Benchmarking Energy Consumption of Quantum Computers

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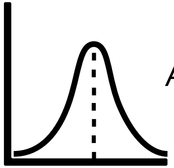
A team of quantum specialists

Our unique strategy to quantum advantage

KEY TECHNOLOGY INGREDIENTS

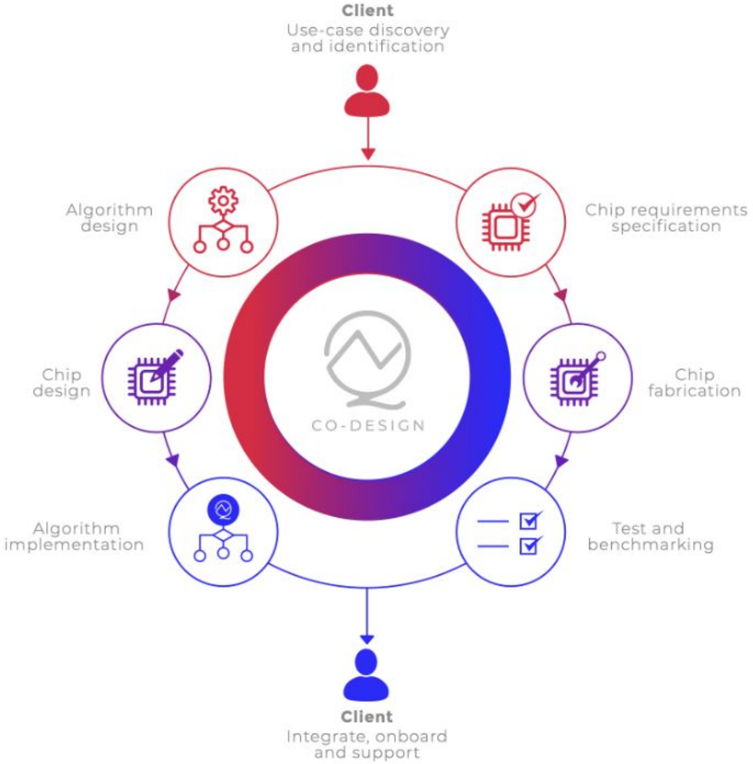


Analog quantum computation

Quality over quantity

Quantum interactions

CO-DESIGN APPROACH



CUCO

- Quantum Computing for Strategic Industries
- Funded by CDTI and supported by the Spanish Ministry of Science.
- Qilimanjaro is responsible for QC in logistics and benchmarking.

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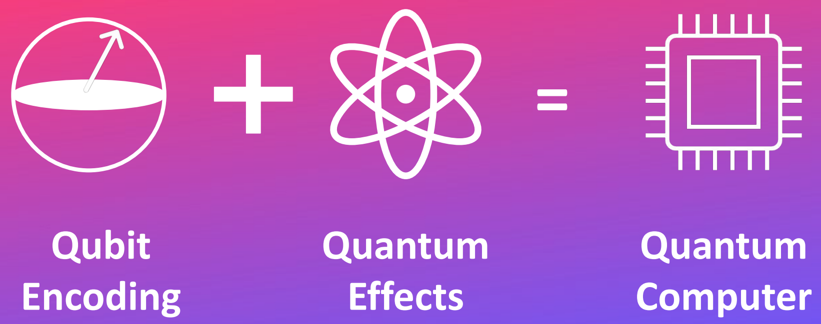
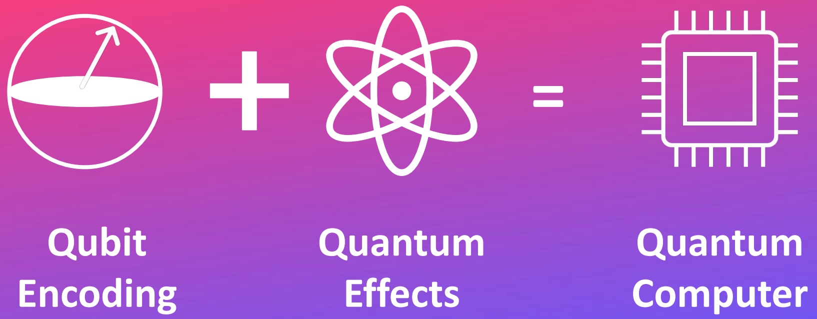
GMV INNOVATING SOLUTIONS · MULTIVERSE COMPUTING · QILIMANJARO QUANTUM·TECH · REPSOL · BBVA · DAS Photonics

