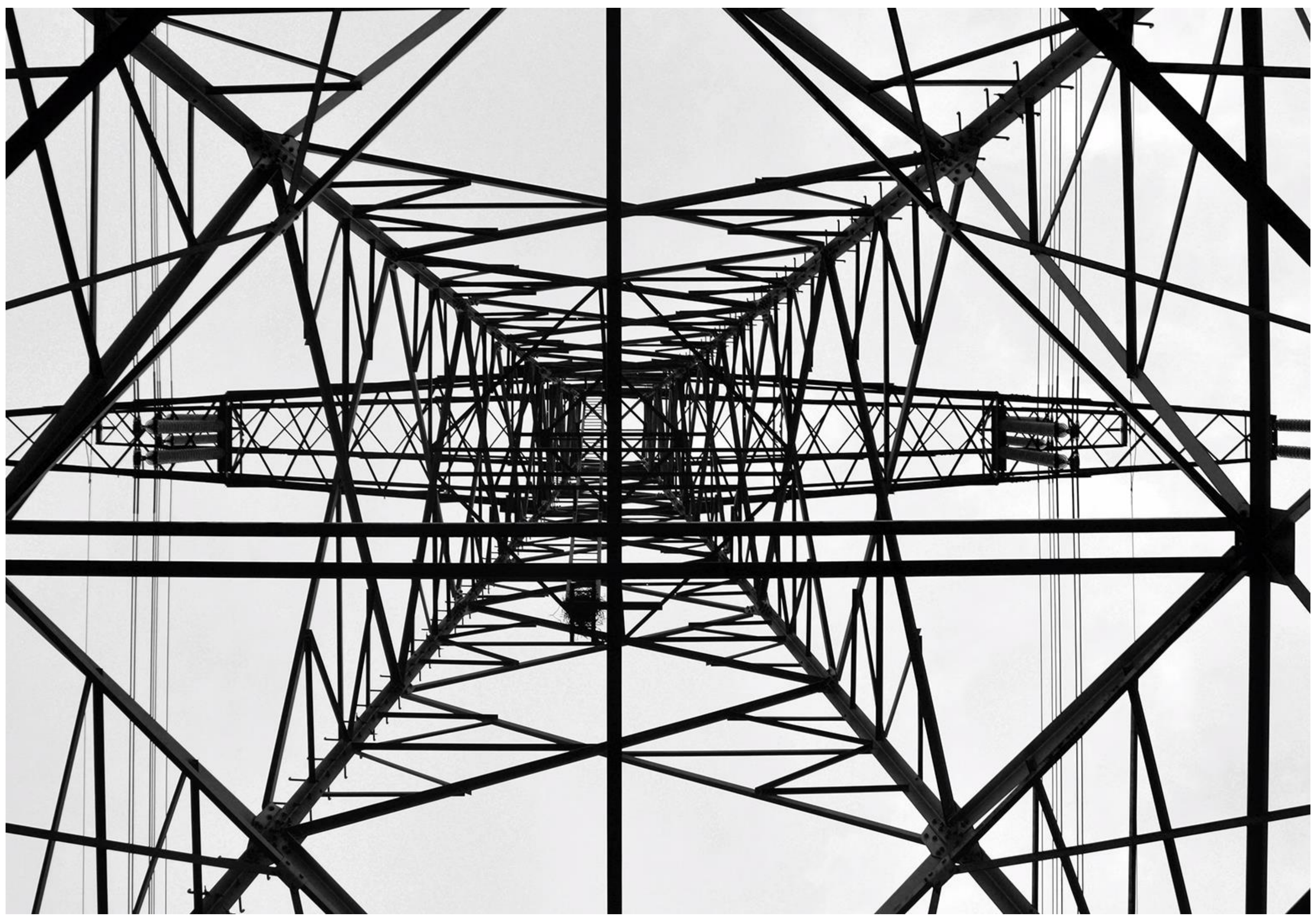
Attraqt'em

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

The goal of the project is to develop the necessary interfaces to solve energy planning and operation optimization problems of future energy systems

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



Source: DLR

Optimization for energy systems

A large number of 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 the large-scale optimization problems, such as a fully resolved German high-voltage grid including sector coupling, since the solving time scales exponentially with the 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 intensive. 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 the quantum advantage applied to large problems can only be projected from studies in the current reduced size of the quantum computers, for those problems where,

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

quantum computers could already show their potential when tested in smaller cases.

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 system, 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).

