals. These initiatives are often driven by stakeholder expectations, as consumers, investors, and employees increasingly demand that companies act responsibly and sustainably (Huber, Kirchler, & Sponhauer, 2017).

By integrating sustainability into their business models, companies can enhance their reputation, meet regulatory requirements, and contribute to the global effort to combat climate change. Multi-stakeholder collaborations are essential for achieving sustainable digital transformation. No single entity—whether a government, company or civil society organization—can address the complex environmental challenges posed by digital technologies on its own. Collaboration between different stakeholders facilitates knowledge sharing, innovation, and the development of comprehensive solutions that take into account diverse perspectives and expertise (Schot & Steinmueller, 2018). For example, partnerships between tech companies and academic institutions can drive research into new sustainable technologies, while collaboration with civil society organizations can ensure that these technologies are deployed in a manner that benefits all members of society. Multi-stakeholder collaborations are thus a key enabler of sustainable digital transformation.

5. Examples of implementation for sustainable digital transformation

Several developing countries have made significant progress in implementing policy frameworks and corporate responsibility initiatives to drive sustainable digital transformation.

For instance, Kenya's adoption of mobile-based digital technologies for financial inclusion has been a game-changer. The government's policy support for mobile banking, particularly through

M-Pesa, has not only promoted financial inclusion but has also had positive environmental impacts by reducing the need for physical bank branches and paper-based transactions (Jack & Suri, 2011). This initiative highlights how policy frameworks can support the development of digital solutions that contribute to sustainability while addressing socio-economic challenges.

Another example is Brazil's National Solid Waste Policy (Política Nacional de Resíduos Sólidos - PNRS), which has played a crucial role in promoting sustainable waste management , including e-waste. This policy framework mandates extended producer responsibility, requiring manufacturers to take back and responsibly manage electronic waste. As a result, companies in Brazil are increasingly adopting CSR initiatives focused on e-waste recycling, which reduces environmental harm and recovers valuable materials for reuse (Brazilian Ministry of the Environment, 2010). This approach showcases the effectiveness of regulatory frameworks in driving corporate responsibility and sustainability in the digital age.

In India, the Digital India initiative has been a pivotal policy framework aimed at transforming the country into a digitally empowered society and knowledge economy. Under this initiative, the Indian government has promoted the use of renewable energy in data centers and incentivized energy-efficient technologies. Additionally, Indian corporations, as part of their CSR activities, have been involved in deploying solar-powered digital infrastructure in rural areas, thereby enhancing digital connectivity while reducing carbon emissions (Government of India, 2015). This example shows the importance of aligning policy frameworks with corporate responsibility to achieve sustainable digital transformation. Case Studies Case studies provide concrete examples of how policy frameworks, CSR initiatives, and multi-stakeholder collaborations can drive sustainable digital transformation.

One such example is the use of artificial intelligence (AI) in smart grids to optimize energy use and reduce emissions. AI algorithms can predict energy demand and adjust supply in real time, minimizing waste and enhancing efficiency (McKinsey & Company, 2018). This not only reduces the environmental impact of energy consumption but also supports the broader goals of sustainable digital transformation by making energy systems more resilient and adaptable to changing conditions.

Another example is the use of blockchain technology to enhance supply chain transparency. Blockchain can provide a secure, transparent record of the movement of goods through the supply chain, enabling companies and consumers to verify that products have been sourced sustainably and ethically (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). This not only helps reduce the environmental impact of supply chains but also promotes ethical consumption by giving consumers the information they need to make informed choices. By leveraging blockchain technology, companies can enhance their CSR efforts and contribute to a more sustainable digital economy.

In the agricultural sector, the Internet of Things (IoT) is being used to improve resource efficiency by providing real-time data on soil conditions, weather, and crop health. This information allows farmers to optimize their use of water, fertilizers, and pesticides, reducing environmental impacts while increasing crop yields (Wolfert, Ge, Verdouw, & Bogaardt, 2017). IoT applications in agriculture demonstrate how digital technologies can be harnessed to support sustainable development goals, contributing to food security while minimizing environmental harm.

These case studies illustrate the potential of policy frameworks, CSR initiatives, and multi-stakeholder collaborations to drive sustainable digital transformation across different sectors. The integration of robust policy frameworks, active corporate responsibility, and collaborative multi-stakeholder partnerships is essential for driving sustainable digital transformation. The examples from both non-developing and developing countries demonstrate that with the right strategies, digital technologies can be harnessed to promote environmental sustainability while addressing socio-economic challenges. As digital transformation continues to reshape economies and societies, sustainability must remain at the forefront of these efforts, ensuring that technological progress benefits both people and the planet.

6. Conclusion

In short, achieving sustainable digital transformation requires a multidimensional approach that combines energy-saving technologies, circular economy principles, green IT practices, and enabling policy frameworks. Thanks to advances in cooling systems, server design, and data management, optimized data centers offer solutions. Circular economy principles, focusing on product lifecycle, repair, reuse, and recycling, are key to addressing e-waste and protecting valuable resources, while green IT practices increase efficiency and recycling. Reducing environmental impact through strategies such as virtualization and cloud computing. Policy frameworks and corporate responsibility play a crucial role in facilitating this transformation. Effective regulations, financial incentives for green innovation, and corporate social responsibility initiatives guide the public and private sectors toward sustainable development actions. The multi-stakeholder collaboration further amplifies these efforts by bringing together diverse expertise and resources, promoting innovation, and ensuring global solutions. Examples from developed and developing countries illustrate the potential of these strategies to promote environmental sustainability and address socio-economic challenges. By continuing to prioritize sustainability in our digital transformation efforts, we can ensure that technological advancements not only drive economic growth but also protect and safeguard our planet for future generations. Adopting these integrated approaches will help build a resilient and sustainable digital economy that benefits all stakeholders while mitigating environmental impacts.

References

International Energy Agency. (2021). Data centers and energy usage. International Energy Agency. https://www.iea.org/reports/data-centers-and-energy-usage

United Nations. (2015). Sustainable Development Goals. United Nations. https://sdgs.un.org/goals

United Nations Conference on Trade and Development. (2019). Digital economy report 2019: Value creation and capture – Implications for developing countries. United Nations. https://unctad.org/webflyer/digital-economy-report-2019

Berkhout, F., & Hertin, J. (2004). De-materialising and re-materialising: Digital technologies and the environment. Futures, 36(8), 903-920. https://doi.org/10.1016/j.futures.2004.01.003

European Commission. (2020). Shaping Europe's digital future. European Union. https://ec.europa.eu/digital-strategy

International Energy Agency. (2021). Data centers and energy usage. International Energy Agency. https://www.iea.org/reports/data-centers-and-energy-usage

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). The global e-waste monitor 2020: Quantities, flows, and the circular economy potential. United Nations University, United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association.

Graedel, T. E., & Reck, B. K. (2016). Six years of criticality assessments: What have we learned so far? Journal of Industrial Ecology, 20(4), 692-699. https://doi.org/10.1111/jiec.12305

Jones, N. (2018). How to stop data centres from gobbling up the world's electricity. Nature, 561(7722), 163-166. https://doi.org/10.1038/d41586-018-06610-y

Ellen MacArthur Foundation. (2013). Towards the circular economy: Economic and business rationale for an accelerated transition. Ellen MacArthur Foundation.

Koomey, J. G. (2011). Growth in data center electricity use 2005 to 2010. Analytics Press.

Murugesan, S. (2008). Harnessing green IT: Principles and practices. IT Professional, 10(1), 24-33. https://doi.org/10.1109/MITP.2008.10

Brazilian Ministry of the Environment. (2010). *Política Nacional de Resíduos Sólidos*. Retrieved from http://www.mma.gov.br/estruturas/253/_arquivos/Lei_12305_72.pdf

Government of India. (2015). *Digital India: Power to Empower*. Retrieved from https://www.digitalindia.gov.in/

Huber, F., Kirchler, M., & Sponhauer, V. (2017). *Sustainable digital transformation: The role of policy and corporate social responsibility*. Journal of Cleaner Production, 168, 834-846. https://doi.org/10.1016/j.jclepro.2017.09.165

Jack, W., & Suri, T. (2011). Mobile money: The economics of M-Pesa. *National Bureau of Economic Research*. https://doi.org/10.3386/w16721

McKinsey & Company. (2018). *Artificial intelligence in smart grids: Optimizing energy use for sustainability*. McKinsey Global Institute.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). *Blockchain technology and its relationships to sustainable supply chain management*. International Journal of Production Research, 57(7), 2117-2135. https://doi.org/10.1080/00207543.2018.1533261

Schot, J., & Steinmueller, W. E. (2018). *Three frames for innovation policy: R&D, systems of innovation and transformative change*. Research Policy, 47(9), 1554-1567. https://doi.org/10.1016/j.respol.2018.08.011

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). *Big data in smart farming – A review*. Agricultural Systems, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Winner Essay
Towards a "Sustainable Future through Applications of Science and Technology – SFAST 2023" international contest (December 2023)

Reducing Greenhouse Gas Emissions with Improved Public Transportation

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The growing climate crisis requires urgent and transformative action to reduce global greenhouse gas emissions. One of the most promising strategies is to reassess and restructure the transport system, including by improving public transport and reducing the use of private cars (Givoni, 2020). Not only does this approach significantly reduce emissions, but it also offers multiple co-benefits that help create a more sustainable and equitable urban future.