ICFO · CSIC Consejo Superior de Investigaciones Científicas · tecnalia MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE · BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación · Universitat Politècnica de València · DIPC Donostia International Physics Center

The promise of quantum



The promise of quantum



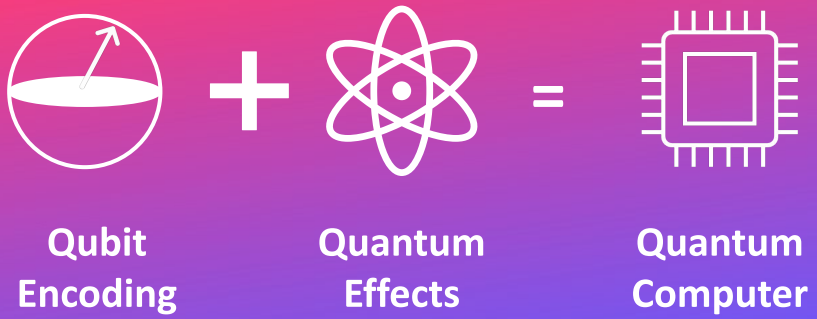
Faster solutions

The promise of quantum

Qubit Encoding + **Quantum Effects** = **Quantum Computer**

Faster solutions	Better accuracy

The promise of quantum



Faster solutions	Better accuracy	More sustainable

The promise of quantum

Qubit Encoding	Quantum Effects	Quantum Computer
Faster solutions	Better accuracy	More sustainable ?

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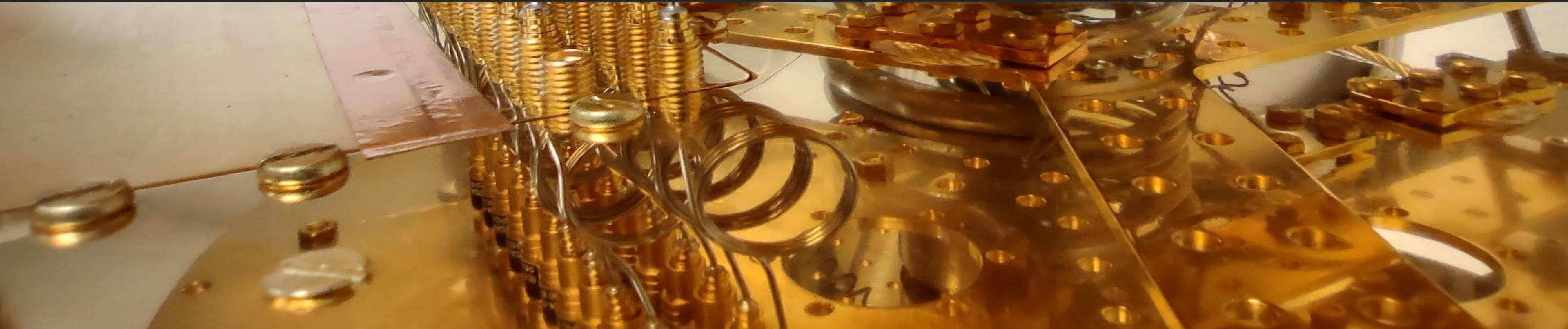
Benchmarks



Benchmarking QC

Desired Properties [1]

- Randomized
- Holistic
- Platform Independent
- Clearly Defined

Relevant Measures

- Time To Solution
- Solution Accuracy
- **Energetic cost**

System Level Benchmarks

- Quantum Volume
- Cross-Entropy Benchmarking
- Randomized Benchmarking (Clifford/Direct)
- ...

