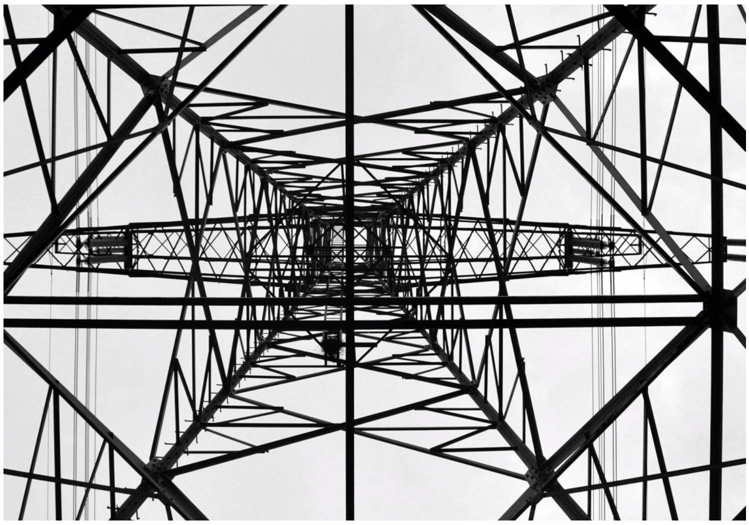
# Attraqt'em

# Applications, interfaces and data formats for quantum computing algorithms in energy systems modelling

The goal of this project is to develop hybrid quantum-classical algorithms for solving energy planning and operation problems of future energy systems.

- Energy System Operation
- Energy System Planning
- Energy System Optimization
- Hybrid Quantum Algorithms



Source: DLR

## Optimization for energy systems

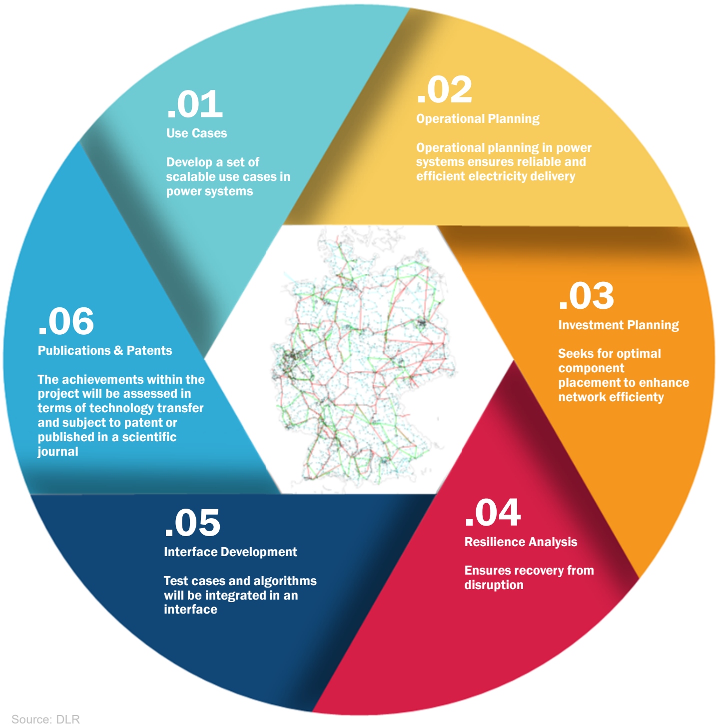
Many challenges in the context of the energy transition can be addressed by energy system models (ESMs). For instance, we can enhance operational and investment decisions by optimizing electricity, gas, and heat supply with high spatial and temporal resolution. However, classical hardware is struggling to handle large-scale optimization problems, such as a fully resolved German high-voltage grid including sector coupling, since the solving time scales exponentially with system size.

ESMs are typically simplified into linear problems in order to get a solution in a reasonable amount of time. However, some research questions require a more complex formulation, like a mixed-integer linear optimization problem (MILP), which is computationally expensive. In Attraqt'em we study the quantum advantage in three optimization problem types of ESMs for which MILP are of high importance:

I. Operational planning
II. Investment planning
III. Scenario analysis for resilient systems

Although quantum advantage for large problems can only be projected from studies with small quantum computers available today, quantum computers could already demonstrate their potential for problems where

- a good enough solution is sufficient for practical purposes, or
- a time constraint prevents exact methods to find the optimal solution.