Public transport, such as buses, trains, and subways, generally have a lower carbon footprint per passenger mile than private cars. High-capacity vehicles such as electric buses can efficiently transport large numbers of passengers, thereby reducing emissions per capita (IEA, 2021). This shift from individual to collective modes of transport is a powerful tool in the fight against climate change because it directly reduces CO2 emissions.

Public transport systems are generally more energy efficient than individual vehicles, particularly when they run on cleaner, renewable energy. Adopting energy-efficient technologies in these systems further improves their environmental sustainability (Sperling and Gordon, 2019). By reducing the energy required to move people across urban landscapes, public transport can minimize emissions and promote responsible energy use.

A robust public transport network can alleviate congestion, thereby improving traffic flow and reducing fuel consumption (Barth and Boriboonsomsin, 2008). Reducing road congestion means that public and private vehicles operate more efficiently, use less fuel, and produce fewer emissions. Reducing congestion also improves air quality, reduces the urban heat island effect, and creates healthier cities.

Encouraging the shift from private cars to public transport is essential to reduce the number of vehicles on the road, which can directly reduce greenhouse gas emissions from the transport sector (Cervero, 2013). Complementing this shift with alternative modes of transport such as walking and cycling can further improve sustainability and foster a culture of active and healthy urban living.

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Smart technologies in public transport, such as real-time tracking, optimized routes, and digital payment systems can significantly improve operational efficiency and attract more users (Zhao et al., 2018). These innovations provide a seamless experience, making public transport a more attractive alternative to private cars.

Investment in public transport is consistent with sustainable urban development, reducing urban sprawl and promoting efficient land use (Newman and Kenworthy, 2015). Carefully planned systems promote mixed-use development, minimize long commutes, and support vibrant, walkable communities.

Prioritizing public transportation ensures equitable access across socioeconomic groups, thereby promoting environmental justice (Bullard et al., 2000). Reducing the use of private cars improves air quality, particularly in disadvantaged communities that are disproportionately affected by pollution, creating a healthier environment for all.

Improving public transportation and reducing the use of private cars are key strategies for reducing greenhouse gas emissions globally. This transformation promotes more sustainable, efficient, and equitable urban living. By investing in infrastructure, and smart technologies, and promoting public transportation, we can create a sustainable future in which public transportation becomes the backbone of urban mobility.

References

Barth, M., & Boriboonsomsin, K. (2008). Real-world carbon dioxide impacts of traffic congestion. Transportation Research Record, 2058(1), 163-171.

Bullard, R. D., Johnson, G. S., & Torres, A. O. (2000). Sprawl City: Race, Politics, and Planning in Atlanta. Island Press.

Cervero, R. (2013). Transit-oriented development in the United States: Experiences, challenges, and prospects. Transportation Research Board.

Givoni, M. (2020). Re-thinking transport policy: How can we limit the externalities of transport?. Transport Policy, 99, 1-3.

IEA (International Energy Agency). (2021). Transport [Data set]. Retrieved from https://www.iea.org/reports/transport

Journal of Latin American Sciences and Culture. (2023, November 24). Invitation to the SFAST 2023 Contest. https://journalasc.org/2023/11/24/scc-contest/

Journal of Latin American Sciences and Culture. (2023, December 22). The second phase results of the SFAST 2023 contest released. Journal of Latin American Sciences and Culture. https://journalasc.org/2023/12/22/the-second-phase-results-of-the-sfast-2023-contest-released/

Journal of Latin American Sciences and Culture. (2024, January 7). Award ceremony for SFAST 2023. https://journalasc.org/2024/01/07/award-ceremony-for-sfast-2023/

Newman, P., & Kenworthy, J. (2015). The end of automobile dependence: How cities are moving beyond car-based planning. Island Press.

Sperling, D., & Gordon, D. (2019). Two billion cars: Driving toward sustainability. Oxford University Press.

Zhao, P., Lu, Z., de Roo, G., & Geertman, S. (2018). Exploring the potential of smart transportation for smart city development. Sustainability, 10(6), 1981.

Review Paper

A Comprehensive Review of Bioenergy Sustainability: Balancing Economic, Environmental, and Social Impacts

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Abstract: This review explores bioenergy's role in the shift from fossil fuels to renewable energy. Bioenergy, derived from biomass like plants and organic waste, promises a reliable, cost-effective, and eco-friendly energy source. However, concerns about its sustainability and feasibility require a com-prehensive assessment of environmental, economic, and social factors. The paper reviews current research on bioenergy types, technological advancements, environmental impacts, and policy frameworks. It covers biomass applications in heat, power, and fuels, and discusses benefits for rural development and waste management. Challenges such as land-use competition and economic viability are also addressed, highlighting the need for integrated approaches and strong regulatory frameworks. The review provides insights into bioenergy's potential and challenges in achieving sustainable global energy goals.

Keywords: Bioenergy; Renewable energy; Biofuels; Carbon emissions; Organic waste

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1. Introduction

In recent years, the world has seen an increased focus on transitioning to renewable and sustainable sources of energy (Osman et al. 2024). Promoting the shift from fossil fuels to renewable energy sources is a key answer for global sustainability (Abernethy and Jackson 2022). Bioenergy, which is produced from biomass materials such as plants, forestry residues, and organic waste, has emerged as a promising alternative to fossil fuels. Bioenergy has the potential to provide a reliable, affordable, and environmentally friendly source of energy (Lehtinen, Juntunen, and Juga 2020). Promoting the shift from fossil fuels to renewable energy sources is a key global solution. Bioenergy is projected to play a significant part in this transition. Bioenergy usage for power and transportation fuels has increased significantly in recent years, driven by increased legislative support (Chunark et al. 2017). However, there are concerns about the sustainability and feasibility of bioenergy production and use. A review of the literature reveals numerous studies on the sustainability of bioenergy. However, most of these are tightly focused, such as on a certain technology or region (Cambero, Sowlati, and Pavel 2016; Igos et al. 2016). Most current studies predominantly concentrate on a single aspect, such as the environmental impact or the economic influence of bioenergy.

For example, (Igos et al. 2016) conducted a case study on forest-based biorefinery supply chains for bioenergy in British Columbia and discovered that social benefits, such as job creation, are expected consequences. (Cambero et al. 2016) investigated the environmental and economic impact of rye as a bioenergy source. Similarly, (Glithero, Ramsden, and Wilson 2012) created an economic model to assess farm systems in the UK. (Vellini, Gambini, and Stilo 2020) conducted a technical and economic feasibility analysis for a cogeneration plant in the agro-food business, and (Efroymson et al. 2013) developed environmental indicators to assess biofuel sustainability. There are few studies that incorporate numerous variables when evaluating bioenergy sustainability (Fantozzi et al. 2014), which presents a difficulty for academics seeking a thorough grasp of the subject. (Robertson et al. 2008) stated that bioenergy sustainability should include environmental, economic, and social considerations. (Solomon 2010) reviewed these three characteristics of bioenergy sustainability using a variety of metrics. (Gelfand et al. 2013; Tilman et al. 2009) have also examined the relationship between bioenergy sustainability, food security, and the utilization of marginal land. Second, numerous studies, such as those conducted by (Makkonen et al. 2015), produce contradicting results, making it difficult for stakeholders, including academia and politicians, to reach an agreement on the sustainability of bioenergy. According to Jeswani et al. (Jeswani, Chilvers, and Azapagic 2020a) the carbon-saving potential of biofuels differs depending on how they are produced. Their findings imply that biofuels sourced from waste biomass or cultivated on abandoned land are more successful at reducing carbon emissions than other varieties. (Daioglou et al. 2017; Hudiburg et al. 2016) conducted an analysis of croplands in the United States and determined that bioenergy from waste biomass is much more useful than crop-based biomass. Jeswani et al. (Jeswani, Chilvers, and Azapagic 2020b) compared the environmental costs and advantages of biodiesel and bioethanol and discovered that biodiesel emits less pollutants than ethanol. Liu et al. (Liu et al. 2021) compared first and second-generation biofuels, emphasizing the policy obstacles associated in their transition. Third, many studies address sustainability challenges in specific regions of the world, such as those by (Amigun, Musango, and Stafford 2011; van Meijl et al. 2018; Mohr and Raman 2013), whereas worldwide viewpoints on bioenergy sustainability are less common. (Walmsley and Godbold 2010) focused on environmental issues, while (Simangunsong et al.

