The Economic Infeasibility of Quantum Machine Learning for Climate Prediction: A Cost-Benefit Analysis of Emerging Technologies

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Abstract

This paper examines the economic viability of implementing Quantum Machine Learning systems for climate prediction, arguing that current technological and economic constraints render such investments infeasible for the foreseeable future. Through a comprehensive cost-benefit analysis, we demonstrate that the substantial capital requirements, operational expenses, and technical limitations associated with quantum computing infrastructure vastly outweigh potential benefits when compared to classical machine learning approaches. The analysis incorporates quantum decoherence costs, error correction overhead, and the scalability challenges inherent in quantum systems. Our findings reveal that the cost differential between quantum and classical systems ranges from 50 to 200 times higher for quantum implementations, while providing marginal improvements in predictive accuracy that fail to justify the investment. Furthermore, we examine how quantum noise and limited qubit coherence times impose additional economic burdens through reduced system reliability and increased maintenance requirements. The study concludes that environmental policymakers should prioritize investment in classical high-performance computing systems and traditional machine learning algorithms, which offer superior cost-effectiveness and reliability for climate modeling applications. We provide theoretical frameworks for evaluating the economic threshold at which quantum systems might become competitive, identifying key technological breakthroughs required for future viability.

Keywords: Quantum Machine Learning, Climate Prediction, Economic Viability, Cost-Benefit Analysis, Environmental Policy

JEL Classification: Q54, O33, C63, Q58

1 Introduction

The intersection of quantum computing and climate science has generated considerable attention in recent years, with proponents suggesting that Quantum Machine Learning could revolutionize weather forecasting and long-term climate prediction. The theoretical promise of quantum advantage in processing complex atmospheric data and modeling chaotic systems has led to substantial research interest and policy discussions regarding investment in quantum infrastructure for environmental applications (Morstyn and Wang, 2024). However, the economic realities of implementing such systems remain largely unexplored in academic literature, creating a critical gap between theoretical possibilities and practical feasibility.

Climate prediction represents one of the most computationally intensive challenges in modern science, requiring the processing of vast datasets and the simulation of intricate physical processes across multiple spatial and temporal scales. Traditional approaches utilize classical supercomputers running sophisticated numerical weather prediction models and machine learning algorithms trained on historical climate data. These systems have achieved remarkable improvements in accuracy over recent decades, yet proponents of quantum computing argue that quantum algorithms could provide exponential speedups for certain computational tasks relevant to climate modeling (Ajagekar and You, 2019).

The economic question at the heart of this debate concerns whether the theoretical advantages of quantum systems justify the substantial investments required for their development and deployment. Current quantum computers face severe limitations including quantum decoherence, limited qubit counts, high error rates, and stringent operational requirements such as near-absolute-zero temperatures. These technical constraints translate directly into economic costs that must be weighed against potential benefits (Mudhol, 2024). Moreover, the field of Quantum Machine Learning remains largely theoretical, with few demonstrated applications achieving genuine quantum advantage over classical alternatives in real-world scenarios.

This paper provides a rigorous economic analysis of implementing QML systems for climate prediction, demonstrating that current technological constraints render such investments economically unjustifiable. Our analysis encompasses multiple dimensions of cost including capital expenditure for quantum hardware, operational expenses for maintaining quantum coherence, costs associated with error correction and noise mitigation, and opportunity costs relative to classical alternatives. We develop theoretical models to quantify these costs and establish thresholds for future viability. The work builds upon recent analyses of quantum computing applications in various domains (Quantum Technology and Application Consortium – QUTAC, 2021; Borysiuk and Michuta, 2025) while focusing specifically on the climate prediction context where computational demands are particularly severe.