Application Level Benchmarks

- Q-Score
- Qpack Scores
- SupermarQ
- QED-C
- ...

[1]https://arxiv.org/abs/2303.02108

Energy Benchmarks in the lab DIY

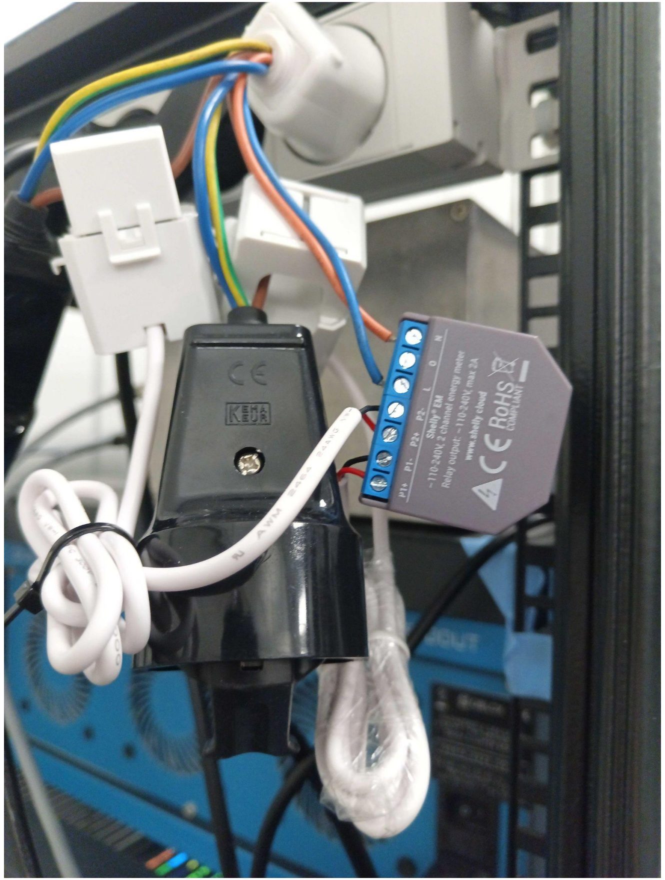
IoT energy meter

Specs

- Electrical consumption < 1 W
- Readout frequency 1 second
- Readout accuracy 1% error

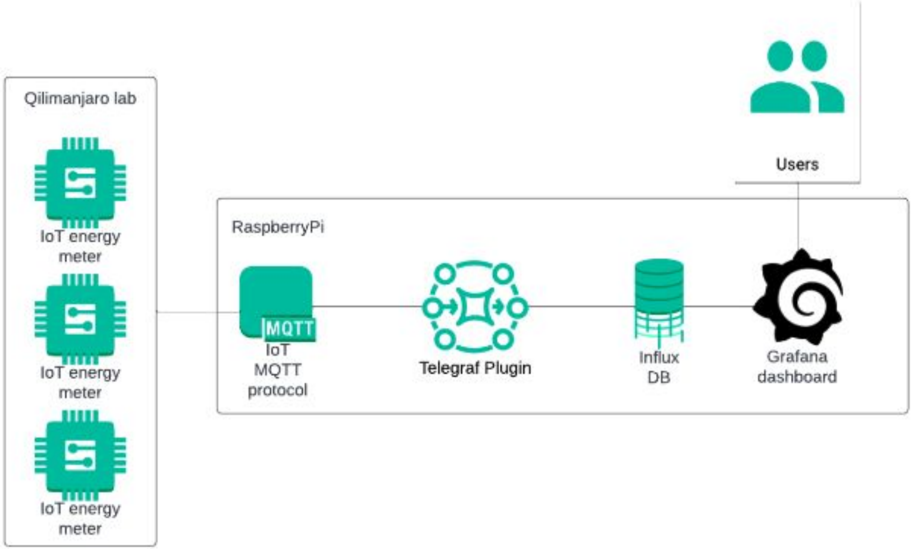
Tracked Components

- Quantum Control and Readout Modules (QCM/QRM)
- Full Rack (rest of components)