2017) assessed the social sustainability of bioenergy, and (Khan et al. 2022) investigated combined land use and environmental aspects for sustainability assessment. Currently, biomass stands as the largest global source of renewable energy and holds substantial potential for increasing the production of heat, electricity, and transport fuels. If managed effectively, the further deployment of bioenergy could significantly increase its share of the global primary energy supply, achieve notable reductions in greenhouse gas emissions, and bring potential environmental improvements (Erickson 2017). Additionally, it could enhance energy security by reducing reliance on imported fossil fuels, provide economic and social benefits for rural communities, and improve waste management through the utilization of residues and waste materials.

2. Background

Bioenergy has been used as a source of energy for centuries, with early humans using biomass materials such as wood for heating and cooking. In the modern era, bioenergy has emerged as a promising alternative to fossil fuels, offering a reliable, affordable, and environmentally friendly source of energy. Bioenergy is produced from biomass materials such as plants, forestry residues, and organic waste, and can be used in various forms, including solid, liquid, and gaseous fuels, for heating, cooling, electricity generation, and transportation (Efroymson et al. 2013).

Compared to other sources of energy, such as fossil fuels and nuclear energy, bioenergy has a number of advantages and disadvantages. One advantage of bioenergy is that it is a renewable source of energy, relying on the growth and regrowth of biomass materials. This means that bioenergy can provide a more sustainable source of energy compared to finite fossil fuels. Bioenergy can also offer significant environmental benefits, such as reduced greenhouse gas emissions and improved waste management. Additionally, bioenergy production can support rural development and improve energy access in developing countries. However, there are also a number of disadvantages associated with bioenergy production and use (Perea-Moreno, Samerón-Manzano, and Perea-Moreno 2019a). One major concern is the potential for negative environmental impacts, such as land-use change, water depletion, and increased greenhouse gas emissions from the production and transportation of biomass materials. Another concern is the potential for competition with food production and other land uses, which could drive up food prices and cause social and economic issues. Additionally, there are concerns about the economic viability of bioenergy, as well as the potential for technological limitations and supply chain issues. To address these concerns, there is a need for a comprehensive assessment of the feasibility and sustainability of bioenergy as a source of energy. This report aims to provide such an assessment, based on a review of the current state of research on bioenergy production and use.

3. Biomass

3.1. Biomass resources

Currently, forestry, agricultural, and municipal residues and **waste** are the principal feedstocks for generating power and heat from biomass, with sugar, corn, and vegetable oil crops accounting for a minor share of liquid biofuel production. Biomass presently contributes roughly 50 exajoules EJ globally, accounting for 10% of total annual primary energy consumption, primarily from traditional biomass used for cooking and heating (Perea-Moreno, Samerón-Manzano, and Perea-Moreno 2019b). There is a great opportunity to increase biomass consumption by exploiting enormous amounts of underutilized residues and garbage. Furthermore, the use of conventional crops for energy can be enhanced while taking into account land availability and food demand (Hudiburg et al. 2016). In the longer term, lignocellulosic crops, both herbaceous and woody, might be produced on marginal, degraded, and surplus agricultural lands to supply a considerable amount of biomass resources. In the long run, aquatic biomass such as algae could make a substantial contribution. Based on this varied spectrum of feedstocks, the technical potential for biomass might be up to 1500 EJ per year by 2050, however most sustainability-conscious scenarios estimate an annual potential of 200 to 500 EJ, excluding aquatic biomass (Perea-Moreno et al. 2019b). Forest and agricultural residues, combined with other organic wastes, might generate 50 to 150 EJ per year, with the remaining coming from energy crops, excess forest growth, and higher agricultural productivity. Global primary energy demand is anticipated to reach 600 to 1000 EJ by 2050, up from around 500 EJ in 2008. Scenarios for low-carbon energy sources predict that future bioenergy demand might be up to 250 EJ per year, which is consistent with sustainable supply potential estimates, implying that biomass could sustainably supply a quarter to a third of the future global energy mix. The realization of this potential will be dependent on bioenergy's cost competitiveness and future regulatory frameworks, such as greenhouse gas emission reduction targets. Various demand and supply issues will influence the growth in biomass resource use through 2030. Strong renewable energy targets at the regional and national levels, such as the European Renewable Energy Directive, are expected to drive up demand, which will be satisfied by increased usage of residues, wastes, sugar, starch, and oil crops, as well as lignocellulosic crops (Perea-Moreno, Samerón-Manzano, and Perea-Moreno 2019c; Perea-Moreno et al. 2019b). The contribution of energy crops will be determined by crop selection and planting rates, which are impacted by agricultural productivity, environmental limits, water availability, and logistical issues. Under ideal conditions, significant expansion is feasible over the next 20 years, while estimates of prospective production increases vary greatly. For example, the potential biomass from leftovers and energy crops in the EU by 2030 is expected to reach between 4.4 and 24 EJ (Perea-Moreno et al. 2019c).

3.2. Biomass conversion technologies

Bioenergy, which is obtained from forestry, agricultural, and municipal residues, as well as garbage, is currently the world's greatest source of renewable energy. It has great promises for increasing the generation of heat, power, and transportation fuels. Converting raw biomass into energy products requires a variety of technologies according to the feedstock's composition and the energy service required (Perea-Moreno, Perea-Moreno, et al. 2017). Palletization, torrefaction, and pyrolysis are examples of methods that improve the transportability and storage of biomass (Shah, Khan, and Kumar 2018). Direct biomass combustion is the most common method of producing heat around the world, with technologies ranging from basic burners to complex equipment. For power, co-combustion in coal plants and specialist biomass combustion plants are less expensive, with anaerobic digestion best suited to wet organic feedstock. Although less prevalent, gasification provides higher efficiency and reduced emissions, with significant future prospects. First-generation biofuels, such as bioethanol and biodiesel, are widely utilized but have limitations due to their dependency on food crops. Second-generation biofuels, which use non-food biomass such organic waste and energy crops, offer lower environmental impact and more sustainability (Wang et al. 2018). These technologies require further research to become commercially viable. Bioenergy technology will become more efficient, reliable, and sustainable across a wide range of applications. In the long run, bioenergy production in biorefineries might co-produce transport biofuels, power, heat, and other marketable goods, increasing resource efficiency and assisting in the transition to a sustainable energy future.

3.3. Biomass storage facilities

Effective biomass storage is crucial for ensuring a consistent supply of feedstock for energy production, particularly given the seasonal and variable nature of biomass resources. Proper storage facilities prevent degradation and loss of biomass quality, which can significantly impact the efficiency and emissions of biomass conversion technologies. One common method is dry storage (Feria et al. 2024), where biomass is kept in open or covered stacks, allowing natural drying processes to reduce moisture content. This method is widely used for forestry residues and agricultural **waste**. For example, in the Scandinavian countries, large volumes of wood chips and pellets are stored in covered facilities to maintain their low moisture content and high energy density, essential for efficient combustion and gasification processes. Another approach involves ensiling, commonly used for wet biomass like silage crops and food waste (Chen et al. 2021; Deepika et al. 2024). This method involves compacting biomass in airtight conditions to promote anaerobic fermentation, which preserves biomass for long periods and is particularly beneficial for feedstocks used in anaerobic digestion. In Germany, numerous biogas plants utilize ensiled maize and other crops, ensuring a steady year-round feedstock supply. Advanced storage technologies are also emerging, such as torrefaction (Tumuluru et al. 2021) and palletization (Wei, Cheng, and Shen 2024), which enhance the stability and energy density of biomass. Torrefaction involves heating biomass in the absence of oxygen to produce a dry, energy-dense material that is easier to store and transport. This technique is increasingly applied to agricultural residues and wood waste, creating a uniform feedstock suitable for co-firing in coal power plants. Similarly, palletization compresses biomass into dense, uniform pellets, which are less susceptible to moisture uptake and microbial degradation. In the United States, large-scale pellet production facilities, particularly in the Southeastern states, supply domestic and international markets, illustrating the global trade potential of biomass pellets. Bulk storage solutions, such as silos and bunkers, are also essential for maintaining the quality of biomass feedstocks. For example, in Canada, the bioenergy industry employs large silos for wood pellets and agricultural residues, ensuring they remain dry and uncontaminated. These storage facilities are often equipped with automated handling systems to streamline the delivery of biomass to conversion plants. Effective biomass storage not only ensures a consistent supply of high-quality feedstock but also supports the scalability of bioenergy projects. By implementing advanced storage solutions, biomass can be utilized more efficiently and sustainably, contributing to the broader goal of transitioning to renewable energy sources.