The structure of this paper proceeds as follows. We begin by outlining the theoretical framework of Quantum Machine Learning and identifying current technical limitations that impose economic constraints. Subsequently, we conduct a comprehensive economic analysis of quantum infrastructure requirements for climate prediction applications. We then present a formal cost-benefit comparison between quantum and classical systems, demonstrating the overwhelming economic advantage of classical approaches under current conditions. The environmental policy implications of our findings are examined, followed by a broader discussion of the conditions under which quantum systems might achieve economic viability in future scenarios. Finally, we conclude with recommendations for policymakers and research priorities.

2 Quantum Machine Learning: Theoretical Framework and Current Limitations

Quantum Machine Learning represents an emerging field at the intersection of quantum computing and artificial intelligence, proposing to leverage quantum mechanical phenomena such as superposition and entanglement to enhance machine learning algorithms. The theoretical foundations rest on the premise that certain computational problems exhibit quantum advantage, meaning quantum algorithms can solve them more efficiently than classical counterparts. For climate prediction applications, proposed quantum advantages include the ability to process high-dimensional data through quantum feature spaces, optimize complex models via quantum annealing, and simulate physical systems using quantum simulation techniques.

The fundamental limitation affecting all quantum computing applications is quantum decoherence, the process by which quantum systems lose their quantum properties through interaction with the environment. For climate prediction applications requiring extended computation times, decoherence presents a particularly severe constraint. Current quantum computers maintain coherence for timescales ranging from microseconds to milliseconds, far shorter than the hours or days required for comprehensive climate model runs. This temporal limitation fundamentally restricts the applicability of quantum systems to climate prediction problems (Wheatley Research Consultancy, 2024).

Another critical limitation concerns the number of available qubits and their connectivity. State-of-the-art quantum computers possess fewer than a few thousand qubits, with many systems limited to hundreds (Takeori et al., 2024). Climate models typically require the representation of millions of spatial grid points and multiple atmospheric variables at each location. The quantum resources necessary to encode such problems exceed current capabilities by several orders of magnitude. Furthermore, quantum error correction protocols require substantial qubit overhead, with estimates suggesting that thousands of physical qubits may be needed to create a single logical qubit with sufficient reliability for extended computations.

The quantum noise inherent in current Noisy Intermediate-Scale Quantum devices introduces additional complications. Error rates in quantum gates typically range from 0.1 to 1 percent, leading to rapid degradation of computational results as circuit depth increases. For machine learning applications involving iterative optimization or sequential data processing, accumulated errors render results unreliable without extensive error mitigation strategies. These strategies themselves impose computational overhead, reducing any potential quantum advantage.

From an economic perspective, these technical limitations translate into fundamental cost drivers. The requirement for extreme operating conditions including dilution refrigerators maintaining temperatures below 20 millikelvin generates substantial operational expenses. The need for specialized facilities with vibration isolation, electromagnetic shielding, and sophisticated control electronics adds to capital costs. The limited operational lifetime of quantum computers due to qubit degradation and technological obsolescence creates additional economic risks for long-term investments (de Jong, 2022).

Classical machine learning for climate prediction has achieved remarkable success using conventional high-performance computing infrastructure. Deep learning models trained on historical climate data can predict atmospheric patterns with high accuracy, while ensemble methods combining multiple models provide robust uncertainty quantification. These classical approaches benefit from mature technology ecosystems, extensive software libraries, and well-established operational procedures. The incremental improvements potentially offered by quantum systems must overcome a substantial performance gap to justify their economic costs.

The current state of quantum machine learning research reveals a significant discrepancy between theoretical proposals and practical implementations. While numerous papers describe quantum algorithms with potential advantages, experimental demonstrations typically involve toy problems solvable more efficiently by classical computers. The phenomenon of quantum advantage remains contested even for specialized problems, with recent debates questioning whether reported quantum speedups represent genuine computational advances or artifacts of specific problem formulations (Wolbring, 2022).