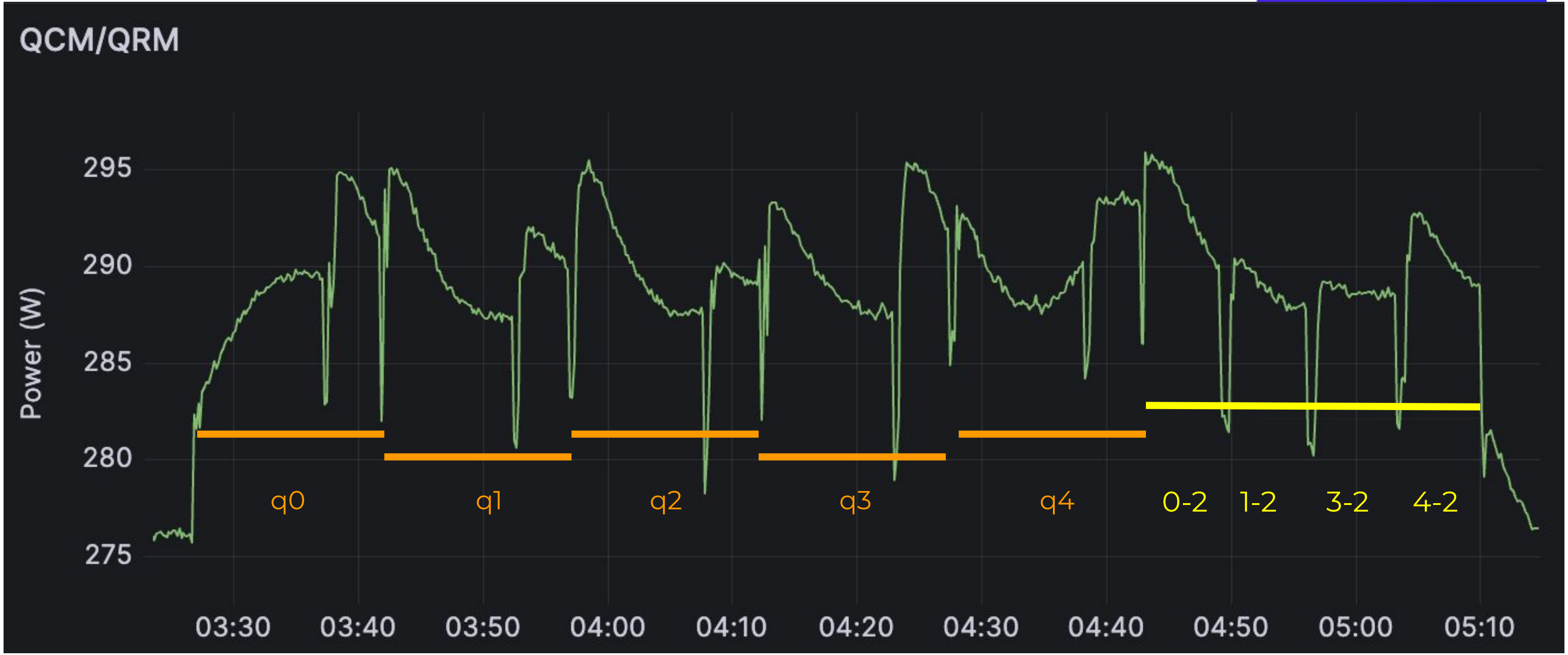
Energy Benchmarks: system's architecture

- Repository available at https://github.com/qilimanjaro-tech/qilisensors
- Deployable into any server or controller such as RaspberryPi or Arduino due to Docker containerization
- Real-time plotting with Grafana.



