AFFORDABLE AND CLEAN ENERGY USING QUANTUM COMPUTING

Andrew SUTCLIFFE & Simon DECONIHOUT

SUMMARY

SUSTAINABLE DEVELOPMENT GOALS

OPEN QUANTUM INSTITUTE PROJECTS

GRID ENERGY MANAGEMENT

UNIT COMMITMENT PROBLEM

CONCLUSION

SUTAINABLE DEVELOPMENT GOALS

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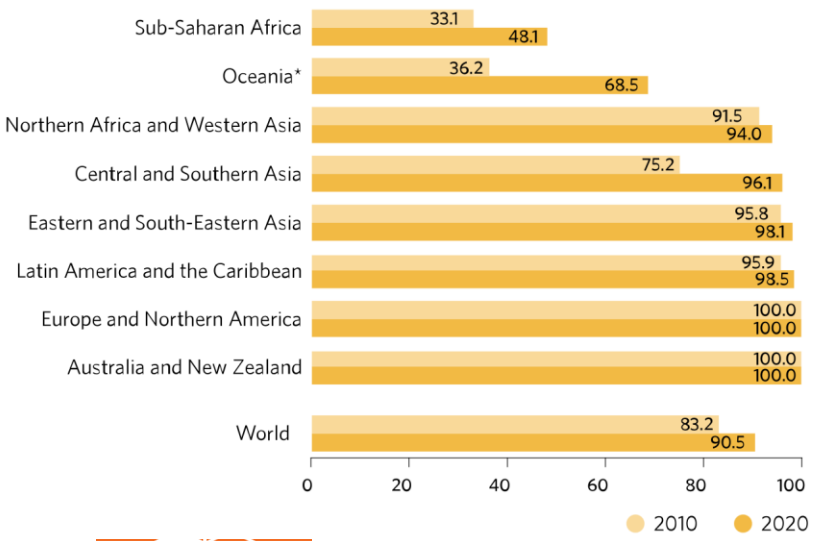

Figure 2: Proportion of population with access to electricity, 2010 and 2020 (percentage)

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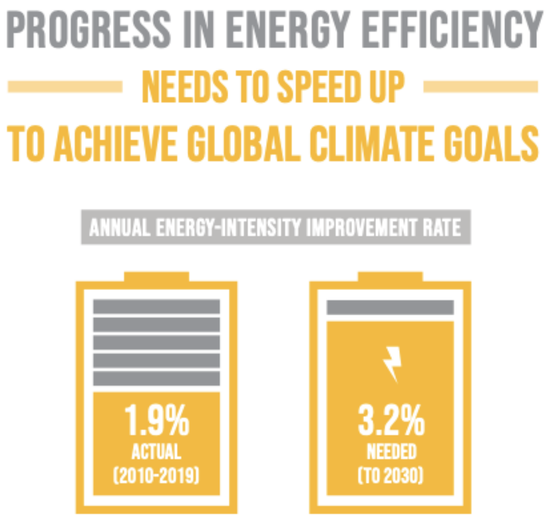

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Figure 3: Progress needed in energy efficiency

OPEN QUANTUM INSTITUTE PROJECTS

Smart Grid Management

SHORT SUMMARY
Quantum optimisation solution to improve the management of large energy grids and efficiently distribute energy.

APPROACH
Combinatorial optimisation (quantum-inspired)

« Smart grid management is a cornerstone of modern infrastructure, supporting the development of resilient infrastructure by enhancing the grid's ability to adapt to real-time supply, demand fluctuations and integrate various energy sources.»

Layout of Turbines in a Wind Farm

SHORT SUMMARY
Quantum optimization solution to efficiently layout turbines in a wind farm and maximise the power produced.

APPROACH
Combinatorial optimisation (quantum-inspired)

«Quantum computers may offer a way to find high-quality windfarm. configurations faster or more accurately than classical approaches.»

FACILITY LOCATION-ALLOCATION PROBLEMS

Quantum computing for energy systems optimization: Challenges and opportunities

Akshay Ajagekar, Fengqi You*

Cornell University, Ithaca, New York 14853, USA

FACILITY LOCATION-ALLOCATION PROBLEMS

Figure 4: Flow between facilities and their locations

FACILITY LOCATION-ALLOCATION PROBLEMS

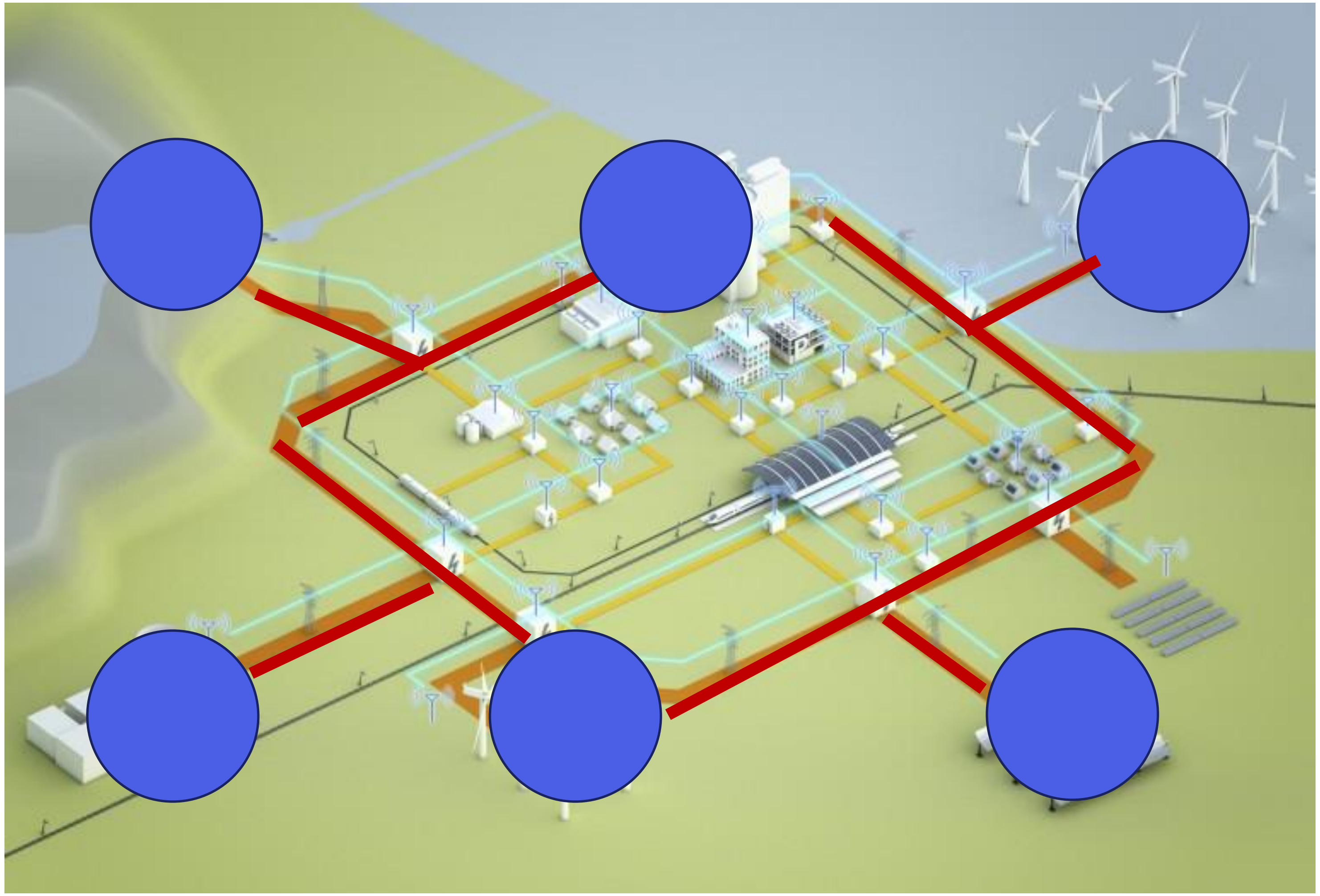


Figure 5: Flow between facilities and their locations map as a QUBO problem

FACILITY LOCATION-ALLOCATION PROBLEMS

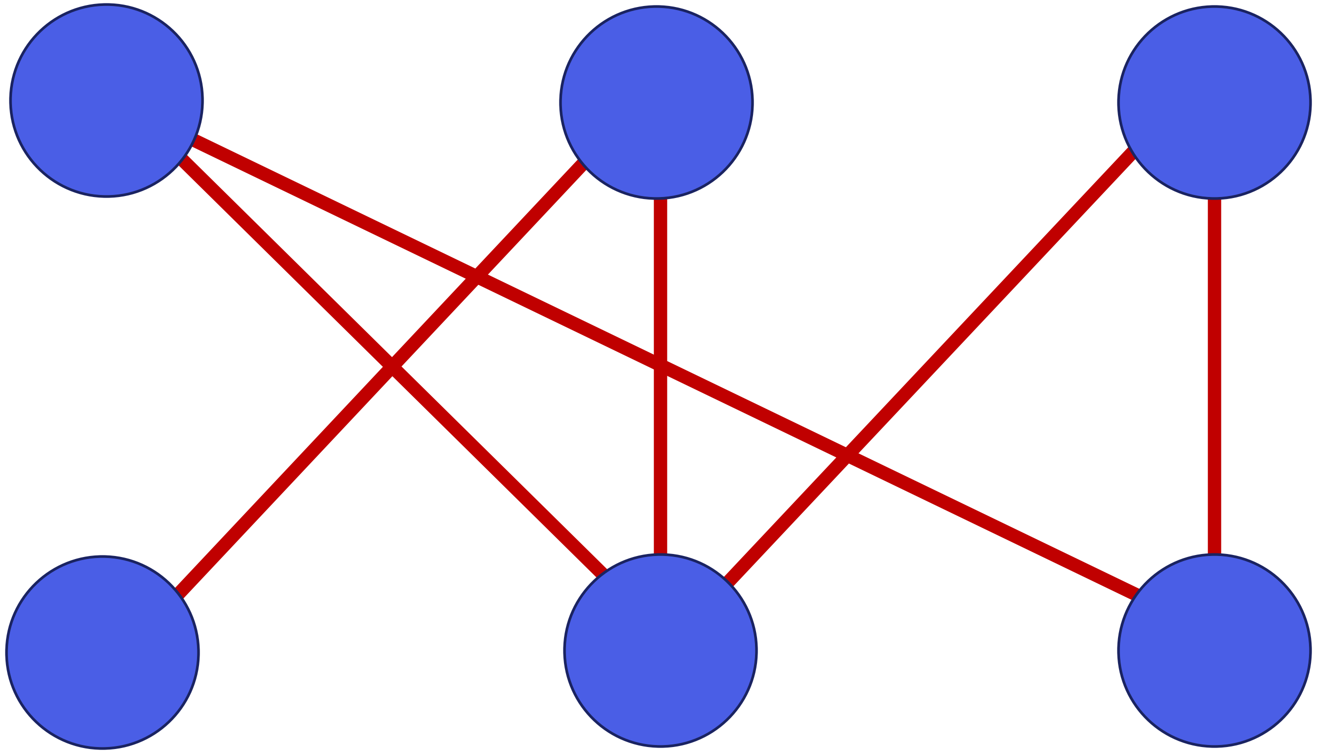


Figure 5: Flow between facilities and their locations map as a QUBO problem

FACILITY LOCATION-ALLOCATION PROBLEMS

number of units of energy to be transported from plant *p* to plant *q*

From Classical discretization…

…To quantum description

$$\min \sum_{q=1}^{n}\sum_{p=1}^{n}\sum_{j=1}^{n}\sum_{i=1}^{n} C_{ij} T_{pq} x_{pi} x_{qj} \quad (1)$$

$$\text{s.t.} \quad \sum_{p=1}^{n} x_{pi} = 1, \ \forall i = 1, 2 \ldots n$$

$$\sum_{i=1}^{n} x_{pi} = 1, \ \forall p = 1, 2 \ldots n$$

$$C(x) = \sum_{q=1}^{n}\sum_{p=1}^{n}\sum_{j=1}^{n}\sum_{i=1}^{n} C_{ij} T_{pq} x_{pi} x_{qj} \quad (2)$$

$$+ A\sum_{i}\left(1-\sum_{p} x_{pi}\right)^2 + A\sum_{p}\left(1-\sum_{i} x_{pi}\right)^2$$

cost of transporting one unit of energy from location *i* to location *j*

“Only problems which can be mapped onto an Ising model or a quadratic unconstrained binary optimization (QUBO) formulation as in Eq. (2) can be solved on a D-Wave system.”

QUANTUM ANNEALING

Adiabatic Theorem:

«A physical system remains in its instantaneous eigenstate
if a given perturbation is acting on it slowly enough and if there is a gap between the eigenvalue and the rest of the Hamiltonian's spectrum.»

$$H(s) = \underbrace{-\frac{A(s)}{2}\sum_a \hat{\sigma}_x^a}_{\text{initial state}} + \frac{B(s)}{2}\underbrace{\sum_a h_a \hat{\sigma}_z^a + \sum_{a,b} J_{a,b}\hat{\sigma}_z^a \hat{\sigma}_z^b}_{\text{final state}}$$

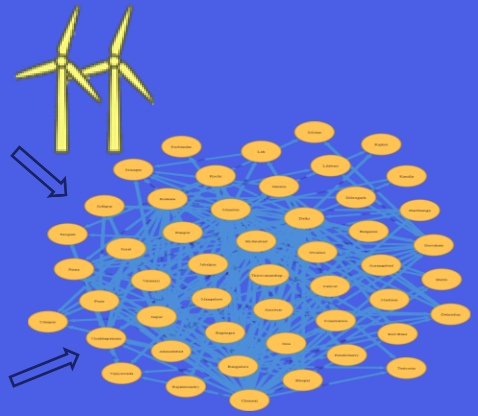
Theoritically:
-Hamiltonian of a Anneling problem going from a easy initial state to the desired state

RESULTS

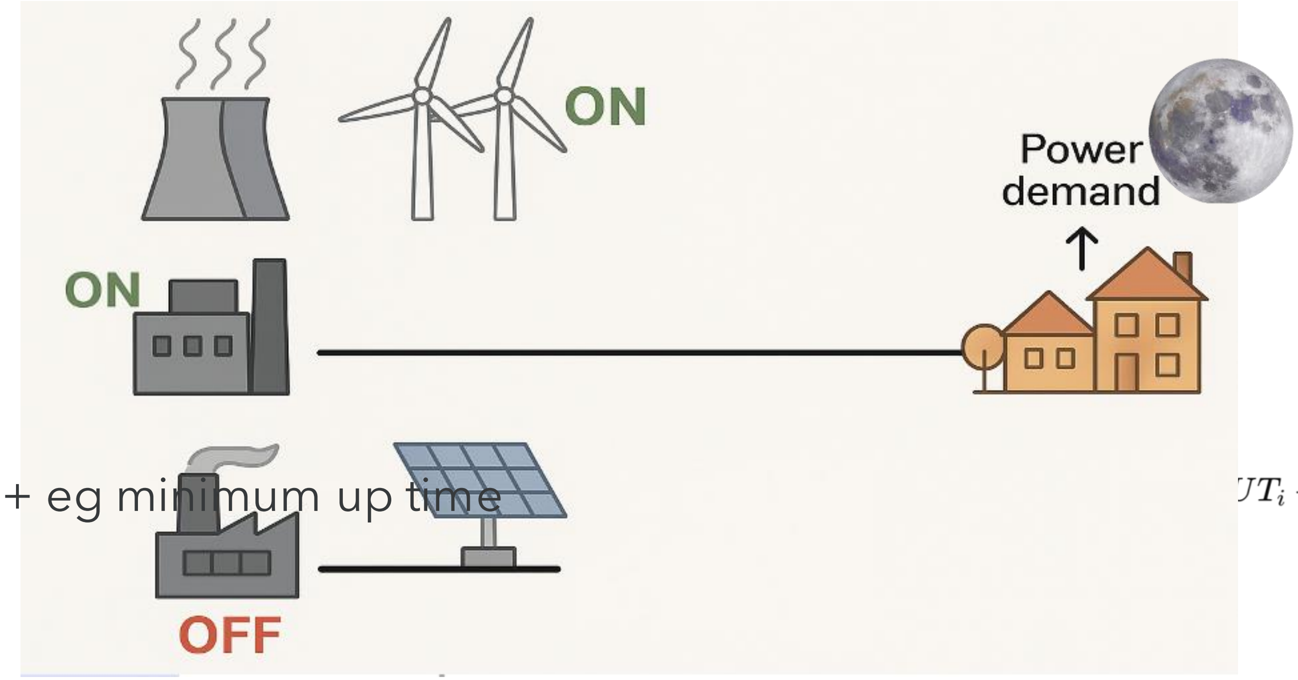
No. facilities	Best known solution	Gurobi solver (single CPU core) time(s)	Gurobi solver (single CPU core) obj. fun.	Quantum solver (D-wave 2000Q) time (s)	Quantum solver (D-wave 2000Q) obj. fun.
3	24	1.33	24	0.024	24
4	32	1.48	32	0.062	32
5	58	1.5	58	0.066	58
6	94	1.35	94	0.043	94
8	214	1.96	214	0.127	214
9	264	2.01	264	445.23	264
12	578	325.68	578	1946.12	578
14	1014	42,010.42	1014	1008.7	1026
15	1150	---*	1160	986.19	1160
17	1732	---*	1750	921.71	1786
20	2570	---*	2674	744.76	2640

* Timeout of 12 hours reached by Gurobi

UNIT COMMITMENT



$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} \left(C_i^{\text{gen}} p_{i,t} + C_i^{\text{start}} \cdot u_{i,t}(1 - u_{i,t-1}) \right)$$



+ eg minimum up time

$UT_i + 1$

Large-scale mixed-integer nonlinear non-convex NP-hard optimization problem

AFFORDABLE AND CLEAN ENERGY

PRIORITY-LIST SCHEMES

X NOT OPTIMAL

DYNAMIC PROGRAMMING (DP)

X EXPONENTIAL IN NUMBER OF UNITS

MILP SOLVERS

✓ BUT SLOW FOR LARGE SYSTEMS

LAGRANGIAN RELAXATION

– POTENTIALLY INFEASIBLE

2305.08482

QUANTUM PROBLEM

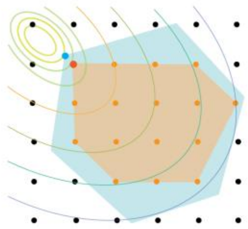
Nonlinear mixed-integer non-convex optimization problem

Continuous variables must be made integer –
a) Naïve: discretise p by bit representation complexity explosion [ref]
b) New paper: [ref]

$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} \left(C_i^{\text{gen}} p_{i,t} + C_i^{\text{start}} \cdot u_{i,t} (1 - u_{i,t-1}) \right)$$

+ embed constraints as penalties

Quadratic unconstrained binary optimisation (QUBO)



QUANTUM SOLUTION

$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} \left(C_i^{\text{gen}} p_{i,t} + C_i^{\text{start}} \cdot u_{i,t}(1 - u_{i,t-1})\right)$$

Master problem - QPU

$$\min_{u,\theta} \quad \sum_{i,t} C_i^{\text{start}} u_{i,t}(1 - u_{i,t-1}) + \theta$$

$$\theta \geq \phi_k(u)$$

90%

Subproblem - CPU

$$\min_{p} \sum_{i,t} C_i^{\text{gen}} p_{i,t}$$

$$\sum_{i=1}^{N} p_{i,t} = D_t \quad \forall t$$

$$P_i^{\min} u_{i,t} \leq p_{i,t} \leq P_i^{\max} u_{i,t} \quad \forall i, t$$

1) Proposes a u -> Answers with p… else “infeasible”
2) new constraint, proposes a u -> Answers with p… else “infeasible
3) Done when upper bound = lower bound

Hybrid quantum annealing decomposition framework for unit commitment

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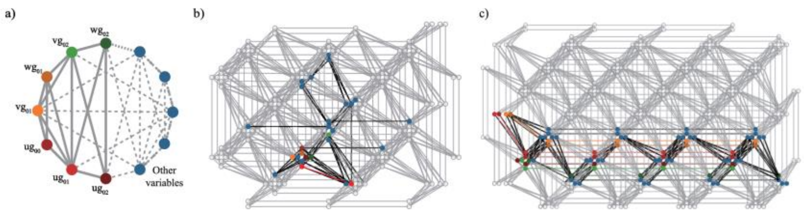
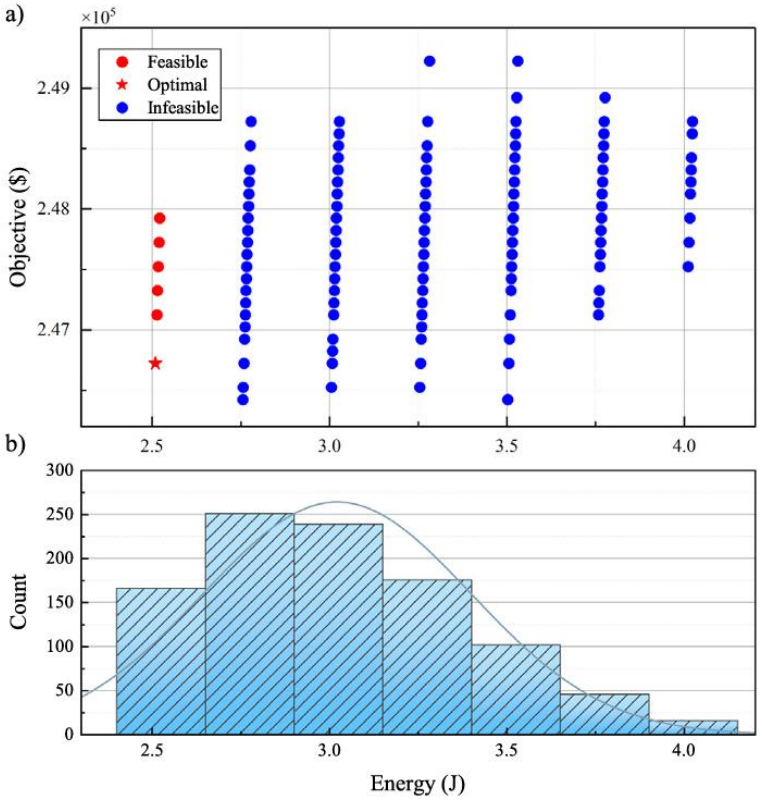
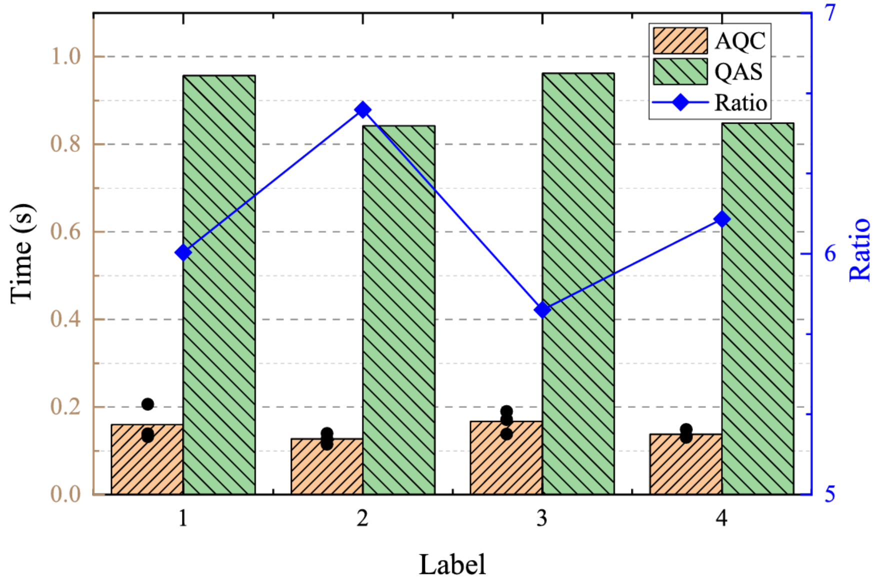


RESULTS



after 2 iterations

- 6.1% optimal solution with 70 qubits
- “In this experiment, about 15% of the samples are concentrated in the interval with the lowest energy solution, and about 50% of the samples fall in an interval with the lowest energy and an interval near the lowest energy”



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