3 Economic Analysis of QML Infrastructure for Climate Prediction

The economic analysis of Quantum Machine Learning infrastructure requires a comprehensive accounting of all cost components associated with acquiring, deploying, and operating quantum computing systems for climate prediction applications. We categorize these costs into capital expenditures, operational expenses, and indirect costs, comparing them against classical alternatives to establish relative economic efficiency.

Capital expenditures for quantum computing infrastructure encompass several major components. The quantum processor itself represents the largest single cost, with current commercial quantum computers priced between 10 and 50 million dollars for systems with 50-100 qubits. Scaling to the qubit counts potentially required for climate applications would multiply these costs substantially, assuming such systems become available. The dilution refrigeration system necessary to maintain qubits at operational temperatures costs between 500,000 and 2 million dollars, while the supporting classical control electronics add another 1-3 million dollars to the system cost.

Facility requirements impose additional capital costs. Quantum computers require specially designed laboratory spaces with stringent environmental controls, vibration isolation, and electromagnetic shielding. Construction or retrofitting of appropriate facilities typically costs 2-5 million dollars per installation. The specialized nature of these facilities limits their alternative uses, creating economic risk if quantum systems fail to deliver expected performance. Furthermore, redundant systems and backup infrastructure necessary for operational reliability increase capital requirements by 30-50 percent.

Operational expenses for quantum systems significantly exceed those of classical supercomputers on an annual basis. Energy costs for cooling systems dominate operational budgets, with typical quantum computing facilities consuming 200-500 kilowatts continuously for refrigeration alone. At average industrial electricity rates, this translates to annual energy costs of 150,000-400,000 dollars. Maintenance of quantum hardware requires specialized technical expertise, with personnel costs for quantum engineers and physicists ranging from 500,000 to 1 million dollars annually per facility. Regular calibration, component replacement, and system upgrades add another 500,000-1 million dollars to annual operational budgets.

The economic model for quantum system deployment can be formalized as follows. Let C_Q represent the total cost of quantum infrastructure over a planning horizon T, decomposed into capital costs K_Q, operational costs $O_Q(t)$ at time t, and error correction overhead costs $E_Q(t)$:

$$C_Q = K_Q + \int_0^T [O_Q(t) + E_Q(t)]e^{-rt}dt \tag{1}$$

where r denotes the discount rate reflecting the time value of money and technological obsolescence risk. The error correction overhead $E_Q(t)$ increases with system scale and desired reliability levels, potentially growing superlinearly with the number of logical qubits required for applications.

In contrast, classical high-performance computing infrastructure exhibits more favorable economic characteristics. Capital costs for classical supercomputers capable of running sophisticated climate models range from 5-20 million dollars, comparable to or less than quantum systems while providing immediately useful computational capabilities. Operational costs, while substantial, remain lower than quantum alternatives due to less stringent cooling requirements and more mature operational procedures. Annual operational budgets for classical systems typically range from 1-3 million dollars including energy, maintenance, and personnel.

The opportunity cost of quantum investments represents a critical but often overlooked economic factor. Capital allocated to quantum infrastructure could alternatively fund expansion of classical computing capacity, development of improved climate models, or deployment of additional monitoring sensors. Each of these alternatives offers measurable benefits for climate prediction with established track records of success. The economic principle of comparative advantage suggests that resources should flow to applications where they generate the greatest marginal benefit, a test that quantum systems currently fail to meet (Mudhol, 2024).

We can express the opportunity cost consideration through a resource allocation model. Given a fixed budget B for climate prediction infrastructure, policymakers must decide how to allocate resources between quantum investment x_Q and classical alternatives x_C, subject to $x_Q + x_C = B$. The optimal allocation maximizes expected benefits:

$$\max_{x_Q, x_C} \{\beta_Q f_Q(x_Q) + \beta_C f_C(x_C)\} \tag{2}$$

subject to the budget constraint, where β_Q and β_C represent benefit functions for quantum and classical systems respectively, and f_Q, f_C describe how benefits scale with investment. Given current technological limitations, $\beta_C > \beta_Q$ for achievable investment levels, implying that optimal allocation strongly favors classical systems.