Energy Benchmarks: live plotting

Energy Benchmarks: calibration plotting



- **Single qubit calibration are composed of qubit characterization, single shot statistics for readout (SSRO) and randomized benchmarking experiments per qubit.**
- **Two qubit gate calibration composed of amplitude correction experiments per coupler.**

Energy Benchmarks: IDLE state consumption

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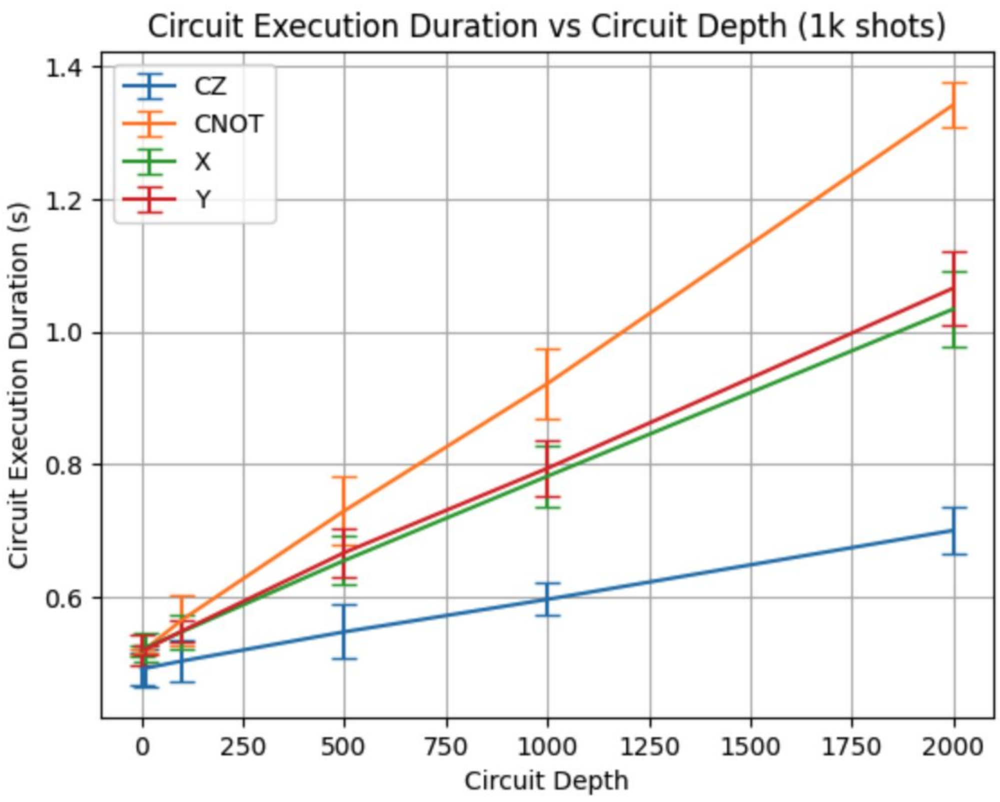
Table of Averaged Constant Costs:

	Equipment Name	Estimated Avg Power Consumption (kW)	Estimated Total Avg Consumption (kW)
Fridge	Vacuum Pumps	8.5×10^{-1}	1.73×10^{1}
	Chillers	2	
	Compressor	1.45×10^{1}	
Supporting Electronics	Total	6.7×10^{-1}	6.7×10^{-1}
Total Idle State Consumption		1.8×10^{1}	