3.4. Environmental functions of bioenergy production

Much attention is presently placed on the negative repercussions of land use change, such as biodiversity loss, greenhouse gas emissions, and soil and water body degradation, notably as a result of forest conversion and farmland development. However, biomass generation for energy can provide major benefits. For example, harvesting forest waste can improve replanting conditions while also lowering the risk of root rot and wildfires. In agriculture, biomass can be grown in multifunctional plantations that offer extra environmental benefits. These plantations can treat nutrient-rich water, restrict erosion, trap nutrients, and reduce the amount of silt and contaminants that reach streams. Perennial crops, such as those utilized in the USDA Conservation Reserve Program, help to reduce soil erosion, improve nutrient retention, and provide organic matter to the soil, ensuring long-term productivity (Soares et al. 2018). Using sewage sludge as fertilizer in vegetation filters can increase these benefits even more. By integrating well-chosen locations, designs, and management practices, biomass production can offer environmental advantages that complement its role in sustainable energy production.

3.5. Climate change impact

Climate change is expected to alter rainfall patterns and increase water transpiration and evaporation as temperatures rise. Predicting the net effect is difficult, with significant variation expected across worldwide regions. Semi-arid and dry regions are especially vulnerable, with lower water supply and increased problems in river basins (Perea-Moreno, García-Cruz, et al. 2017). Overall, climate change's negative effects are expected to outweigh the advantages of freshwater systems, reducing water supply and irrigation potential in many areas. Biomass poses both environmental dangers and advantages, depending on appropriate management. Maximizing biomass's potential for reducing greenhouse gas emissions necessitates understanding and avoiding related risks, as well as accepting trade-offs for long-term benefits.

4. Biomass Applications

Biomass has diverse applications, ranging from energy production to environmental benefits. Below are some key applications of biomass.

4.1. Biomass for heat applications

Producing heat from biomass is the traditional way to utilize this energy source, and biomass-to-heat systems are commercially viable and often economically competitive. The cost-effectiveness of these systems depends on specific context and the price of fossil fuel alternatives. Combustion, the oldest and most common method for converting solid biomass to energy, remains a straightforward and well-understood process. It supports a wide range of commercial technologies suited to various biomass types and application scales. These technologies include domestic heating systems, district heating and cooling networks, industrial systems, and gasification systems (García et al. 2015). Biomass combustion systems have proven adaptable and scalable, making them a viable option for both small-scale residential use and large-scale industrial applications. As technology evolves, further improvements in efficiency and emissions control are anticipated, enhancing the viability of biomass as a sustainable energy source for heat production across diverse settings.

4.2. Biomass for power and CHP applications

There are numerous combinations of feedstock and conversion technologies for producing power and combined heat and power (CHP), each at various stages of development and deployment. The economic viability of a bioenergy option for power and CHP depends not only on the specific technology (including capital and operating costs, conversion efficiency, process reliability, and economies of scale) but also on local conditions for biomass supply (quality, type, availability, and cost) and final energy demand (cost of alternative energy production, heat demand and value, grid accessibility, support policies, etc.) (Bagherian et al. 2021). The broad range of costs for most technologies indicates the significance of economies of scale (e.g., for steam turbines) and that many technologies are still in the demonstration stage. Several conversion power technologies include biomass-based power plants (steam turbine cycles), municipal solid waste-to-energy plants, biomass-based cogeneration (CHP) plants, distributed cogeneration units (Stirling engine and Organic Rankine Cycle), co-firing, gasification, and anaerobic digestion (Coady and Duquette 2021).

4.3. Biomass for transport applications

Biofuels for transport applications are typically categorized into different ‘generations’ based on their developmental stage and the feedstocks utilized, though these classifications are not universally standardized. First-generation biofuels include established technologies for producing bioethanol from sugar and starch crops, biodiesel and renewable diesel from oil crops and animal fats, and biomethane from the anaerobic digestion of wet biomass. Second-generation biofuels cover a range of innovative biofuels derived from new feedstocks, such as bioethanol and biodiesel produced from novel starch, oil, and sugar crops like Jatropha, cassava, or Miscanthus, as well as various conventional and novel biofuels (e.g., ethanol, butanol, syndiesel) made from lignocellulosic materials (fibrous biomass like straw, wood, and grass) using biochemical and thermochemical technologies still in the demonstration phase. Third-generation biofuels, or advanced biofuels, involve production methods in the early stages of research and development or far from commercialization, such as biofuels from algae and hydrogen from biomass (Gracia, Velázquez-Martí, and Estornell 2014). There are several pathways to produce diesel-type fuels from biomass, with transesterification and hydrogenation being mature and commercially available first-generation technologies that create biodiesel from vegetable oil and animal fats. Transesterification is a straightforward catalytic process and is the dominant technology in this category. Alternatively, biogas can be upgraded to biomethane and injected into the natural gas network for use in gas-powered vehicles. Biomass-to-Liquids (BTL) processes convert a wide variety of biomass feedstocks into liquid and gaseous transport fuels like synthetic diesel and gasoline, methanol, ethanol, dimethyl ether (DME), methane, and hydrogen through thermochemical conversion. Gasification-based methods combine gasification with the catalytic upgrading of syngas to liquid fuels, such as through the Fischer Tropsch process, to produce synthetic biofuels (synfuels) with low greenhouse gas intensity. These methods are particularly attractive and have received significant attention in Europe and North America. Additionally, liquid-phase catalytic processing of biomass-derived compounds and hydrogen production from biomass are emerging areas in the biofuel sector (Wang, Shuai, and Chen 2007).

4.4. Biomass for industrial applications

Biomass is increasingly used in industrial applications due to its versatility and renewable nature. One of the key uses is in the production of bio-based chemicals and materials. Biomass can be processed into a variety of bioproducts such as bioplastics, solvents, adhesives, and pharmaceuticals. These bioproducts are derived from biomass through processes like fermentation, enzymatic conversion, and thermochemical methods. For example, lignocellulosic biomass can be converted into biochemicals that serve as building blocks for bioplastics, offering a sustainable alternative to petrochemical-derived plastics (Kalak 2023). Furthermore, biomass can be used in industrial boilers to generate process heat and steam, which are essential for various manufacturing processes (Proskurina et al. 2017). This not only reduces the reliance on fossil fuels but also lowers greenhouse gas emissions, contributing to a more sustainable industrial sector. The integration of biomass into industrial processes is supported by advancements in biorefinery technologies, which enable the efficient conversion of biomass into a spectrum of high-value products, thus enhancing the economic viability of biomass utilization in industries.

4.5. Biomass for construction

Biomass as material, extracted from plant and animal products, is known to be renewable (Al-Hamamre et al. 2017) and has many uses in construction (Ryłko-Polak, Komala, and Białowiec 2022). Biomass is common in the formation of bio-concrete; this is concrete that has been strengthened by organic fibers, the use of which decreases the emissions of carbon dioxide. Smitha et al. (Smitha et al. 2022) studied the microbiological induction of bacterial biomass in concrete mixtures to enhance the mechanical and durability properties. He concluded that the induction of bacillus megaterium into concrete mixtures can be used to improve the mechanical and durability properties of concrete. Concrete made with **c**ells/ml bacillus megaterium exhibited compressive strength, split tensile strength, and flexural strength 11.3%, 97.5%, and 8.6%, respectively higher than the control at 28 days (Smitha et al. 2022). A large application is in bio composites for which materials such as hemp are made to form panels, insulation, and other structures in construction. Muhit et al. (Muhit, Omairey, and Pashakolaie 2024) study presents a comprehensive examination of the characteristics of hemp fibre and hempcrete as construction materials, delving into their suitability for building and highway applications. His study concludes hempcrete's significant application as a building insulation material due to its exceptional hygrothermal properties. The material also shows promise in enhancing the asphalt mix for pavement construction. Evidence from life cycle analysis supports the claim that hempcrete can be considered a carbon-negative material (Muhit et al. 2024). Wood, a typical biomass material, continues to be widely used because of the prospects of low-carbon construction when sourced from renewable sources.(Švajlenka, Kozlovská, and Spišáková 2017) concluded that the modern method of construction based on wood contributes to sustainability by several of its properties and parameters. Bamboo, a plant that has the fastest growth rate and is lightweight while strong, is used for construction purposes such as beams, and flooring, among others (Fahim et al. 2022). (Manandhar, Kim, and Kim 2019) study suggests bamboo can be used for the speedy construction of houses, either permanent or temporary, in disaster-stricken areas like post-earthquake areas. Rice husks and coconut coir from agricultural operations can be used to make boards and bricks as well as insulation material for housing. (Pode 2016) concludes rice husk ash (RHA) is an economical and sustainable construction material. In Cambodia, its high silica content makes RHA-concrete a viable low-cost option. In Bangladesh, RHA has been effectively used to develop building bricks, thermal insulating bricks, and pozzolanic cement, demonstrating enhanced strength and durability properties (Pode 2016). Thus, the incorporation of these biomass materials into construction processes enables meeting the goals of Sustainability while also improving energy consumption and waste management in the construction industry.