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## A Hybrid algorithm approach

Many ESM optimization problems can be formulated as MILPs. The resolution of those problems can be often parallelized using a decomposition algorithm. In this project, we apply Benders Decomposition to operational planning and resilience analysis as well as Dantzig-Wolfe decomposition to unit commitment. Both methods decompose the problem into a master problem and a sub-problem. This decomposition reduces the complexity of the problem at the price of an iterative solving process, since the master and subproblem are solved multiple times until a convergence criterion is satisfied. For the Benders (Dantzig-Wolfe) decomposition, the master (sub-) problem will be solved using a quantum computer. To this end, the master (sub-) problem is translated into a quadratic unconstrained binary optimization problem. The subproblem (master problem), on the other hand, will be solved by a classical computer. Such an approach has already been demonstrated for a version of the investment planning problem (Figure 2). In the Dantzig-Wolfe case, we apply QAOA to the sub-problem and further reduce the resource requirements via circuit cutting.

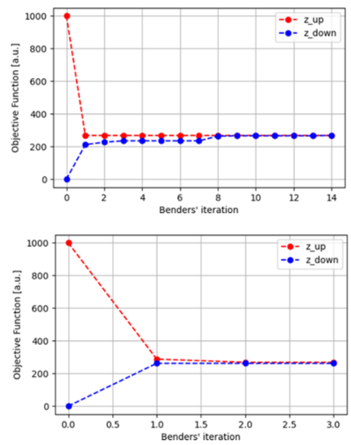


Figure 2: Comparison of a MILP problem solved with Benders Decomposition using a hybrid quantum-classical solver without a classical check stopping criterion (top) versus with it (bottom).

## Use cases

The integration of decentralized weather-dependent renewables, new storage and sector coupling technologies, and demand side management significantly increases the complexity of the grid. While there are well-known test cases for the simulation of power systems, fewer are available for investment planning. We developed our own family of scalable test cases which allow us to explore how quantum algorithms perform and scale across various optimization problem formulations (Figure 1).

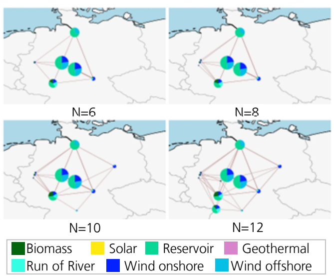


Figure 1: Scalable test-case family of networks by consecutive clustering of a larger network.

## I. Operational planning – Unit commitment

Operational planning of a power system involves coordinating the generation and distribution of energy to meet demand reliably and efficiently. This includes scheduling of power plants, load forecasting, resource allocation, and real-time adjustments to ensure that the energy supply aligns with the demand while minimizing costs and maintaining system reliability. In this project, we consider the unit commitment problem (UCP), which asks for a commitment schedule of power generating units over a given time horizon. For each point in time, the schedule specifies which unit generates what amount of power. The schedule should meet an expected load profile at a minimum production cost. Solving the UCP is NP-hard due to numerous technical and operational constraints.

## II. Investment planning

The investment planning problem aims to find the optimal number of components and their location in a given network. The optimization can take into account many different components at the same time. However, considering a large number of components increases drastically the complexity of the problem making it intractable for current classical hardware in a reasonable amount of time. For this reason, there are multiple variants of the investment planning problem depending on what components are taken into account. This applies to investment planning for heat, power and gas networks where the knowledge about future locations and quantities of energy producers and consumers is uncertain. For instance, the transmission network expansion planning problem is an NP-hard problem that decides which transmission lines to build for a given scenario in the most efficient way.

## III. Scenario analysis for resilient systems

Resilience is the ability of a system to return to normal operation after a disruptive event. The resilience of the future energy systems to unforeseen events must be ensured. Such events can take many forms, thus, there is not a unique approach to do resilience analysis in ESM. Usually, it is associated to the challenges posed by decarbonization measures. These challenges derive from the increase of distributed energy resources, which increase the unpredictability and the volume of data needed to operate the energy system. Problems which can be used to study resilience include grid partitioning, fault diagnoses, observability, outage management, or event-specific resilience.

**More information about the project on our website**


**A project of**

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