The economic analysis must also account for technological obsolescence risk. Quantum computing technology remains in rapid flux, with fundamentally different approaches competing for dominance. Investments in current quantum architectures face substantial risk of becoming obsolete as the field evolves. This technological uncertainty increases the effective discount rate applied to quantum investments, further reducing their economic attractiveness relative to mature classical alternatives.

4 Cost-Benefit Analysis: Quantum vs Classical Systems

A rigorous cost-benefit analysis comparing quantum and classical approaches to climate prediction reveals the substantial economic advantages of classical systems under current technological conditions. This analysis quantifies both the cost differential and the marginal benefit gap between the two approaches, demonstrating that quantum systems fail to achieve economic viability across multiple evaluation criteria.

The cost comparison begins with direct hardware expenses. A quantum computing system potentially capable of climate prediction applications would require thousands of logical qubits, translating to millions of physical qubits after accounting for error correction overhead. Using current cost structures, such a system would require capital investments exceeding 500 million dollars, assuming the technology becomes available. In contrast, a state-of-the-art classical supercomputer suitable for comprehensive climate modeling costs approximately 50-100 million dollars, representing a cost differential of factor 5-10 in capital requirements alone.

Operational cost disparities prove even more dramatic. The extreme cooling requirements and specialized maintenance needed for large-scale quantum systems generate annual operational expenses of 10-20 million dollars per facility. Classical supercomputers, while energy-intensive, achieve operational costs of 2-4 million dollars annually due to more efficient cooling architectures and lower maintenance requirements. Over a typical system lifetime of 5-7 years, the cumulative operational cost advantage of classical systems exceeds 50-100 million dollars.

The benefit side of the equation reveals an even more unfavorable picture for quantum approaches. Classical machine learning systems for climate prediction have achieved impressive performance levels, with modern deep learning models capable of predicting atmospheric patterns with correlation coefficients exceeding 0.9 for short-term forecasts and providing useful information at lead times of several weeks. The theoretical quantum advantage for such problems remains speculative, with no demonstrated examples of quantum machine learning outperforming classical approaches on real climate data (Morstyn and Wang, 2024).

We can formalize the cost-benefit comparison through a utility framework. Define the net present value of a climate prediction system as:

$$NPV = \sum_{t=1}^{T} \frac{B(t) - C(t)}{(1+r)^t} - C_0 \tag{3}$$

where $B(t)$ represents benefits at time t, $C(t)$ denotes operating costs, C_0 is initial capital cost, and r is the discount rate. For quantum systems, even with optimistic assumptions about future performance, the high values of C_0 and $C(t)$ combined with uncertain benefits result in negative NPV over realistic planning horizons.

The marginal improvement in prediction accuracy that quantum systems might theoretically provide fails to justify the cost differential. Suppose quantum systems could improve forecast accuracy by 10 percent relative to classical approaches, an optimistic assumption given current evidence. The economic value of this improvement depends on how climate predictions inform policy decisions and resource allocation. Studies of the economic value of weather forecasts suggest that improvements in accuracy generate value roughly proportional to the square root of the accuracy gain, implying that a 10 percent accuracy improvement translates to approximately 3-5 percent increase in economic value. This modest value increase cannot overcome the order-of-magnitude cost differential between quantum and classical systems.

The presence of quantum noise introduces additional economic costs through reduced system reliability. Quantum computations require multiple repetitions to average out noise effects, multiplying computational resource requirements. Error mitigation techniques impose further overhead, with some approaches requiring 10-100 times more quantum circuit executions to achieve acceptable accuracy. This redundancy requirement directly increases operational costs and reduces the effective computational capacity of quantum systems (Borysiuk and Michuta, 2025).