Energy Benchmarks: Initial results

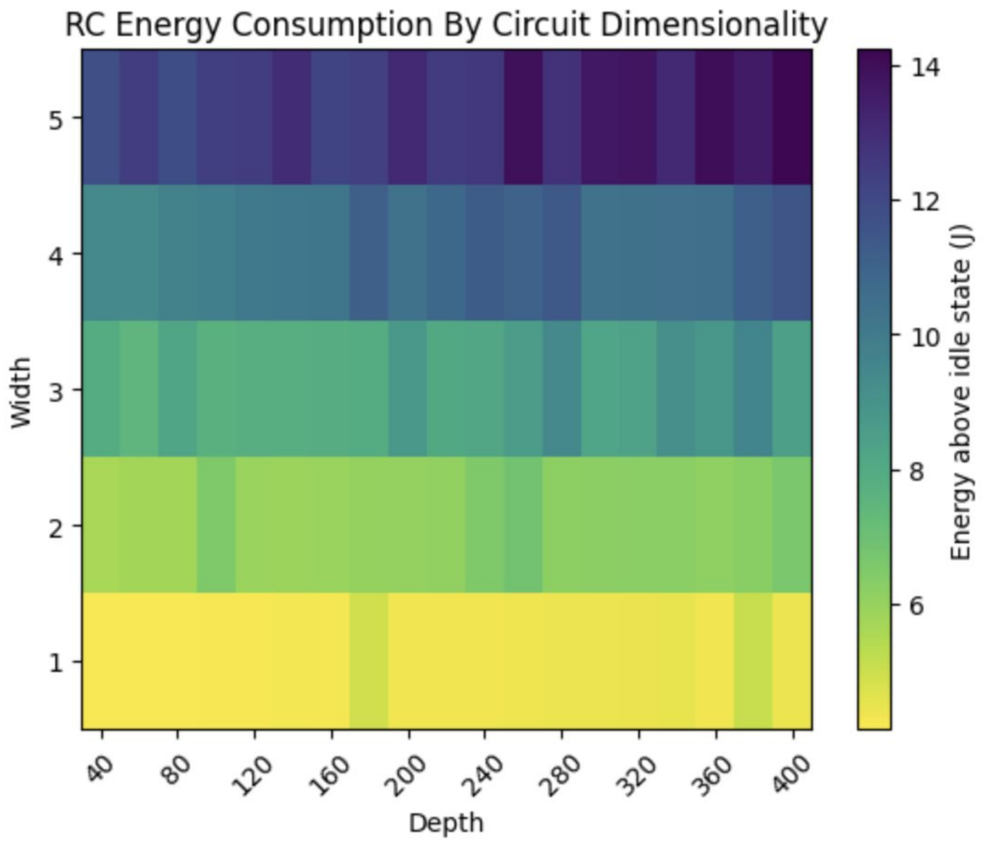
- Native gates are X, Y, Z, CZ
- Implementation of Z gates are '*Virtual Z Gates*'[1] which in duration are equivalent to identities.
- Plot generated with two qubits (1-2). 100 circuit executions per data point, each circuit 1k shots.
- **Assumption of linear scaling since drag pulses are applied at a per qubit basis.**



[1]https://arxiv.org/abs/1612.00858

Energy Benchmarks: Initial results

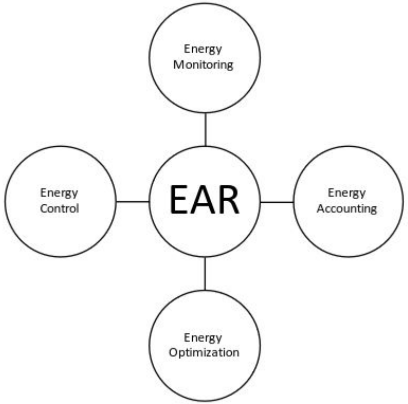
- 5-qubits superconducting chip used with star coupling, qubit 2 at the center
- Increase in power ranges between 7-10W. The image shows the upper bound energy increase at 10W increase each.
- At low depths, largest increase in energy consumption is due to number of qubits (width).
- **No noticeable increase in power metrics for up to 5 qubits aside from circuit execution duration.**