4.6. Biomass for residential and commercial applications

Biomass has significant potential in residential and commercial settings, primarily for heating and cooking purposes. In many rural and developing regions, biomass remains a primary source of energy for household cooking and heating. Traditional biomass stoves are being replaced by improved cookstoves that are more efficient and emit fewer pollutants, thereby improving indoor air quality and reducing health risks. In urban and suburban areas, biomass pellet stoves and boilers are gaining popularity for residential heating. These systems use compressed biomass pellets made from wood waste, agricultural residues, or energy crops, providing a clean and efficient heating solution (Stephen et al. 2016). Additionally, commercial buildings and institutions such as schools and hospitals are adopting biomass heating systems to reduce energy costs and environmental impact. These systems can be integrated with existing heating infrastructure, making the transition to biomass relatively straightforward (Toka et al. 2014). The use of biomass in residential and commercial applications is further supported by government incentives and policies aimed at promoting renewable energy sources and reducing carbon footprints.

4.7. Biomass for agricultural applications

Biomass plays a crucial role in sustainable agriculture by providing renewable energy and enhancing soil health. Agricultural residues, such as straw, husks, and manure, can be utilized to produce bioenergy through processes like anaerobic digestion and direct combustion. Anaerobic digestion of agricultural waste produces biogas, which can be used for heating, electricity generation, or as a vehicle fuel, while the digestate can be used as a nutrient-rich fertilizer. This creates a closed-loop system that maximizes resource efficiency and minimizes waste (Nguyen and Toan 2024). Additionally, the incorporation of biochar, a stable form of carbon produced from biomass through pyrolysis, into agricultural soils can improve soil fertility, water retention, and crop yields. Biochar also sequesters carbon, helping to mitigate climate change. Farmers can also grow dedicated energy crops, such as switchgrass and miscanthus, which can be harvested for bioenergy production without competing with food crops. These energy crops can be integrated into crop rotation systems, providing additional income streams and enhancing farm sustainability (Hamidzadeh et al. 2023). The use of biomass in agriculture not only supports energy self-sufficiency but also contributes to more resilient and sustainable farming practices.

5. Global implementation of bioenergy

Bioenergy is under gradual implementation in many countries, and this has led to the use of various technologies and methods Figure 1, illustrate the use of biomass technologies in different parts of the world. In Brazil and Poland particularly, bioethanol which is produced from sugarcane is blended with gasoline and widely used in the transport sector (Mączyńska et al. 2019). Brazil has always been the pioneer in the application of bioethanol as a main fuel for automobiles (Luo, van der Voet, and Huppes 2009) . The United States is the global leader in biomass power with the ability to convert agricultural and forestry residuals into electricity. Agricultural and forestry residues, animal manure and municipal solid waste are replenishable and widely available in the United States. The utilization of all available wastes and residues in the contiguous United States can generate 3.1–3.8 exajoules (EJ) of renewable energy (Liu and Rajagopal 2019) .Sweden is among the leaders in district heating systems with wood pellets and other types of biomasses as the source of heat for homes and commercial buildings (Werner 2017). India pays significance to biogas from agricultural residuals, especially in rural regions where cow dung and crop residues are used for power production. In rural regions of India, biomass has been used as a fundamental source of domestic energy for cooking and lighting. Animal dung, agricultural leftovers including bagasse and rice husk, and wood fuels including waste wood and charcoal are examples of biomass energy (Duarah et al. 2022). Germany uses biomass in the generation of electricity through co-combustion with coal (Hartmann and Kaltschmitt 1999). On the other hand, China funds biomass-electricity projects to convert agricultural and forestry residue into electricity to cater to its increasing power demand. An example that can be made to understand how a much more extended biogas application has been managed in China is the "Hebei Rural Renewable Energy Development Project" launched in 2015 and operational until 2021 for the sustainable use and production of biogas. It embraces broad biogas facilities management with six plants in Hebei region for recycling agricultural wastes to stable clean energy for the villagers (Tagne et al. 2021).

6. Social impact and community engagement

Bioenergy projects offer significant social benefits, particularly in terms of community development, job creation, and rural livelihoods (Rogers et al. 2012). By utilizing local biomass resources, these projects can stimulate economic activity in rural areas where traditional industries may be declining or absent. They create employment opportunities not only in the construction and operation of bioenergy facilities but also in ancillary sectors such as biomass collection and processing. This can lead to improved income levels and enhanced quality of life for rural populations. Moreover, bioenergy initiatives can contribute to community development by funding local infrastructure projects, supporting educational programs, and fostering community engagement (Eswarlal et al. 2014). However, to maximize these benefits, it is crucial to ensure active involvement of local communities and stakeholders throughout the project lifecycle. Engaging with local populations early in the planning process helps to address concerns, gather valuable input, and build trust. This collaborative approach can prevent conflicts, enhance social acceptance, and ensure that the benefits of bioenergy projects are equitably distributed. By prioritizing stakeholder engagement and incorporating local perspectives, bioenergy projects can achieve greater sustainability and contribute positively to the social fabric of the communities they serve.

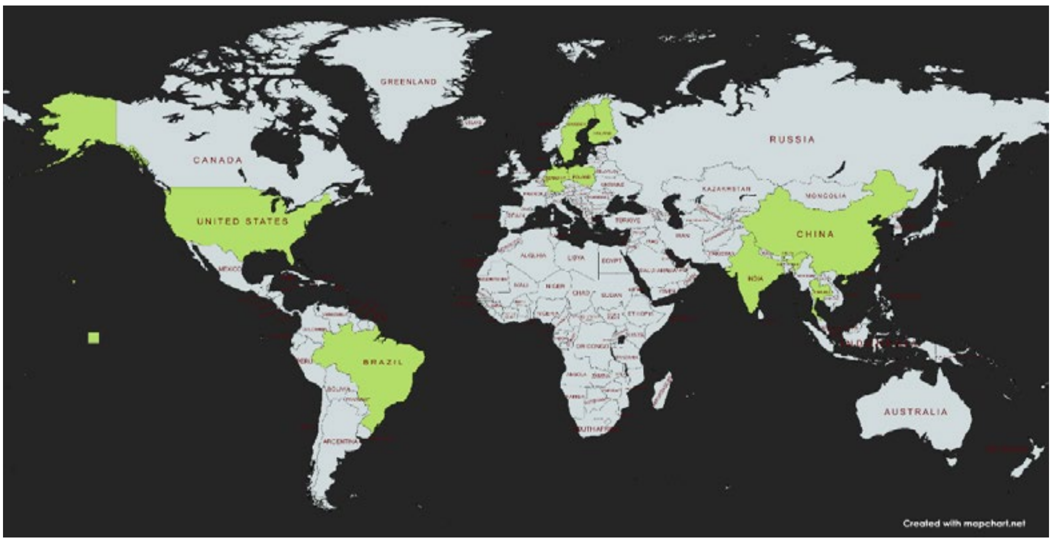

Figure 1. Biomass implementation in different countries

7. Discussions

The role of biomass in the future energy landscape is multifaceted, and its impact on sustainable development extends beyond mere energy production. It is critical to evaluate biomass energy not only for its potential to reduce greenhouse gas emissions but also for its broader environmental, social, and economic implications. For instance, sustainable biomass production can support rural development by creating jobs and generating income in agricultural communities. This socio-economic benefit is particularly significant in developing countries, where rural poverty is prevalent. However, ensuring that these benefits are equitably distributed requires careful planning and governance. Policies must be designed to protect smallholders and local communities, preventing land grabs and ensuring that biomass production does not lead to the displacement of vulnerable populations. Moreover, the integration of biomass into the energy mix must be balanced with the need to preserve biodiversity and maintain ecosystem services. The cultivation of energy crops should avoid monoculture practices that can lead to soil degradation, water scarcity, and loss of habitat. Instead, adopting agroforestry systems and intercropping can enhance biodiversity, improve soil health, and provide additional ecosystem services. These practices also contribute to carbon sequestration, further amplifying the climate benefits of biomass energy. To achieve these outcomes, a holistic approach to land-use planning is essential, one that considers the ecological, economic, and social dimensions of sustainability.