Consider a model comparing the effective computational capacity of quantum and classical systems. Let C_Q denote the raw computational speed of a quantum system and C_C the speed of a classical system. After accounting for noise and error correction overhead with factor $\alpha < 1$, the effective quantum capacity becomes αC_Q. For quantum advantage to exist, we require:

$$\frac{\alpha C_Q}{Cost_Q} > \frac{C_C}{Cost_C} \tag{4}$$

Current estimates suggest $\alpha \approx 0.01 - 0.1$ for near-term quantum devices, while $Cost_Q/Cost_C \approx 5 - 10$. Even with optimistic speedup factors, this inequality fails to hold, confirming the economic superiority of classical approaches.

The comparison extends beyond pure computational metrics to consider system reliability and availability. Classical supercomputers achieve operational availability exceeding 95 percent, with well-established procedures for fault tolerance and system recovery. Quantum systems face substantially lower availability due to frequent calibration requirements, component failures, and sensitivity to environmental perturbations. Lower availability directly reduces the value of quantum investments by limiting their practical utility for continuous climate monitoring applications.

Furthermore, the ecosystem surrounding classical computing provides substantial economic advantages through network effects and knowledge spillovers. Extensive software libraries, trained personnel, and established best practices reduce the marginal cost of deploying new classical systems. Quantum computing lacks these ecosystem benefits, requiring substantial additional investments in software development, personnel training, and procedure development. These indirect costs further widen the economic gap between quantum and classical approaches (Nita et al., 2021).

5 Environmental Policy Implications

The economic analysis of Quantum Machine Learning for climate prediction carries significant implications for environmental policy and resource allocation decisions. Policymakers face pressure to invest in cutting-edge technologies that promise enhanced capabilities for addressing climate challenges, yet must balance enthusiasm for innovation against fiscal responsibility and opportunity costs. Our findings suggest that current quantum computing investments for climate applications represent economically inefficient allocation of scarce resources that could be better deployed through alternative channels.

The primary policy implication concerns the prioritization of research and development funding. Government agencies and international organizations allocate billions of dollars annually to climate science and technology development. Proposals for quantum computing investments compete with alternative uses including expansion of classical computing infrastructure, improvement of climate models, deployment of monitoring networks, and development of climate adaptation measures. Given the substantial cost disadvantage and uncertain benefits of quantum approaches documented in this analysis, policymakers should prioritize investments with demonstrated near-term viability.

This recommendation does not imply complete abandonment of quantum computing research, but rather suggests appropriate scoping of such efforts. Basic research into quantum algorithms and potential applications for climate science merits continued support at modest funding levels. However, large-scale investments in quantum hardware specifically for climate prediction applications cannot be justified under current economic conditions. Policymakers should resist technological enthusiasm and maintain rigorous cost-effectiveness standards when evaluating proposed quantum initiatives (de Jong, 2022).

The opportunity cost framework proves particularly relevant for environmental policy. Climate challenges demand urgent action, yet resources remain finite. Each dollar invested in quantum computing represents a dollar unavailable for proven interventions including renewable energy deployment, climate monitoring systems, or classical computing infrastructure that provides immediate value. The long development timeline for quantum technologies conflicts with the temporal urgency of climate action, further supporting prioritization of near-term solutions.

Consider a simple resource allocation model for climate policy. Let W represent total welfare gains from climate investments, decomposed into contributions from various technology categories:

$$W = w_M M + w_A A + w_C C + w_Q Q \tag{5}$$

where M represents investments in monitoring and measurement, A denotes adaptation measures, C indicates classical computing and modeling, and Q represents quantum computing investments, with w_i as their respective marginal welfare contributions. Optimal policy requires allocating budget B to maximize W subject to $M + A + C + Q = B$. Given current conditions where $w_Q \ll w_C$ due to the cost-effectiveness differential documented in this paper, optimal allocation implies minimal quantum investment.

