Flexible solutions to advance low-carbon district heating & power generation

Case studies on commercial and regulatory insights

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Disclaimer

Our mandate and the applied methodology

- This study was commissioned by Wärtsilä Development & Financial Services Oy (“Wärtsilä”).
- The aim of the study was to:
  - showcase ways to decarbonise fossil (particularly coal) based district heating systems in a commercially viable way and the role flexible generation technologies (particularly gas-engines) could play in this transition;
  - identify roadblocks to decarbonisation in the fields of market structure, regulation, capabilities and market trends.
- The study establishes the stack of revenues available for internal combustion engine combined heat and power installations – ICE-CHPs):
  - heat sale revenues,
  - electricity wholesale market revenues (incl. longer-term flexibility),
  - provision of ancillary services (aFRR/mFRR),
  - revenue from capacity remuneration mechanisms (CRMs),
  - congestion management revenues, and
  - subsidies.
- For each of the identified revenue streams the study analyses
  - the relevant regulatory framework on a European level, and
  - future trends (hurdles or drivers) relevant for ICE-CHPs capturing the relevant revenues (e.g. competitive environment, technological criteria).
- The study also includes country case studies inter alia for Poland, Hungary, Estonia, and Denmark providing insights on national regulatory and market environments.
- The results are complemented with insights from interviews with district heating operators, ICE-CHP operators, and associations inter alia in Poland, Hungary, Estonia and Denmark
- Specific aspects regarding the heat and power generation of ICE-CHPs are moreover illustrated using operational data from DH operators and Wärtsilä’s in-house modelling (where referenced).

Contents

Note: An extended version of this study is available from Wärtsilä

1.

Executive Summary

Executive Summary: Context (1/2)

Both the EU's district heating and power sectors still use significant share of coal and other fossil fuels. Political targets and sector measures aim for decarbonisation – putting particular pressure on the DH sector.

Context 1: The European district heating sector and its decarbonisation transition and challenges

- Already today, district heating (DH) plays a relevant role in providing on average c.11% of comfort heating in Europe in 2022.
  - The importance of district heating, however, varies significantly across Europe – with Sweden and Denmark reaching 50+% of comfort heating demand met by district heating in 2022.
  - In 2022 comfort heating made-up 22% of the EU's final energy demand.
- In a majority of European countries, DH is still largely fossil based – coal or lignite still plays an important role (>10% share in heat generation in 10 countries)
- Public data suggests that there are several hundred district heating systems in Europe that still rely on coal in their heat generation mix.
- EU-level policies drive district heating decarbonisation – the EU emission trading system (ETS) and the Energy Efficiency Directive (EED) with its specification of "efficient district heating" currently exert the most pressure.
- While there is no EU-level target for the growth of district heating, several national governments have projected or set targets for the growth of district heating over the next years.

Context 2: European power sector and its decarbonisation transition and challenges

- Despite decreasing usage, hard coal and lignite are still widely used for power generation, in 2022 accounting for 18% in the EU and the six West Balkans.
- Electricity and heat generation from coal in 2022 accounted for c. 12% of total EU emissions and c. 58% of EU emissions in electricity and heat generation.
- The EU has set ambitious decarbonisation goals for which the power sector plays an important role.
- Despite decreasing coal emissions after 2012, more than half of the emissions in the transformation sector (heat, gas, electricity) still stem from coal-firing.
- Of those countries still using significant shares of coal-fired generation, several have established the policy goal to increase gas-fired capacities – overall these countries plan for 18.5 GW additional capacity by 2030.

Source: Compass Lexecon analysis

Executive Summary: Context (2/2)

Among the thermal generation options investigated, gas engines provide the highest flexibility for producing heat and power; even when running on natural gas ICE-CHPs produce significantly lower emissions than best in class coal-fired generation.

Context 3: Gas engines, their ability and their revenue generation opportunities

- Among the thermal generation options investigated (gas engines and various set-ups of gas turbines), gas engines tend to be the most flexible and modular technology
- Already running on natural gas ICE-CHPs produce significantly lower emissions than even best in class coal fired CHPs; by (partly) substituting for biomethane (or biogas) emissions can be further reduced.
- Gas-engine CHPs can tap into various markets to generate revenues ("revenue stacking") – key revenues sources are:
  - Heat sale revenues
  - Electricity wholesale market revenues (incl. the monetisation of longer-term flexibility)
  - Ancillary services – incl. mFRR ("tertiary reserve") and aFRR ("secondary reserve")
  - Revenue from CRMs (Capacity Remuneration Mechanisms)
  - Congestion management revenues
  - Subsidies

Abbreviation: CHP … combined heat and power, mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve.
Source: Compass Lexecon analysis

Executive Summary: Potential applications and case studies (1/4)

ICE-CHPs can complement electrified generation portfolios allowing for dynamic reaction to power prices; even when running on natural gas they support keeping the efficient district heating designation at least until 2034 and by blending-in decarbonised gases also until 2044 (no or partial blending) and beyond.

The role of gas engines in district heat production

- ICE-CHPs compete with various other low-/no-carbon technologies – but technologies can also complement each other (as will be shown in case studies) – moreover, most low-/no-carbon heat generation technologies face some sort of limitations (e.g. in terms of usable potentials or achievable temperature levels)
- The complementarity of technologies is illustrated by two case studies:
  - **Case Study**: In Skagen (Denmark) a portfolio comprising heat-pumps, electrical boilers and ICE-CHPs allows to produce heat also during high power prices. Conversely, electrical heat sources can be used during periods of low power prices.
  - **Case Study**: For the system in Grudziądz (Poland) Wärtsilä's modelling illustrates how a currently static, coal-dominated system could be transformed into a flexible portfolio of generation assets.
- ICE-CHPs running on natural gas are within the EED-emission-limits for efficient DH until at least 2034 – beyond 2034 compliance depends on the allocation methodology – blending-in renewable gases may be required.

Abbreviation: RES … renewable energy sources, CHP … combined heat and power, ICE … internal combustion engine.
Source: Compass Lexecon analysis

Executive Summary: Potential applications and case studies (2/4)

Beyond the heating market Gas engines can access multiple other revenue streams in the power market.

The role of gas engines on wholesale electricity markets and the provision of longer-term flexibility

- **Case Study**: Deployment of solar and wind capacities drives the need for power sector flexibility across all time-scales – this is illustrated by the projected developments in the Czech Republic, Romania, Poland. Finland, Germany and Spain
- **Case Study**: As showcased for Finland, increased renewable generation will change the structure of wholesale power market prices – thereby changing revenues capturable by technologies providing long-term flexibility
- In providing longer-term flexibility ICE-CHPs compete against other types of generation assets, but they are often limited by their potentials (e.g. hydropower), or by acceptability (e.g. nuclear).
- **Case Study**: For Skagen (Denmark) CHP's ability to provide intraday and longer-term flexibility is illustrated by the operation of existing gas-engine CHPs in a country with an already high RES-penetration

The role of gas engines on ancillary services markets

- Balancing services markets remunerate market participants for reacting quickly to TSO signals in order to ensure system stability.
- The need for aFRR is driven by unplanned outages and small frequency variations
- The need for mFRR is driven mostly by outages of large generation or interconnection assets; for mFRR ICE-CHPs compete currently against hydropower and other thermal assets
- **Case Study**: The ability to generate synergies from the co-location of gas engines and batteries is illustrated on the Hungarian ancillary services market, where gas engines and batteries sometimes even share the grid connection and batteries are charged independent of grid electricity directly from the gas engine's production.

Abbreviation: RES … renewable energy sources, CHP … combined heat and power, TSO… transmission system operator, mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, ICE … internal combustion engine.
Source: Compass Lexecon analysis

Executive Summary: Potential applications and case studies (3/4)

Beyond the heating market gas engines can access multiple other revenue streams in the power market.

The role of gas engines on capacity remuneration mechanisms

- Capacity remuneration mechanisms (CRMs) are established in many European countries to ensure security of supply amid increasing intermittent generation.
- **Case study**: Coal and gas plants play still a significant role in the polish CM although a wider variety of technologies is contracted under the Polish CRM.
- **Case Study**: The German Power Plant Strategy aims at securing electricity supply in light of increasing RES shares and aimed coal exist. In foresees several GW of new gas fired generation.

The role of gas engines in grid congestion management

- Congestion cost could increase significantly, due to the need for decarbonisation and uncertainty around network reinforcement.
- There are three different type of management congestion value, on both side of the network bottleneck: Energy redispatching, reserve and countertrading. Gas engines can be remunerated for all these services, if they are located behind grid bottlenecks and upward activation is needed.

Abbreviation: CHP … combined heat and power.
Source: Compass Lexecon analysis

Executive Summary: Potential applications and case studies (4/4)

Gas engine CHPs can access support schemes if they are efficient enough, including investment support, subsidies and exemptions

Gas engines and subsidies

- Support schemes for CHPs in Europe can take various forms – the availability usually differentiates between fuels and installation sizes.
- **Case Study**: The Czech CHP subsidy regime is a case study for a scheme that is also open for natural gas fired high-efficient co-generation
- In line with the EU Taxonomy efficient natural gas-fired CHPs can contribute to mitigate climate change by a) replacing coal and other fossil fuel generation or b) having very low lifecycle $CO2_{eq}$ emissions.
- ICE-CHPs running on natural gas are within regulatory emission limits of the EU Taxonomy.

Abbreviation: CHP … combined heat and power plant, ICE … internal combustion engine.
Source: Compass Lexecon analysis

2.

Introduction to the European district heating sector

Key conclusions: Introduction to the European district heating sector

The EU district heating sector still uses significant share of coal and other fossil fuels. Political targets and sector measures aim for decarbonisation – putting particular pressure on the district heating sector.

- Already today, district heating (DH) plays a relevant role in providing on average c.11% of comfort heating in Europe in 2022.
  - The importance of district heating, however, varies significantly across Europe – with Sweden and Denmark reaching 50+% of comfort heating demand met by district heating in 2022.
  - In 2022 comfort heating made-up 22% of the EU's final energy demand.
- In a majority of European countries, DH is still largely fossil based – coal or lignite still plays an important role (>10% share in heat generation in 10 countries).
- Public data suggests that there are several hundred district heating systems in Europe that still rely on coal in their heat generation mix.
- EU-level policies drive district heating decarbonisation – the EU emission trading system (ETS) and the Energy Efficiency Directive (EED) with its specification of "efficient district heating" currently exert the most pressure.
- While there is no EU-level target for the growth of district heating, several national governments have projected or set targets for the growth of district heating over the next years.

Source: Compass Lexecon analysis

The role of district heating in European heating supply

Already today, district heating plays a relevant role in providing comfort heating in Europe. Its importance, however, varies significantly across Europe.

In 2021, a significant share of household comfort heat demand in the EU is covered by district heating.

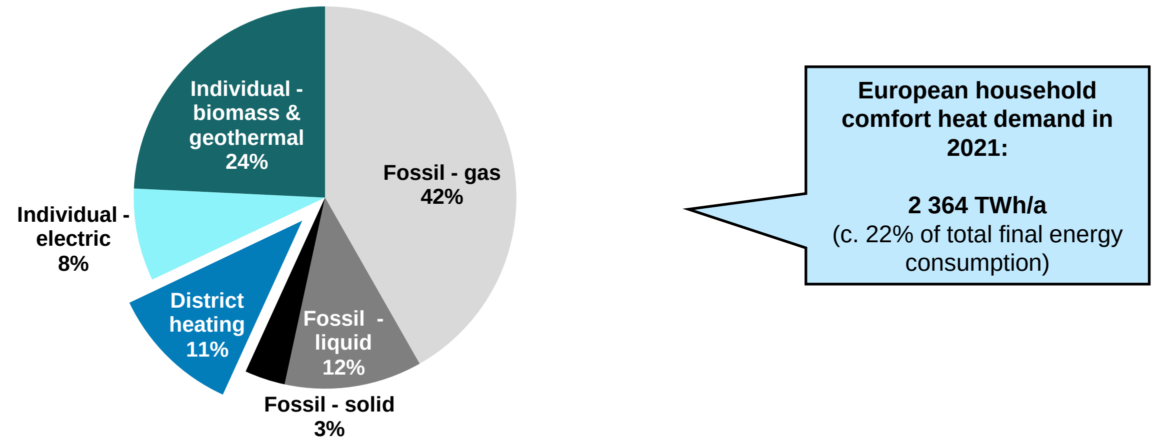
- The majority (more than 50% of household comfort heat demand) is supplied by **individual, fossil installations**
- District heating represents one of the options to **reduce emission intensity** in the European heating sector.
- Currently the share of **emissions in comfort heat** in overall emissions in the EU is 8%.

In 2022, Nordic countries were the most developed countries in terms of district heating's share in total national heat demand.

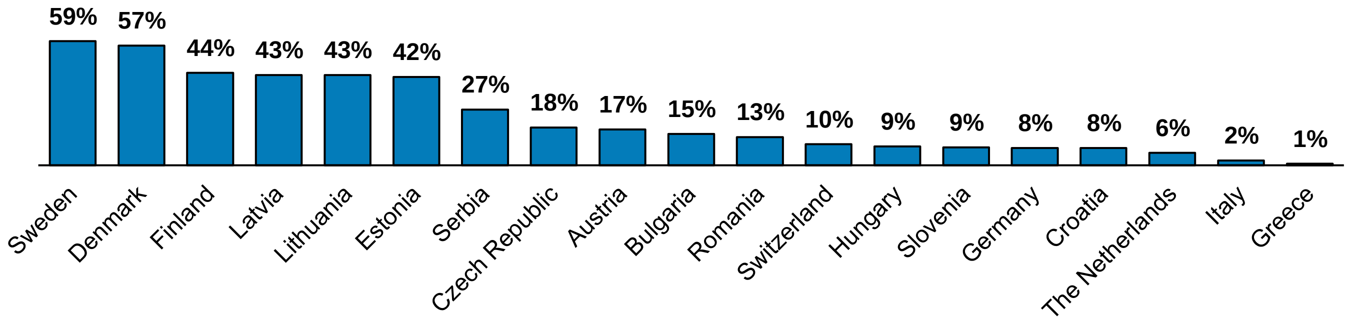
- There is large heterogeneity in the role of district heating in heat supply. National shares of connected households to district heating range between 0%[1] and almost 50%.
- Well-developed district heating sectors are located predominantly in Northern and Eastern European countries. District heating is negligible in some Southern European countries.

In 2018 the total district heating supply in the EU amounted to 513 TWh, which is equal to a 5% share of district heating in final EU energy demand.

Role of district heating in meeting households' comfort heat demand in the EU in 2021 [% household comfort heat demand]



Share of district heating in national heat demand [%]



Note:[1] There is no district heating in Spain, Ireland, Luxemburg, Cyprus and Malta; no data available for Poland
Source: Compass Lexecon analysis based on JRC IDEES 2021 and Euro Heat and Power.

The role of fossil fuels and particularly coal in European district heating

In a majority of European countries, district heating (DH) is still largely fossil based – with coal or lignite playing an important role in a number of countries (>10% share in heat production in 11 countries).

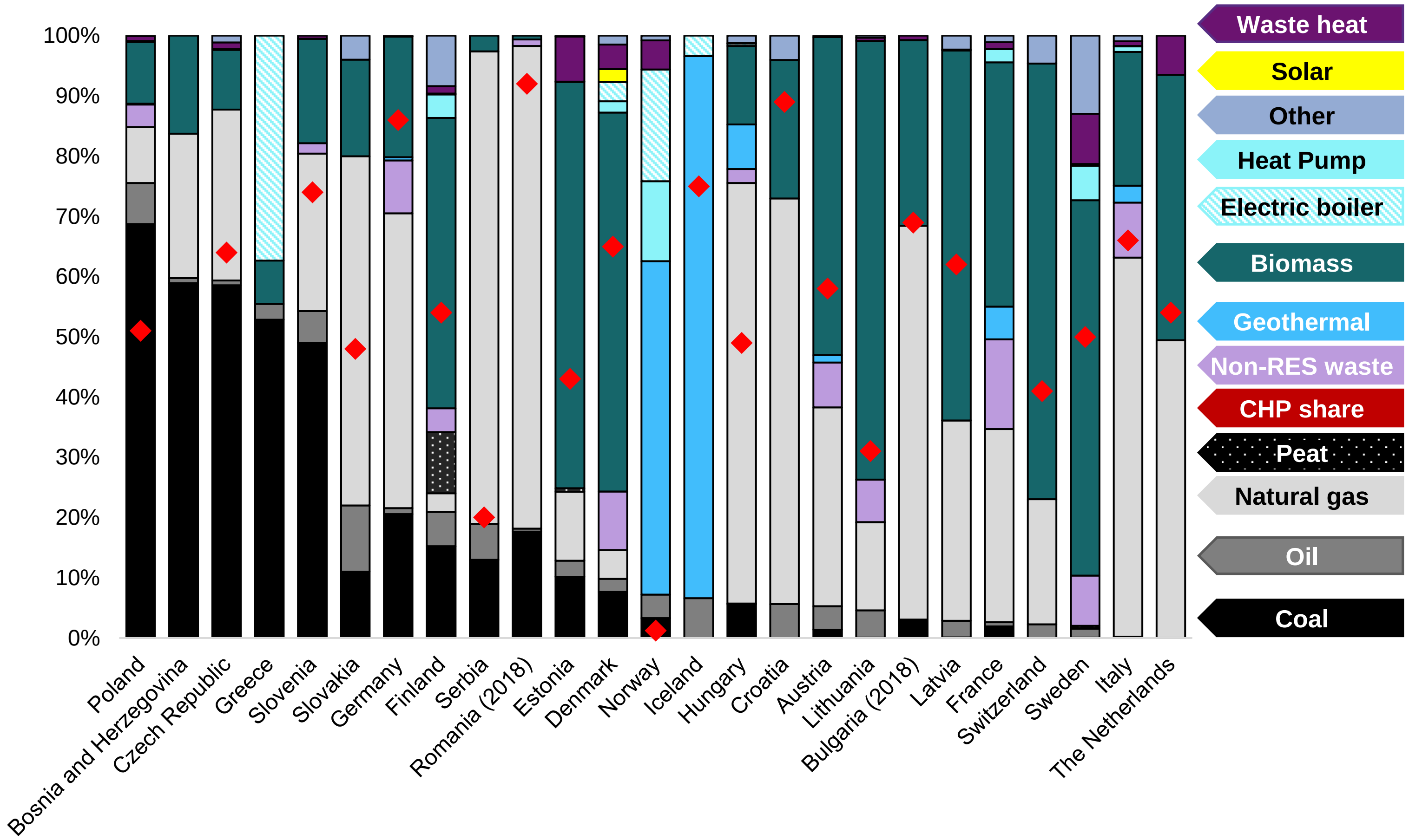
The level of decarbonisation of DH varies significantly among European markets

- In 2022, most European countries' district heating generation still relied predominantly on fossil fuels.
- Of the EU-27, coal-based district heat generation was most-relevant in 2022 (latest available data) in Poland, Czech Republic, Slovenia, Slovakia, Germany, Finland, Romania (2018 data) and Estonia.[2]
- With the exception of mainly some Nordic countries, the majority of countries produced a significant share of district heat from natural gas.
- Renewable generation (particularly biomass, heat pumps, geothermal heat) was common in Nordic and Western European countries.

Despite important differences in fuel mixes, cogeneration constitutes the majority of district heat generated in the EU

- All countries produced more than 30% of their district heat in cogeneration – in most countries the share was > 60%.

Fuel shares and cogeneration share in European district heating 2022 [%][1, 2]



Note: [1] Due to missing data, we report values from 2018 for Romania and Bulgaria. [2] Greek 2011 census revealed that only 0.49% of households use district heating (Balaras et al., 2016), moreover the largest Greek lignite plant (Koznani) supplies the neighbouring town (Panoutsou, 2008).
Abbreviations: RES … renewable energy source, CHP … combined heat and power plant
Source: Compass Lexecon analysis based Euro Heat and Power data.

Prevalence of coal in European district heating networks

In coal-reliant European countries, there are several hundred district heating systems that still employ coal in their heat generation mix.

	Poland	Czech Republic	Germany	Finland
Coal share of supplied heat	69 %	59 %	21%	15%
Total number of systems	407	637	4 088	400
Number of district heating systems using coal	c. **240 – 400**	c. **60 – 130**	at least **47**	at least **12**

Several hundred **DH systems** in Europe's most coal-reliant DH sectors still use coal for heat generation

Abbreviation: DH … district heating. Note: due to lacking data availability, we do not report numbers for other countries with significant coal shares in district heating (Bosnia and Herzegovina, Slovenia, Slovakia, Serbia, Estonia, Romania).
Source: Compass Lexecon Analysis based on Bundesnetzagentur – Kraftwerksliste, Czech Energy Regulatory Office, Finnish Energy.

Key EU-level regulatory drivers for district heating DH decarbonisation

EU-level policies drive DH decarbonisation with the ETS and the EPB exerting the most pressure.

ETS / ETS2 **EU Emission Trading System Directive** (last amended by Regulation EU/2024/795)	… leads to rising cost for carbon allowances thereby making fossil fuel usage increasingly expensive and potentially uncompetitive
EPB **Energy Performance of Buildings Directive** (Directive EU/2024/1275)	… permits the usage only of efficient district heating (see EED) in new buildings by 2026 and also in the wider building stock by 2050
EED **Energy Efficiency Directive** (Directive EU/2023/1791)	Specifies criteria for high-efficient cogeneration and efficient district heating
RED **Renewable Energy Directive** ("RED III") (amending Directive EU/2023/2413)	… allows end-users to disconnect from non-efficient DH systems … allows for third party access to non-efficient DH systems … sets indicative targets for district heating decarbonisation
Taxonomy **European sustainable investment Taxonomy** (EU/2020/852)	makes access to debt and subsidies increasingly difficult for non-taxonomy-compliant assets

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Abbreviation: DH … district heating.
Sources: Compass Lexecon analysis based on European Taxonomy, Renewable Energy Directive , Energy Efficiency Directive, CEEAG 2022, Energy Performance of Buildings Directive, European Emission Trading System and interviews with district heating operators and their associations

National targets for the growth of district heating

While there is no EU-level target for the growth of district heating, several national governments have projected or set targets for the growth of district heating over the next years.

National targets / projections ▼	Slovenia	Romania	Germany	Netherlands	Denmark
District heating energy supplied	decreasing	**+ 1.5 TWh/a (2020-2030)**	—	**+ 0.8 TWh/a (2021-2030)**	—
End-user growth	**“significant increase”**	—	**“significant expansion”**	**+ 500 000 new connections (2020 – 2030)**	**+ 120 000 to 200 000 new households (2022-2028)**

In several EU countries governments explicitly target significant growth of district heating

Source: *Compass Lexecon analysis based on NECP Poland, NECP Slovenia, NECP Germany, NECP Denmark, NECP Czech Republic, NECP Netherlands, NECP Romania Danish Agreement on Green Power and Heat (2022), Danish Energy Reform (2022)*

3.

