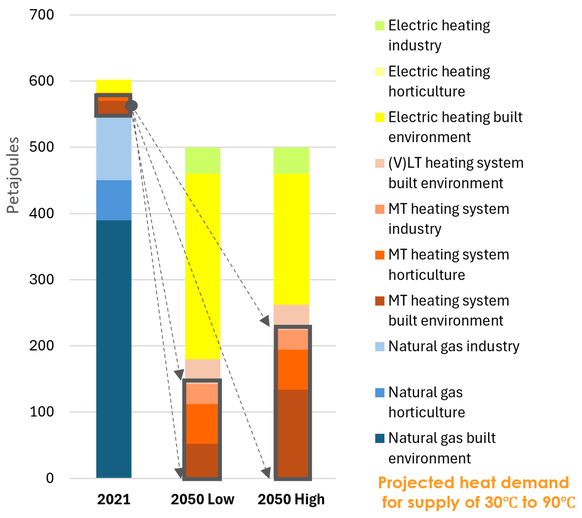
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Geothermal energy and the heat transition: An outline for roadmaps to unlock their potential and accelerate investments

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REDUCING IMPORTED GAS



Integral roadmaps for the development of sustainable collective heating systems based on active demand aggregation and supply by geothermal heat, waste heat, possible other sources, and heat storage could accelerate investments significantly in the Netherlands, as well as in Europe to the benefit of all.

Large-scale sustainable heat supply will still be necessary in 2050 due to persistent demand from homes, buildings, and greenhouses. Even after insulation improvements, total demand remains substantial, especially in cities and greenhouse areas.

Figure 1. Example of the projected final demand for 30-90° heat in the built environment and horticulture for a lower and higher scenario of mid-temperature (MT) collective heating systems in the Netherlands in 2050 (NL, 2023; TNO, 2018; ECN, TNO, 2020).

INDICATIVE ZONES FOR SUSTAINABLE HEATING SOLUTIONS

Different neighbourhoods require different sustainable heat solutions depending on building type, insulation level, and cost-effectiveness.



Figure 2. Example of the indicative zones of sustainable heating solutions in part of the Province of South Holland based on lowest national cost calculations (PBL, 20251).

TCOH & ACTIVE DEMAND AGGREGATION

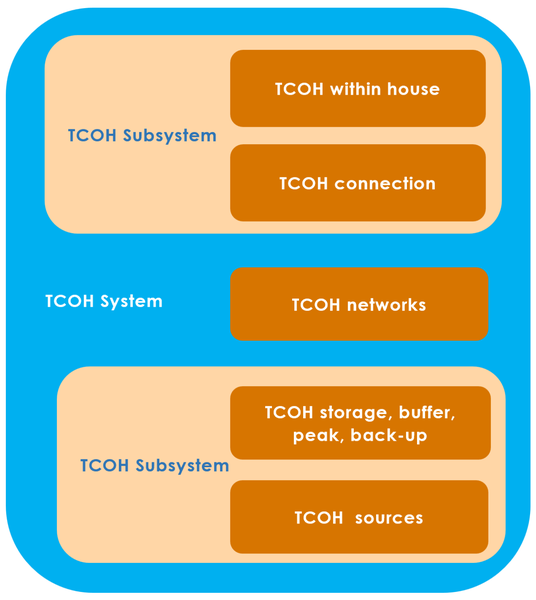


Figure 3. The concept of TCOH

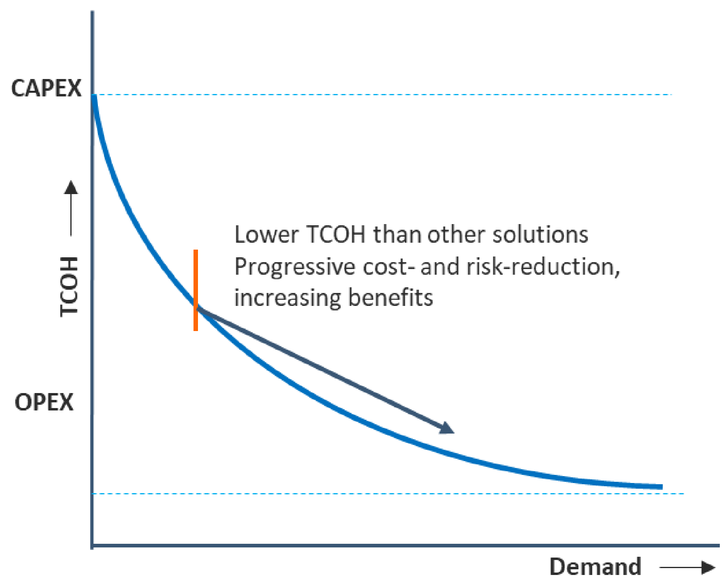


Figure 4. The value of active demand aggregation (I).

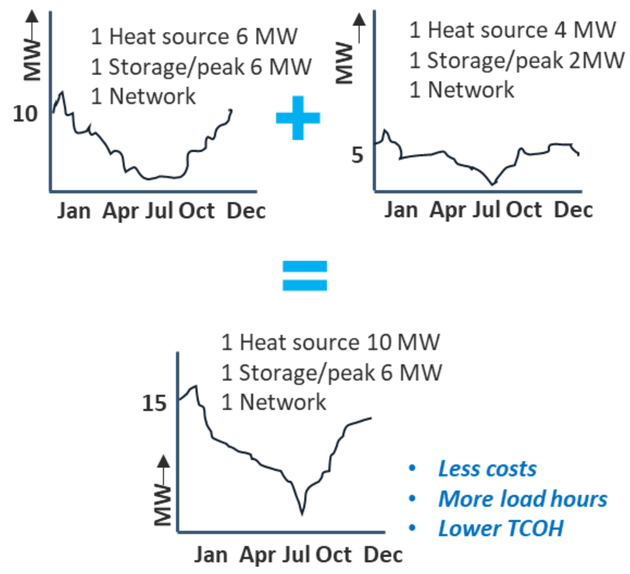


Figure 5. The value of active demand aggregation (II).

