

# The energetic challenges of fault-tolerant quantum computing

Marco Fellous-Asiani,<sup>1</sup> Pierre-Emmanuel Emeriau,<sup>2</sup> Jeremy Stevens,<sup>3</sup>  
Marco Pezzutto,<sup>4, 5, 6</sup> Yasser Omar,<sup>7, 4, 5, 6, 8</sup> and Olivier Ezratty<sup>9, 10, \*</sup>

<sup>1</sup>*Université de Lorraine, CNRS, INRIA, LORIA, 54000 Nancy, France*

<sup>2</sup>*Quandela*

<sup>3</sup>*Alice&Bob*

<sup>4</sup>*PQI – Portuguese Quantum Institute, Portugal*

<sup>5</sup>*Physics of Information and Quantum Technologies Group,*

*Centro de Física e Engenharia de Materiais Avançados (CeFEMA), Portugal*

<sup>6</sup>*LaPMET – Laboratory of Physics for Materials and Emerging Technologies, Portugal*

<sup>7</sup>*Instituto Superior Técnico, Universidade de Lisboa, Portugal*

<sup>8</sup>*Quantum Green Computing, Ltd.*

<sup>9</sup>*EPITA Research Lab*

<sup>10</sup>*Quantum Energy Initiative*

(Dated: March 12, 2026)

Fault-tolerant quantum computing (FTQC) is essential for achieving quantum advantage with demanding applications. Its reliance on quantum error correction introduces substantial resources overhead in qubit count and classical operations. This will lead to increased material costs and energy consumption, raising sustainability and economic concerns. In this perspective, we explain how to assess and optimize the energetic footprint of FTQC systems, across qubit modalities. We integrate a mixed scientific and engineering approach to guide systems design. We also incorporate some economic reasoning to size the global FTQC power consumption and with defining the notion of energy acceptability from an end-user economical standpoint. We identify the components which can be individually optimized (in a reductionist approach) and those with interdependent figures of merit (holistic approach). For the later ones, we explain how the MNR framework introduced in [1] can be naturally extended to optimize FTQC QPUs (quantum processing units) energy efficiency under various, possibly simultaneous, constraints like results accuracy, computing time, accessible electrical power, or even total cost (in \$). This warrants hardware and software co-design approaches. We explain that for reducing the energetic bill, some solutions are technological (making device more energy efficient at the individual level), and some are methodological (use the technology as it is, and optimize the architecture at the system level, and potentially at the application level, with looking at interdependencies). The latter optimizations have the advantage of incurring no incremental costs in terms of pure technological developments. We conclude with highlighting multiple scientific and engineering challenges or opportunities for the industry vendor and academic community on the question. In particular, we discuss how fundamental research could help in maximizing the energy-efficiency of future fault-tolerant quantum computers.

---

[1] M. Fellous-Asiani, J. H. Chai, Y. Thonnart, H. K. Ng, R. S. Whitney, and A. Auffèves, Optimizing resource ef-

iciencies for scalable full-stack quantum computers, PRX Quantum 10.1103/prxquantum.4.040319 (2023).

---

\* olivier@oezratty.net