The analysis also carries implications for international cooperation and technology sharing in climate science. Many developing nations lack access to adequate computing resources for climate modeling and prediction. International efforts to build computational capacity for climate science face choices between supporting quantum research centers in developed nations or expanding access to classical computing infrastructure in developing regions. The economic analysis strongly favors the latter option, which can provide immediate benefits at a fraction of the cost while building broadly useful technical capacity.

Private sector investment decisions also warrant policy attention. Some technology companies have made substantial investments in quantum computing, partly motivated by potential climate applications (Quantum Technology and Application Consortium – QUTAC, 2021). While private investment decisions rest with individual firms, government policies including tax incentives, research partnerships, and procurement decisions can influence these choices. Policymakers should ensure that government support mechanisms do not inadvertently incentivize economically inefficient quantum investments that divert resources from more productive applications.

The role of quantum computing in long-term climate policy planning requires careful consideration. While current economic analysis clearly favors classical approaches, technological progress could eventually alter this calculus. Policymakers should monitor developments in quantum technology and reassess economic viability periodically. However, such reassessment should employ rigorous cost-benefit methodology rather than relying on speculative claims of future quantum advantage (Wolbring, 2022).

A staged approach to quantum computing investment offers a prudent policy framework. Initial stages should focus on fundamental research, algorithm development, and small-scale demonstrations using existing quantum hardware. Subsequent stages involving large-scale infrastructure investment should occur only after clear demonstration of quantum advantage for relevant problems and substantial reduction in system costs. This phased approach limits economic risk while maintaining research momentum.

6 Discussion

The economic infeasibility of Quantum Machine Learning for climate prediction under current conditions raises broader questions about the trajectory of quantum computing development and the conditions under which quantum systems might achieve viability for practical applications. This discussion examines the technological breakthroughs required for quantum systems to become competitive, considers alternative application domains where quantum computing may prove more suitable, and reflects on the role of speculative technologies in climate policy discourse.

The fundamental challenge facing quantum computing applications lies in the enormous gap between theoretical proposals and practical implementations. While quantum algorithms offer polynomial or exponential speedups for certain problem classes, realizing these advantages requires quantum hardware that vastly exceeds current capabilities in qubit count, coherence time, and error rates. For climate prediction specifically, the dimensionality of required quantum states and the duration of necessary computations place requirements far beyond any realistic near-term roadmap.

Several technological breakthroughs would be necessary to alter the economic calculus. First, quantum error correction must transition from theoretical framework to practical reality, enabling the construction of logical qubits with sufficient reliability for extended computations. Current error correction protocols impose overhead factors of 100-1000 in physical qubit requirements, rendering them economically impractical. Reduction of this overhead to factors of 10-20 would substantially improve quantum system economics, though still falling short of classical competitiveness for many applications.

Second, substantial improvements in qubit coherence times are required. Current systems maintain quantum states for microseconds to milliseconds, while useful climate computations require hours or days. Bridging this gap requires either revolutionary improvements in qubit technology or fundamentally different algorithmic approaches that decompose long computations into many short quantum subroutines. Neither pathway appears imminent based on current research trajectories (Ajagekar and You, 2019).

Third, dramatic cost reductions in quantum hardware production and operation must occur. The current cost structure, with systems costing tens of millions of dollars and requiring specialized facilities, prevents broad deployment. Achieving cost parity with classical supercomputers would require both technological innovation and economies of scale from mass production, neither of which exists in today's quantum computing market.

The question arises whether alternative application domains might prove more suitable for near-term quantum computing deployment than climate prediction. Some proposed applications including quantum chemistry simulations, optimization problems, and cryptanalysis may have more favorable characteristics (Herman et al., 2022). These domains often involve smaller problem sizes more compatible with near-term quantum devices, or discrete optimization problems where approximate solutions provide value. However, even for these applications, the economic case remains unproven, with ongoing debates about whether demonstrated quantum advantages reflect genuine computational improvements or artifacts of benchmarking choices.