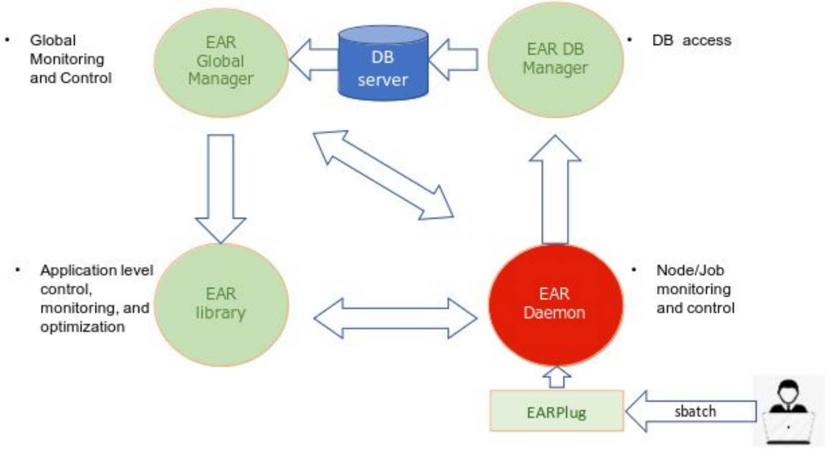


Energy Benchmarks: comparison with HPC

Gather detailed metrics from HPC systems at runtime:

- Resource managing system (SLURM)
- Dedicated solutions: EAR (BSC's spin-off company EAS - Energy Aware Solutions)

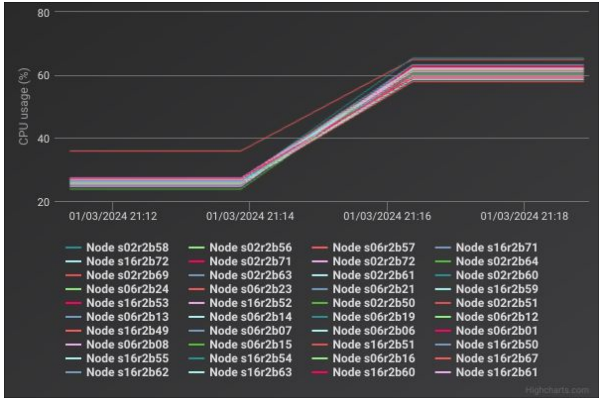




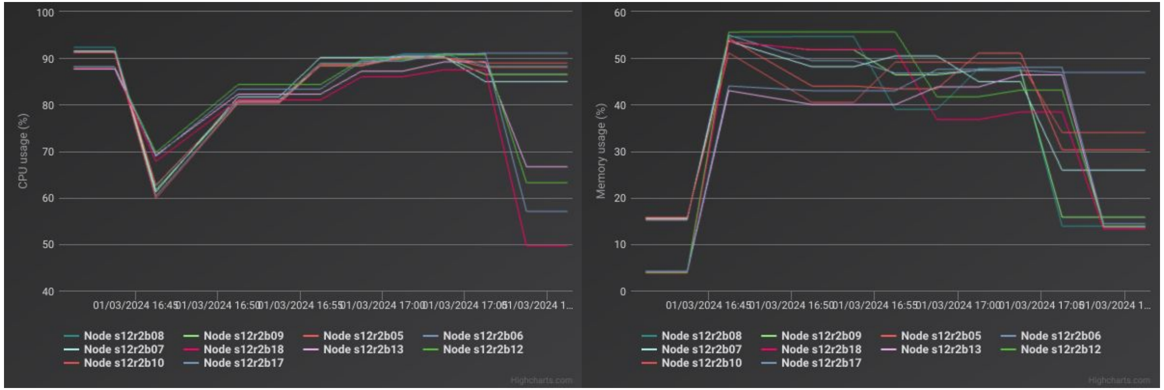
Energy Benchmarks: comparison with HPC

- Use of power is not a constant, with strong dependence on the activity
- Each node (2 CPU): **100-200 W sustained**
- Simulations range between **10 to 30 minutes**
- CPU is using a large portion of the power consumption
- Simulations with Tensor Networks, doing exact contractions.