As biomass energy scales up, the challenge of maintaining sustainability becomes more pronounced. Large-scale bioenergy projects must incorporate robust environmental and social safeguards to prevent adverse impacts. For instance, lifecycle assessments can help identify potential hotspots of greenhouse gas emissions and resource use, enabling the design of more efficient and sustainable supply chains. Advances in technology, such as precision agriculture and biotechnological improvements, can enhance the efficiency of biomass production and conversion processes, reducing environmental footprints. However, the deployment of these technologies must be coupled with strong regulatory frameworks to ensure that they are used responsibly and equitably. The interplay between bioenergy and food security remains a critical issue. The competition for land between food and fuel crops can exacerbate food insecurity, particularly in regions where land and water resources are already scarce. To mitigate these risks, it is vital to promote the use of marginal lands for energy crops and to develop second and third-generation biofuels that do not compete directly with food production. Additionally, enhancing agricultural productivity and reducing food waste can alleviate some of the pressures on food systems, enabling a more harmonious coexistence of food and biofuel production.

Furthermore, the global bioenergy market is influenced by a complex web of economic, political, and environmental factors. International trade policies, subsidies, and carbon pricing mechanisms all play crucial roles in shaping the viability and sustainability of bioenergy projects. Transparent and consistent policy frameworks are needed to provide stability and encourage long-term investments in sustainable bioenergy. International cooperation and knowledge-sharing can also accelerate the development and deployment of best practices, ensuring that bioenergy contribute positively to global energy security and climate goals. Finally, it is essential to recognize that bioenergy is not a silver bullet solution. It should be part of a diversified energy strategy that includes a mix of renewable energy sources, energy efficiency measures, and demand-side management. By integrating biomass with other renewable technologies, such as solar and wind, we can create more resilient and sustainable energy systems. This integrated approach will help us transition to a low-carbon economy while addressing the multifaceted challenges of sustainable development.

8. Conclusion

Bioenergy holds a significant promise as a sustainable energy source capable of reducing greenhouse gas emissions, enhancing energy security, and providing economic and social benefits, particularly in rural areas. However, the sustainability of bioenergy production and use is complex and multifaceted, encompassing environmental, economic, and social dimensions.

Key Points:

1. Advancements in Technology: Innovations in biomass conversion technologies and the utilization of diverse biomass resources are making bioenergy more efficient and viable.
2. Environmental and Economic Benefits: Bioenergy can significantly reduce greenhouse gas emissions and provide economic opportunities, particularly in rural and agricultural communities.
3. Challenges: Despite its potential, bioenergy faces challenges such as environmental impacts, competition with food production, and the need for robust regulatory frameworks.
4. Holistic Approach: Sustainable bioenergy development requires integrating sustainable land-use practices, technological innovations, and comprehensive policy support.

Future research should focus on addressing these challenges to maximize the potential of bioenergy in contributing to a sustainable energy future. By doing so, bioenergy can play a crucial role in the global transition to renewable energy, supporting sustainable development goals and helping to mitigate climate change.

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References

Abernethy, Sam, and Robert B. Jackson. 2022. "Global Temperature Goals Should Determine the Time Horizons for Greenhouse Gas Emission Metrics." Environmental Research Letters 17(2):024019. doi: 10.1088/1748-9326/ac4940.

Al-Hamamre, Zayed, Motasem Saidan, Muhanned Hararah, Khaled Rawajfeh, Hussam E. Alkhasawneh, and Mohammad Al-Shannag. 2017. "Wastes and Biomass Materials as Sustainable-Renewable Energy Resources for Jordan." Renewable and Sustainable Energy Reviews 67:295–314. doi: 10.1016/J.RSER.2016.09.035.

Amigun, Bamikole, Josephine Kaviti Musango, and William Stafford. 2011. "Biofuels and Sustainability in Africa." Renewable and Sustainable Energy Reviews 15(2):1360–72. doi: 10.1016/j.rser.2010.10.015.

Bagherian, Mohammad Ali, Kamyar Mehranzamir, Shahabaldin Rezania, Zulkurnain Abdul-Malek, Amin Beiranvand Pour, and Seyed Morteza Alizadeh. 2021. "Analyzing Utilization of Biomass in Combined Heat and Power and Combined Cooling, Heating, and Power Systems." Processes 9(6):1002. doi: 10.3390/pr9061002.

Cambero, Claudia, Taraneh Sowlati, and Mihai Pavel. 2016. "Economic and Life Cycle Environmental Optimization of Forest-Based Biorefinery Supply Chains for Bioenergy and Biofuel Production." Chemical Engineering Research and Design 107:218–35. doi: 10.1016/j.cherd.2015.10.040.

Chen, Wei-Hsin, Bo-Jhih Lin, Yu-Ying Lin, Yen-Shih Chu, Aristotle T. Ubando, Pau Loke Show, Hwai Chyuan Ong, Jo-Shu Chang, Shih-Hsin Ho, Alvin B. Culaba, Anélie Pétrissans, and Mathieu Pétrissans. 2021. "Progress in Biomass Torrefaction: Principles, Applications and Challenges." Progress in Energy and Combustion Science 82:100887. doi: 10.1016/j.pecs.2020.100887.

Chunark, Puttipong, Bundit Limmeechokchai, Shinichiro Fujimori, and Toshihiko Masui. 2017. "Renewable Energy Achievements in CO2 Mitigation in Thailand's NDCs." Renewable Energy 114:1294–1305. doi: 10.1016/j.renene.2017.08.017.

Coady, Joe, and Jean Duquette. 2021. "Quantifying the Impacts of Biomass Driven Combined Heat and Power Grids in Northern Rural and Remote Communities." Renewable and Sustainable Energy Reviews 148:111296. doi: 10.1016/j.rser.2021.111296.

Daioglou, Vassilis, Jonathan C. Doelman, Elke Stehfest, Christoph Müller, Birka Wicke, Andre Faaij, and Detlef P. van Vuuren. 2017. "Greenhouse Gas Emission Curves for Advanced Biofuel Supply Chains." Nature Climate Change 7(12):920–24. doi: 10.1038/s41558-017-0006-8.

Deepika, Charu, Mrinal, Cheryl Bernice Pohrmen, Km Smriti Jaiswal, B. Sangmesh, Krishna Kumar Jaiswal, Arun Prasath Ramasamy, and Amit K. Jaiswal. 2024. "Hydrothermal Liquefaction of Wet Microalgal Biomass for Biofuels and Platform Chemicals: Advances and Future Prospects." Discover Applied Sciences 6(5):245. doi: 10.1007/s42452-024-05911-4.

Duarah, Prangan, Dibyajyoti Haldar, Anil Kumar Patel, Cheng Di Dong, Reeta Rani Singhania, and Mihir Kumar Purkait. 2022. "A Review on Global Perspectives of Sustainable Development in Bioenergy Generation." Bioresource Technology 348:126791. doi: 10.1016/J.BIORTECH.2022.126791.

Efroymson, Rebecca A., Virginia H. Dale, Keith L. Kline, Allen C. McBride, Jeffrey M. Bielicki, Raymond L. Smith, Esther S. Parish, Peter E. Schweizer, and Denice M. Shaw. 2013. "Environmental Indicators of Biofuel Sustainability: What About Context?" Environmental Management 51(2):291–306. doi: 10.1007/s00267-012-9907-5.

Erickson, Larry E. 2017. "Reducing Greenhouse Gas Emissions and Improving Air Quality: Two Global Challenges." Environmental Progress & Sustainable Energy 36(4):982–88. doi: 10.1002/ep.12665.

Eswarlal, Vimal Kumar, Geoffrey Vasudevan, Prasanta Kumar Dey, and Padma Vasudevan. 2014. "Role of Community Acceptance in Sustainable Bioenergy Projects in India." Energy Policy 73:333–43. doi: 10.1016/j.enpol.2014.04.019.