Introduction to the European power sector

Key conclusions: Introduction to the European power sector

The EU power sector still use significant share of coal and other fossil fuels. Political targets and sector measures aim for decarbonisation.

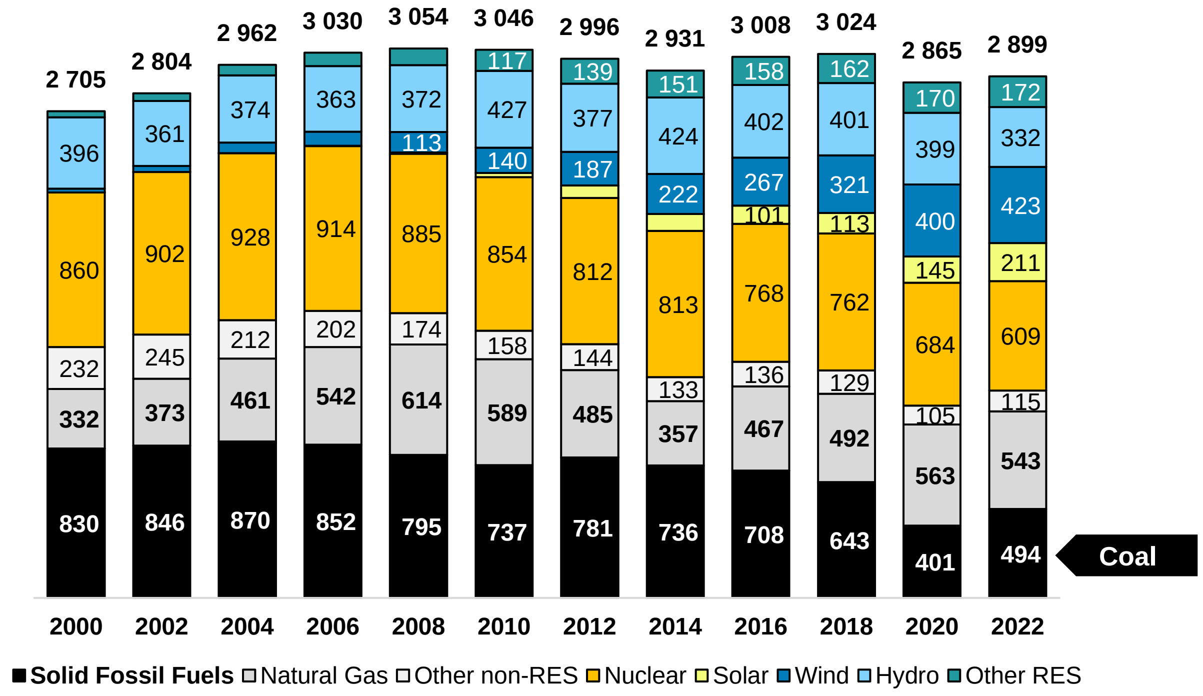
- Despite decreasing usage, hard coal and lignite are still widely used for power generation in Europe, accounting for 18% of power generation in the EU and the six West Balkan countries in 2022.
- Electricity and heat generation from coal in 2022 accounted for c. 12% of total EU emissions and c. 58% of EU emissions in electricity and heat generation.
- The EU has set ambitious decarbonisation goals for which the power sector plays an important role.
- Despite the decrease of emissions from coal starting after 2012, more than half of the emissions in the transformation sector (heat, gas, electricity) still stem from coal-firing.
- Of those countries still using significant shares of coal-fired generation, several have established the policy goal to increase gas-fired capacities – overall these countries plan for 18.5 GW additional capacity by 2030.

Source: Compass Lexecon analysis

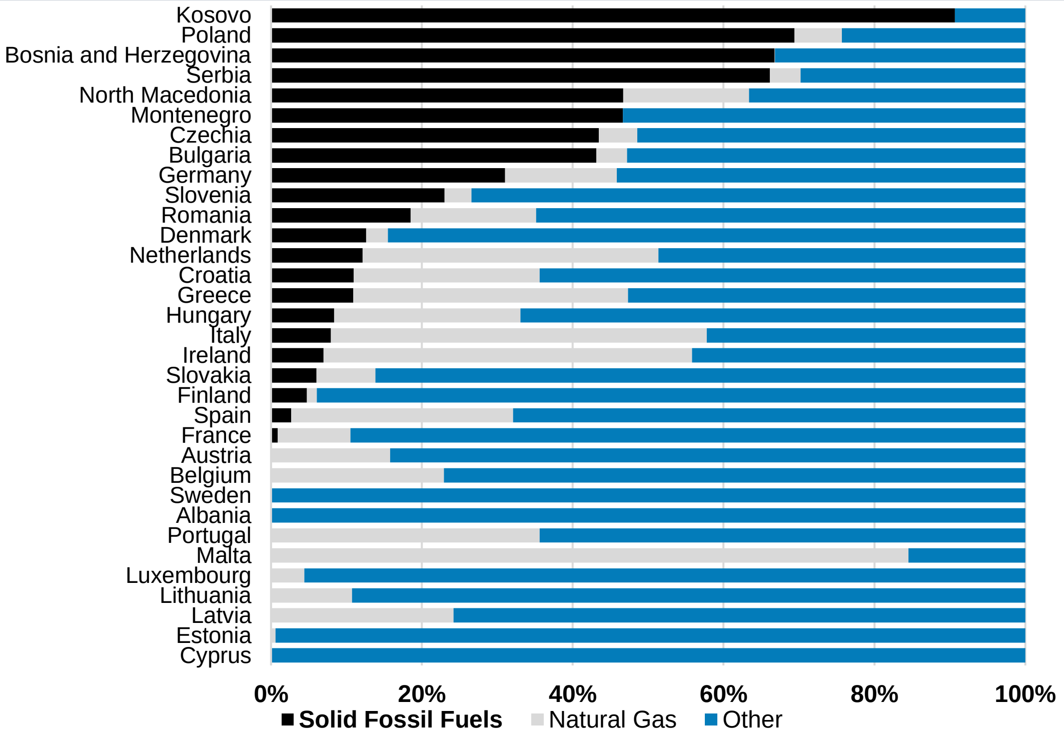
European power sector: Coal in the generation mix

Despite decreasing usage, hard coal and lignite are still widely used for power generation in Europe.

EU27 and West-Balkan 6 electricity generation mix 2000-22 [TWh]



Share of natural gas and solid fossil fuels in the EU27 and West-Balkan 6 countries electricity generation in 2022[1] [%]



The share of solid fossil fuels (i.e. coal) in European gross electricity generation **started decreasing in the early 2000s but still remains significant** up until today. Electricity generation from coal in 2022 accounted for **c. 12% of total EU emissions** and c. **58% of EU emissions in electricity and heat generation.**

Coal-fired power generation remains particularly common in **central and Eastern Europe.**

Notes: [1] 'Other' refers to all RES (solar, wind, hydro), nuclear and other non-RES energy sources.
Abbreviations: RES … renewable energy sources
Sources: Compass Lexecon analysis based on data from Eurostat

Evolving targets for the decarbonisation of the European power sector

The EU has set ambitious decarbonisation goals in which the power sector plays an important role.

CO_2	**EU Climate & Energy Package 20-20-20** (2008)	**Clean Energy Package** (Adopted in 2019)	**Fit-for-55** (published on 14 July 2021; further supplemented by an additional proposal as part of the **REPower EU Plan** – see next slide)
Overall GHG emission reduction target Not directly legally binding for EU member states	**- 20% by 2020** vs. 1990 levels	**- 40% by 2030** vs. 1990 levels	**- 55% by 2030** vs. 1990 levels

	RED I adopted on June 5, 2009 (repealed)	**RED II** adopted on Dec. 11, 2018 (in force)	**RED III** adopted on Oct. 9, 2023 (not yet implemented by EU member states)
Renewable Energy Share	**20% by 2020** of the final energy consumption	**32% by 2030** of the final energy consumption	**42.5% by 2030** of the final energy consumption

This is equivalent to an RES-E share of about 70%

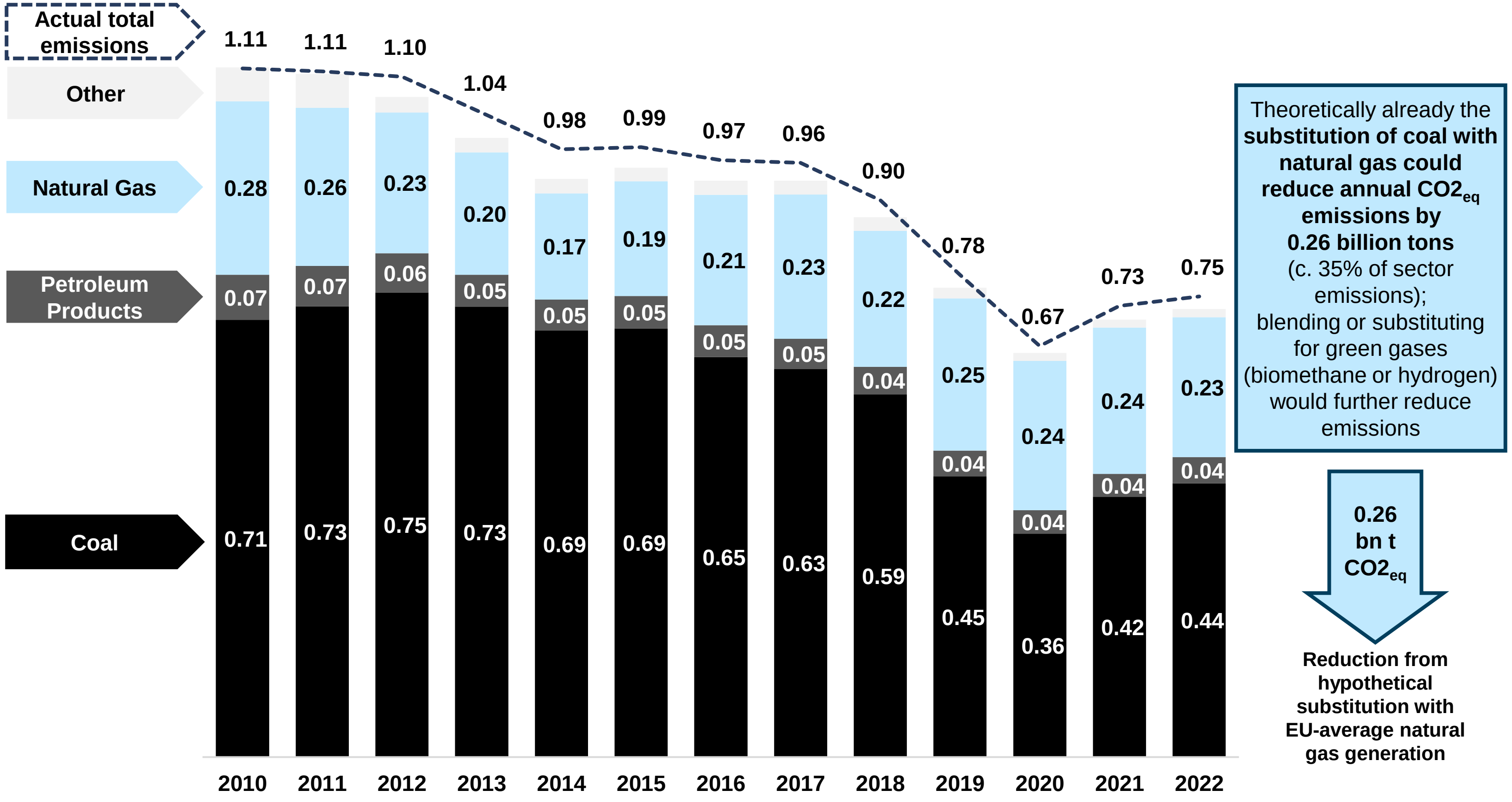
Abbreviation: GHG … greenhouse gas, RED … Renewable Energy Directive, MS … member state.
Source: CL analysis, RED I, RED II, RED III, EED, EC (2022) RED - non-paper on complementary economic modelling

Role of coal in the $CO2_{eq}$ emissions from electricity and heat generation

Despite the decrease of emissions from coal starting after 2012, more than half of the emissions in the transformation sector (heat, gas, electricity) still stem from coal-firing.

- Total emissions in the transformation sector (heat, gas, electricity) have been **reduced by c. 32%** since 2010.
- This reduction has been driven largely a reduction of **emissions from coal** (c. - 38% since 2010).
- The allocation of emissions to energy carriers is an estimate based on **Eurostat energy balances** and **EC emission factors for direct $CO2_{eq}$ emissions**.

Direct $CO2_{eq}$ emissions from electricity & heat generation[1] in the EU-27 (totals and estimates for per fuels emissions) [bn. tons]



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Abbreviations: EC … European Commission
Note: [1] Supply of electricity, gas, steam and air conditioning.
Source: Compass Lexecon based on Eurostat Air Emissions, Eurostat Energy Balances, Commission Delegated Regulation (EU) 2023/1185

Planned expansion of gas-fired generation in selected EU countries

Of those countries still using significant shares of coal-fired generation, several have established the policy goal to increase gas-fired capacities – overall these countries plan for 18.5 GW additional capacity by 2030.

	Poland	Czech Republic	Slovenia	Germany	Romania	Croatia
"Current" gas fired capacities	2020: **2.7 GW**	2022: **1.8 GW**	2023: **0.6 GW**	2023: **35.9 GW**	2021: **2.9 GW**	2021: **0.8 GW**
Planned gas-fired capacities in 2030	**11 GW**	**3.4 GW**	**1.1 GW**[1]	**45.9 GW**[1]	**5.8 GW**	**1.1 GW**
Additional capacities up until 2030	**+8.3 GW**	**+1.6 GW**	**+0.5 GW**	min. **5 GW** (+5 H2-ready)	**+2.9 GW**	**+0.3**

Overall, at least 18.5 GW new gas-fired generation until 2030

Abbreviation: DH … district heating.
Note: [1] We calculated the planned capacities on top of the currently existing
Source: Compass Lexecon Analysis based on NECP Poland , NECP Slovenia, NECP Germany, NECP Czechia, CEPS - Resource Adequecy Assessment, BMWK – Kraftwerkssicherheitsgesetz; BNetzA - Monitoring Report 2023 ENTSO-E - Installed Capacity Slovenia

4.

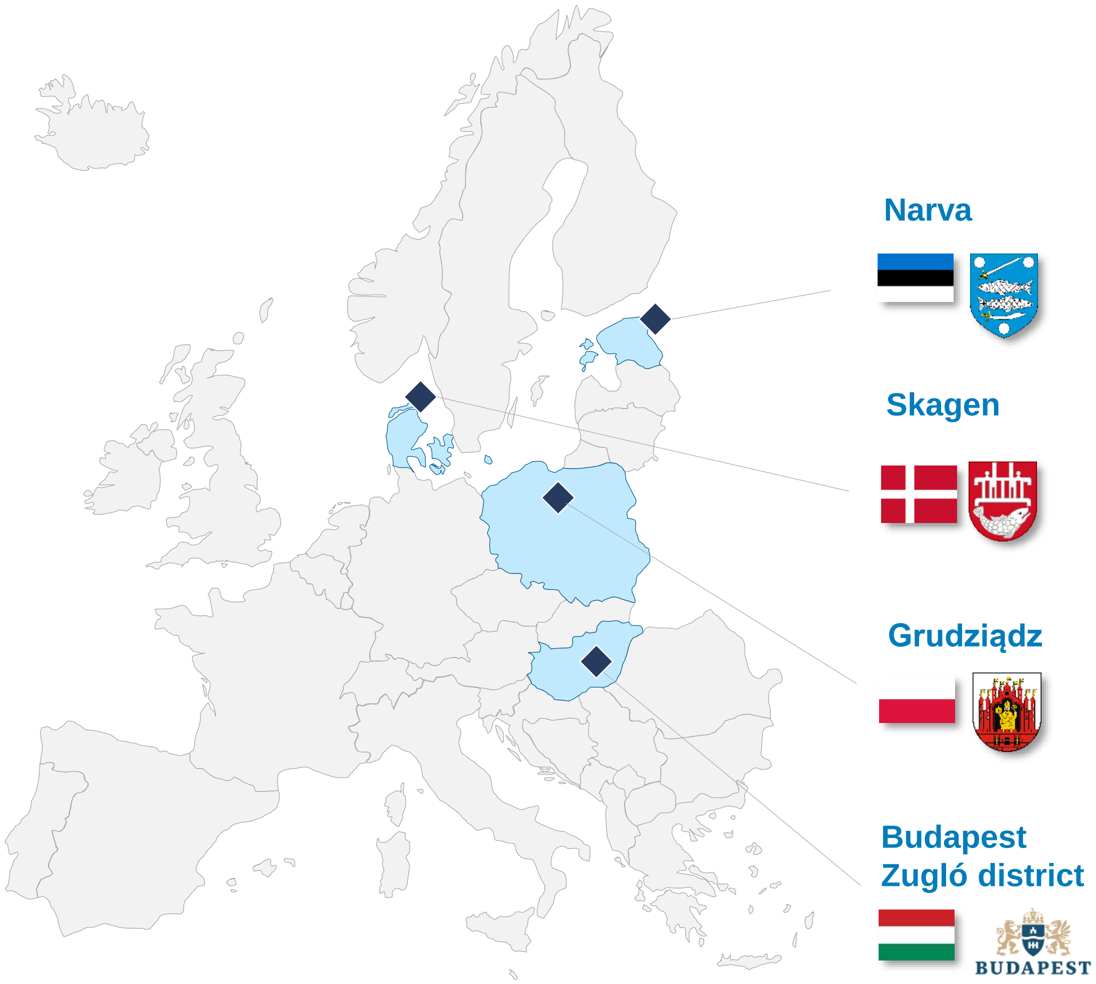
Introduction to the case studies covered

Case Studies: Overview

In this study we have analysed four DH-systems in the EU in detail: Narva, Skagen, Grudziądz and Zugló.

This study explores four systems in the form of case studies.

Each of the case studies relates to specific commercial, regulatory and environmental analyses in the context of gas-fired CHPs.



Abbreviation: DH … district heating, CHP … combined heat and power.
Source: Compass Lexecon analysis

Case Studies: Covered cities and characteristics

We cover small to mid-sized cities with diverse backgrounds to illustrate the different operational strategies and business models of gas engines.

	Narva (Estonia)	Grudziądz (Poland)	Skagen (Denmark)	Zugló / Budapest (Hungary)	
General City Data				Budapest	Zugló district
Population	53 360	89 081	7 476	1 778 052	117 155
City area (km²)	69	58	8	525	18
Population density (/km²)	777	1 542	957	3 386	6 462
DH System structure					
DH system operator	Narva Soojusvõrk	OPEC Grudziądz	Skagen Varmeværk	FŐTÁV	
CHP-operator (if any)	Eesti Energia	—	Skagen Varmeværk	Alteo	
End-users connected (2022/2023)	770	c. 50% of population	3 988	246 800	—
Heat supplied (GWh_{th}) (2022/2023)	405	245	59	2 410	—
Electricity generation capacity installed (MW_{el})	215	18	11	—	18
Total heat generation capacity installed (MW_{th})	40	171	89	—	17
Coal & lignite-based generation capacity installed (MW_{th})	0	170	0	—	—
Gas fired CHP capacity installed in 2023	0 MW_{el} 0 MW_{th}	0 MW_{el} 0 MW_{th}	11 MW_{el} 12 MW_{th}	—	18 MW_{el} 17 MW_{th}
Electricity generated (GWh_{el}) (2022/2023)	—	—	11	106	—
Analysed operational strategies in case studies	**"role of the regulatory DH framework in investment decisions"**	**"substitution of coal and participation in a CRM"**	**"hedging against power prices & longer-term flexibility"**	**"short-term flexibility"**	

Abbreviation: DH … district heating, CHP … combined heat and power plant.
Note: OPEC Grudziądz operates a coal fired CHP and a biogas heating plant. The Narva Balti CHP plant fires shale oil and has a reserve gas boiler.
Source: Detailed information is in the Annex.

5.

Introduction to gas engines and their revenue generation

Key conclusions: Introduction to gas engines and their revenue generation

Among the thermal generation options investigated, gas engines provide the highest flexibility for producing heat and power; even when running on natural gas ICE-CHPs produce significantly lower emissions than best in class coal-fired generation.

