QUANTUM COMPUTING'S CONTRIBUTION TO SUSTAINABLE DEVELOPMENT[1]

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Abstract

By tackling the significant issues that different sectors encounter, computing advancements have proven to be essential instruments in accomplishing the sustainable development goals. Quantum hardware and quantum algorithms are two of the many subfields that make up the field of quantum computing. This innovative method makes it possible to perform calculations that swiftly solve incredibly complex problems using the fundamental physics concepts. In quantum computing, the basic unit of information is called a qubit, short for quantum bit. Qubits are able to exist in a superposition of both states at the same time, unlike classical bits that can only exist in one of two states (0 or 1). Because of this, a continuum of states between 0 and 1 may be expressed, enabling much more sophisticated information processing and storage. Quantum computing has the potential to completely transform sustainability activities by addressing issues with materials, energy, the climate, and waste management. Certain problems could be resolved by quantum computers far more energy-efficiently than by traditional computers. This technology will soon enable researchers to run simulations that will deepen our knowledge of global warming and possible solutions. Additionally, the computers will be appropriate for both optimizing the management of natural resources and conducting research into eco-friendly products. Significant sustainability potential is presented by quantum computing, especially in terms of how it will advance environmentally friendly technology and identify strategies to reduce carbon emissions. These technologies' contribution to solving the world's environmental problems will surely grow as they develop further.

Keywords: Quantum Computing, Sustainable Development, Qubit, Environmentally Friendly Technology

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INTRODUCTION

Sustainability acknowledges that existing social and economic trends are unsustainable for the globe and that humans have had and do have an impact on the environment (de Vries, 2024). The enhanced capabilities of quantum technology, which surpass the limitations of conventional computing, are gradually revolutionizing a number of industries. With the escalation of resource management concerns, energy crises, and climate change, quantum technology presents particular opportunities to attain sustainable growth (Singh, 2024).

The market for quantum computing is anticipated to be the largest contributor to the market for quantum technologies, with optimistic forecasts suggesting that the market revenue would reach 93 billion US dollars by 2040. Quantum communications and quantum sensing are additional commercial niches for quantum technologies (Alsop, 2024a). In the ensuing years, growth continues, culminating in a noteworthy total market value of 460.7 billion USD in 2032. (Pangarkar, 2025).

Applications of quantum computing for sustainable use cases are currently underway. From improving materials science and energy grid efficiency to speeding up medication discovery, quantum technology is opening the door for creative solutions that meet the problems of global sustainability. For efficient environmental management and conservation, real-time, precise data collection is made possible by these insights. Long-term sustainability objectives are aided by quantum technologies, which improve our capacity to observe and safeguard ecosystems (Pasqal, 2025). The economics of decarbonization could be completely changed by the new technology of quantum computing, which could also play a significant role in keeping global warming below the 1.5°C target (Cooper et al., 2022). Quantum computers operate at -273°C and consume no heat, in contrast to traditional computers that emit a lot of energy in the form of ambient heat. Instead, their cooling systems present an energy efficiency problem. The commercialization of quantum computers is expected to coincide with significant advancements in this area. Once cooled, the technique has shown itself to be very energy efficient. Furthermore, there are ongoing efforts underway to construct room-temperature photon-based quantum computers (Safonov, 2025).

LITERATURE REVIEW

The ability of quantum computing to solve problems tenfold quicker than traditional computers is one of its defining features (Jozsa & Linden, 2003). By utilizing the unique characteristics of quantum physics, quantum computers have shown that they can finish some jobs ten times faster than traditional computers and solve issues that are too complex for conventional calculation (Baltezarević, 2024). Subatomic particles like photons and electrons are used in quantum computing. These particles are able to exist in various states (i.e., 1 and 0) simultaneously because of quantum bits, or qubits (Frankenfield, 2023). These qubits, which are specific to superconducting materials with negligible electrical flow resistance, encode quantum information in the configuration of electromagnetic fields. The qubit states are controlled by microwave pulses with a gigahertz frequency. However, complex vacuum and cooling systems are required to cool the qubits to fractions of a degree above absolute zero in order to preserve superconducting. Even while superconducting qubits work quickly, manufacturing difficulties make it challenging to produce them consistently, requiring constant recalibration. Additionally, they show comparatively short data stability lives; at most, quantum information is destroyed in minutes (Kjaergaard et al., 2020). The atom's electrons store and alter quantum information through laser pulses. For every qubit, trapped ions have the advantage of having the same characteristics because all atoms of the same isotope and charge are comparable. Trapped-ion qubits need more time to manipulate than superconducting qubits, despite having longer lifetimes (Bruzewicz et al., 2019).

The fundamentals of quantum mechanics, the study of subatomic particles, particularly quantum entanglement and quantum superposition, provide the basis for quantum technology. Despite how difficult it may sound, using the technology does not require a thorough understanding of quantum mechanics. In essence, compared to conventional technologies, quantum technology may provide solutions that are more accurate, secure, complicated, and quick. Telecommunications, aerospace, automotive, biological sciences, energy and chemicals, and banking are among the industries investigating quantum technologies (Alsop, 2024b).

