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Geothermal for Resilient Cities: Managing Dual-Demand in Urban CHP Infrastructure

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INTRODUCTION

Cities play a central role in the energy transition. As urban populations grow and governments pursue rapid decarbonization, electricity and heat systems, once planned and regulated separately, are increasingly interdependent. In cold climates, this coupling presents a dual challenge: both electricity and heat demand peak during extreme weather events, often when renewable generation is constrained. Electrification of heating and transport further amplifies these simultaneous peaks, demanding energy systems that can sustain reliability without fossil backup.

Geothermal combined-heat-and-power (CHP) plants offer a unique approach to this dilemma. By producing both electricity and district heat from the same geothermal source, they enable high overall efficiency and integrated resource use. Yet this integration also introduces operational trade-offs: steam allocated to heat exchangers cannot drive turbines, and increasing heat output inevitably reduces power generation. Balancing these competing demands both a technical task, and it reflects how societies value comfort, security, and economic efficiency when energy becomes scarce.

This presentation examines these dynamics through a case study from Iceland. ON Power operates two high-enthalpy geothermal CHP plants that supply electricity to the national grid and hot water for district heating in the Reykjavík metropolitan area (hereinafter referred to as Reykjavík). Reykjavík is one of the few urban regions worldwide powered entirely by renewables. Unlike most cities, Iceland has no fossil fuel to rely on in day- to-day operations: no gas turbines, coal plants, or oil-fired heating to stabilize the system under stress. This makes Reykjavík a full-scale demonstration of how a city functions solely on renewable energy, even during severe winter conditions.

In December 2022, a prolonged cold spell provided a rare, real-world stress test of this fully renewable configuration. Both electricity and heat demand surged, forcing ON to reallocate production capacity in real time between two essential services. The analysis presented here shows how geothermal CHP enabled the city to maintain stability without fossil support, and how this experience reveals the broader challenge now facing all decarbonizing cities: when both electricity and heat depend on renewables, resilience is no longer about adding capacity but about reallocating limited energy resources between essential needs in real time.

1 SYSTEM OVERVIEW

1.1 ON Power's Geothermal CHP Plants

ON Power operates two high-enthalpy geothermal CHP plants on the Hengill volcanic system:

- Hellisheiði Power Plant: Seven turbines, 303 MWe capacity
- Nesjavellir Power Plant: Four turbines, 120 MWe capacity

Together, they supply both electricity to the national grid and district-heating water to the capital region. The combined output reaches roughly 55 million tonnes of hot water per year, equivalent to 2.600 L/s, saving approximately 3,1 TWh of electricity that would otherwise be required for electric heating. This saving corresponds to the entire annual electricity consumption of Icelandic households, underlining the system's national importance.

Iceland's geothermal infrastructure was built not from environmental idealism, but from necessity. The oil-price shocks of 1973-74 (and again in 1979) triggered a decisive policy shift in Iceland, prompting the government to prioritise geothermal heating and reduce oil imports see Melsted (2021) and Orkustofnun (2024). This pragmatic

decision created the foundation for Reykjavík's district-heating network; and, decades later, a uniquely resilient urban energy system.

1.2 Integration with District Heating

Reykjavík's district-heating network is supplied exclusively by geothermal water at 80-85 °C. The geothermal CHP configuration enables cascaded utilization:

- Dry steam → electricity generation
- Residual steam + brine → heat exchangers for district heating
- Further cooled fluids → re-injection

The system therefore achieves very high overall thermal efficiency and minimal carbon footprint. The availability of abundant, low-cost geothermal heat has shaped urban life in Reykjavík, enabling dense district heating, year-round hot-water supply, and public amenities such as swimming pools. These features show how the geothermal system has become part of daily life in Reykjavík.