Active demand aggregation connects all economically viable heat users (both core and peripheral) to a collective heating system. Every additional unit of demand that pays more than marginal operating costs contributes directly to recovering the high upfront investments (CAPEX) required for geothermal wells, waste-heat sources, storage, and distribution networks. As more demand is connected, fixed costs are spread across a larger base, reducing the Total Cost of Heat (TCOH) for all users.

Once a critical demand threshold is reached, larger connected systems operate more efficiently, at lower average cost, and with greater security of supply. In short, expanding demand aggregation strengthens the business case for sustainable collective heating by driving down costs, improving resilience, and accelerating investment.

INTEGRAL PROGRAMMING

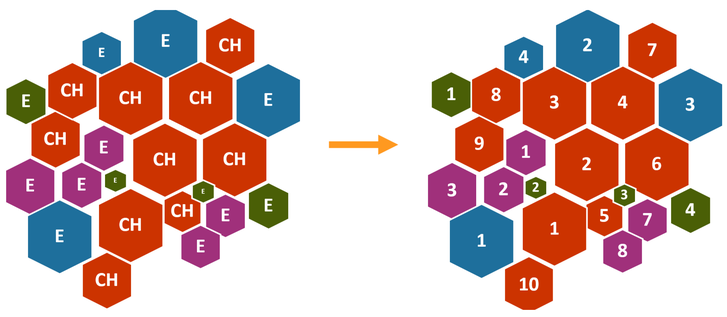


Figure 6. Identifying heating zones for S1, S2, S3 and S4, and their sequence to develop. CH = Central Heating. E = Electrification

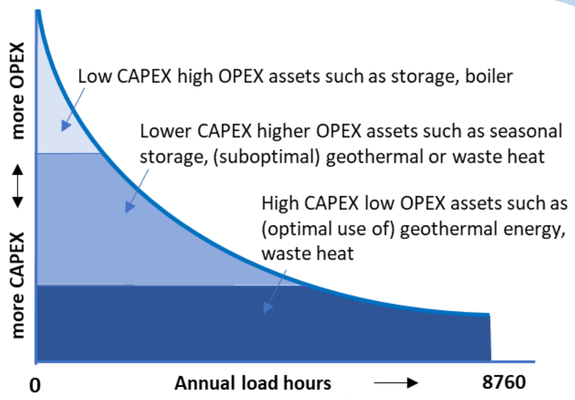


Figure 7. Load duration curve (LDC) and appropriate assets in collective heating systems based on load hours, and their relative CAPEX and OPEX levels.

Strategic phasing of neighbourhoods greatly improves cost-efficiency and speeds up implementation of sustainable heating systems. Figure 6 shows a schematic how municipalities can divide their territory into S1–S4 zones and create a logical sequence for their development to optimise investment timing, demand growth, and heat source deployment, and manage expectations of the supply chain and citizens alike. As can be seen in Figure 7 different heat production assets (geothermal baseload, midload sources, peak sources, seasonal storage) match the aggregated demand profile across the year. Storage is shown as a key component for peak shaving and security of supply.

ITERATIVE ADAPTIVE PROGRAMMING PROCESS

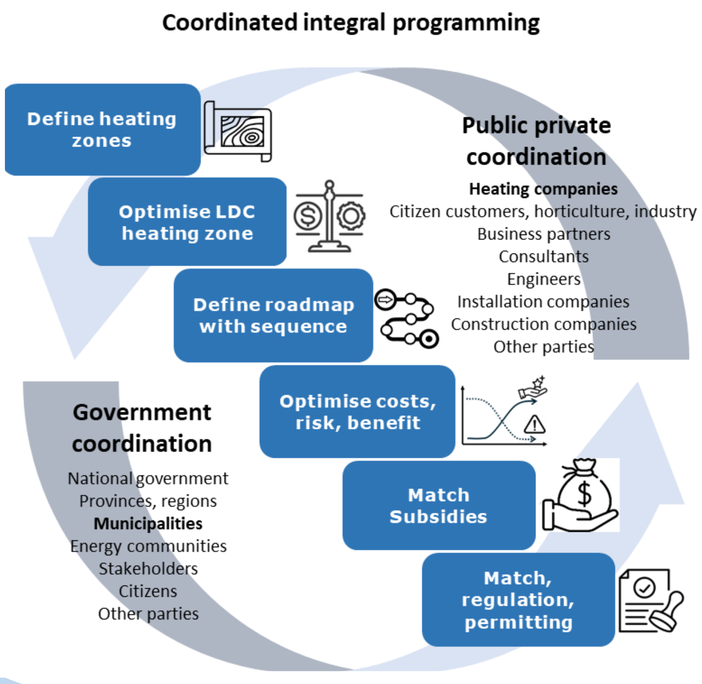


Figure 8. Iterative adaptive portfolio process of integral programming in roadmaps.

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