Fahim, Muhammad, Muhammad Haris, Wajid Khan, and Saeed Zaman. 2022. "Bamboo as a Construction Material: Prospects and Challenges." Advances in Science and Technology. Research Journal Vol. 16(no 3):165–75. doi: 10.12913/22998624/149737.

Fantozzi, Francesco, Pietro Bartocci, Bruno D'Alessandro, Stratos Arampatzis, and Basil Manos. 2014. "Public–Private Partnerships Value in Bioenergy Projects: Economic Feasibility Analysis Based on Two Case Studies." Biomass and Bioenergy 66:387–97. doi: 10.1016/j.biombioe.2014.04.006.

Feria, F., C. Aguado, J. Benavides, J. Benavides, R. Canencia-Hernanz, M. Cristobal-Beneyto, J. Fernández García, H. Galán, C. González, A. Hernandez-Avellaneda, L. E. Herranz, G. Jimenez, L. Martínez, J. C. Martinez-Murillo, A. Milena-Pérez, A. Palacio Alonso, J. Penalva, R. Plaza, D. Perez-Gallego, L. Rey, N. Rodriguez-Villagra, J. Ruiz-Hervias, J. Saiz de Omeñaca Tijero, and P. Viñas-Peña. 2024. "Spanish R&D in Dry Storage of Spent Fuel: Outcomes and Outlook." Nuclear Engineering and Design 416:112772. doi: 10.1016/j.nucengdes.2023.112772.

García, Roberto, Consuelo Pizarro, Ana Álvarez, Antonio G. Lavín, and Julio L. Bueno. 2015. "Study of Biomass Combustion Wastes." Fuel 148:152–59. doi: 10.1016/j.fuel.2015.01.079.

Gelfand, Ilya, Ritvik Sahajpal, Xuesong Zhang, R. César Izaurralde, Katherine L. Gross, and G. Philip Robertson. 2013. "Sustainable Bioenergy Production from Marginal Lands in the US Midwest." Nature 493(7433):514–17. doi: 10.1038/nature11811.

Glithero, N. J., S. J. Ramsden, and P. Wilson. 2012. "Farm Systems Assessment of Bioenergy Feedstock Production: Integrating Bio-Economic Models and Life Cycle Analysis Approaches." Agricultural Systems 109:53–64. doi: 10.1016/j.agsy.2012.02.005.

Gracia, Carlos, Borja Velázquez-Martí, and Javier Estornell. 2014. "An Application of the Vehicle Routing Problem to Biomass Transportation." Biosystems Engineering 124:40–52. doi: 10.1016/j.biosystemseng.2014.06.009.

Hamidzadeh, Zahra, Payam Ghorbannezhad, Mohammad Reza Ketabchi, and Bijan Yeganeh. 2023. "Biomass-Derived Biochar and Its Application in Agriculture." Fuel 341:127701. doi: 10.1016/j.fuel.2023.127701.

Hartmann, D., and M. Kaltschmitt. 1999. "Electricity Generation from Solid Biomass via Co-Combustion with Coal: Energy and Emission Balances from a German Case Study." Biomass and Bioenergy 16(6):397–406. doi: 10.1016/S0961-9534(99)00017-3.

Hudiburg, Tara W., WeiWei Wang, Madhu Khanna, Stephen P. Long, Puneet Dwivedi, William J. Parton, Melannie Hartman, and Evan H. DeLucia. 2016. "Impacts of a 32-Billion-Gallon Bioenergy Landscape on Land and Fossil Fuel Use in the US." Nature Energy 1(1):15005. doi: 10.1038/nenergy.2015.5.

Igos, Elorri, Katarzyna Golkowska, Daniel Koster, Bram Vervisch, and Enrico Benetto. 2016. "Using Rye as Cover Crop for Bioenergy Production: An Environmental and Economic Assessment." Biomass and Bioenergy 95:116–23. doi: 10.1016/j.biombioe.2016.09.023.

Jeswani, Harish K., Andrew Chilvers, and Adisa Azapagic. 2020a. "Environmental Sustainability of Biofuels: A Review." Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 476(2243). doi: 10.1098/rspa.2020.0351.

Jeswani, Harish K., Andrew Chilvers, and Adisa Azapagic. 2020b. "Environmental Sustainability of Biofuels: A Review." Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences 476(2243). doi: 10.1098/rspa.2020.0351.

Kalak, Tomasz. 2023. "Potential Use of Industrial Biomass Waste as a Sustainable Energy Source in the Future." Energies 16(4):1783. doi: 10.3390/en16041783.

Khan, Sawar, Ayesha Nisar, Bo Wu, Qi-Li Zhu, Yan-Wei Wang, Guo-Quan Hu, and Ming-xiong He. 2022. "Bioenergy Production in Pakistan: Potential, Progress, and Prospect." Science of The Total Environment 814:152872. doi: 10.1016/j.scitotenv.2021.152872.

Lehtinen, Ulla, Jouni Juntunen, and Jari Juga. 2020. "Evaluating the Feasibility of Bio-Energy Based Heat and Power Production in Rural Community." Biomass and Bioenergy 139:105578. doi: 10.1016/j.biombioe.2020.105578.

Liu, Bo, and Deepak Rajagopal. 2019. "Life-Cycle Energy and Climate Benefits of Energy Recovery from Wastes and Biomass Residues in the United States." Nature Energy 2019 4:8 4(8):700–708. doi: 10.1038/s41560-019-0430-2.

Liu, Yuzhong, Pablo Cruz-Morales, Amin Zargar, Michael S. Belcher, Bo Pang, Elias Englund, Qingyun Dan, Kevin Yin, and Jay D. Keasling. 2021. "Biofuels for a Sustainable Future." Cell 184(6):1636–47. doi: 10.1016/j.cell.2021.01.052.

Luo, Lin, Ester van der Voet, and Gjalt Huppes. 2009. "Life Cycle Assessment and Life Cycle Costing of Bioethanol from Sugarcane in Brazil." Renewable and Sustainable Energy Reviews 13(6–7):1613–19. doi: 10.1016/J.RSER.2008.09.024.

Mączyńska, Joanna, Małgorzata Krzywonos, Adam Kupczyk, Karol Tucki, Michał Sikora, Hanna Pińkowska, Anna Bączyk, and Izabela Wielewska. 2019. "Production and Use of Biofuels for Transport in Poland and Brazil – The Case of Bioethanol." Fuel 241:989–96. doi: 10.1016/J.FUEL.2018.12.116.

Makkonen, Marika, Suvi Huttunen, Eeva Primmer, Anna Repo, and Mikael Hildén. 2015. "Policy Coherence in Climate Change Mitigation: An Ecosystem Service Approach to Forests as Carbon Sinks and Bioenergy Sources." Forest Policy and Economics 50:153–62. doi: 10.1016/j.forpol.2014.09.003.

Manandhar, Rashmi, Jin Hee Kim, and Jun Tae Kim. 2019. "Environmental, Social and Economic Sustainability of Bamboo and Bamboo-Based Construction Materials in Buildings." Journal of Asian Architecture and Building Engineering 18(2):52–62. doi: 10.1080/13467581.2019.1595629.

van Meijl, H., I. Tsiropoulos, H. Bartelings, R. Hoefnagels, E. Smeets, A. Tabeau, and A. Faaij. 2018. "On the Macro-Economic Impact of Bioenergy and Biochemicals – Introducing Advanced Bioeconomy Sectors into an Economic Modelling Framework with a Case Study for the Netherlands." Biomass and Bioenergy 108:381–97. doi: 10.1016/j.biombioe.2017.10.040.

Mohr, Alison, and Sujatha Raman. 2013. "Lessons from First Generation Biofuels and Implications for the Sustainability Appraisal of Second Generation Biofuels." Energy Policy 63:114–22. doi: 10.1016/j.enpol.2013.08.033.

Muhit, Imrose B., Eman L. Omairey, and Vahid Ghorbani Pashakolaie. 2024. "A Holistic Sustainability Overview of Hemp as Building and Highway Construction Materials." Building and Environment 256:111470. doi: 10.1016/J.BUILDENV.2024.111470.

Nguyen, Thi Khanh Chi, and Nguyen Quoc Toan. 2024. "Developing Biomass Energy from Agricultural By-Products in the Context of Trade Development." Energy Strategy Reviews 54:101417. doi: 10.1016/j.esr.2024.101417.

Osman, Ahmed I., Bingbing Fang, Yubing Zhang, Yunfei Liu, Jiacheng Yu, Mohamed Farghali, Ahmed K. Rashwan, Zhonghao Chen, Lin Chen, Ikko Ihara, David W. Rooney, and Pow-Seng Yap. 2024. "Life Cycle Assessment and Techno-Economic Analysis of Sustainable Bioenergy Production: A Review." Environmental Chemistry Letters 22(3):1115–54. doi: 10.1007/s10311-023-01694-z.