2 OPERATIONAL DYNAMICS OF GEOTHERMAL CHP

While geothermal CHP is efficient, it introduces interdependence between electricity and heat outputs. Key operational characteristics include:

- Baseload generation profile: Geothermal plants maintain high utilization factors but limited ramping ability compared with hydropower or gas turbines.
- Thermal-electric coupling: Increasing heat output typically diverts steam from turbines, reducing electricity generation.
- Reservoir evolution: Over time, wells tend to produce wetter steam, gradually shifting the energy balance toward heat production.
- Legal and social priorities: Under Icelandic regulations, hot-water delivery has legal precedence over electricity sales, reflecting heating's role as an essential public service.

3 CASE STUDY: THE DECEMBER 2022 COLD SPELL

3.1 Background

In late November 2022, temperatures across southwest Iceland dropped sharply, freezing local lakes and driving record heating demand. Despite the geothermal system's robustness, both electric and thermal loads increased concurrently—a rare stress test for the integrated system.

3.2 Observations

In order to demonstrate the story we show in Figure 1 examples of typical electricity consumption (green) and ON Power's electricity production (orange) during the initial days of the event. Consumer demand exhibits strong regularity, with evening peaks and night-time bottom. The CHP plants operated near baseload with the dip reflecting scheduled maintenance.

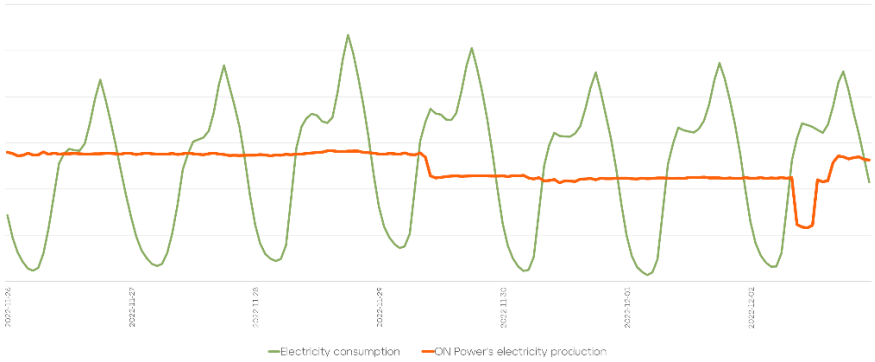


Figure 1: Typical electricity consumption (green) and ON Power's electricity production (orange) during the initial days of December 2022 cold spell.

As cold conditions persisted, ON progressively reduced power output to maximize hot-water supply (Figure 2). The decision process was guided by:

- Social responsibility to ensure sufficient heat to households and critical facilities.
- Legal obligation to maintain heating service to households and critical facilities.
- Market coordination, as ON must purchase additional electricity when its generation falls below contractual sales.

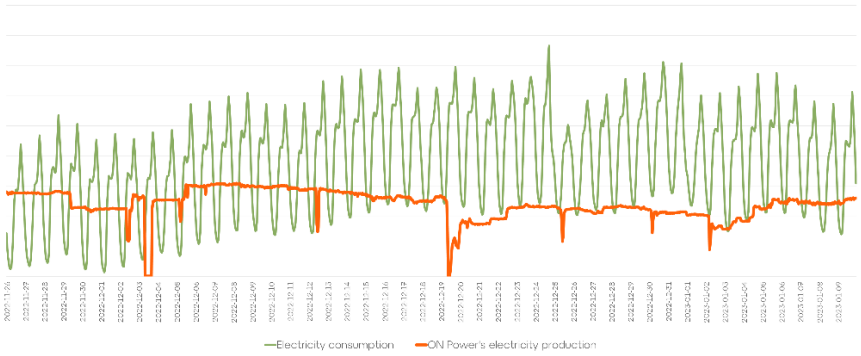


Figure 2: Extended period graph showing ramp down of electricity production and recovery.

3.3 Consequences

The shift from balanced sales and purchases to net buying status underscored geothermal CHP's dual nature: it provides system stability under normal conditions but absorbs flexibility from elsewhere during extreme cold. Iceland's hydropower system, absorbed this burden.