Sustainability entails ensuring biodiversity and sustaining ecosystem integrity while also safeguarding human well-being and quality of life (Mino & Kudo, 2016). The ability of quantum computing to produce computations, simulations, and models at a rate 158 million times faster than any current supercomputer accounts for its sustainability (Ray Allison, 2024). To make sure sustainable technologies are operating at their peak performance, these computations can envision and test ideas of efficiency and operational improvement. This implies that technologies like solar energy, batteries for storing electricity, and hydrogen generation may function at a level that would satisfy all of our energy requirements while significantly lowering our need for fossil fuels (Singtel, 2024).

Although quantum technology has enormous potential for sustainability, there are still some difficult obstacles to be addressed before it can have a significant influence. The sensitivity of quantum computing hardware (it needs very frigid temperatures and a carefully regulated environment to work) makes it expensive and difficult to use and maintain. Since many quantum algorithms and software are still in their infancy, the majority of practical applications in sustainability are currently experimental. However, developments are anticipated to increase quantum systems' energy efficiency and mobility, enhancing their accessibility. The best features of both technologies are combined in hybrid quantum-classical systems, which are being investigated by numerous businesses as a workable solution to challenging sustainability issues (Singh, 2024).

A significant reduction in the world's energy usage and carbon footprint may result from the unique ability of quantum computing to solve challenging basic science problems. It can, for instance, enhance the Haber process's (the main industrial procedure for the production of ammonia) efficiency in fertilizer production, aid in the development of new medications, model climate change, simulate battery chemistry and nuclear fusion reactions for greener energy, and streamline the supply chain (Nivedita & Prem, 2024). The development of mineralization-based building materials for affordable carbon mineralization (in which minerals naturally react with carbon dioxide (CO_2) and transform carbon from gas to solid) could be aided by quantum computing. By skimming and capturing CO_2 in a concentrated stream that can be compressed, moved, and stored, it might be a method of removing the gas from the environment. By simulating molecules, quantum computing can help develop novel catalysts that are expected to use less energy. It can also lower the cost of synthetic hydrocarbons and provide scalable negative-emission solutions through direct air capture. Concrete, polymers, and metals may all be made with this trapped CO_2 (Navelkar & Gupta, 2025). Moreover, some concepts for quantum heat engines might enhance the efficiency of conventional engines by storing and processing energy in unique ways. However, as far as their theoretical and scientific growth is concerned, these ideas are still in their infancy (Niedenzu et al., 2018).

According to Witold Kowalczyk, Global Channel Partnership Director at Zapata Computing, a company that specializes in quantum computing, the following five Sustainable Development Goals (SDGs) will be impacted by the development of quantum computing: clean water and sanitation (better water treatment capabilities); affordable, clean energy (optimization of energy systems); climate action (better weather modeling and analysis); good health and well-being (faster and less expensive drug development); and zero hunger (more effective nitrogen fixation to improve food supplies) (Pathstone, 2021). Without significant advancements in climate technologies that are not currently attainable, nations and certain businesses will not be able to meet their commitment to achieve net-zero emissions. Some of these issues cannot be resolved by even the most potent supercomputers now on the market. In certain fields, quantum computing might prove revolutionary. It is possible that the world might fulfill the 1.5°C target by 2035 if quantum computing helps develop climate technologies that can reduce the annual impact of an extra 7 gigatons of CO_2 (Cooper, 2022). According to research, consumers from younger generations are more likely to have sustainable opinions (Baltezarević et al., 2022). This evidence points to a promising future.

Nonetheless, there is a commonality across the existing quantum algorithms: the constraints of existing technologies. Applying the quantum algorithms with the resources at hand would not produce satisfactory outcomes. In particular, the extent of issues with energy grid planning and sustainable energy production is constantly expanding. In order for quantum algorithms to yield significant and long-lasting outcomes, considerable improvements in fault tolerance and hardware are required (Heinen, 2024).

CONCLUSION

Qubits, also known as quantum bits, are used in quantum computing. Due to a property known as superposition, these bits can simultaneously represent and store data in both 0 and 1 states. In addition to superposition, quantum computers also make use of entanglement, another phenomenon of quantum physics where two qubits' states carry identical information despite their physical separation. This makes it possible to create intricate quantum states that can process and represent massive volumes of data at once.

The development of sustainable technologies and materials made possible by quantum computing holds great promise for advancing sustainable development. Quantum computers have a wide range of possible uses in the renewable energy sector. Their processing capacity will enable quicker and more thorough simulations for enhancing wind farms and solar generating plants. Energy grid optimization will be possible thanks to quantum-based machine learning. Furthermore, the deployment of clean alternative energy sources like hydrogen power can be aided by quantum computers. Additionally, the application of quantum computing will accelerate the sustainable development of novel materials. These possibilities include novel superconductors, renewable fuels for the automotive industry, and eco-friendly battery technology.