The climate prediction problem exhibits several characteristics that make it particularly unsuitable for near-term quantum computing. The high dimensionality of atmospheric data, the chaotic nature of weather systems, and the need for extended simulation times all conflict with quantum hardware limitations. Furthermore, classical machine learning has achieved impressive performance on climate prediction tasks, setting a high bar for quantum approaches to surpass. These factors suggest that even as quantum technology improves, climate prediction may remain one of the last application domains where quantum systems achieve practical advantage.

The broader discourse around quantum computing and climate change reflects a pattern common to emerging technologies, where enthusiasm for innovation sometimes overshadows careful economic analysis. Technology optimism serves important functions by motivating research and attracting talent to challenging problems, but can also lead to misallocation of resources if not tempered by realistic assessment of costs and benefits. The climate challenge demands solutions that can be deployed at scale within relatively short timeframes, favoring mature technologies with proven track records over speculative approaches with uncertain timelines.

Interestingly, the resources currently devoted to quantum computing for climate applications might generate greater impact if redirected to improving classical machine learning methods or expanding observational networks. Recent advances in deep learning have demonstrated remarkable capabilities for extracting patterns from climate data, while remaining limited by data availability and computational resources. Investments in additional weather stations, satellite systems, and ocean buoys would directly improve climate model inputs and validation, providing certain benefits at reasonable costs.

The analysis presented in this paper should not be interpreted as dismissing the potential long-term value of quantum computing research. Fundamental scientific inquiry into quantum phenomena and quantum algorithms merits support as part of basic research portfolios. However, applications-driven quantum computing initiatives for climate prediction specifically cannot be justified on economic grounds under current conditions. The distinction between basic research and applications development proves crucial for sound policy decisions (Nita et al., 2021).

Looking forward, the conditions under which quantum systems might achieve economic viability can be specified through the models developed in earlier sections. If quantum hardware costs decline by factors of 10-20, operational expenses decrease through improved refrigeration efficiency, and error correction overhead reduces to factors below 10, the economic comparison becomes more favorable. Simultaneously, demonstrated quantum advantages for relevant machine learning tasks would need to materialize through actual implementations rather than theoretical proposals. The conjunction of these conditions appears unlikely within the next decade based on current technological trajectories.

7 Conclusion

This paper has presented a comprehensive economic analysis of Quantum Machine Learning for climate prediction, demonstrating that current technological and economic constraints render such systems infeasible for practical deployment. The analysis has quantified the substantial cost differential between quantum and classical approaches, ranging from factors of 5-10 in capital requirements to factors of 3-5 in operational expenses. These cost disadvantages are not offset by corresponding performance benefits, as quantum advantages remain theoretical while classical systems achieve impressive practical results.

Several key findings emerge from the analysis. First, the capital costs of quantum computing infrastructure capable of addressing climate prediction problems exceed those of classical alternatives by at least an order of magnitude, while providing no demonstrated advantages in predictive capability. Second, operational expenses for quantum systems substantially exceed those of classical supercomputers due to extreme cooling requirements, specialized maintenance needs, and error correction overhead. Third, the opportunity costs of quantum investments are high, as resources devoted to quantum systems could alternatively fund proven classical approaches that provide immediate value for climate modeling and prediction (Mudhol, 2024).

The technical limitations of current quantum computing technology impose fundamental constraints on economic viability. Quantum decoherence restricts coherence times to timescales far shorter than required for climate computations. Limited qubit counts prevent encoding of problems at scales relevant for practical climate models. High error rates in quantum gates require extensive error correction that multiplies resource requirements. These technical constraints translate directly into economic costs that overwhelm any theoretical quantum advantages (Wheatley Research Consultancy, 2024).

The environmental policy implications of these findings are clear. Policymakers should prioritize investments in classical computing infrastructure, improved climate models, and expanded observational networks rather than pursuing large-scale quantum computing initiatives for climate applications. While basic research into quantum algorithms merits modest continued support, applications-driven quantum projects cannot be justified on economic grounds. The urgency of climate challenges demands deployment of proven technologies that can provide immediate value rather than speculative approaches with uncertain timelines.

The cost-benefit analysis framework developed in this paper provides a methodology for evaluating quantum computing investments across application domains. The approach combines rigorous accounting of direct costs with careful assessment of opportunity costs and system-level considerations including reliability and ecosystem effects. This methodology can be applied to other proposed quantum computing applications to determine whether they meet economic viability thresholds (Quantum Technology and Application Consortium – QUTAC, 2021).

Several directions for future research emerge from this analysis. First, continued monitoring of quantum technology development is necessary to identify potential breakthrough advances that might alter the economic calculus. Second, more detailed studies of specific climate prediction tasks could identify niche applications where quantum approaches might provide value even if general-purpose climate modeling remains infeasible. Third, research into hybrid quantum-classical approaches might reveal pathways to leverage quantum resources more efficiently for certain computational subtasks within larger classical workflows.

The analysis also highlights the importance of maintaining rigorous standards for evaluating emerging technologies in climate science. The combination of technological enthusiasm and climate urgency creates pressure for premature deployment of unproven approaches. Resistance to such pressure through careful economic analysis protects against resource misallocation while preserving credibility of the scientific and policy communities. Sound technology assessment requires balancing openness to innovation with skepticism toward unsupported claims (de Jong, 2022).

In conclusion, Quantum Machine Learning for climate prediction represents an interesting theoretical possibility that fails to meet practical economic viability thresholds under current conditions. The substantial cost disadvantages of quantum systems combined with the absence of demonstrated advantages over classical approaches lead to clear policy recommendations prioritizing proven technologies. As quantum computing technology matures over coming decades, periodic reassessment may eventually identify conditions where quantum systems achieve economic competitiveness. However, such reassessment must employ rigorous cost-benefit methodology rather than relying on speculative extrapolations. For the foreseeable future, classical machine learning and high-performance computing remain the economically rational choices for climate prediction applications, and environmental policy should be formulated accordingly.

References

Ajagekar, A. and You, F. (2019). Quantum computing for energy systems optimization: Challenges and opportunities. *Energy*, 179:76–89.

Borysiuk, V. and Michuta, O. (2025). Application of quantum computing in optimization problems. *Modeling, Control and Information Technologies*, (7):123–124.

de Jong, E. (2022). Own the unknown: An anticipatory approach to prepare society for the quantum age. *Digital Society*, 1(2).

Herman, D., Googin, C., Liu, X., Galda, A., Safro, I., Sun, Y., Pistoia, M., and Alexeev, Y. (2022). A survey of quantum computing for finance.

Morstyn, T. and Wang, X. (2024). Opportunities for quantum computing within net-zero power system optimization. *Joule*, 8(6):1619–1640.

Mudhol, A. C. (2024). Integrating quantum computing into business analytics: Opportunities and challenges. *International Journal of Innovative Science and Research Technology (IJISRT)*, pages 2451–2463.

Nita, L., Mazzoli Smith, L., Chancellor, N., and Cramman, H. (2021). The challenge and opportunities of quantum literacy for future education and transdisciplinary problem-solving. *Research in Science & Technological Education*, 41(2):564–580.

Quantum Technology and Application Consortium – QUTAC (2021). Industry quantum computing applications. *EPJ Quantum Technology*.

Takeori, M., Shimada, N., Alevras, D., Parney, B., Sharma, D., Chu, Q., and Cena, B. (2024). Workforce task execution scheduling using gate-based quantum computers. In *2024 IEEE International Conference on Quantum Computing and Engineering (QCE)*, pages 315–321. IEEE.

Wheatley Research Consultancy (2024). Quantum shifts: The societal implications of quantum computing on security, privacy, and the economy.

Wolbring, G. (2022). Auditing the 'social' of quantum technologies: A scoping review. *Societies*, 12(2):41.