Perea-Moreno, Alberto-Jesús, Amós García-Cruz, Nuria Novas, and Francisco Manzano-Agugliaro. 2017. "Rooftop Analysis for Solar Flat Plate Collector Assessment to Achieving Sustainability Energy." Journal of Cleaner Production 148:545–54. doi: 10.1016/j.jclepro.2017.02.019.

Perea-Moreno, Alberto-Jesús, Miguel-Ángel Perea-Moreno, Quetzalcoatl Hernandez-Escobedo, and Francisco Manzano-Agugliaro. 2017. "Towards Forest Sustainability in Mediterranean Countries Using Biomass as Fuel for Heating." Journal of Cleaner Production 156:624–34. doi: 10.1016/j.jclepro.2017.04.091.

Perea-Moreno, Miguel-Angel, Esther Samerón-Manzano, and Alberto-Jesus Perea-Moreno. 2019a. "Biomass as Renewable Energy: Worldwide Research Trends." Sustainability 11(3):863. doi: 10.3390/su11030863.

Perea-Moreno, Miguel-Angel, Esther Samerón-Manzano, and Alberto-Jesus Perea-Moreno. 2019b. "Biomass as Renewable Energy: Worldwide Research Trends." Sustainability 11(3):863. doi: 10.3390/su11030863.

Perea-Moreno, Miguel-Angel, Esther Samerón-Manzano, and Alberto-Jesus Perea-Moreno. 2019c. "Biomass as Renewable Energy: Worldwide Research Trends." Sustainability 11(3):863. doi: 10.3390/su11030863.

Pode, Ramchandra. 2016. "Potential Applications of Rice Husk Ash Waste from Rice Husk Biomass Power Plant." Renewable and Sustainable Energy Reviews 53:1468–85. doi: 10.1016/J.RSER.2015.09.051.

Proskurina, Svetlana, Jussi Heinimö, Fabian Schipfer, and Esa Vakkilainen. 2017. "Biomass for Industrial Applications: The Role of Torrefaction." Renewable Energy 111:265–74. doi: 10.1016/j.renene.2017.04.015.

Robertson, G. Philip, Virginia H. Dale, Otto C. Doering, Steven P. Hamburg, Jerry M. Melillo, Michele M. Wander, William J. Parton, Paul R. Adler, Jacob N. Barney, Richard M. Cruse, Clifford S. Duke, Philip M. Fearnside, Ronald F. Follett, Holly K. Gibbs, Jose Goldemberg, David J. Mladenoff, Dennis Ojima, Michael W. Palmer, Andrew Sharpley, Linda Wallace, Kathleen C. Weathers, John A. Wiens, and Wallace W. Wilhelm. 2008. "Sustainable Biofuels Redux." Science 322(5898):49–50. doi: 10.1126/science.1161525.

Rogers, Jennifer C., Eunice A. Simmons, Ian Convery, and Andrew Weatherall. 2012. "Social Impacts of Community Renewable Energy Projects: Findings from a Woodfuel Case Study." Energy Policy 42:239–47. doi: 10.1016/j.enpol.2011.11.081.

Ryłko-Polak, Iwona, Wojciech Komala, and Andrzej Białowiec. 2022. "The Reuse of Biomass and Industrial Waste in Biocomposite Construction Materials for Decreasing Natural Resource Use and Mitigating the Environmental Impact of the Construction Industry: A Review." Materials 2022, Vol. 15, Page 4078 15(12):4078. doi: 10.3390/MA15124078.

Shah, Mudasir Akbar, M. N. S. Khan, and Vimal Kumar. 2018. "Biomass Residue Characterization for Their Potential Application as Biofuels." Journal of Thermal Analysis and Calorimetry 134(3):2137–45. doi: 10.1007/s10973-018-7560-9.

Simangunsong, B. C. H., V. J. Sitanggang, E. G. T. Manurung, A. Rahmadi, G. A. Moore, L. Aye, and A. H. Tambunan. 2017. "Potential Forest Biomass Resource as Feedstock for Bioenergy and Its Economic Value in Indonesia." Forest Policy and Economics 81:10–17. doi: 10.1016/j.forpol.2017.03.022.

Smitha, Muraleedharan Pillai, Dhanaraj Suji, Mercy Shanthi, and Adeyemi Adesina. 2022. "Application of Bacterial Biomass in Biocementation Process to Enhance the Mechanical and Durability Properties of Concrete." Cleaner Materials 3:100050. doi: 10.1016/J.CLEMA.2022.100050.

Soares, João, Armando C. Oliveira, Simon Dieckmann, Dirk Krüger, and Francesco Orioli. 2018. "Evaluation of the Performance of Hybrid CSP/Biomass Power Plants." International Journal of Low-Carbon Technologies 13(4):380–87. doi: 10.1093/ijlct/cty046.

Solomon, Barry D. 2010. "Biofuels and Sustainability." Annals of the New York Academy of Sciences 1185(1):119–34. doi: 10.1111/j.1749-6632.2009.05279.x.

Stephen, James D., Warren E. Mabee, Amadeus Pribowo, Sean Pledger, Randy Hart, Sheldon Tallio, and Gary Q. Bull. 2016. "Biomass for Residential and Commercial Heating in a Remote Canadian Aboriginal Community." Renewable Energy 86:563–75. doi: 10.1016/j.renene.2015.08.048.

Švajlenka, J., M. Kozlovská, and M. Spišáková. 2017. "The Benefits of Modern Method of Construction Based on Wood in the Context of Sustainability." International Journal of Environmental Science and Technology 14(8):1591–1602. doi: 10.1007/S13762-017-1282-6/METRICS.

Tagne, Rufis Fregue Tiegam, Xiaobin Dong, Solomon G. Anagho, Serena Kaiser, and Sergio Ulgiati. 2021. "Technologies, Challenges and Perspectives of Biogas Production within an Agricultural Context. The Case of China and Africa." Environment, Development and Sustainability 23(10):14799–826. doi: 10.1007/S10668-021-01272-9/FIGURES/9.

Tilman, David, Robert Socolow, Jonathan A. Foley, Jason Hill, Eric Larson, Lee Lynd, Stephen Pacala, John Reilly, Tim Searchinger, Chris Somerville, and Robert Williams. 2009. "Beneficial Biofuels—The Food, Energy, and Environment Trilemma." Science 325(5938):270–71. doi: 10.1126/science.1177970.

Toka, Agorasti, Eleftherios Iakovou, Dimitrios Vlachos, Naoum Tsolakis, and Anastasia-Loukia Grigoriadou. 2014. "Managing the Diffusion of Biomass in the Residential Energy Sector: An Illustrative Real-World Case Study." Applied Energy 129:56–69. doi: 10.1016/j.apenergy.2014.04.078.

Tumuluru, Jaya Shankar, Bahman Ghiasi, Nick R. Soelberg, and Shahab Sokhansanj. 2021. "Biomass Torrefaction Process, Product Properties, Reactor Types, and Moving Bed Reactor Design Concepts." Frontiers in Energy Research 9. doi: 10.3389/fenrg.2021.728140.

Vellini, Michela, Marco Gambini, and Tommaso Stilo. 2020. "High-Efficiency Cogeneration Systems for the Food Industry." Journal of Cleaner Production 260:121133. doi: 10.1016/j.jclepro.2020.121133.

Walmsley, J. D., and D. L. Godbold. 2010. "Stump Harvesting for Bioenergy - A Review of the Environmental Impacts." Forestry 83(1):17–38. doi: 10.1093/forestry/cpp028.

Wang, Jianliang, Yuru Yang, Yongmei Bentley, Xu Geng, and Xiaojie Liu. 2018. "Sustainability Assessment of Bioenergy from a Global Perspective: A Review." Sustainability 10(8):2739. doi: 10.3390/su10082739.

Wang, Jianxin, Shijin Shuai, and Hu Chen. 2007. "Application and Development of Biomass Fuels for Transportation in China." Tsinghua Science and Technology 12(2):223–30. doi: 10.1016/S1007-0214(07)70031-7.

Wei, Ziqi, Zheqi Cheng, and Yafei Shen. 2024. "Recent Development in Production of Pellet Fuels from Biomass and Polyethylene (PE) Wastes." Fuel 358:130222. doi: 10.1016/j.fuel.2023.130222.

Werner, Sven. 2017. "District Heating and Cooling in Sweden." Energy 126:419–29. doi: 10.1016/J.ENERGY.2017.03.052.

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