Although quantum computing methods are expected to have a huge impact in the future, present technologies will not be significantly impacted by them due to existing restrictions. In any case, quantum computing has the potential to significantly advance more sustainable global developments in the future.

LITERATURE

Alsop, T. (2024a). Quantum technology market revenue worldwide 2040, by segment. Retrieved from: https://www.statista.com/statistics/1317754/global-quantum-technology-market-revenue-forecast/ (Accessed: 05.04.2025.)

Alsop, T. (2024b). Quantum computing - statistics & facts. Retrieved from: https://www.statista.com/topics/9647/quantum-computing/ (Accessed: 06.04.2025.)

Baltezarević, R., Baltezarević, B. & Baltezarević, V (2022). The role of travel influencers in sustainable tourism development. *International Review, No 3-4, pp.125-129.*

Baltezarević, R. (2024). Quantum computing's potential impact on the global economy. III. International Cankaya Scientific Studies Congress, 28-29 February, 2024, Proceedings: IKSAD - Congress Book, (Ed. Prof. Dr. Gökhan Acar), Ankara-Türkiye: IKSAD Institute. pp. 142 – 147. ISBN: 978-625-8254-35-8.

Bruzewicz, C., Chiaverini, J., McConnell, R. & Sage, J.M. (2019). Trapped-ion quantum computing: Progress and challenges. *Appl. Phys. Rev.*, 6, 021314.

Cooper, P., Ernst, P., Kiewell, D. & Pinner, D. (2022). Quantum computing just might save the planet. Retrieved from: https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-just-might-save-the-planet#/ (Accessed: 06.04.2025.)

de Vries, BJM (2024). Sustainability science, Second edition. Cambridge University Press, Cambridge, UK.

Frankenfield, J. (2023). Quantum Computing: Definition, How It's Used, and Example. Retrieved from: https://www.investopedia.com/terms/q/quantum-computing.asp (Accessed: 06.04.2025).

Heinen, X. (2024). Quantum Computing Algorithms in Sustainable Energy Production. Student thesis. Retrieved from: https://purl.utwente.nl/essays/101066 (Accessed: 07.04.2025.)

Jozsa, R. & Linden, N. (2003). On the role of entanglement in quantum-computational speed-up, Proceedings of the Royal Society of London.Series A: Mathematical, Physical and Engineering Sciences 459, pp. 2011–2032.

Kjaergaard, M., Schwartz, M., Braumuller, J., Krantz, P., Wang, J.I.J., Gustavsson, S., Oliver, W.D. (2020). Superconducting qubits: Current state of play. *Annu. Rev. Condens. Matter Phys.*, 11, 369–395.

Mino, T. & Kudo, S. (2016). Framing in sustainability science. In: Framing in sustainability science: Theoretical and practical approaches. Springer, Singapore, p 3–16.

Navelkar, V. & Gupta, R. (2025). Can quantum computing show the way to sustainable development? Retrieved from: https://www.tcs.com/what-we-do/pace-innovation/white-paper/quantum-computing-for-esg-accelerate-un-sdg (Accessed: 04.04.2025.)

Niedenzu, W., Mukherjee, V., Ghosh, A. (2018). Quantum engine efficiency bound beyond the second law of thermodynamics. *Nat. Commun.*, 9, 165.

Nivedita, A. & Prem, K. (2024). Sustainable Quantum Computing: Opportunities and Challenges of Benchmarking Carbon in the Quantum Computing Lifecycle. ArXiv. e-Print: 2408.05679; arXiv:2408.05679

Pangarkar, T. (2025). Quantum Computing Statistics 2025 By Value in Revolutionary Data. Retrieved from: https://scoop.market.us/quantum-computing-statistics/ (Accessed: 05.04.2025.)

Pasqal (2025). How quantum supports sustainability. Retrieved from: https://www.pasqal.com/how-quantum-supports-sustainability/ (Accessed: 06.04.2025.)

Pathstone (2021). Quantum Boosts for Sustainable Development. Retrieved from: https://pathstone.com/quantum-boosts-for-sustainable-development/#_ftn1 (Accessed: 08.04.2025.)

Ray Allison, P. (2024). What is quantum computing? Retrieved from: https://www.livescience.com/quantum-computing (Accessed: 07.04.2025.)

Safonov, G. (2025). Quantum computers assisting with sustainable development. Retrieved from: https://www.pwc.de/en/digitale-transformation/quantum-computing/quantum-computing-as-a-driver-of-esg-initiatives.html (Accessed: 07.04.2025.)

Singh, A. (2024). The Role of Quantum Technology in Sustainable Development. Retrieved from: https://www.azoquantum.com/Article.aspx?ArticleID=556 (Accessed: 07.04.2025.)

Singtel (2024). Is quantum computing our solution to climate change? Retrieved from: https://www.singtel.com/business/articles/is-quantum-computing-our-last-chance-solution-to-climate-change (Accessed: 08.04.2025.)