- Among the thermal generation options investigated (gas engines and various set-ups of gas turbines), gas engines tend to be the most flexible and modular technology.
- Already running on natural gas ICE-CHPs produce significantly lower emissions than even best in class coal fired CHPs; by (partly) substituting for biomethane (or biogas) emissions can be further reduced.
- Gas-engine CHPs can tap into various markets to generate revenues (“revenue stacking”) – key revenues sources are:
  - Heat sale revenues
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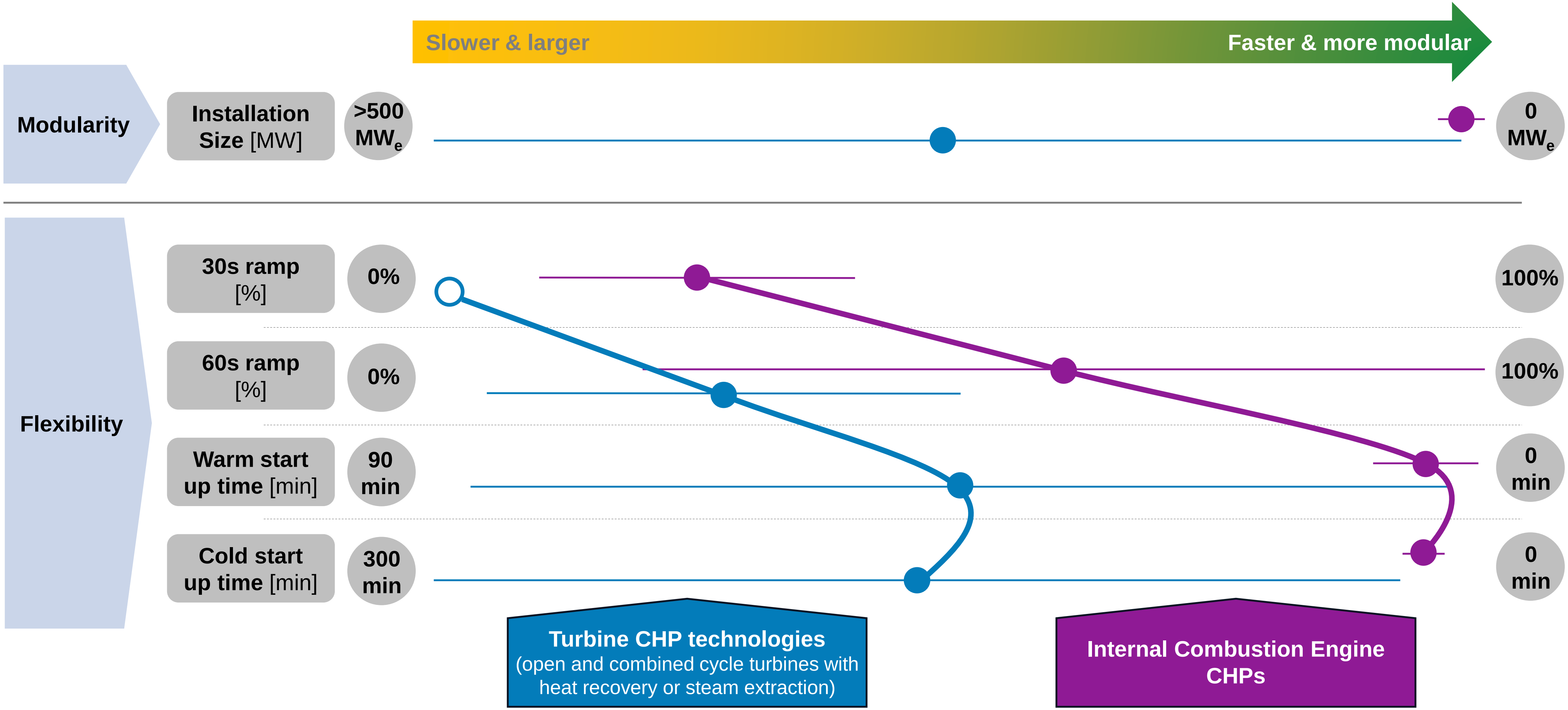
  - Revenue from CRMs (Capacity Remuneration Mechanisms)
  - Congestion management revenues
  - Subsidies

Source: Compass Lexecon analysis

Technological comparison of gas-fired CHP technologies

Gas engines tend to be more flexible and modular than gas turbines



Abbreviations: NCV … net calorific value
Note: [1] in condensing mode
Source: Compass Lexecon analysis based on Danish Energy Agency - Generation of Electricity and District heating, DEA - Corresponding excel file

CO2 emissions of gas CHPs compared to coal fired CHPs

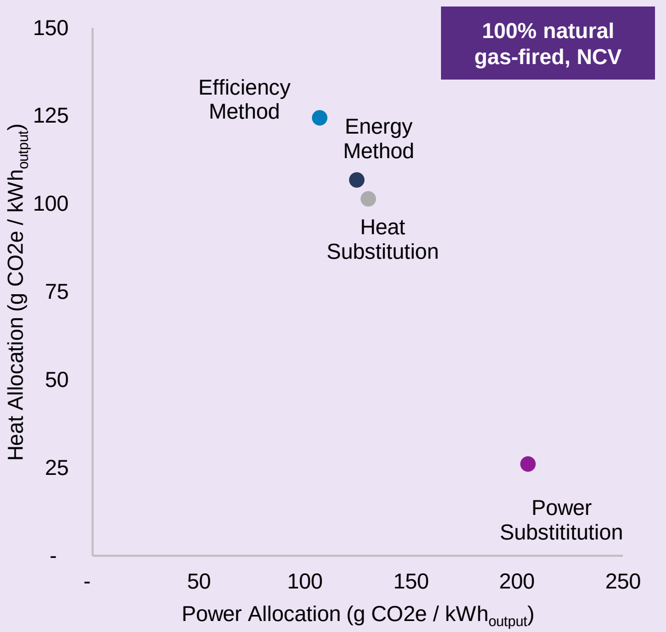
Already running on natural gas ICE-CHPs produce significantly lower emissions than even best in class coal fired CHPs; by (partly) substituting for biomethane (or biogas) emissions can be further reduced.

Exemplary Wärtsilä Internal Combustion Engine CHP ("ICE-CHP")

Electrical Efficiency: **47%**
Heat Efficiency: **40%**
Total System Efficiency ("TSE"): **87%**
Power-to-heat ratio: **1.17**
Assumption: efficiencies refer to **NCV**

Direct emissions per energy carrier	TSE	Direct emissions per unit of total energy output
Natural gas **202** g $CO2_{eq}/kWh_{NCV}$ **182** g $CO2_{eq}/kWh_{GCV}$	TSE 87%	**Natural gas** **231** g $CO2_{eq}/kWh_{Output}$
Alternative:		**Alternative:**
Biomethane **0** g $CO2_{eq}/kWh$	TSE 87%	**Biomethane** **0** g $CO2_{eq}/kWh_{Output}$
Climate neutral hydrogen[2] **0** g $CO2_{eq}/kWh$	TSE 87%	**Climate neutral hydrogen** **0** g $CO2_{eq}/kWh_{Output}$
Hard Coal **353** g $CO2_{eq}/kWh_{NCV}$	TSE 56%[1]	**Hard Coal** **630** g $CO2_{eq}/kWh_{Output}$
Lignite **365** g $CO2_{eq}/kWh_{NCV}$	TSE 47%[1]	**Lignite** **777** g $CO2_{eq}/kWh_{Output}$

Direct emissions per type of energy output



Note: There is a wide range of **methodologies for the allocation of emissions to power and heat** output. The different methodologies have a wide range of different allocation outcomes.

Notes: [1] … EU-27 average based on 2022 Eurostat data for electricity and heat production and coal and lignite consumption. [2] to the extent hydrogen can be used at the stated efficiencies in gas engines. Abbreviations: GCV … gross calorific value, NCV … net calorific value, ICE … internal combustion engine, CHP … combined heat and power plant; Source: Compass Lexecon analysis based on data from Wärtsilä, Eurostat Energy Balances, Commission Delegated Regulation (EU) 2023/1185, Directive (EU) 2018/2001, Mauch et al.

Revenue Stacking for gas-engine CHPs – Overview

Gas-engine CHPs can generate revenues in the heat and electricity sector (incl. various sub-markets)

Revenue Source		
Heat sale revenues		▪ If the CHP-operator also operates the DH system, heat produced can be sold directly to end-users ▪ If the DH system is operated by third party operator the heat produced can be sold to the DH operator.
Electricity wholesale market revenues incl. longer-term flexibility		▪ The electricity wholesale market operates across various timescales (long-term forward or futures markets, day-ahead and intra-day markets) ▪ Revenue is received for electricity actually generated and supplied
Ancillary services [1]	**mFRR** (“tertiary reserve”)	▪ Manual Frequency Restoration Reserves provide increased (“up”) or decreased (“down”) generation within 12.5 min (EU-harmonisation) after activation by the TSO to maintain the grid frequency ▪ Revenues can be generated from reservation (capacity fee) and actual activation (energy fee)
	aFRR (“secondary reserve”)	▪ Automatic Frequency Restoration Reserves provide increased (“up”) or decreased (“down”) generation fully automatically within 5 minutes (EU-harmonisation) after activation by TSOs to maintain the grid frequency ▪ Revenues can be generated from reservation (capacity fee) and actual activation (energy fee)
Revenue from CRMs (Capacity Remuneration Mechanisms)		▪ CRMs aim at remunerating capacities available to produce during times of scarcity. ▪ Those mechanisms remunerate available capacity, not the energy provided. ▪ A variety of adequacy or capacity mechanisms exist in Europe.
Congestion management revenues		▪ Redispatch is needed when the market outcome results in generation and consumption schedules that would lead to a potential violation of operational limits. ▪ Re-dispatching involves the alteration of the generation (or load) pattern by the system operator
Subsidies		▪ Subsidies for investment in or operation of a gas fired CHP

Notes: [1] there are more ancillary services (e.g. also primary reserve (frequency containment reserve) but not all are accessible by gas engines – see also the respective chapter; Abbreviation: CHPs … Combined heat and power plants, DH … district heating, mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, TSO … transmission system operator, CRM … capacity remuneration mechanism. Source: Compass Lexecon analysis

6.

The role of gas engines in district heat production

Key conclusions: The role of gas engines in district heat production

ICE-CHPs can complement electrified generation portfolios allowing for dynamic reaction to power prices; even when running on natural gas they support keeping the efficient district heating designation at least until 2034 and by blending-in decarbonised gases also until 2044 (no or partial blending) and beyond.

- ICE-CHPs compete with various other low-/no-carbon technologies – but technologies can also complement each other (as will be shown in case studies) – moreover, most low-/no-carbon heat generation technologies face some sort of limitations (e.g. in terms of usable potentials or achievable temperature levels).
- The complementarity of technologies is illustrated by two case studies:
  - **Case Study:** In Skagen (Denmark) a portfolio comprising heat-pumps, electrical boilers and ICE-CHPs allows to produce heat also during high power prices. Conversely, electrical heat sources can be used during periods of low power prices.
  - **Case Study:** For the system in Grudziądz (Poland) Wärtsilä's modelling illustrates how a currently static, coal-dominated system could be transformed into a flexible portfolio of generation assets.
- ICE-CHPs running on natural gas are within the EED-emission-limits for efficient DH until at least 2034 – beyond 2034 compliance depends on the allocation methodology – blending-in renewable gases may be required.

Source: Compass Lexecon analysis

Outline: heat sale revenues for gas engines

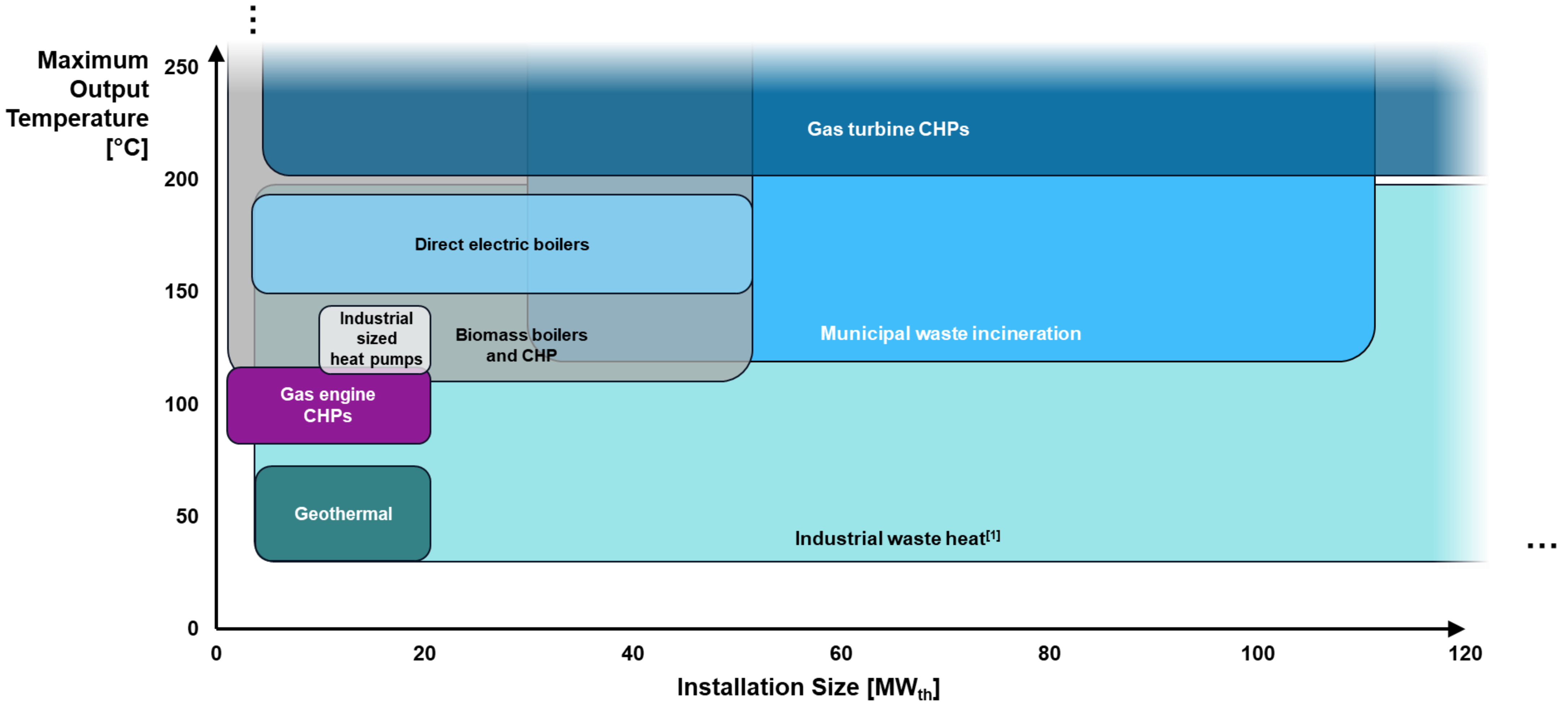
Revenue Source	
Heat sale revenues	
Electricity wholesale market revenues incl. longer-term flexibility	
Ancillary services	mFRR ("tertiary reserve")
	aFRR ("secondary reserve")
Revenue from CRMs (Capacity Remuneration Mechanisms)	
Congestion management revenues	
Subsidies	

- **Competition and complementarity of ICE-CHPs with other heat generation technologies**
- **Case study Skagen: Role of existing ICE CHPs in a district heating system with a portfolio of generation technologies**
- **Case study Grudziądz: Potential Role of new ICE CHPs in a coal-based district heating system**
- **ICE CHPs and EED emission thresholds**

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, CHP … combined heat and power, RES … renewable energy sources.
Source: Compass Lexecon analysis

Technological comparison of district heat generation technologies

There are various low-/no-carbon technologies available that can also complement each other.

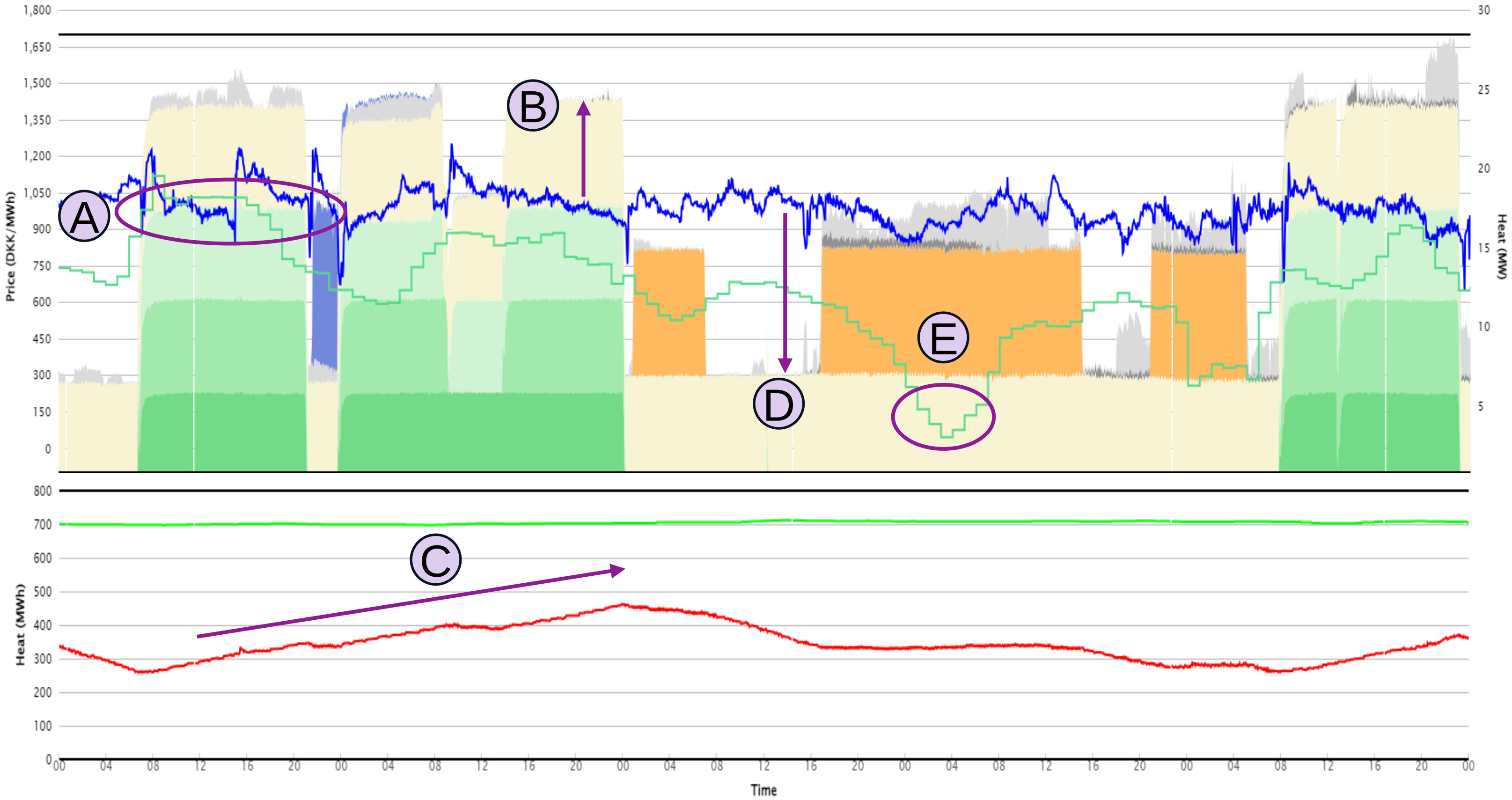


Notes: [1] Industrial waste heat size and temperature are strongly dependent on the industrial installation.
Abbreviation: CHP … combined heat and power plant, RED … Renewable Energy Directive, ICE … internal combustion engine;
Source: Compass Lexecon Analysis based inter alia on data from Directive 2010/75/EU, European Heat Pump Summit, GOV - Combined Heat and Power – Technologies, EPA - CHP technologies, Danish Energy Agency - Generation of Electricity and District heating, Liu et al (2022); Energiewende Bauen

Case study: Generation portfolio effects in Skagen (Denmark)

A portfolio comprising heat-pumps, electrical boilers and ICE-CHPs allows to produce heat also during high power prices, while electrical heat sources can be used during periods of low power prices.

Heat generation asset dispatch in the context of winter electricity prices



- **A** During periods of **high power prices**, it is attractive for the CHPs to generate electricity (and heat).
- **B** In the exemplary period, **heat generation exceeds heat demand** due to the production of the CHPs.
- **C** As heat production exceeds heat demand, the **amount of stored heat increases**.
- **D** Subsequently, during periods with less attractive power prices (to the CHPs), the district heating system can **rely on stored heat** (previously produced by the CHPs).
- **E** As low power prices continue, the direct electrical boiler produces the necessary heat. In contrast to the CHPs, **low power prices are attractive** to the direct electrical boiler.

A generation portfolio with both heat consumption & production allows to **fully optimize against the electricity price** (i.e. "buy low, sell high")

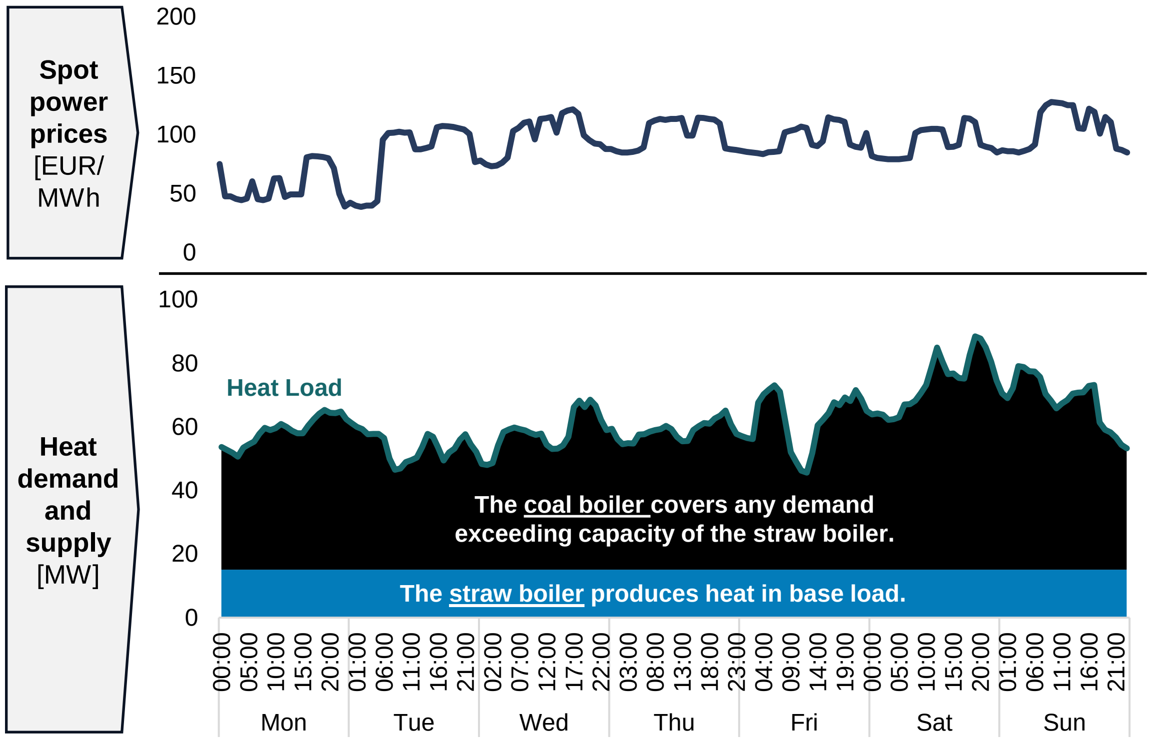
Abbreviation: CHP … combined heat and power plant, ICE … internal combustion engine.
Note: The illustration shows the period 7 – 11 December 2023.
Source: Compass Lexecon analysis based on Energyweb.dk

Case study: Substitution of coal by ICE-CHPs in Grudziądz (Poland)

Wärtsilä's modelling illustrates how a currently static, coal-dominated system could be transformed into a flexible portfolio of generation assets.

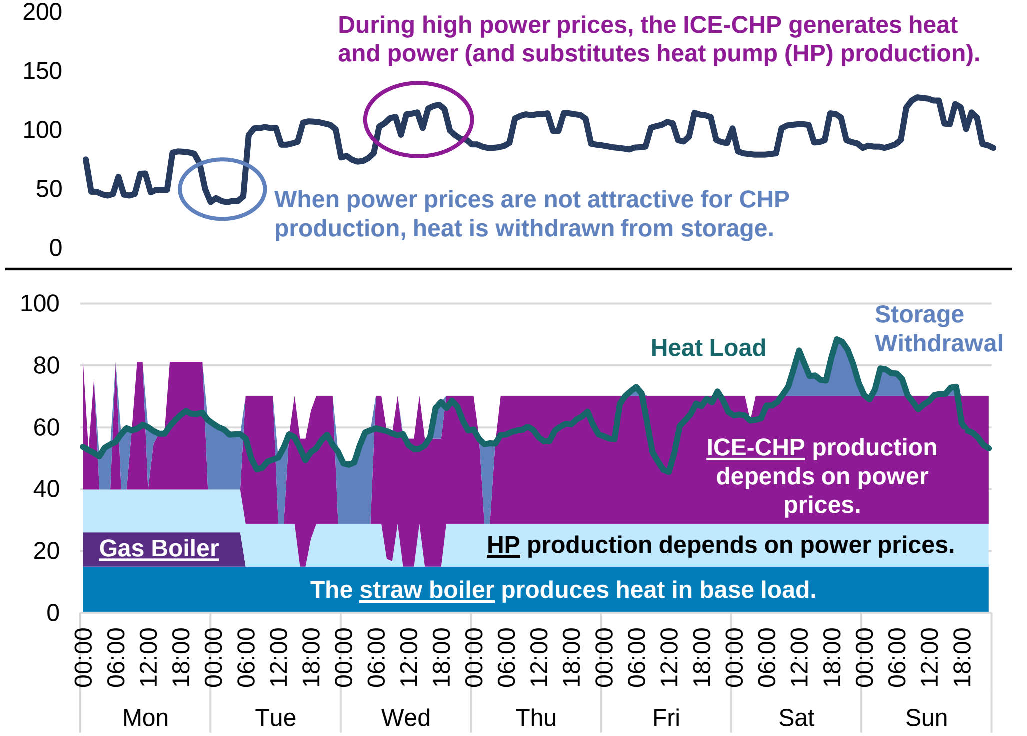
OPEC GRUDZIĄDZ

Exemplary (modelled) heat generation in status-quo setup [MW]



- Heat is produced in heat-only boilers, fully independent from power prices (both from consumption or production perspective)
- The current setup does not include any storage capacities, i.e. heat demand equals heat generation at all times.

Exemplary (modelled) heat generation after transition to portfolio with heat pump and ICE-CHPs [MW]



- The combination of heat storage, a heat pump and ICE-CHPs allows for flexible production – depending on power prices.
- Periods of unattractive power prices can be bridged by withdrawal of heat from heat storage.

Abbreviations: HP … heat pump, DH … district heating, CHP … combined heat and power plant, ICE … internal combustion engine.
Source: Modelling by Wärtsilä

ICE-CHPs and the EED emission thresholds

ICE-CHPs running on natural gas are within the EED-limits for efficient DH until at least 2034 – beyond 2034 compliance depends on the allocation methodology – blending-in renewable gases may be required.

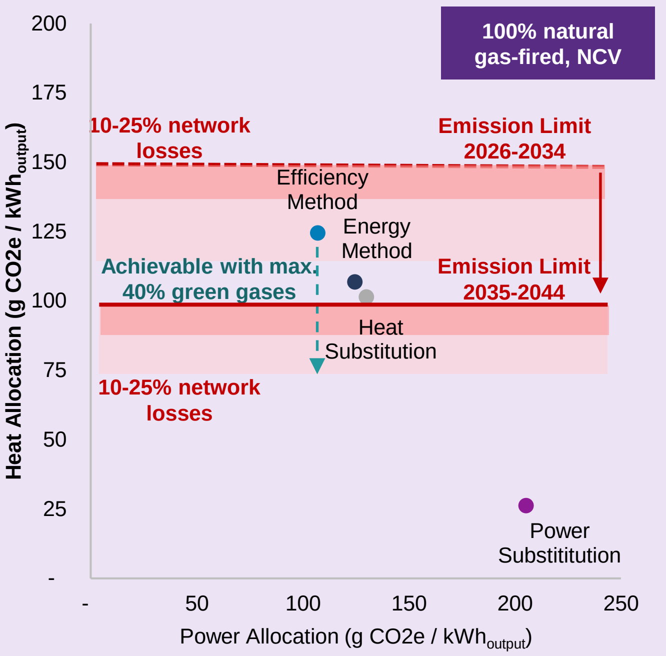
Exemplary Wärtsilä Internal Combustion Engine CHP ("ICE-CHP")	Direct emissions per energy carrier	Direct emissions per unit of total energy output	Direct emissions per type of energy output

Regulatory emission thresholds
EU Energy Efficiency Directive ("EED")

Energy efficiency directive (EED) limits[2]
150 g $CO2_{eq}$/ $kWh_{delivered\ heat}$ (2026-2034)
100 g $CO2_{eq}$/ $kWh_{delivered\ heat}$ (2035-2044)

Electrical Efficiency: **47%**
Heat Efficiency: **40%**
Total System Efficiency ("TSE"): **87%**
Power-to-heat ratio: **1.17**
Assumption: efficiencies refer to **NCV**

Direct emissions per energy carrier		Direct emissions per unit of total energy output
Natural gas: **202** g $CO2_{eq}/kWh_{NCV}$; **182** g $CO2_{eq}/kWh_{GCV}$	TSE 87%	Natural gas: **231** g $CO2_{eq}/kWh_{Output}$
Biomethane: **0** g $CO2_{eq}/kWh$		Biomethane: **0** g $CO2_{eq}/kWh_{Output}$
Climate neutral hydrogen: **0** g $CO2_{eq}/kWh$		Climate neutral hydrogen: **0** g $CO2_{eq}/kWh_{Output}$



Notes: [1] EED criterium for high-efficient cogeneration. [2] Criteria when defining efficient district heating via emission intensity.
Abbreviation: CHP … combined heat and power plant, DH … district heating, NCV … net calorific value, GCV … gross calorific value , ICE … internal combustion engine; Source: Compass Lexecon analysis based on Energy Efficiency Directive, Wärtsilä modelling assumptions, Commission Delegated Regulation (EU) 2023/1185, Directive (EU) 2018/2001, Allokationsmethoden für CO2-Emissionen von Strom und Wärme aus KWK-Anlagen

7.

The role of gas engines on wholesale electricity markets and the provision of longer-term flexibility

Key conclusions: The role of gas engines on wholesale electricity markets and the provision of longer-term flexibility

Gas engines can generate revenues from wholesale electricity markets – thereby also providing ever more important longer-term flexibility.

- **Case Study:** Deployment of solar and wind capacities drives the need for power sector flexibility across all time-scales – this is illustrated by the projected developments in the Czech Republic, Romania, Poland. Finland, Germany and Spain
- **Case Study:** As showcased for Finland, increased renewable generation will change the structure of wholesale power market prices – thereby changing revenues capturable by technologies providing long-term flexibility
- In providing longer-term flexibility ICE-CHPs compete against other types of generation assets, but they are often limited by their potentials (e.g. hydropower), or by acceptability (e.g. nuclear).
- **Case Study:** For Skagen (Denmark) CHP's ability to provide intraday and longer-term flexibility is illustrated by the operation of existing gas-engine CHPs in a country with an already high RES-penetration

Abbreviation: RES … renewable energy sources, CHP … combined heat and power, ICE … internal combustion engine.
Source: Compass Lexecon analysis

Outline: electricity wholesale market revenues

Revenue Source	
Heat sale revenues	
Electricity wholesale market revenues incl. longer-term flexibility	
Ancillary services	**mFRR** (“tertiary reserve”)
	aFRR (“secondary reserve”)
Revenue from CRMs (Capacity Remuneration Mechanisms)	
Congestion management revenues	
Subsidies	

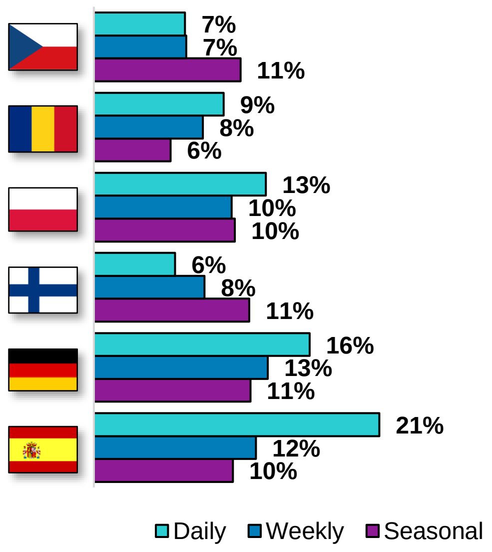
- **Case Study: Increasing flexibility needs across all time-scales**
- **Case Study: Changes in the electricity wholesale price structure in Finland**
- **Competition in providing flexibility**
- **Case Study: provision of intraday flexibility to power markets in Skagen / Denmark**

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, RES … renewable energy source.
Source: Compass Lexecon analysis

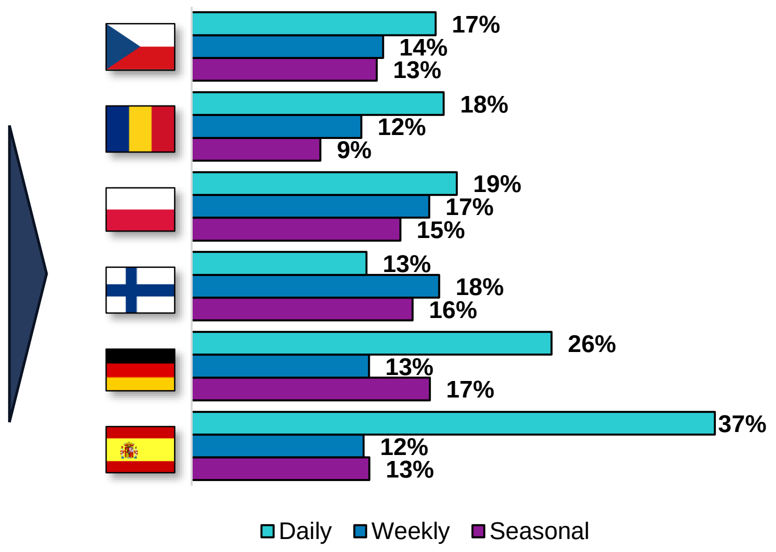
Case Studies: Increasing flexibility needs across all time scales

Deployment of solar and wind capacities drives the need for power sector flexibility across all time-scales.

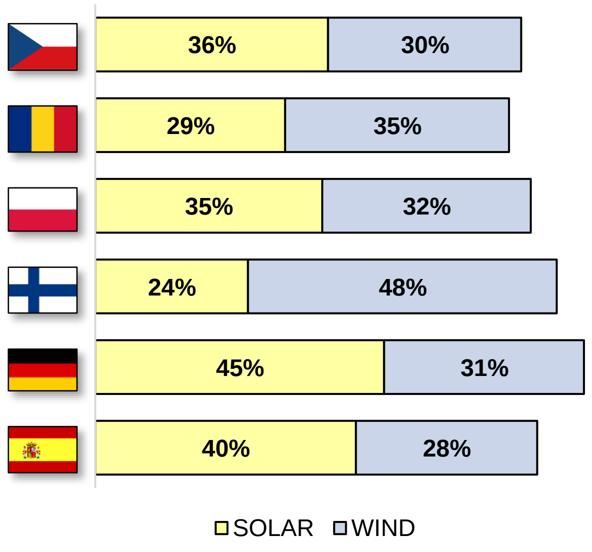
Flexibility needs as share of customer load in 2025 [%]



Total flexibility needs as share of customer load in 2040 [%]



Share of PV and wind in 2040 capacity mix [%]



For a given country, flexibility needs at different timesteps vary and **depend on its geography and generation mix**:

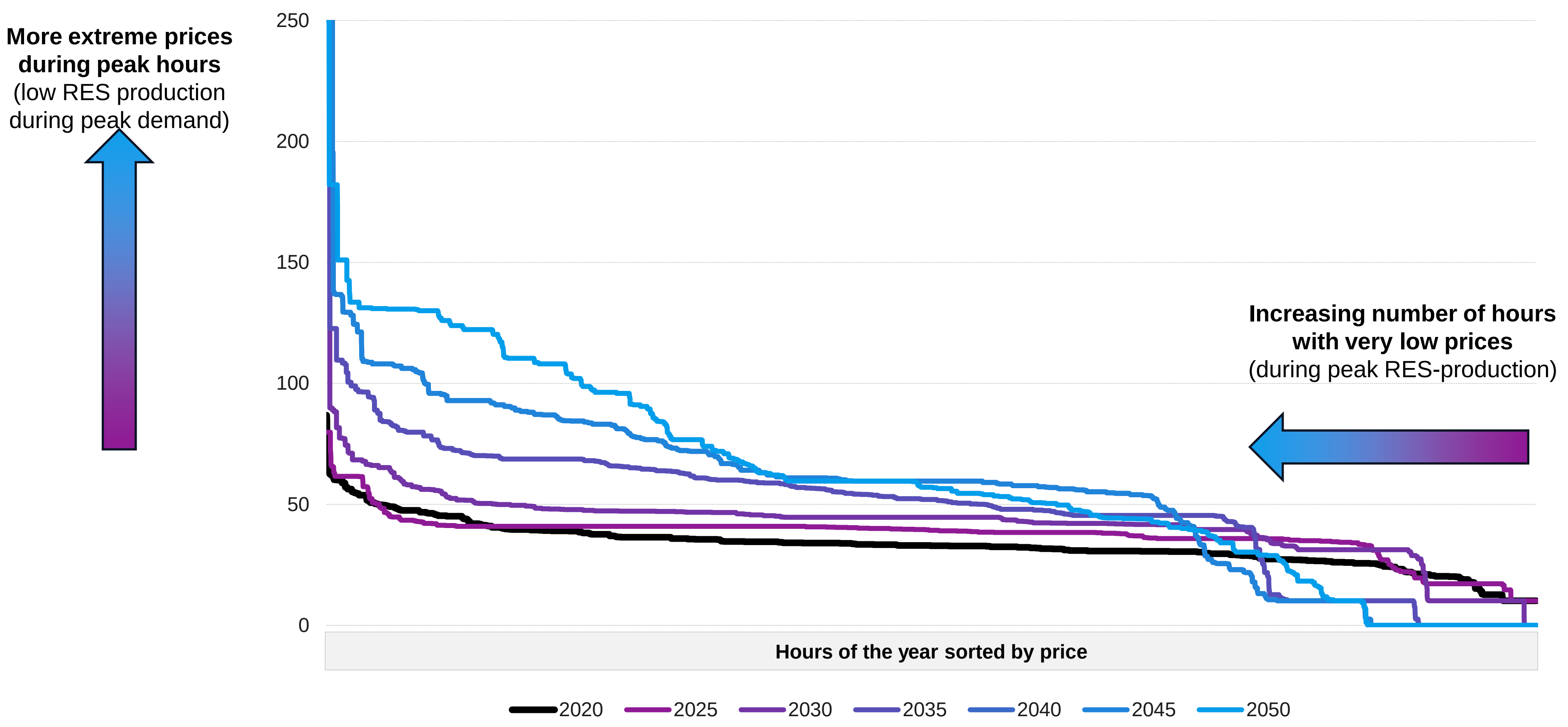
- **Compared** to countries in the **south**, countries in the **north** tend to have **higher seasonal flexibility needs** mainly due to **higher heating** needs in winter and **lower cooling** needs in summer;
- **Wind-dominated** countries such as Finland tend to have **higher weekly needs** than daily and seasonal needs as the intermittence of wind generation is more significant on a weekly level;
- Countries in the **south** such as Spain tend to have **higher daily** needs than weekly and seasonal needs due to the daily bell shape of solar generation. In addition, those countries tend to have **higher daily** needs **than countries in the North** as i) they tend to have higher solar capacity because of their geography ii) daily solar peak capacity factor is higher in countries in the south, creating higher daily flexibility needs.

Note: Annual flexibility needs refer to the sum of absolute needs in both direction (upwards and downwards). Calculations are based on generation and demand profiles of 2009 as a climatic year. Electrolysis demand is not included in the calculations as it is considered as a flexibility provider.
Source: Compass Lexecon analysis

Case study: Changes in the electricity wholesale market price structure

Increased renewable generation will change the structure of wholesale power market prices – thereby changing revenues capturable by technologies providing long-term flexibility.

Price Duration Curves: Modelled evolvement of the Day-ahead price structure in Finland [EUR/MWh]



Abbreviation: RES … renewable energy source.
Source: Compass Lexecon analysis from our study for Sitra: Enabling cost-efficient electrification in Finland (2021)

Technologies to provide long-term flexibility

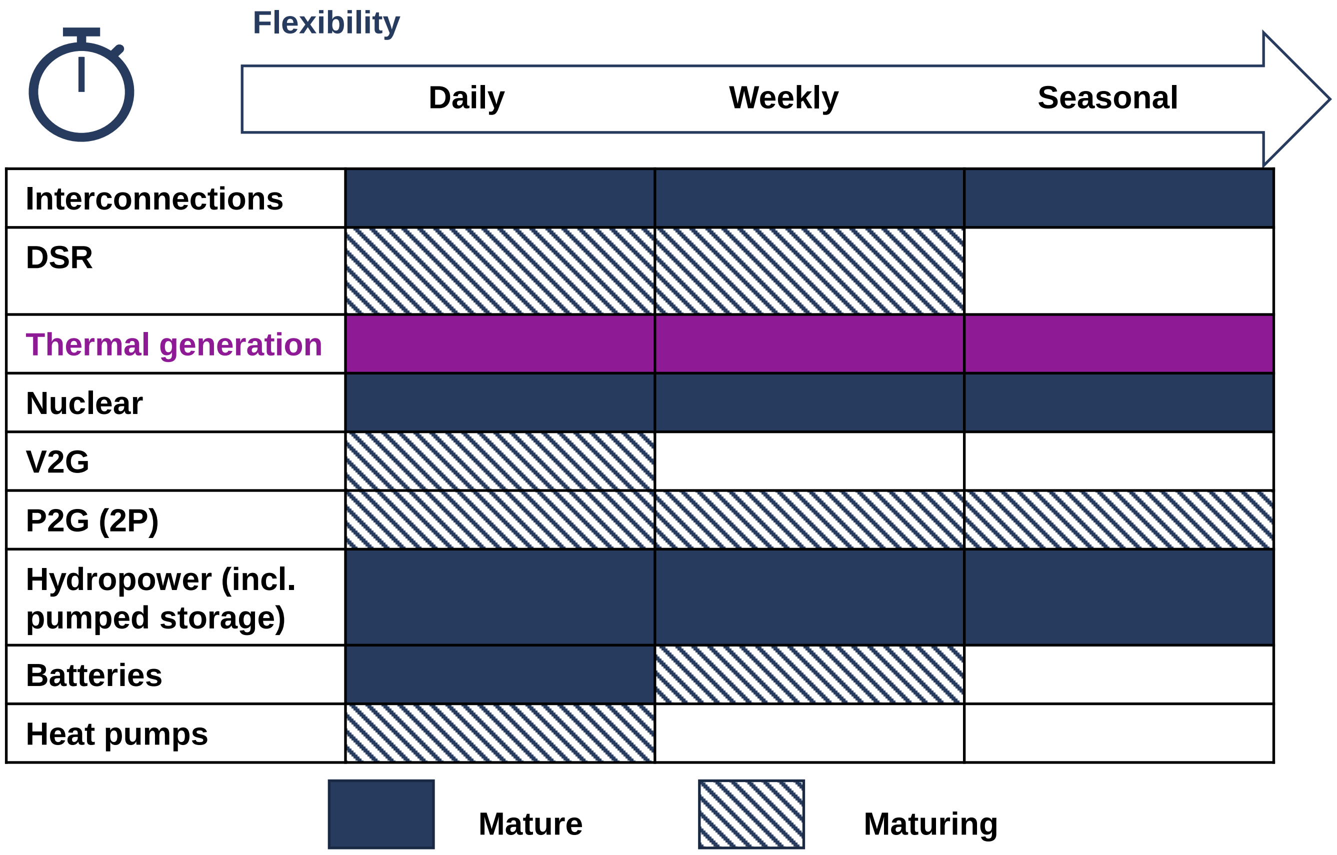
There are several technologies available to provide longer-term flexibility, but they are often limited by their potentials, like hydropower, or acceptability, like nuclear

Each technology type presents specific characteristics that allow it to respond to different system needs

- Technology features that are directly relevant for their ability to answer system needs include **dispatchability, energy-limits, ramping rate**…
- Ensuring security of supply as well as a cost-effective decarbonization will require **consideration of all resources and types of assets**

While several – also clean – technologies exist to address short term flexibility needs, there are fewer longer-term flexibility technologies and most face constraints

- Technologies able to provide short-term flexibility are generally mature, such as thermal generators, batteries or interconnectors
- There are fewer solutions – especially clean solutions – able to provide seasonal flexibility, of which Hydropower potentials are already well developed in several countries, Nuclear capacity expansion has long lead-times and is not accepted in all countries and P2G2P still is in early stages of commercial scale application
- Thermal generation can provide flexibility on all time scales and can do so in a decarbonised way using green gases.

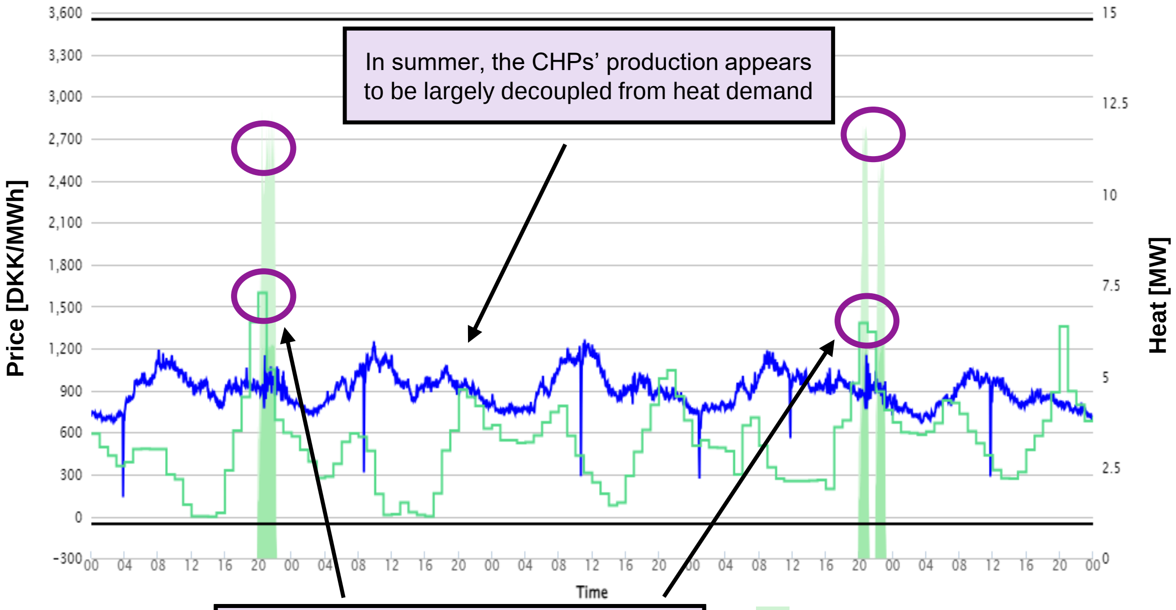


Abbreviation: CHP … combined heat and power plant, DSR, … demand side response, V2G … vehicle-to-grid, P2G … power-to-gas , ICE … internal combustion engine.
Source: Compass Lexecon analysis

Case study: CHPs providing intraday flexibility in Skagen (Denmark)

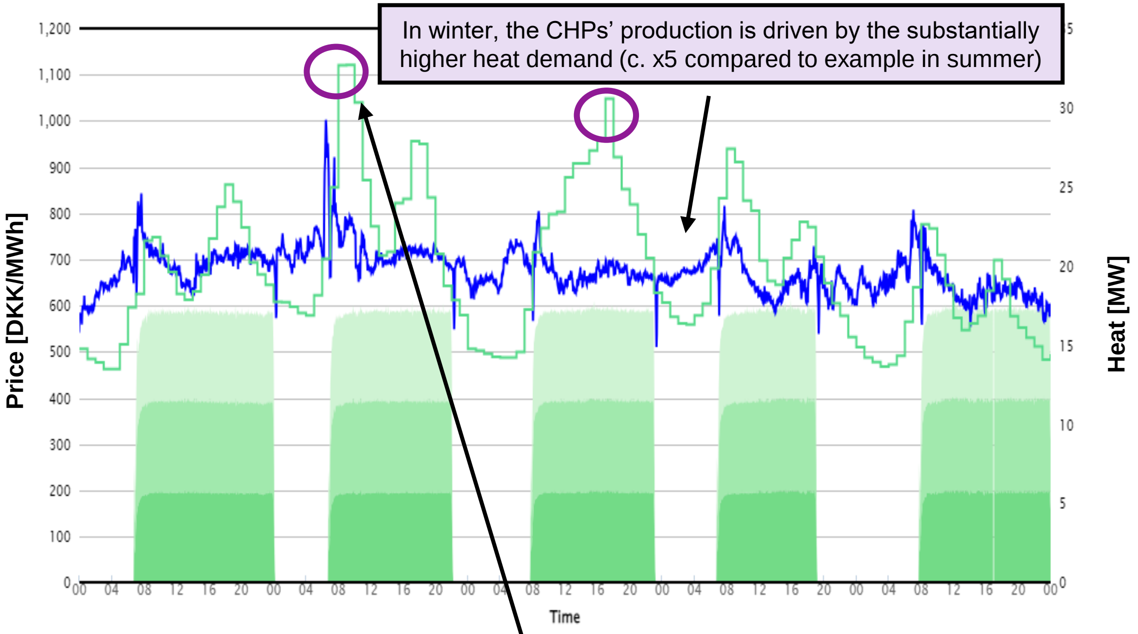
The CHPs' dispatch during summer is largely driven by the power-markets flexibility needs and the resulting revenue potentials for dispatchable technologies.

CHPs' dispatch during a typical 5-day period in summer



The CHPs provide flexibility to the electricity system by producing during hours of scarcity (evening peak with reduced RES production)

CHPs' dispatch during a typical 5-day period in winter



CHP Load | Heat Load | Power Price

Although CHP dispatch is heat-driven, it does capture typical price peaks on electricity markets (i.e. provides electricity to the system during the scarcest hours)

Note: The axes of the two graphs are not to the same scale. Other generation assets' generation are omitted from the graphs for illustration (direct-electric boiler, heat-pump, gas-boiler, waste heat, waste incineration). The illustration shows the period of July 15th – 19th, 2024 (left graph) and January 15th – 19th, 2024 (right). Abbreviation: CHP … combined heat and power plant, RES … renewable energy source.
Source: Energyweb.dk

8.

The role of gas engines on ancillary services markets

Key conclusions: The role of gas engines on ancillary services markets

Beyond the heating market Gas engines can access multiple other revenue streams in the power market.

- Balancing services markets remunerate market participants for reacting quickly to TSO signals in order to ensure system stability.
- The need for aFRR is driven by unplanned outages and small frequency variations.
- The need for mFRR is driven mostly by outages of large generation or interconnection assets; for mFRR ICE-CHPs compete currently against hydropower and other thermal assets.
- **Case Study:** The ability to generate synergies from the co-location of gas engines and batteries is illustrated on the Hungarian ancillary services market, where gas engines and batteries sometimes even share the grid connection and batteries are charged independent of grid electricity directly from the gas engine's production.

Abbreviation: CHP … combined heat and power, TSO… transmission system operator, mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, ICE … internal combustion engine.
Source: Compass Lexecon analysis

Outline: ancillary services

Revenue Source

- **Heat sale revenues**
- **Electricity wholesale market revenues** incl. longer-term flexibility
- **Ancillary services**
  - **mFRR** (“tertiary reserve”)
  - **aFRR** (“secondary reserve”)
- **Revenue from CRMs** (Capacity Remuneration Mechanisms)
- **Congestion management revenues**
- **Subsidies**

- **Introduction to ancillary services markets**
- **Outlook on future aFRR needs and provision**
- **Outlook on future mFRR needs and provision**
- **Case study: aFRR provision in Hungary/Zuglo**

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, AS … ancillary services, CHP … combined heat and power , ICE … internal combustion engine.
Source: Compass Lexecon analysis

Introduction to ancillary services markets

Balancing services markets remunerate market participants for reacting quickly to TSO signals in order to ensure system stability.

When frequency deviates from the 50Hz objective, different type of reserves are activated to restore the optimal frequency

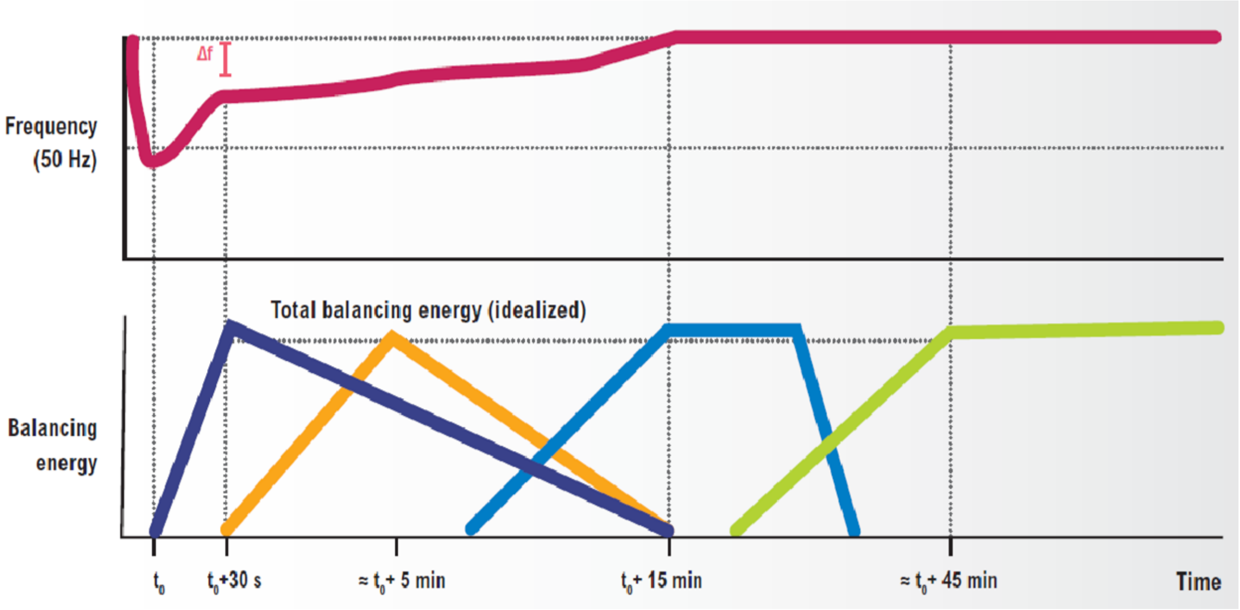
- **Upward reserve** when there is a lack of energy, i.e., demand in the system exceeds the injected energy
- **Downward reserve** if there is too much energy, i.e., energy injected into the system exceeds the demand
- **Competitive auctions** are usually in place for the reservation of capacity and the activation of energy

Market participants can be remunerated through capacity and/or energy activation

- Successful market participants in reservation auctions receive a payment for **capacity reservation** (payment in €/MW/h). They receive this payment even if they end up not being activated.
- In case market participants are actually activated to provide reserve, they also receive a payment for the **energy activation** (in €/MWh).
- Market participants that are not reserved can also place free bids in balancing markets, and receive a payment for energy activation if selected

Activation of successive reserves in case of imbalance [1]

FCR	aFRR	mFRR	RR
• Automatic activation • symmetrical • Reaction time 5 s	• Automatic activation • Asymmetrical • Reaction time 30s	• Semi-automatic or manual activation • Asymmetrical • Within 15 min	• Semi-automatic or manual activation • Asymmetrical • Within 15 min



Abbreviation: TSO … transmission system operator, FCR … frequency containment reserve, mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, RR … replacement reserve. Source: Compass Lexecon analysis based on ENTSO-E (2018) Electricity Balancing in Europe

aFRR demand and provision evolvement

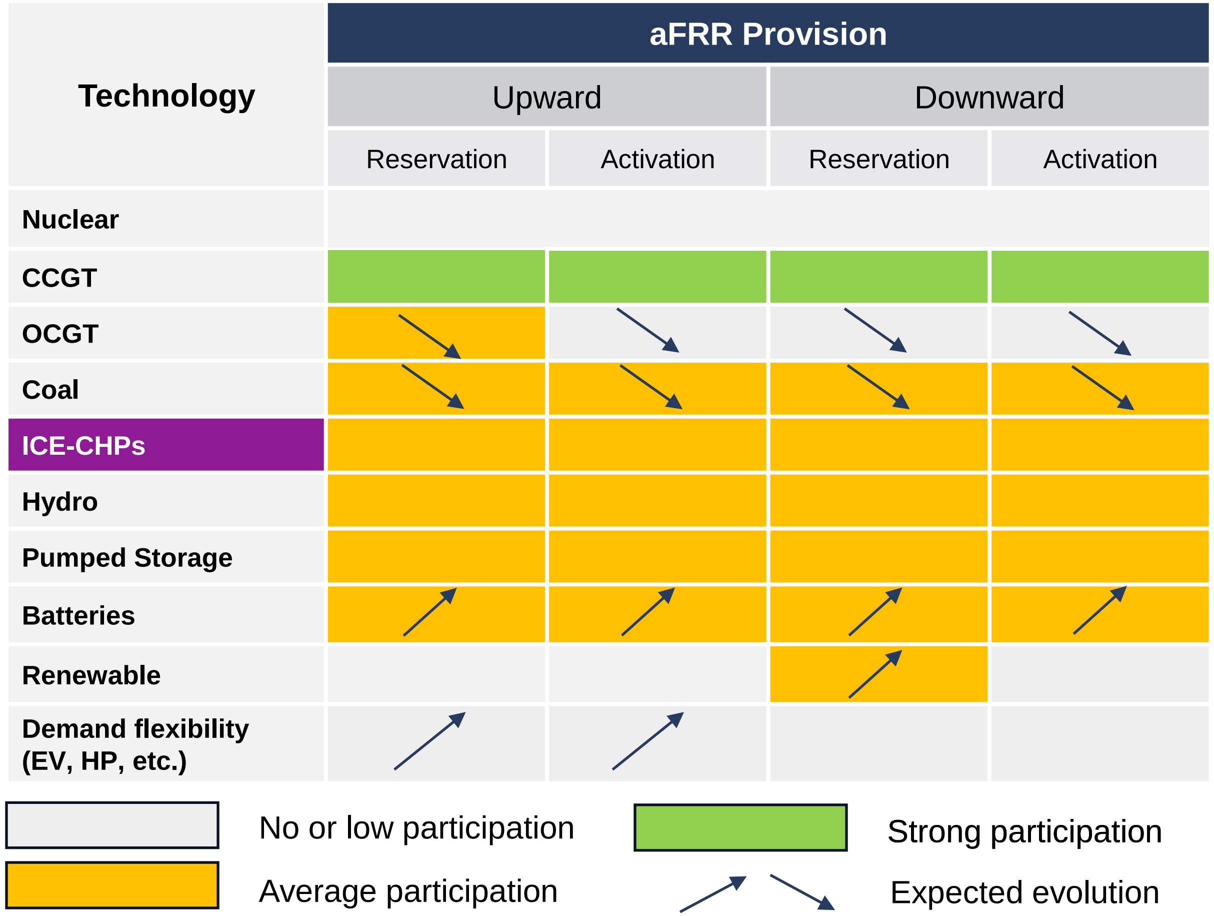
The need for aFRR is driven by unplanned outages and small frequency variations and ICE-CHPs are currently competing against hydropower and other thermal assets with an increasing competition from batteries and new flexibilities.

Dimensioning methodology for aFRR:

- In general, the dimensioning of the capacity reserve is such that the reserve capacity is enough to cover both (i) most frequent loads deviations and (ii) most frequent outages, generally designed to cover c.99% of potential outages.
- More specifically, aFRR is designed to cover small frequency variations and provide first mitigation in the event of a major outage.

Drivers of aFRR demand:

Upward	Downward
▪ Increase in renewable generation capacity	▪ Decommissioning of large thermal units ▪ Improving renewable and demand forecasting systems ▪ Increase in Intraday trading



Abbreviation: aFRR … automatic frequency restoration reserve, CCGT … combined-cycle gas turbine, OCGT … open-cycle gas turbine, EV … electric vehicle, HP … heat pump, ICE … internal combustion engine, CHP … combined heat and power plant.
Source: Compass Lexecon analysis.

mFRR demand and provision evolvement

The need for mFRR is driven by large outages and ICE-CHPs compete currently against hydropower and other thermal assets

Dimensioning methodology for mFRR:

- mFRR is designed to cover large outages.
- It is used to supplement the aFRR if the latter is depleted or insufficient to cope with the network imbalance but can also be used to replace the primary and secondary reserves, or to anticipate an imbalance.

Drivers of mFRR demand:

Upward ↗	Downward ↘
▪ Development of large offshore wind farms ▪ New large cross border line	▪ Decommissioning of large thermal units ▪ Increase in Intraday trading

Technology	mFRR Provision			
	Upward		Downward	
	Reservation	Activation	Reservation	Activation
Nuclear	No or low participation	No or low participation	No or low participation	No or low participation
CCGT	Average participation	Average participation	Average participation	Average participation
OCGT	Strong participation	Average participation	Strong participation	Average participation
Coal	Average participation ↘	Average participation ↘	Average participation ↘	Average participation ↘
ICE-CHPs	Strong participation	Average participation	Strong participation	Average participation
Hydro	Average participation	Strong participation	Average participation	Strong participation
Pumped Storage	Average participation	Strong participation	Average participation	Strong participation
Batteries	No or low participation ↗	No or low participation ↗	No or low participation ↗	No or low participation ↗
Renewable	No or low participation	No or low participation	Average participation ↗	No or low participation
Demand flexibility (EV, HP, etc.)	No or low participation ↗	No or low participation ↗	No or low participation	No or low participation

Legend: No or low participation; Strong participation; Average participation; ↗ ↘ Expected evolution

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve CCGT … combined-cycle gas turbine, OCGT … open-cycle gas turbine, EV … electric vehicle, HP … heat pumpICE … internal combustion engine, CHP … combined heat and power plant. Source: Compass Lexecon

Case study: Gas engines on the Hungarian ancillary services market

FCR and aFRR provision is currently dominated by nuclear and gas-fired capacities (incl. gas engines). Due to grid-constraints also co-locations of gas engines and BESS are increasingly deployed

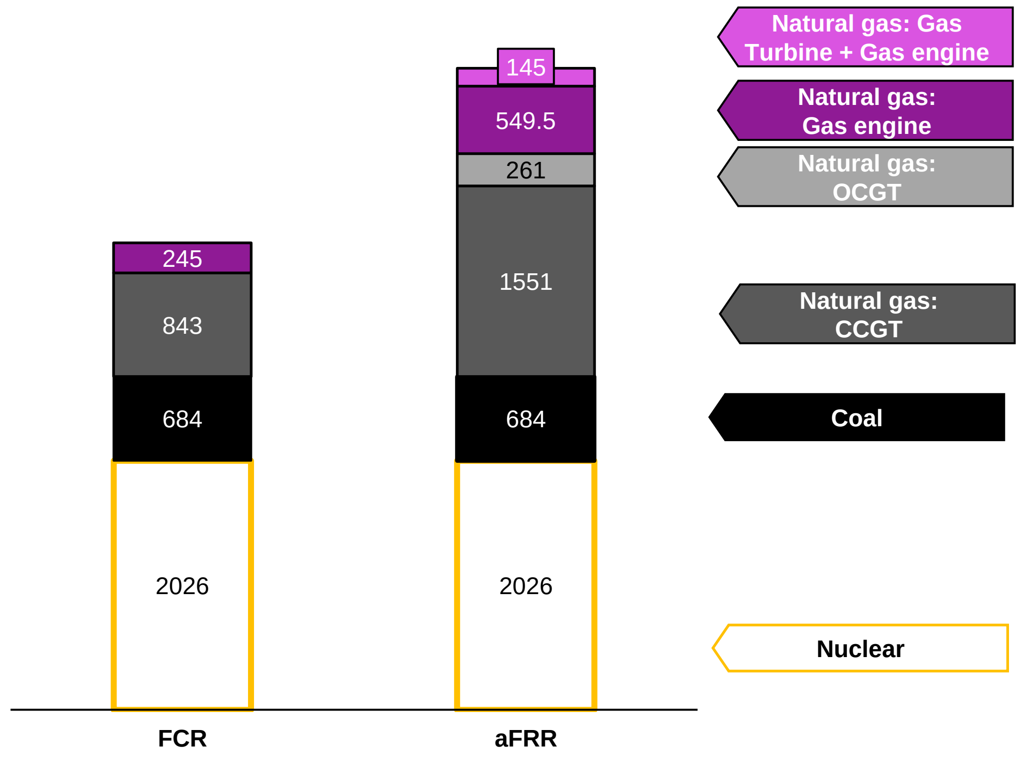
Apart from a nuclear plant providing both services, FCR and aFRR are provided by fossil fuel technologies in Hungary, including significant natural gas fired capacities

- In 2022, there was 3789 MW participating in the FCR market, and 5217 MW in the aFRR market. These are both dominated by the participation of the four nuclear reactors in Hungary (Paks 1 to 4, total of 2026 MW) and coal power (to a level of 684 MW)
- The remaining capacity provided by gas powered plants, including gas engines (245 MW in the FCR market and 550+ MW in the aFRR market in 2022)

The main revenues of ICE-CHP and batteries in Hungary are FCR and aFRR respectively, as well as wholesale market

- Political uncertainty around the future power market dynamics in Hungary as well as a lack of grid connection capacity are creating a context of low competition and limited new investments.
- This leads to high ancillary service prices in Hungary, mainly in the activation remuneration[1], complemented by revenues in the wholesale market. In this context, heat revenues are currently secondary for ICE CHP
- In some case, BESS are installed behind the same connection as gas engines, allowing a higher level of flexibility than a standalone gas engine

Total installed capacities of Hungarian FCR- & aFRR-Providers, 2022 [MW]



Abbreviations: FCR … Frequency Containment Reserve, aFRR … automatic Frequency Restoration Reserve, BESS … Battery Energy Storage System, OCGT… Open-Cycle Gas Turbine, CCGT … Combined-Cycle Gas TurbineICE … internal combustion engine, CHP … combined heat and power plant. Source: Compass Lexecon analysis based on MEKH and MAVIR: Data of the Hungarian Electricity System 2022, 1) ENTSOE Transparency data

9.

The role of gas engines on capacity remuneration mechanisms

Key conclusions: The role of gas engines on capacity remuneration mechanisms

Beyond the heating market, gas engines can access multiple other revenue streams in the power market.

- Capacity remuneration mechanisms (CRMs) are established in many European countries to ensure security of supply amid increasing intermittent generation.
- **Case Study**: Coal and gas plants play still a significant role in the Polish CM although a wider variety of technologies is contracted under the Polish CRM.
- **Case Study**: The German Power Plant Strategy aims at securing electricity supply in light of increasing RES shares and aimed coal exist. It foresees several GW of new gas fired generation.

Source: Compass Lexecon analysis

Outline: Revenue from capacity remuneration mechanisms (CMRs)

Revenue Source

Heat sale revenues

Electricity wholesale market revenues
incl. longer-term flexibility

Ancillary services
- **mFRR** (“tertiary reserve”)
- **aFRR** (“secondary reserve”)

Revenue from CRMs
(Capacity Remuneration Mechanisms)

- **Introduction to European CRMs**
- **Case Study: ICE-CHPs in the Polish CRM**
- **Case Study: The German Power Plant Strategy**

Congestion management revenues

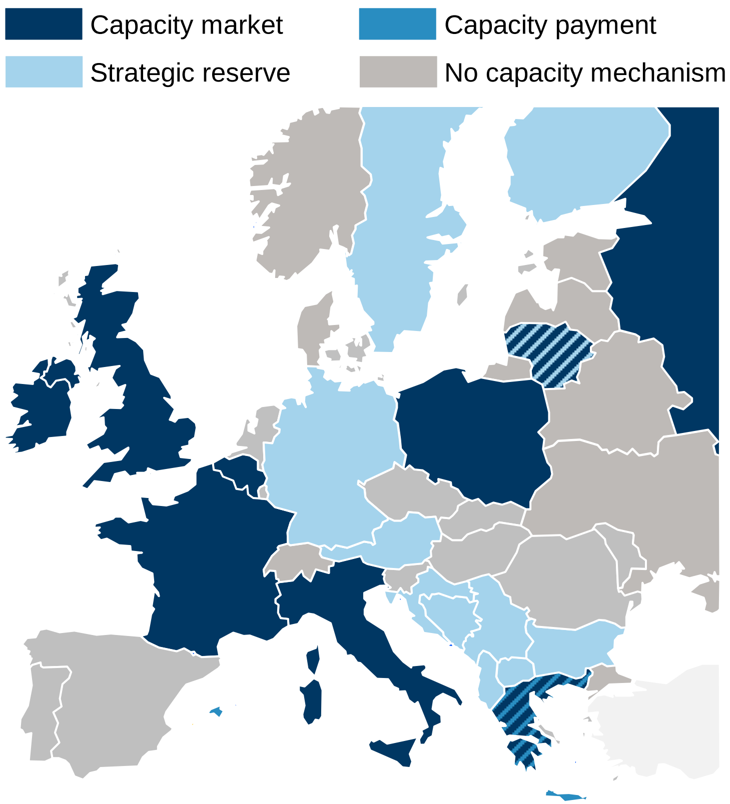
Subsidies

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, ICE … internal combustion engine, CHP … combined heat and power plant.
Source: Compass Lexecon analysis

Introduction to capacity remuneration mechanisms

Capacity remuneration mechanisms (CRMs) are established in many European countries to ensure security of supply amid ever increasing intermittent generation

Capacity mechanisms in Europe



Capacity remuneration mechanisms aim to cover the missing money of assets contributing to security of supply

- In order to ensure security of supply, capacity remuneration mechanisms ("CRM"), can be implemented. Those mechanisms aim at providing additional revenues to capacity available during peak hours.
- These payments intend to favour investments and/or prevent decommissioning so that enough capacity is available to meet peak power demands.
- Different CRM design can be envisaged and present different benefits and drawbacks, as illustrated on the next slide.

CRMs have become a cornerstone of the European market design

- At the European level, EU Member States present examples of all CRMs under the EC definition including market-wide CRMs, Strategic reserves (including network reserves and interruptability schemes), specific tenders for new capacity, and targeted capacity payments. Market wide capacity remuneration mechanism are developing.
- CRMs are now recognized as an integral part of the European electricity market, as confirmed by the European Commission during the Electricity Market Design reform.

COMPASS LEXECON

Abbreviation: EC … European Commission.
Source: Compass Lexecon, European Commission - Final Report of the Sector Inquiry on Capacity Mechanisms, CEEM - Capacity Remuneration in power markets: an empirical assessment of the cost of precaution

Case study: Participation of natural gas CHP in Poland CRM

Coal and gas plants play still a significant role in the polish CM although a wider variety of technologies is contracted under the Polish CRM.

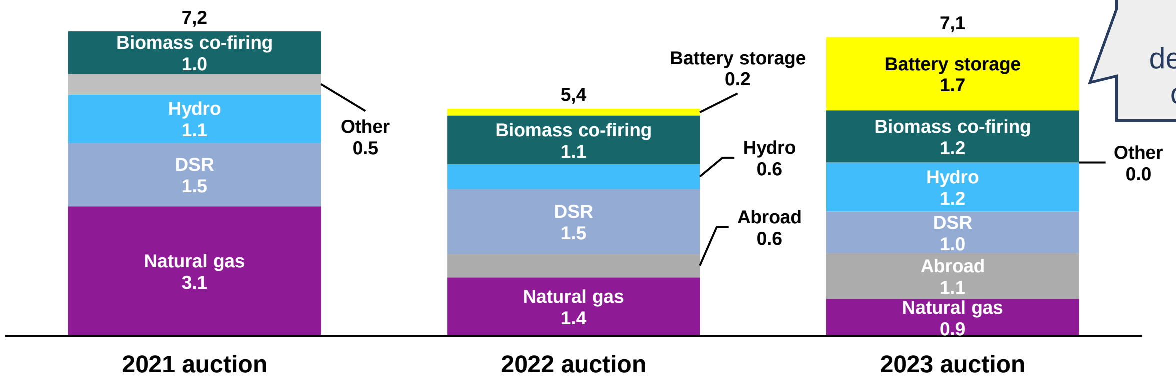
General info:

- Was introduced in 2018 and is open to all technologies (existing and new).
- Auctions are split into one main (T-5) auction where the capacity for delivery 5 years later is procured and 4 (T-1) auctions each year for additional capacity in the following year.
- The winning units can get contracts of **up to 17 years** depending on the spent CAPEX.

Results:

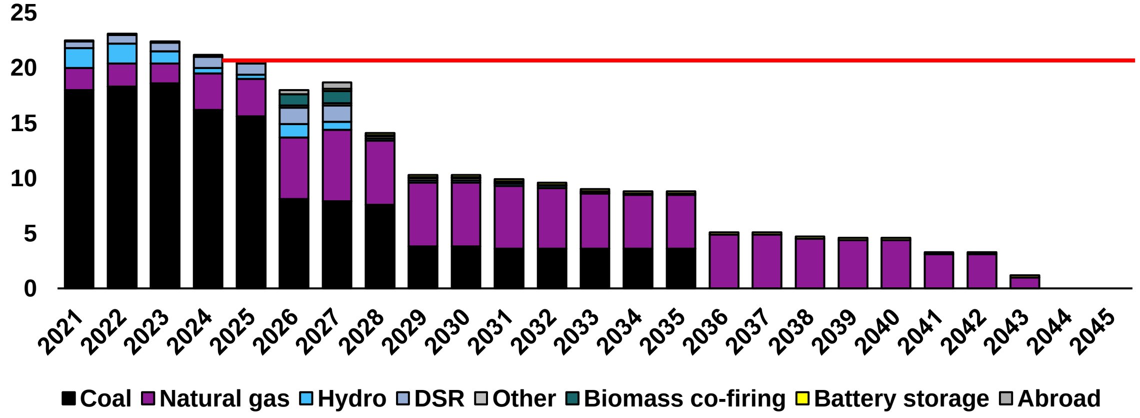
- The price level dropped in the 2023 auction for delivery in 2028 from 87 000 EUR/MW in the previous two years to about **56 000 EUR/MW**.
- Although coal-fired units could not compete in the auctions from 2021 onwards there are still **significant amounts of coal-fired units** contracted until the mid 2030s from previous auctions, as can be seen in the graph to the right.
- In the last auction a wider variety of winning technologies was awarded. Especially **battery storages** increased their awarded capacity more than ten times to the previous year when they first appeared.
- Gas-fired power plants on the other hand see a decrease in awarded amounts. In the last auction **no new gas capacities** have won contracts.
- Nevertheless, the capacity market has supported since the start the creation of **5.4 GW of new gas capacities.**

Contracted technologies in last capacity market auctions (T-5) [GW]



Until 2023 battery storages had just like conventional plants a derating factor of only5 %.

Contracted capacity for each year and technology [GW]



Notes: Category "Other" for the year 2021 includes foreign units; The assignment of technologies to contracted capacities is based on press releases of and media reports
Abbreviations: CHP … Combined Heat and Power, CM … Capacity remuneration mechanism, CAPEX … capital expenditures
Source: ACER (2023) - Security of EU electricity supply; ACER (2023) - Demand response and other distributed energy resources: what barriers are holding them back?; Commission Decision SA.46100 (PL), Forum Energii - Eighth capacity market auction, Forum Energii - Conclusions from the 7th capacity market auction, Forum Energii - The capacity market in Poland

Case Study: The German Power Plant Strategy

The Federal Government is developing a Power Plant Strategy which aims at securing electricity supply in light of increasing RES shares and aimed coal exist. In foresees several GW of new gas fired generation.

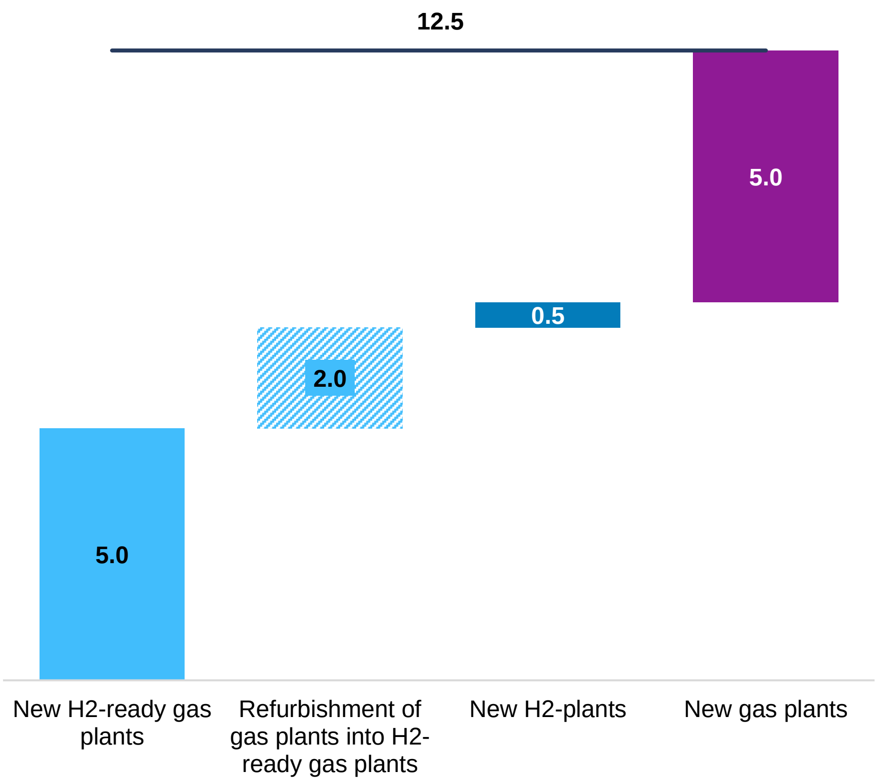
The Power Plant Strategy

- The Federal Government has agreed on a **Power Plant Strategy** (Kraftwerksstrategie) to address security of supply issues in July 2024.
- Within the scope of the strategy, the Federal Government intends to tender **5 GW of hydrogen-ready gas-fired power plants** and **2 GW of refurbished hydrogen-ready** gas-fired power plants that will switch to hydrogen starting in the eighth year of operation.
- Furthermore, Germany plans to tender 5 GW of new gas plants bridging towards a capacity mechanism (operational by 2028)
- As Germany is currently developing a capacity mechanism, the Federal Government plans to design the support for the hydrogen-ready power plants to ensure **compatibility with the capacity mechanism**.

The need for flexible gas-fired power plants

- With rising RES-shares and decreasing conventional generation capacity Germany faces **security of supply issues** as
  - renewable generation is in the North while industry and population centers are in the South.
  - Hence, after the nuclear and coal exit, most new plants will be in the West of the country close to industry and population centers.
- The construction of highly flexible gas-fired power plants is deemed a viable solution since the **build-out of transmission lines is going slowly and storage cannot solve seasonality issues**.

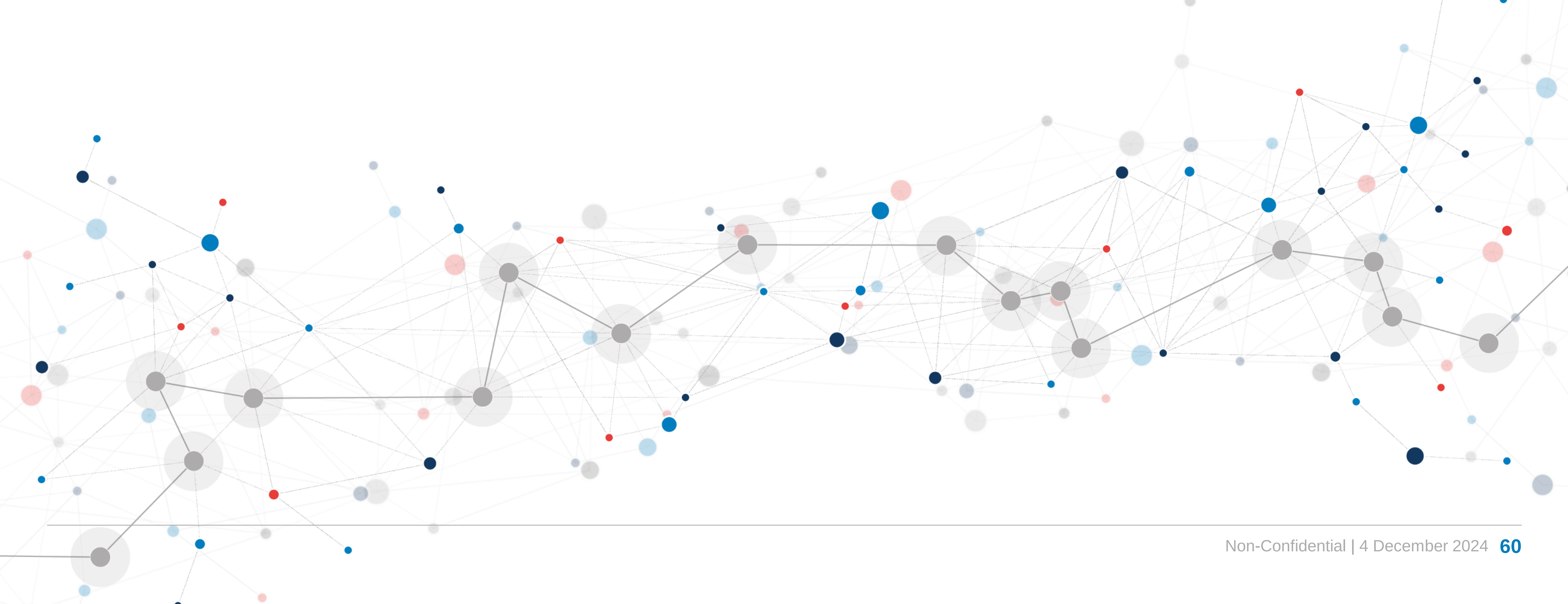
Capacities to be tendered as part of the "Kraftwerksstrategie" [GW]



Sources: Compass Lexecon analysis based on BMWK Press Release July 2024, EWI 2023

10.

The role of gas engines in grid congestion management



Key conclusions: The role of gas engines in grid congestion management

Beyond the heating market Gas engines can access multiple other revenue streams in the power market.

- Congestion cost could increase significantly, due to the need for decarbonisation and uncertainty around network reinforcement.
- There are three different type of management congestion value, on both side of the network bottleneck: Energy redispatching, reserve and countertrading. Gas engines can be remunerated for all these services, if they are located behind grid bottlenecks and upward activation is needed.

Source: Compass Lexecon analysis

Outline: congestion management revenues

Revenue Source

- **Heat sale revenues**
- **Electricity wholesale market revenues** incl. longer-term flexibility
- **Ancillary services**
  - **mFRR** ("tertiary reserve")
  - **aFRR** ("secondary reserve")
- **Revenue from CRMs** (Capacity Remuneration Mechanisms)
- **Congestion management revenues**
  - Congestion management: Need and outlook
  - Congestion management & opportunities for gas engines
- **Subsidies**

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, RES … renewable energy source, DSO … distribution system operator.
Source: Compass Lexecon analysis

Congestion management: Need and outlook

Congestion costs have increased since the beginning of the 2020s, with network reinforcement investment lagging behind the roll-out of renewable generation capacity

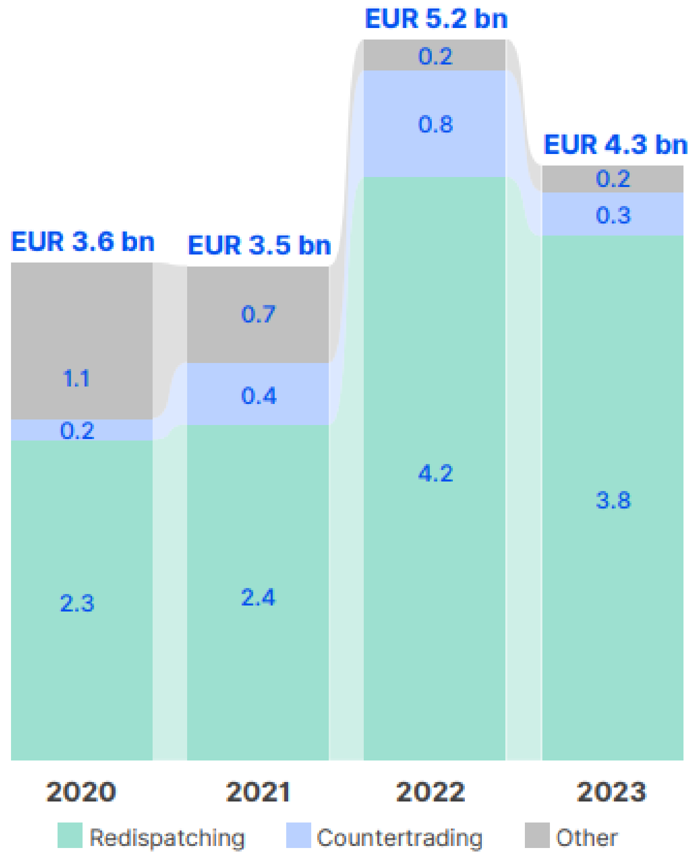
Congestion management cost has been rising recently, due to network reinforcement lagging behind the roll-out of renewable generation capacity

- Congestion management specifically has seen a rise in volume and costs in the past decade due to an increasing number of periods in which the current networks experience local constraints such as voltage drops or capacity limits
- It includes the cost of:
  - Redispatching: activation of bids and offers in specific network nodes, often through the balancing market. This includes cross-border redispatching when generators in a different zone help resolve a local congestion
  - Countertrading: Exchange of bids and offers between bidding zones and TSOs to trade against the congestion cause, thus address cross zonal congestions

These congestion management costs (= revenues for flexibility providers) could continue increasing in the future

- Congestion cost could continue growing if renewable development increases at a faster pace than network reinforcement, as there will be an increasing amount of hours for which the network will not manage to convey the energy to the load
- With the amount of renewables needed to achieve climate goals, and the cost of needed network reinforcement, it is likely that congestion management will remain a key component of system management. **An increasing amount of flexible generation would then be needed to ensure security of supply, creating value for assets like gas engines**

Evolution of EU congestion management cost (€bn, nominal)



Source: ACER – Transmission capacities for cross-zonal trade of electricity and congestion management in the EU

Congestion management and opportunities for gas engines

There are three different types of management congestion value, on both side of the network bottleneck; depending on their location ICE-CHPs can benefit from associated remunerations.

Value	Opportunities for gas engines
Energy redispatching (including cross-border)	• Gas engines that participate in the balancing market, intraday or day-ahead market can benefit from redispatching revenues, **depending on the market design** • They are particularly likely to be called, if they are installed in **zones or lines that are often congested**.
Congestion management reserve	• Gas engines may participate in congestion management auctions, if they are in locatio**ns that have been identified as congested**, and if the market organises such auction
Countertrading	• Countertrading does not target specific generators (unlike redispatching), but gas engines **participating in energy markets could be activated**

Abbreviation: mFRR … manual frequency restoration reserve, TSO … transmission system operator.
Source: ACER – Transmission capacities for cross-zonal trade of electricity and congestion management in the EU

11.

Gas engines and subsidies

Key conclusions: Gas engines and subsidies

Gas engine CHPs can access support schemes if they are efficient enough, including investment support, subsidies and exemptions

- Support schemes for CHPs in Europe can take various forms – the availability usually differentiates between fuels and installation sizes.
- **Case Study:** The Czech CHP subsidy regime is a case study for a scheme that is also open for natural gas fired high-efficient co-generation.
- In line with the EU Taxonomy efficient natural gas-fired CHPs can contribute to mitigate climate change by a) replacing coal and other fossil fuel generation or b) having very low lifecycle $CO2_{eq}$ emissions.
- ICE-CHPs running on natural gas are within regulatory emission limits of the EU Taxonomy.

Source: Compass Lexecon analysis

Outline: gas engines and subsidies

Revenue Source	
Heat sale revenues	
Electricity wholesale market revenues incl. longer-term flexibility	
Ancillary services	**mFRR** (“tertiary reserve”)
	aFRR (“secondary reserve”)
Revenue from CRMs (Capacity Remuneration Mechanisms)	
Congestion management revenues	
Subsidies	

- **Toponomy of CHP aid**
- **Case Study: The Czech DH subsidy scheme**
- **Criteria of the EU taxonomy for natural gas CHPs**
- **CO2 emissions and compliance with the Taxonomy**

Abbreviation: mFRR … manual frequency restoration reserve, aFRR … automatic frequency restoration reserve, CRM … capacity remuneration mechanism, CHP … combined heat and power plant.
Source: Compass Lexecon analysis

Toponomy of CHP support schemes

Support schemes for CHPs in Europe can take various forms – the availability usually differentiates between fuels and installation sizes.

Type of support	Examples for implementation
Investment support	▪ **Germany**: investment subsidies by the Market Incentive Program (MAP) for biogas CHPs. Under the federal support scheme for efficient heating networks (BEW) communes can secure additional funding for CHPs.[3,4]
Feed-in-tariff (FiT)	▪ **Germany**: National support scheme for renewable heating: biogas & biomass CHP FiT through Renewable Energy Act (EEG) and the CHP Act (KWK-G)[1,3,4]
Feed-in-Premium (FiP)	▪ **Finland**: Fixed premium: CHP producers receive 50 EUR/MWh (biogas) or 20 EUR/MWh (wood)[2]
	▪ **Germany**: German Combined Heat and Power Generation Act 2023 (KWKG 2023): support of new and modernised CHPs. CHPs have to offer their electricity on the market and receive a fixed premium on top of the market price.[2]
	▪ **Czech Republic:** Technologies that generate electricity from high-efficiency CHP installations (except solid fossil fuels, diesel and oil) are eligible to take part in tenders for a feed-in-premium for a duration of 15 years.[8]
Tax exemptions / rebates	▪ **Germany:** Small CHPs (<2MW) are exempt from electricity tax (§ 12b Abs. 5 StromStV)[5]
	▪ **EU:** In the proposed Revision of the Energy Taxation Directive CHPs are included as optional tax exemptions.[6]
Efficiency certificate scheme	▪ **Belgium:** Under the combined heat and power (CHP) certificates scheme, high-efficiency cogeneration installations receive one certificate for each MWh of energy saving they realise.[8]

Sources: Compass Lexecon analysis based on [1] EC (2021), District Heating and Cooling in the European Union, [2] EC (2021), District Heating and Cooling in the European Union Annexes 3-5 [3] EC (2021), District Heating and Cooling in the European Union Annexes 6-7, [4] Bundesverband Kraft-Wärme-Kopplung [5] ASUE Fördermittel [6] EP (2024), Revision of the Energy Taxation Directive: Fit for 55 package [7] Kraft- und Wärmekopplungsgesetz 2023; [8] VREG , [9] Cogen Europe Country Focus Webinar Series: Spain

Case study: Czech CHP subsidy regime

The Czech government supports newly commissioned or modernised low-carbon CHPs by auctioning a fixed market premium with a price ceiling for 15 years.

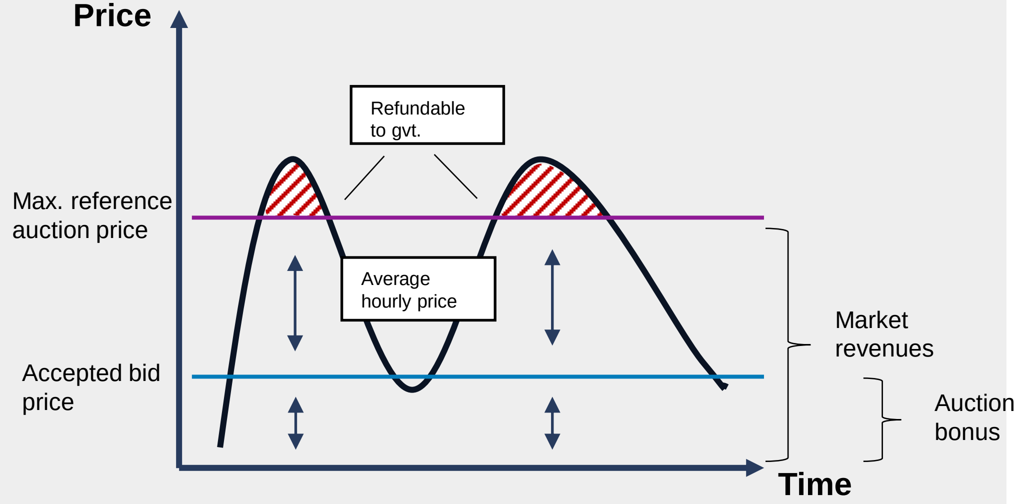
The Czech government offers a fixed market premium with a ceiling price for the modernisation or commissioning of new efficient CHPs.

- The Czech government offers a fixed market premium to replace coal-fired CHPs with efficient CHPs (over 1 MW), using biomass, biogas, mine gas, or natural gas (if renewable or low-carbon replacement is demonstrated by 2050). Support is provided for 15 years.
- If the hourly price exceeds the tendered reference price, the operator must refund the difference.

The price ceiling is adjusted on a yearly basis in reference to German electricity Futures, historic emission allowances and fuel acquisition cost

- The maximum reference auction price is updated yearly, combining electricity, allowance, and fuel acquisition costs.
- It is based on the Phelix Future electricity price for Germany of the following year from January to June, the previous year's weighted average emission allowance price, and the arithmetic average of the EEX (THE) natural gas price from the previous year.

Czech CHP subsidy regime summary[1]



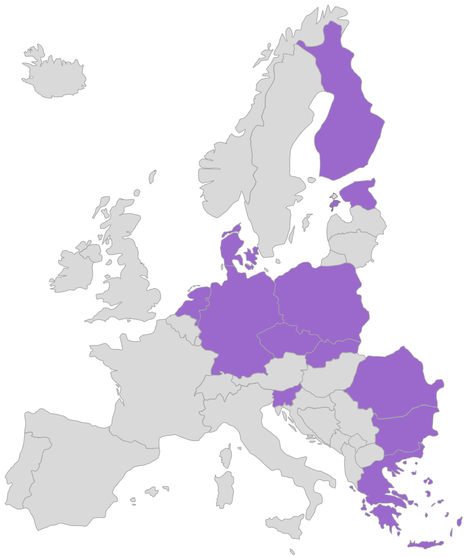
Tender Details[1,2]	
Type of scheme	▪ Feed-in-premium (Installations>1MW)
Max. Quantity	▪ 3 300 hours/a
Max. reference price	▪ *2024 Auction:* 4 190 CZK/MWh (167 EUR_{2024}/MWh)
Duration	▪ 15 years
Supported capacity	▪ *2024 Auction:* 1 280 MW_{el} out of total 3 090 Mw_{el}
Supported fuels	▪ Biomass, Biogas and Mine Gas, Natural Gas (fuel-switch until 2050)

Abbreviation: CHP … combined heat and power.
Sources: Compass Lexecon analysis based on [1] Ministry of Industry and Trade (2024) Press Release: Announcement of the first call to support high-efficiency combined heat and power generation. [2] Ministry of Industry and Trade (2024) Announcement of an auction for operating support for electricity from high-efficiency combined heat and power generation

EU Taxonomy: Eligibility for natural gas-fired CHPs

Efficient natural gas-fired CHPs can contribute to mitigate climate change when replacing coal and other fossil fuel generation

	No	Condition	Satisfied by gas CHP?
	Natural gas CHPs "mitigate climate change" if a) other fossil generation is replaced (see 1.-9.) …		
	1.	Construction permit by **31 December 2030**	✓ **c. 6 years** remaining
Geo-graphical condition	2.	**Replacement of a high-emitting system**	✓ Highest potential in **central and Eastern Europe**
Geo-graphical condition	3.	Capacity does **not exceed replaced capacity**	
Geo-graphical condition	4.	Member state must have **committed to coal phase-out**	
	5.	**Switch to renewable / low-carbon fuel by 31 Dec 2035**	? Requires individual assessment
	6.	Use of renewable energy sources **not possible**	
Techno-logical conditions	7.	CHP must achieve at least **10% energy saving**[1]	✓ **Fulfilled by state-of-technology ICE CHPs**
Techno-logical conditions	8.	Direct GHG emissions have to be **lower than 270 g CO2e/kWh**	
Techno-logical conditions	9.	Reduction of **GHG emissions by at least 55%** per kWh_{output}	✓ if **switch from coal electricity-only plant, some CHPs and boilers**
	… or if b) life-cycle GHG emissions are very low (see 10.) – not covered in detail here		



Significant role of solid / liquid fossil fuels and **commitment to coal-phase out** [3]

Abbreviation: CHP … combined heat and power plant, CCS … carbon capture and storage. Notes: [1] compared to separate production of heat and electricity, acc. to Energy Efficiency Directive [3] Only EU, excluded Greece because of very small DH sector, [4] Estonia does not use coal for energy generation. However, it has committed to phase out production of electricity from shale oil until 2030. Abbreviations: TSE … Total System Efficiency, CHP … combined heat and power, CSS … carbon capture and storage. Source: Compass Lexecon analysis based on NECP Romania, NECP Slovakia, NECP Poland , NECP Slovenia, NECP Germany, NECP Denmark, NECP Estonia, NECP Czechia, NECP Croatia, NECP Finland, NECP Netherlands, European Commssion article on Greek coal phase-out, EC Assessment of Croatian NECP, EU Taxonomy - Nuclear and Natural Gas .

CO_2 emissions of gas CHPs and compliance with the Taxonomy

ICE-CHPs running on natural gas are within regulatory emission limits of the EU Taxonomy.

Exemplary Wärtsilä Internal Combustion Engine CHP ("ICE-CHP")

Electrical Efficiency: **47%**
Heat Efficiency: **40%**
Total System Efficiency ("TSE"): **87%**
Power-to-heat ratio: **1.17**
Assumption: efficiencies refer to **NCV**

Direct emissions per energy carrier

Natural gas
202 g $CO2_{eq}/kWh_{NCV}$
182 g $CO2_{eq}/kWh_{GCV}$

Biomethane
0 g $CO2_{eq}/kWh$

Climate neutral hydrogen[2]
0 g $CO2_{eq}/kWh$

TSE 87%

Direct emissions per energy output

Natural gas
231 g $CO2_{eq}/kWh_{Output}$

Biomethane
0 g $CO2_{eq}/kWh_{Output}$

Climate neutral hydrogen
0 g $CO2_{eq}/kWh_{Output}$

<

EU-Taxonomy direct emissions limit for installation before 2030

EU Taxonomy
270 g $CO2_{eq}$ / kWh

Notes: [1] EED criterium for high-efficient cogeneration. [2] Criteria when defining efficient district heating via emission intensity. Abbreviation: CHP … combined heat and power plant, DH … district heating, NCV … net calorific value, GCV … gross calorific value, ICE … internal combustion engine. Source: Compass Lexecon analysis based on European Taxonomy, Wärtsilä modelling assumptions, Commission Delegated Regulation (EU) 2023/1185, Directive (EU) 2018/2001, Allokationsmethoden für CO2-Emissionen von Strom und Wärme aus KWK-Anlagen.

12.

Appendix: Full case studies

Interview Partners

This study has been informed by insights from a diverse range of stakeholders.

Associations

Euroheat & Power

COGEN EUROPE

ASSOCIATION FOR DISTRICT HEATING of the Czech Republic

Chamber of Commerce Polish District Heating

Companies

Skagen Varmeværk

FŐTÁV Budapesti Távhőszolgáltató Zrt. Budapest

alteo

opec

ALPIQ

Eesti Energia

Source: Compass Lexecon

12.1

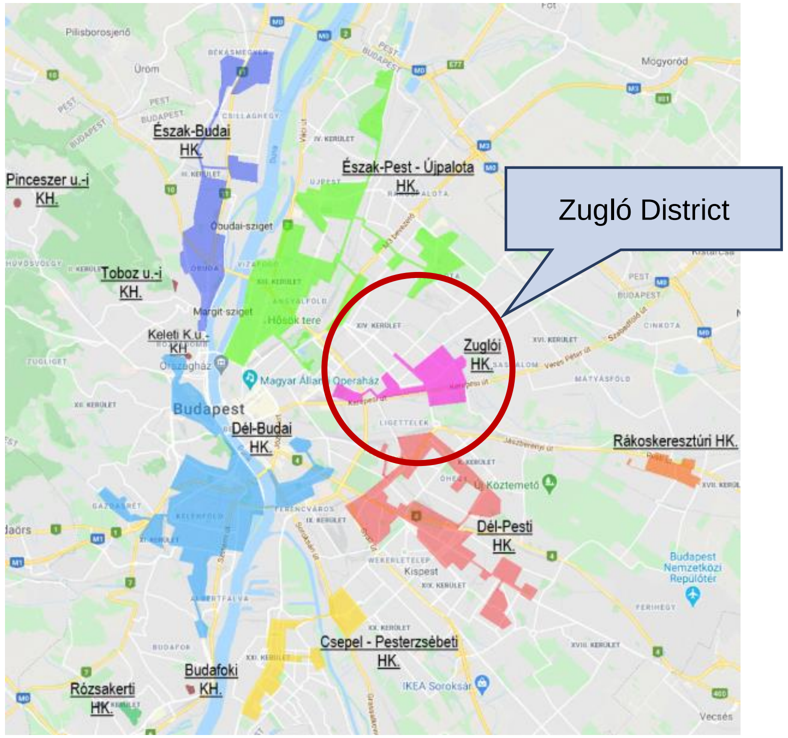
Case Study: Zuglo (Hungary)

Budapest – Zugló district (Hungary)

The district heating system of the Zugló district is part of (but not connected to) Budapest’s district heating system which supplies 245 000 households with c. 2.5 TWh of heat annually.

General City Data (2023)		
Name	Budapest	Zugló district
Population	1 778 052	117 155
City area (km²)	525	18
Population density (1/km²)	3 386	6 462
GDP per capita (EUR_{2022})	39 417	
DH System structure[1] (2023)		
DH system operator	FŐTÁV, subsidiary of BKM	
End-users connected	245 000 residential / 1 800 non residential	-
Heat supplied (GWh_{th})	2 701	-
Electricity generation capacity installed (MW_{el})	-	18
Total heat generation capacity installed (MW_{th})	-	17
Coal and lignite-based generation capacity installed (MW_{th})	0	0
Heat generated (GWh_{th})	307	-
Electricity generated (GWh_{el})	106	-

Budapest FŐTÁV district heating system and the Zugló district



Notes:[1] The generated heat and electricity includes purchases from other power plant operators.
Source: Compass Lexecon Analysis based on Data from the Hungarian Central Statistical Office , and documents from BKM Budapest Public Utilities Final Report 2023 and Kraftszer: Füredi Street Thermal Power Plant

Budapest – Zugló district: DH generation mix and transformation

FŐTÁV mainly relies on waste and natural gas for heat generation. For the future, it aims at increasing energy efficiency and RES share.

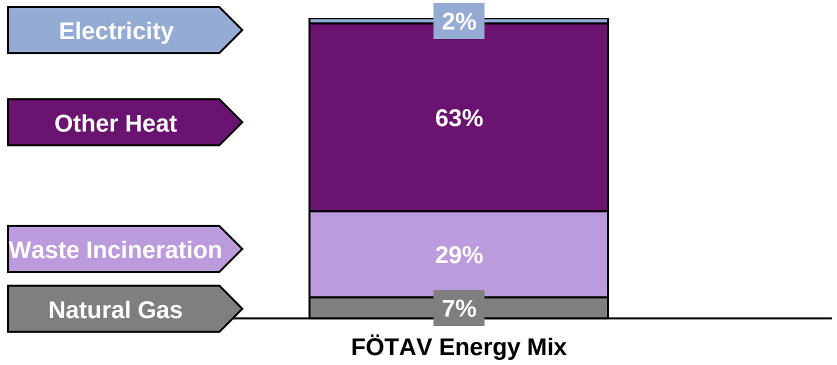
The current generation mix of the Budapest FŐTÁV operator relies on natural gas and waste to supply the district heating system.

- FŐTÁV, the municipal system operator serves 30% of the Budapest district heating market, including the Zuglo district. Approximately 90% of the heat for district heating is bought from external heat producers.
- The district heating network is supplied with heat by 16 CHP plants, two waste incineration plants, and four block boilers. FŐTÁV on its own operates five CHPs, four of which run on natural gas, one on waste. The Zuglo district is supplied with a gas fired CHP plant.

The operator aims at improving the energy efficiency of the district heating system and increase the RES share to 5%.

- FŐTÁV aims at improving the energy efficiency of its operation according to the EU Energy Efficiency Directive. In 2023 it was able reduce its energy input consumption on average by 30%. Most savings were achieved by reducing the use of natural gas. In the future, the operator plans to expand its district heating by adding geothermal energy and heat pumps to the wastewater treatment facilities to increase the RES share in a first step to 5%.[2]

FŐTÁV energy mix, 2023 [%] [1]



	FŐTÁV Budapest DH supply sources[1]	
Generation source	FŐTÁV Capacity	External Capacity
Waste	• 1 CHP	• 1 Incineration plant
Natural Gas	• 5 CHPs	• 12 CHPs
Electrical Energy		• 4 Block boiler
Total Heat sold 2023	2.41 TWh	

Source: *Compass Lexecon Analysis based on Data from documents from [1] BKM Budapest Public Utilities Final Report 2023 [2] Future plans are based on interviews with the operator.*

12.2

Case Study: Skagen (Denmark)

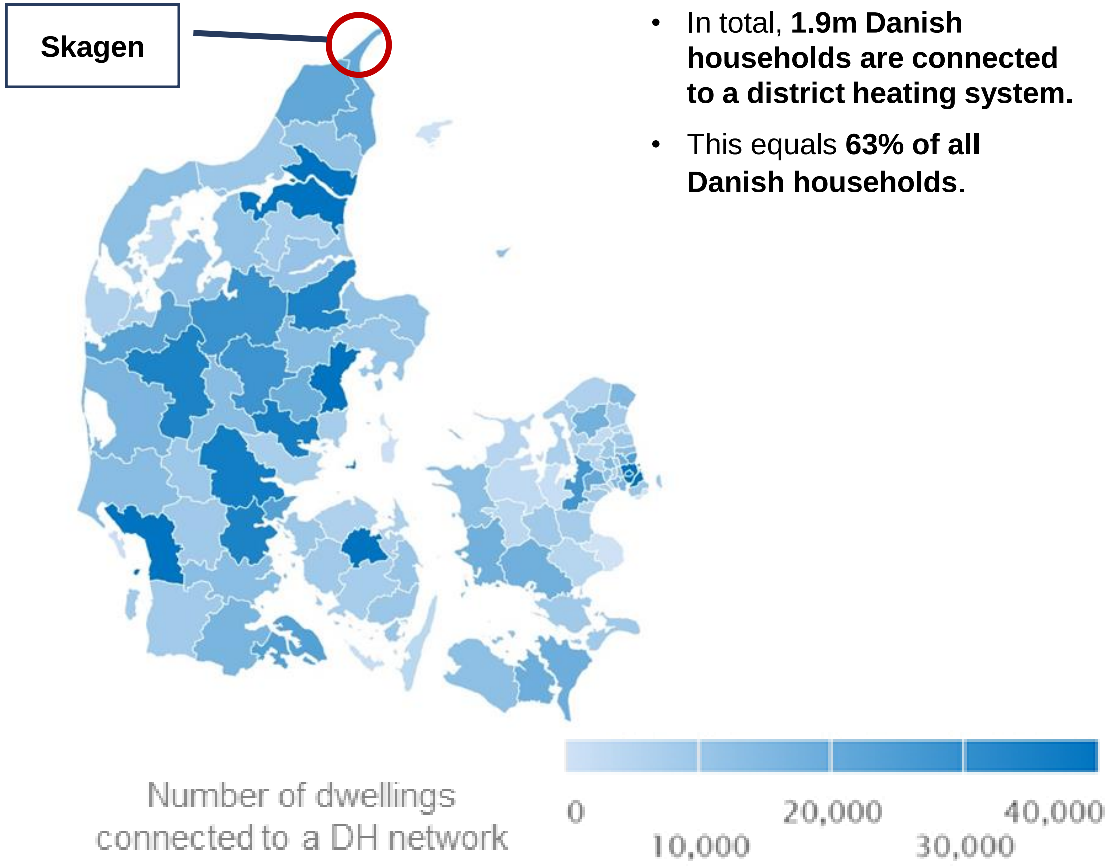
Skagen (Denmark): District Heating system overview

The district heating grid of Skagen supplies ca. 50% of its population with heat. The heat generation is free of coal and lignite.

General City Data (2023)	
Name	Skagen
Population	7 476
City area (km²)	7.81
Population density (1/km²)	956.6
Nordjylland 2022 GDP per capita (EUR_{2024})	48 670

DH System structure	
DH system operator	**Skagen Varmeværk**
End-users connected (2023)	3 189
Heat supplied (2023) (GWh_{th})	69
Electricity generation capacity installed (MW_{el})	4
Total heat generation capacity installed (2023) (MW_{th})	89
Coal and lignite-based generation capacity installed (2023) (MW_{th})	0
Heat generated (2023) (GWh_{el})	68 (+17 waste heat purchased)
Electricity generated (2023) (GWh_{th})	8

Heat map of Danish households connected to a district heating system [num. households]



- In total, **1.9m Danish households are connected to a district heating system.**
- This equals **63% of all Danish households**.

Note: The GDP data for Skagen was not available so the regional GDP is displayed. Abbreviation: DH … district heating.
Source: Compass Lexecon Analysis based on the Varmevaerk Annual Report 2023, Skagen Varmevaerk Financial statement of the year 2022, Danish Energy Ministry data website, and Danmarks Statistik, The role of district heating in the energy system,, the Green Conversion Investment Plan for Skagen Varmevaerk and Countryeconommy Data Platform

Skagen Varmeværk: District heating generation mix & transformation

The primary source of energy for district heating in Skagen is electricity, supplemented by gas-fired CHPs.

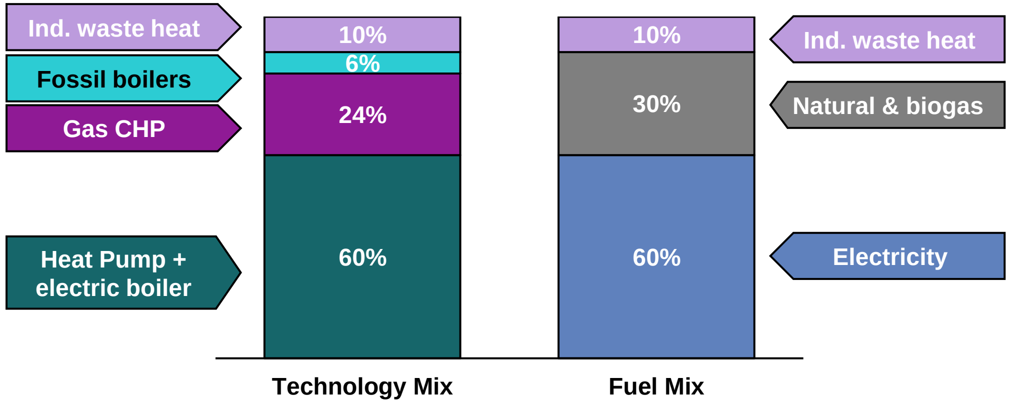
Air to water heat pump is the primary source of heat, accounting for about 60% of heat.

- The district heating grid of Skagen currently supplies approximately 50% of the local population with heat and is continuously expanding to connect a greater number of end-users to the system.
- Approximately 60% of the supplied heat is produced by heat pumps and electric boilers.
- In 2022, gas-fired CHPs produced approximately 24% of the heat mix.
- Natural gas is substituted by biogas when it is available within the Skagen gas grid.

Further decarbonisation is planned, but there are no plans to phase out natural gas entirely.

- Over the past decade, Skagen Varmevaerk has implemented a number of environmentally-focused initiatives, including the utilisation of waste heat from the production of fishmeal and fish oil at FF Skagen.
- Nevertheless, there is no plan for the phase-out of gas engines.

Heat generation mix, 2022 [%] [2]



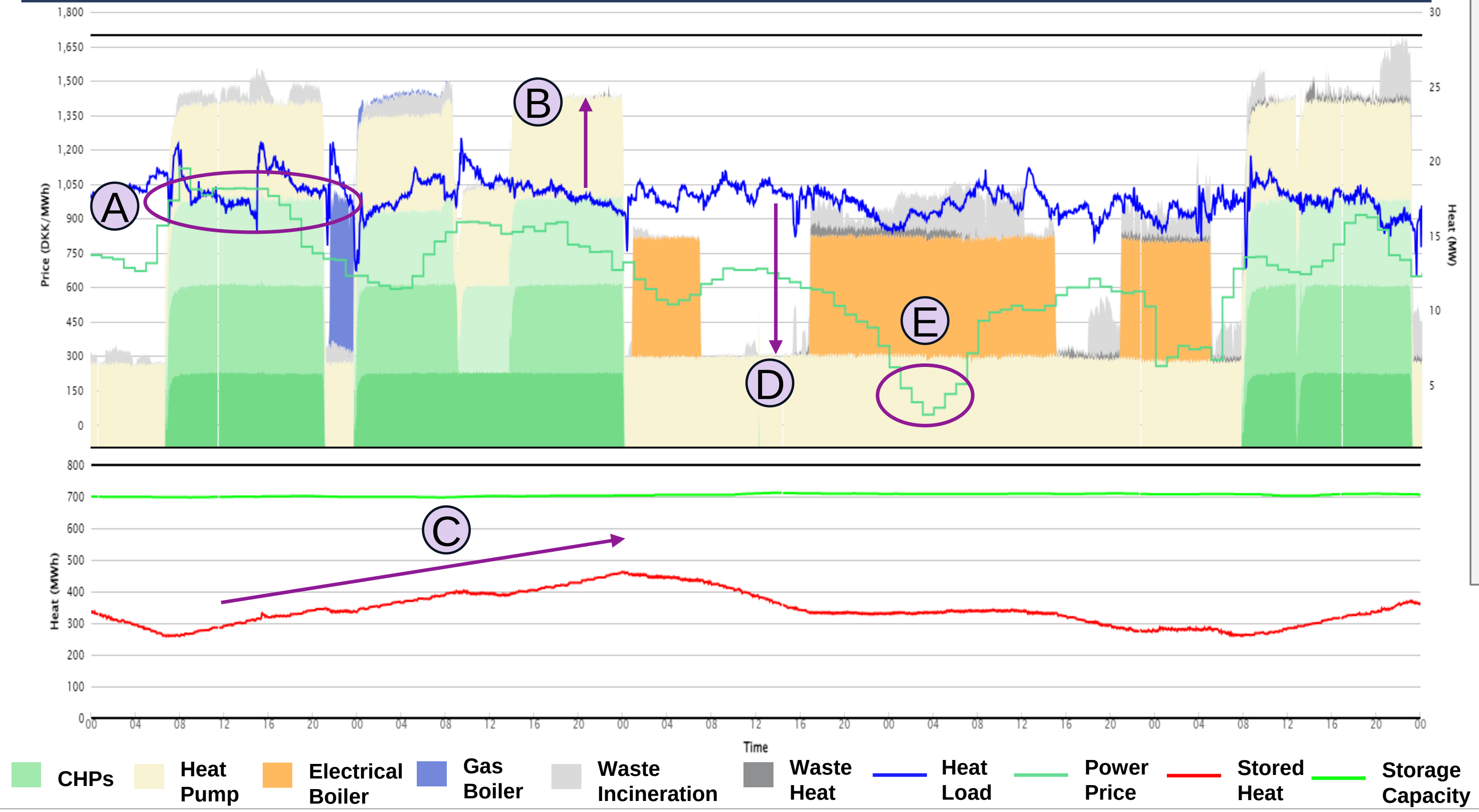
	Skagen Varmeværk DH supply sources[1]
Generation source	Internal Capacity
Waste (external)	▪ 1 Wastewater heat recovery ▪ 1 Industrial waste heat
Natural gas & Biogas	▪ 3 ICE-CHPs ▪ Gas boiler
Electrical Energy	▪ Heat Pumps ▪ Electric boiler
Total Heat sold 2023	69 GWh

Notes: The gas boiler and CHPs run on both, natural and biogas, depending on the season.
Abbreviations: ICE … internal combustion engine, CHP … combined heat and power plant.
Source: Compass Lexecon analysis based on data from [1] EMD International, [2] Danish Energy Agency and stakeholder interviews.

Case study: Generation portfolio effects in Skagen (Denmark)

In a portfolio comprising heat-pumps, electrical boilers and ICE-CHPs allows to produce heat also during high power prices. Conversely, electrical heat sources can be used during periods of low power prices.

Heat generation asset dispatch in the context of winter electricity prices



Ⓐ During periods of **high power prices**, it is attractive for the CHPs to generate electricity (and heat).

Ⓑ In the exemplary period, **heat generation exceeds heat demand** due to the production of the CHPs.

Ⓒ As heat production exceeds heat demand, the **amount of stored heat increases**.

Ⓓ Subsequently, during periods with less attractive power prices (to the CHPs), the district heating system can **rely on stored heat** (previously produced by the CHPs).

Ⓔ As low power prices continue, the direct electrical boiler produces the necessary heat. In contrast to the CHPs, **low power prices are attractive** to the direct electrical boiler.

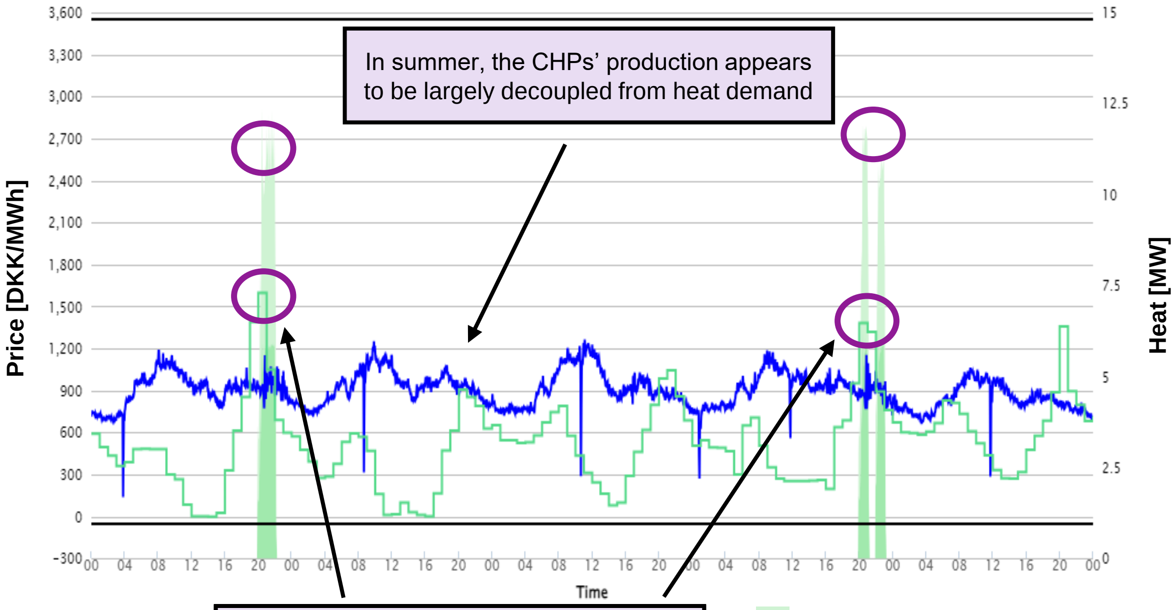
A generation portfolio with both heat consumption & production allows to **fully optimize against the electricity price** (i.e. "buy low, sell high")

Note: The illustration shows the period 7 – 11 December 2023.
Abbreviation: ICE … internal combustion engine, CHP … combined heat and power plant.
Source: Compass Lexecon analysis based on Energyweb.dk

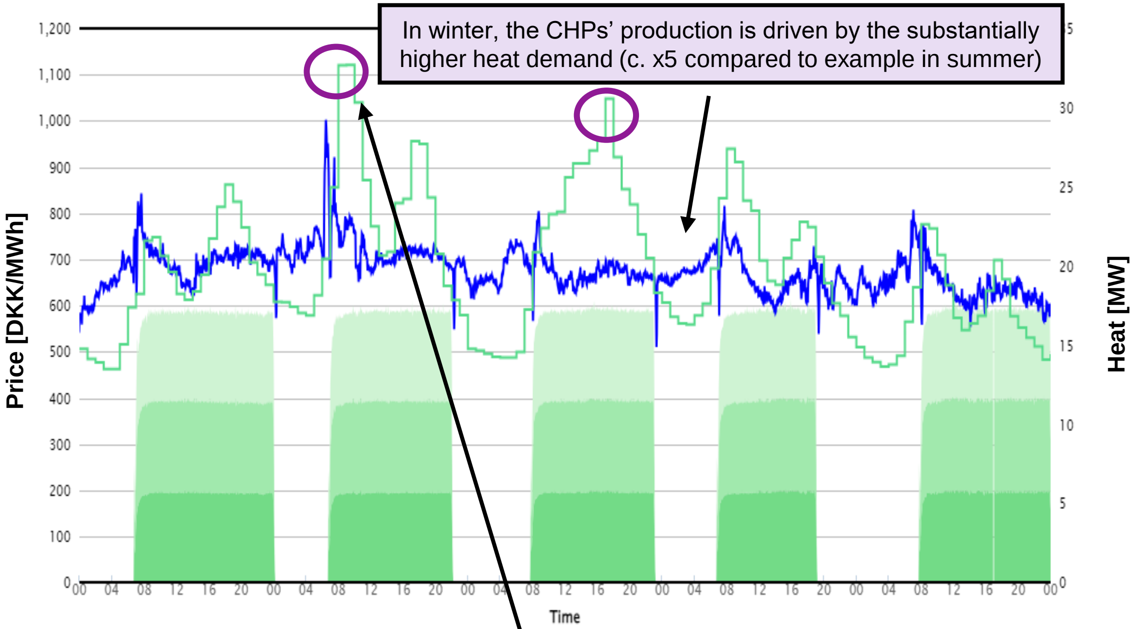
Case study: CHPs providing intraday flexibility in Skagen (Denmark)

The CHPs' dispatch during summer is largely driven by the power-markets flexibility needs and the resulting revenue potentials for dispatchable technologies.

CHPs' dispatch during a typical 5-day period in summer



CHPs' dispatch during a typical 5-day period in winter



CHP Load | Heat Load | Power Price

Note: The axes of the two graphs are not to the same scale. Other generation assets' generation are omitted from the graphs for illustration (direct-electric boiler, heat-pump, gas-boiler, waste heat, waste incineration). The illustration shows the period of July 15th – 19th, 2024 (left graph) and January 15th – 19th, 2024 (right). Source: Energyweb.dk

12.3

Case Study: Grudziądz (Poland)

Grudziądz (Poland): District Heating system overview

The district heating system of Grudziądz serves c. 50% of its population. The heat is generated almost entirely in a lignite-based CHP.

General City Data (2023)	
Name	Grudziądz
Population	89 081
City area (km²)	58
Population density (1/km²)	1 542
Province 2022 GDP per capita[1] (EUR_{2022})	14 613

DH System structure	
DH system operator	OPEC Grudziądz
End-users connected (2023)	c. 50% of population
Heat supplied (2023) (GWh_{th})	245 (incl. losses)
Electricity generation capacity installed (MW_{el})	18
Total heat generation capacity installed (2023) (MW_{th})	171
Coal and lignite-based generation capacity installed (2023) (MW_{th})	170
Gas fired CHP capacity installed in 2023	0 MW_{el} 0 MW_{th}
Heat generated (GWh_{th})	-
Electricity generated (GWhel)	-

Location of Grudziądz in Poland

Source: Citypopulation Grudziądz

Notes: [1] We use the GDP per capita of the region Kujawsko-pomorskie from Eurostat.
Source: Compass Lexecon Analysis based on OPEC Grudziądz and WIP Renewable Energies Upgrade DH Grudziądz, and the Central Statistical Office, Eurostat

Grudziądz (Poland): DH generation mix and transformation

The current generation mix relies on coal generation and to a smaller share on biomass. It is targeted to increase the renewable share to 54% by 2025 and 100% by 2030.

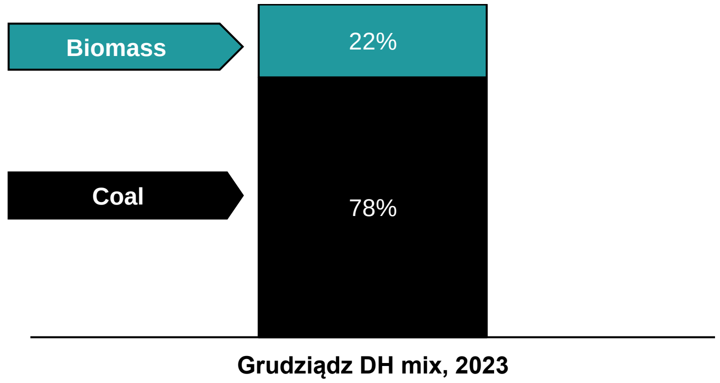
The majority of heat supplied in Grudziądz is supplied by burning coal and to a smaller extent biomass.

- The district heating system in Grudziądz is supplied by the 169.5 MW Łąkowa CHP coal plant[1] and a 1.9 MW biogas heating plant.
- In 2023, 78% of primary energy was coal and 22% biomass.[1]

In the short term the DH system is expected to use 54% of its primary energy from renewables by 2025 and increase this share to 100% by 2030.

- The operator of the district heating system plans to increase the share of renewable energy. In the short term, the renewable share in primary energy consumption is expected go up to 45% in 2024 and 54% in 2025.
- This should partially be achieved by co-firing biomass with coal.
- Furthermore, the operating company targets to increase the RES share up to 100% by 2030, **but it has not yet published a transformation path**.[2]

Heat generation primary energy mix, 2023 [%] [1]



	OPEC Grudziądz DH supply sources[1]
Generation source	Capacity
Coal and Biomass	CHP Plant: **169.5 MW**
Biogas	Biogas Heating Plant: **1.9 MW**
Total Heat Generated 2023	245 GWh

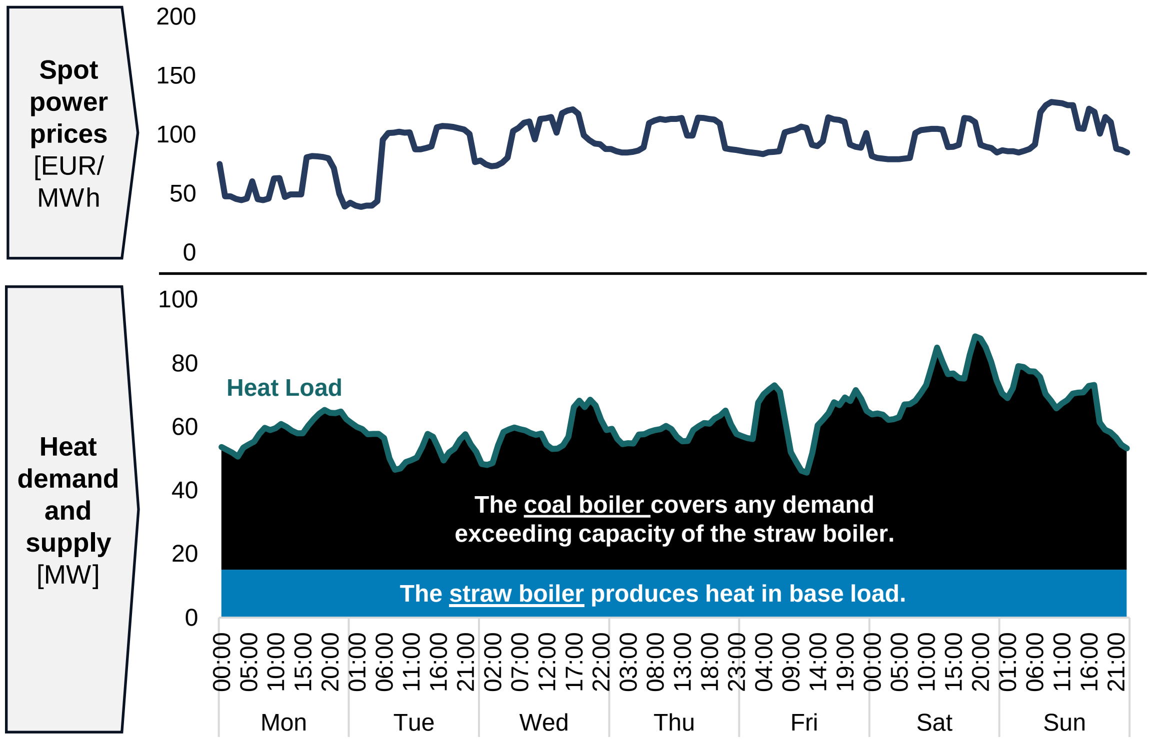
Abbreviation: DH … district heating, CHP … combined heat and power plant, RES … renewable energy source.
Source: Compass Lexecon Analysis based on [1] OPEC Grudziadz [2] District Heating Cities: Decarbonising District Heating in Europe

Case study: Substitution of coal by an ICE-CHP in Grudziądz (Poland)

OPEC GRUDZIĄDZ

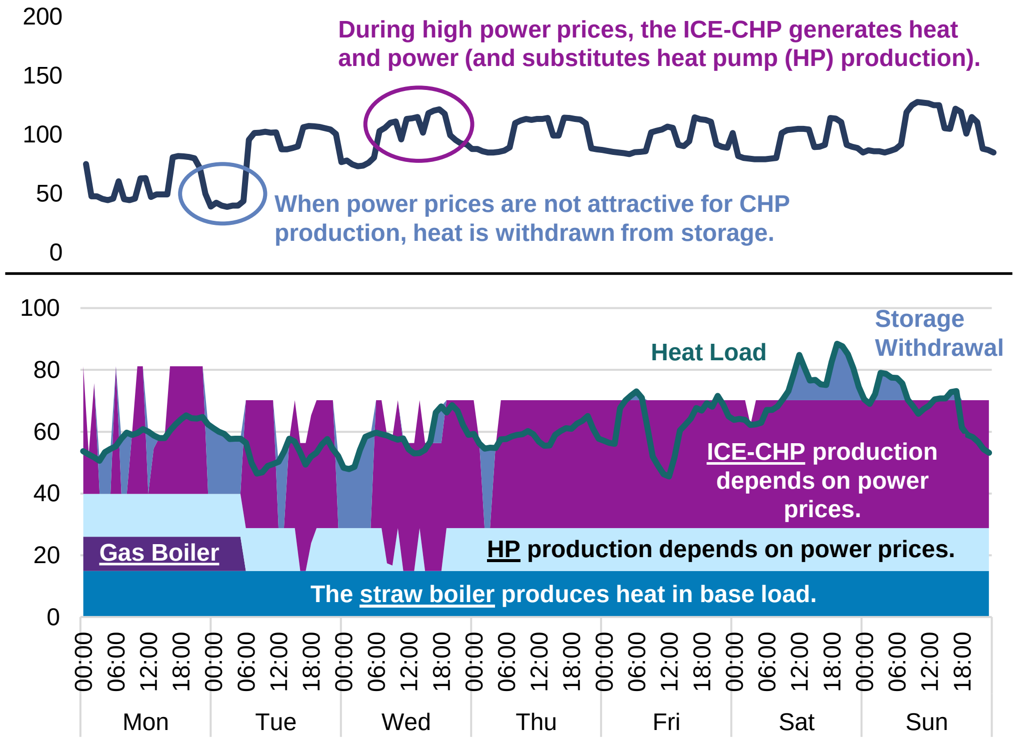
Wärtsilä's modelling illustrates how a currently static, coal-dominated system could be transformed into a flexible portfolio of generation assets.

Exemplary (modelled) heat generation in status-quo setup [MW]



- The base setup does not include any storage capacities, i.e. heat demand equals heat generation at all times.
- Heat is produced in heat-only boilers, fully independent from power prices (both from consumption or production perspective)

Exemplary (modelled) heat generation after transition to portfolio with heat pump and ICE-CHPs [MW]



- The combination of heat storage, a heat pump and ICE-CHPs allows for flexible production – depending on power prices.
- Periods of unattractive power prices can be bridged by withdrawal of heat from heat storage.

Abbreviations: HP … heat pump, DH … district heating, ICE … internal combustion engine, CHP … combined heat and power plant.
Source: Modelling by Wärtsilä

12.4

Case Study: Narva (Estonia)

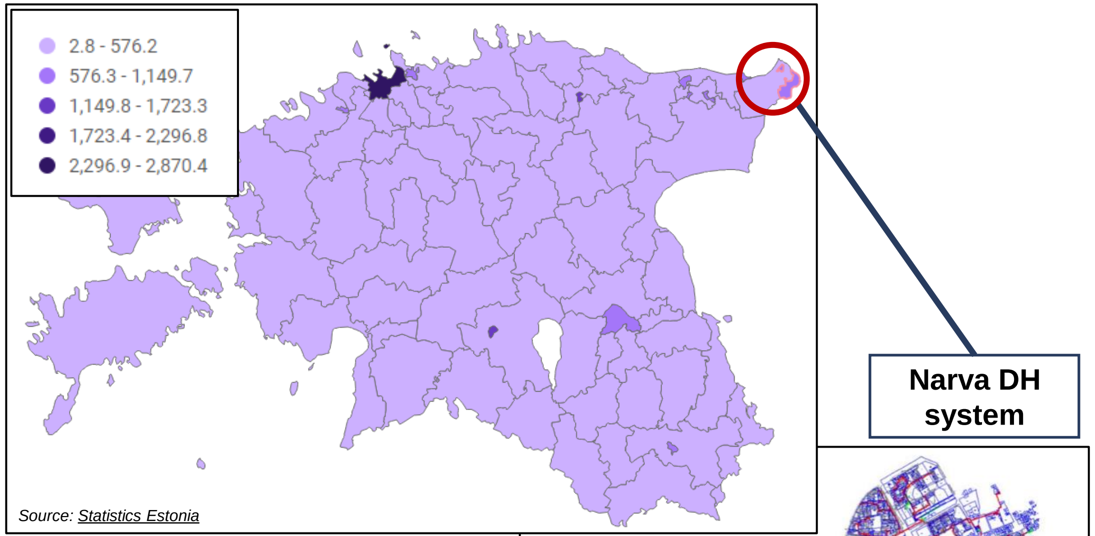
Narva (Estonia): District Heating system overview

In 2023, the district heating system of Narva supplied 770 end-users with 405 GWh of heat.

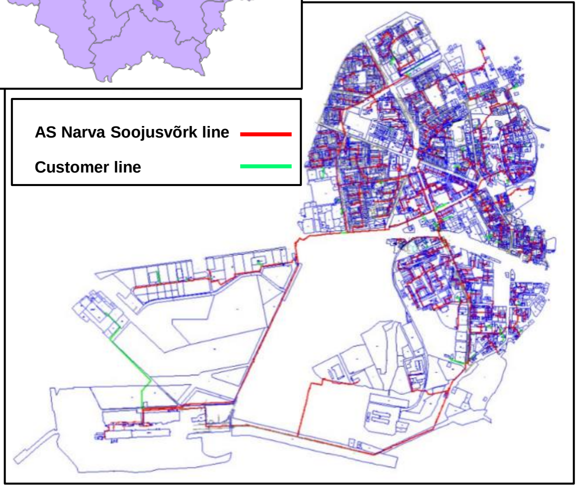
General City Data (2023)	
Name	Narva
Population	53 360
City area (km²)	68.71 km²
Population density (/km²)	777/km²
GDP per capita (EUR_{2022})	19 777 EUR[1]

DH System structure	
DH system operator	Narva Soojusvõrk AS, subsidiary of Eesti Energia group
End-users connected (2023)	770
Heat supplied (2023) (GWh_{th})	405
Electricity generation capacity installed (MW_{el})	215
Total heat generation capacity installed (2023) (MW_{th})	160 + 240
Coal and lignite-based generation capacity installed (2023) (MW_{th})	0
Gas fired CHP capacity installed in 2023	0 MW_{el} 0 MW_{th}
Heat generated (2021) (GWh_{th})	463
Electricity generated (2022) (GWh_{el})	—

Population Density of Estonia and Narva [inhabitants per km²]



Source: Statistics Estonia



Note: [1] We use the GDP per capita of Estonia. The data for Narva in isolation is unavailable.
Source: Compass Lexecon Analysis based on population and GDP data from Statistics Estonia and World Bank, Energex (2023) