OQI Use Case: Multi-objective Food Optimization Model

Edoardo Spigarolo, Douaa Salah, Constantin Wehrbach
EPFL

Summary

Global food systems face the challenge of producing nutritious, affordable, and environmentally sustainable food in the context of limited land and rising demand. Optimizing land use to balance nutrition, sustainability, and economic viability is a complex problem that often involves conflicting objectives and strict constraints. In this project, we explore how advanced optimization techniques—particularly hybrid classical-quantum algorithms—can help solve such multi-objective problems at scale.

We focus on a land-use allocation model that assigns different crops to multiple farms based on nutritional value, environmental impact, affordability, and sustainability scores. The goal is to maximize total utility across these objectives, subject to constraints such as land limits, food diversity, and minimum social benefit on each farm. This formulation leads to a Mixed-Integer Linear Program (MILP), a class of problems known to be computationally intensive.

To solve it, we apply Benders' decomposition: a technique that breaks the MILP into two linked problems. The first, called the master problem, decides which crops should be planted where (in binary). The second, the subproblem, determines how much of each crop to plant, given the land constraints. This decomposition enables more scalable solving, and we benchmark both a full classical implementation and several quantum-inspired approaches.

In particular, we transform the binary master problem into a Quadratic Unconstrained Binary Optimization (QUBO) form, making it compatible with quantum algorithms such as the Mean Field Approximate Optimization Algorithm and QAOA (Quantum Approximate Optimization Algorithm). These algorithms are run in simulation, providing a proof-of-concept of how quantum computing may support complex sustainability planning in the future.

Our results show that while classical solvers (like PuLP and Benders) currently outperform quantum-inspired ones in terms of accuracy and runtime, the latter are capable of producing feasible, interpretable solutions. As quantum hardware evolves, such hybrid approaches could help optimize real-world food systems, contributing to the UN's Sustainable Development Goal 2 (Zero Hunger) by supporting healthy and sustainable food production.

Keywords

Benders Decomposition, Quantum Optimization, Food Systems, SDG 2, Hybrid MILP-QUBO

References

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