Metrics obtained for medium scale simulations on Marenostrum 5 with Marenostrum 4 settings (64 qubits, shallow circuit of max depth of 12):



Execution using 40 nodes

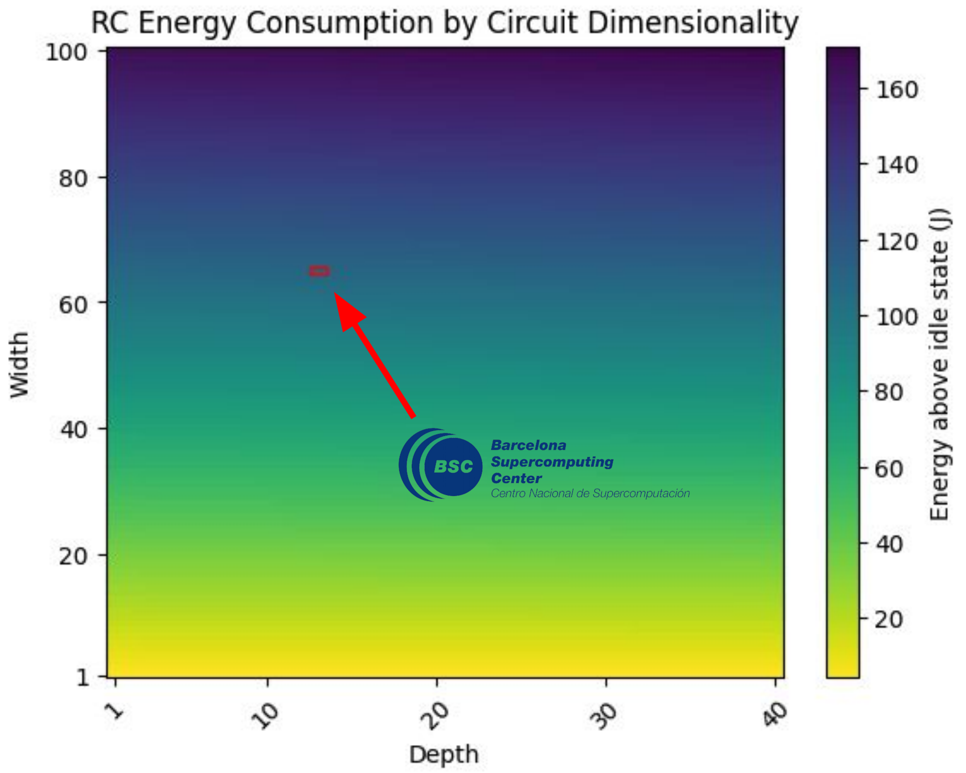


Execution using 10 nodes

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Energy Benchmarks: comparison with HPC

- QC data extrapolation at BSC circuit simulation (64 qubits x 12 depth) dimension yields **an additional energy requirement of ~ 108 J**
- BSCs estimated lower bound in energy consumption of CPUs for the simulation using TNs is **~ 300 kJ** while **total** QC energy cost is **~ 41 kJ**
- Initial rough estimates indicate an **energy cost decrease of ~ 86%** at presented task.



Next steps

- Perform **relevant applicative task comparisons** between QC and HPC
- **Formal definition of a comparative benchmark** of quantum systems vs HPC, considering **TTS, solution accuracy, and energy consumption** following ideal benchmark guidelines.
- Introduce tensor network bond dimension adjustment for **energetic study related to error calculation.**
- Obtain exhaustive, more granulated measurements with **peak CPU performance** in MareNostrum5.
- Implement **state of the art methods** in both systems for fair comparison.

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https://github.com/qilimanjaro-tech/qilisensors

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