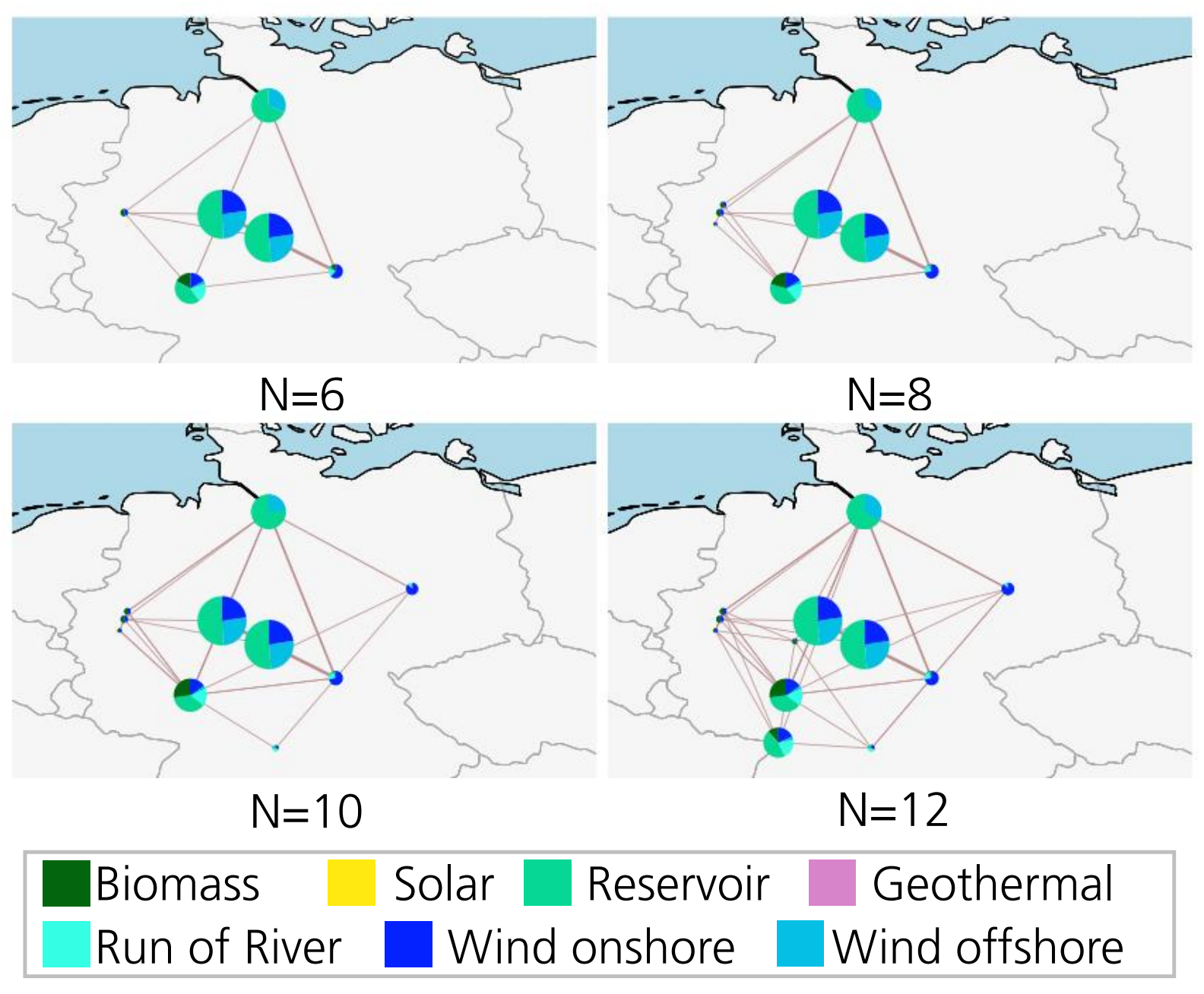
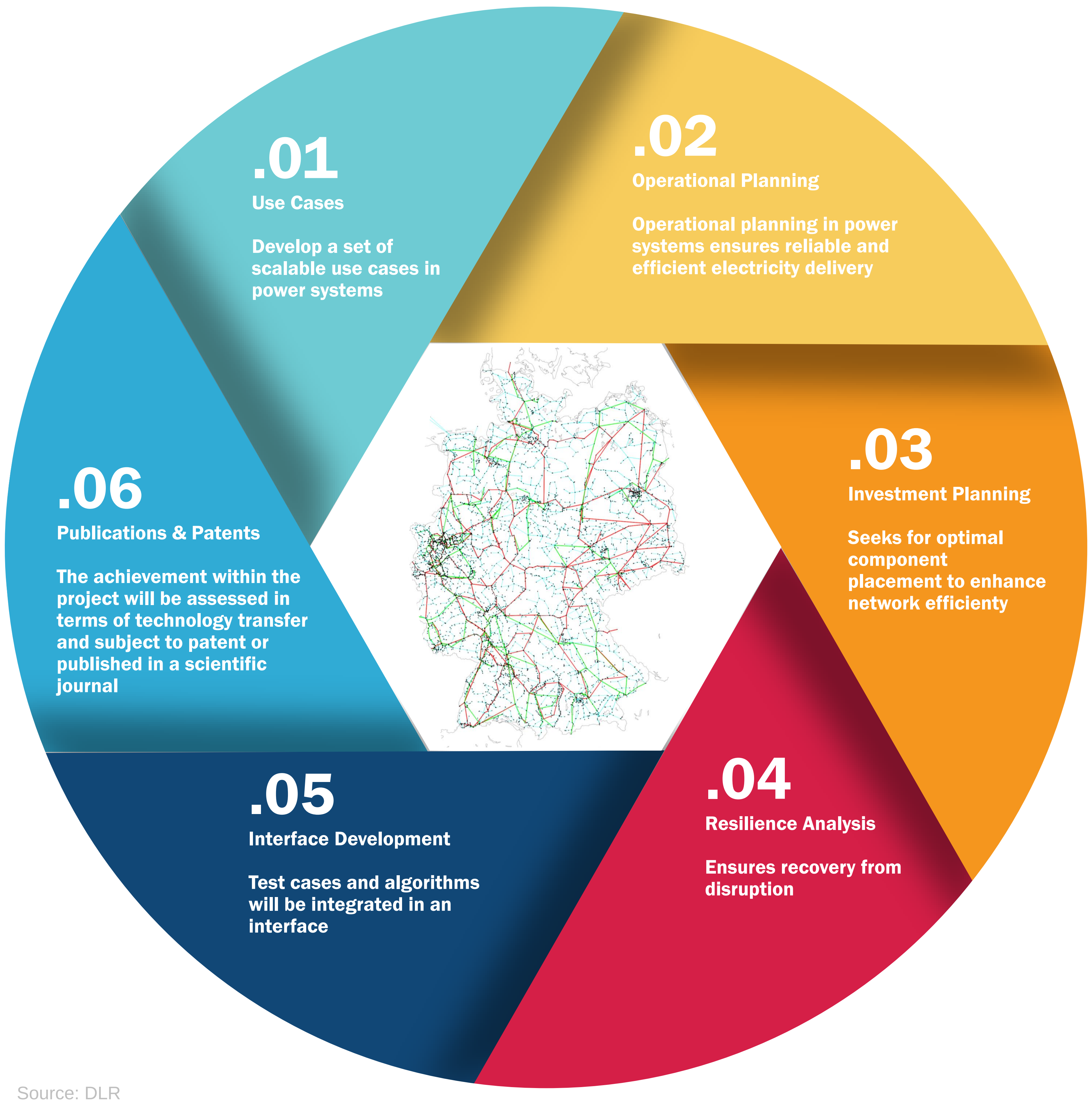