A separate incident further stressed the system: a temporary malfunction at one of the hot-water pumping stations, forced temporary curtailment of non-critical users such as swimming pools. Despite these challenges, no residential heating outages occurred, confirming geothermal CHP's role as a resilience backbone for urban Iceland.

4 DISCUSSION

4.1 Heat-Led Flexibility

Iceland's experience reflects a pragmatic approach: a system built on local resources, shaped by decades of operation, and trusted by the public because it consistently delivers.

Traditional power markets define flexibility in electrical terms, ramping generation or adjusting demand. The flexibility potential of CHP systems has been explored in the literature, particularly in relation to their role in balancing electricity systems under variable demand and renewable fluctuations (Beiron et al., 2017).

In fully renewable systems, however, flexibility must also be social e.g., the capacity to prioritize vital heat supply over market efficiency during extreme events.

Geothermal CHP embodies this form of *heat-led flexibility*, where operational choices are guided by social necessity rather than price signals.

In Iceland, where no gas, coal, or oil reserves are maintained for backup, this principle is not theoretical, it is operational reality. The 2022 cold spell revealed how geothermal CHP transforms resilience from a planning concept into a lived practice: operators must reallocate limited renewable resources between essential needs in real time. This experience highlights that energy security in a fossil-free context is also dependent on system design that allows essential services to take precedence when stress arises.

Recognizing and valuing this *thermal dimension of resilience* is essential for regions developing district-heating or hybrid renewable systems. As cities electrify, they will increasingly face similar dual-demand stresses, where both electricity and heat peak simultaneously and where fossil fallback can no longer smooth the curve.

4.2 Comparative Perspective

Many European cities are now expanding district-heating networks using geothermal, biomass, or heat pumps, yet nearly all retain gas or other fossil reserves for backup. Reykjavík stands apart as one of the only urban regions worldwide operating without such fossil contingency, relying solely on geothermal and hydropower to maintain year-round supply.

As electrified heating spreads across Europe and Asia, the Icelandic model shows how power and heat systems can converge, and how governance may need to adapt to manage that coupling. Dual-demand management extends the concept of sector coupling by operationalizing it under real stress conditions: it shows how heat and power coordination can preserve societal resilience when fossil support is absent.

From a policy perspective, the case suggests that as systems move beyond fossil backup, market mechanisms alone cannot guarantee resilience under stress. They must be complemented by institutional frameworks that recognize heat security as a public necessity, and by capacity metrics that account for the role of thermal flexibility. In other words, heat security should be measured and valued as carefully as electricity reliability in planning and market design

The Icelandic experience therefore offers three lessons for urban planners and system operators:

- Integrated planning: Electric and heat networks must be co-optimized.
- Market design: Capacity and ancillary-service markets should account for CHP's dual role.
- Resilience metrics: Heat supply should be treated as a critical reliability metric—measured and valued alongside electricity reliability indices.

5 CONCLUSIONS

Geothermal CHP systems, as exemplified by ON Power's Hellisheiði and Nesjavellir plants, illustrate how renewable infrastructure can simultaneously deliver efficiency and adaptability. They also reveal a deeper lesson: in fossil-free systems, resilience can come from the capacity to repurpose renewable energy flows between essential needs.

During the December 2022 cold spell, ON prioritized heat supply, meeting legal and social obligations, while maintaining electrical stability through market balancing. The case shows that energy resilience is not only about maintaining generation capacity, but about designing systems capable of reallocating resources in real time to meet essential needs.

Iceland's experience offers a rare glimpse into the operational realities of a fully renewable system, where resilience must be engineered from within, not borrowed from fossil reserves. As climate variability increases and electrification expands, dual-demand management will become a defining test of post-fossil resilience.

The strength of Reykjavík's geothermal CHP network lies not only in its physical assets, but in its institutional coherence: clear priorities, cross-sector coordination, and public trust. For cities worldwide, achieving similar resilience will require alignment between heat and power planning, operational priorities and public welfare.

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