Figure 1: Scalable test-case family of networks by consecutive clustering of a larger network.



.01
Use Cases
Develop a set of scalable use cases in power systems

.02
Operational Planning
Operational planning in power systems ensures reliable and efficient electricity delivery

.03
Investment Planning
Seeks for optimal component placement to enhance network efficiency

.04
Resilience Analysis
Ensures recovery from disruption

.05
Interface Development
Test cases and algorithms will be integrated in an interface

.06
Publications & Patents
The achievement within the project will be assessed in terms of technology transfer and subject to patent or published in a scientific journal

Source: DLR

I. Operational planning

Operational planning of a power system involves coordinating the generation and distribution of energy to meet demand reliably and efficiently. This includes short-term scheduling of power plants, unit commitment decisions, 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. For instance, in traditional power plant scheduling, numerous power generators must be coordinated to meet energy demand within a specific timeframe. Modelling and solving this issue is challenging because some generators, such as thermal power plants, have specific start-up and shut-down times. Decisions must be made about whether or not to activate a generator for a certain duration to meet energy needs at the lowest possible cost.

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 big amount 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.

A Hybrid algorithm approach

Many ESM optimization problems can be formulated as MILP. The resolution of those problems can be often parallelized using a Benders' Decomposition (algorithm which divides the problem into a master problem, that keeps the integers variables, and a subproblem with the continuous variables. This decomposition reduces the complexity of the problem but at the price of an iterative solving process, since the master and subproblem are solved multiple times until a convergence criterion is satisfied. In order to take the maximum advantage of each technology, the master problem will be solved using a quantum computer by adapting the integer problem into a quadratic unconstrained binary optimization (QUBO) problem and the subproblem will be solved by a classical computer. Such approach has been already tested in a version of the investment planning problem (Figure 2), but it also has some drawbacks that need further investigation, such as:

- How does the heuristic behavior of the quantum solver affect the quality of the solution?
- What is the best strategy for mapping a problem that slightly changes in every iteration to real quantum hardware?

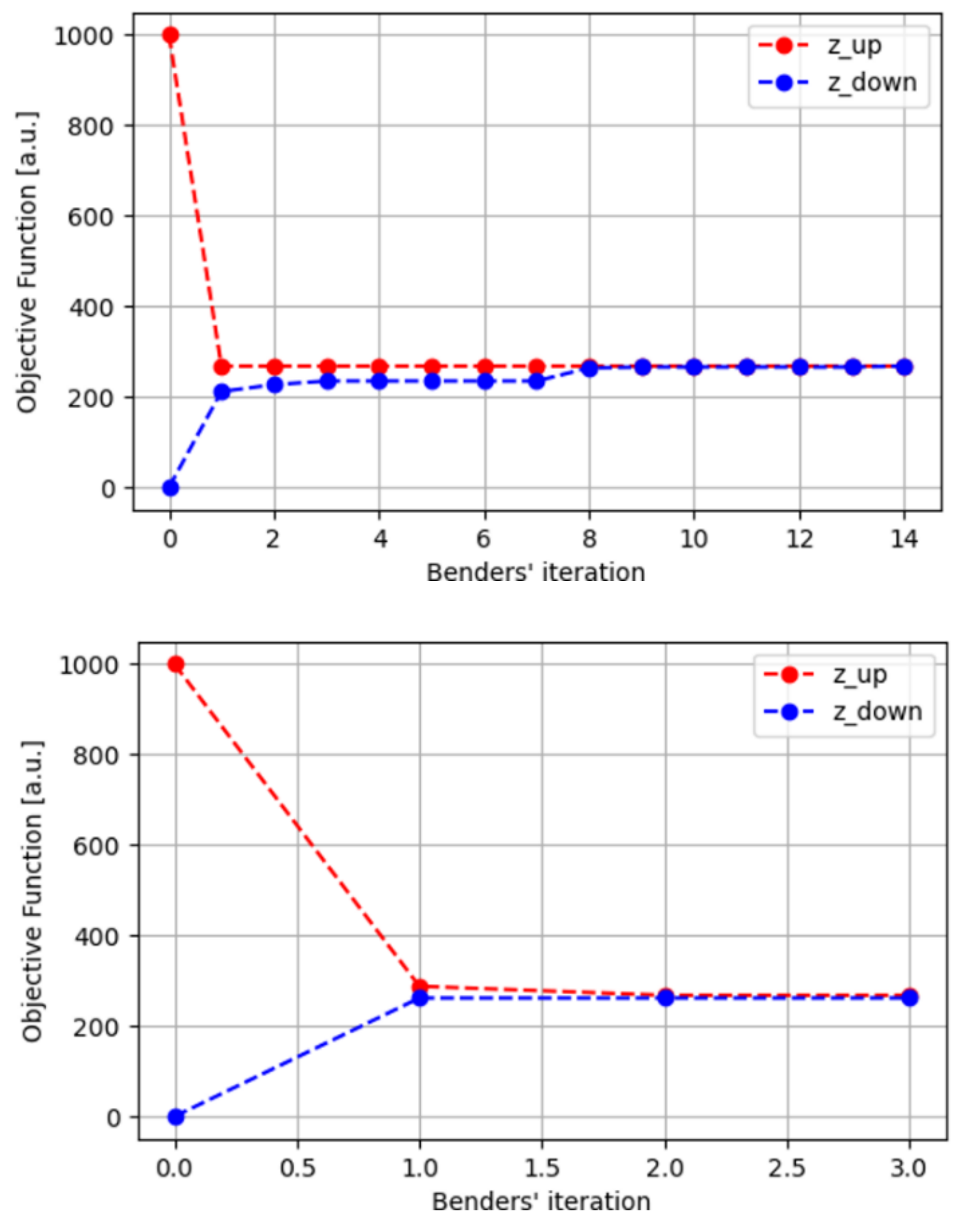


Figure 2: Comparison of a MILP problem solved with Benders Decomposition using a hybrid quantum-classical solver without a classical-check stopping criterion (**top**) versus with it (**bottom**).

More information about the project on our website

A project of

DLR
Institute of Networked Energy Systems

Contractor

To be decided

Contact

Oriol Raventós Morera
Julian Bartels
Karl-Kiên Cao

Get in touch.
We enable quantum!

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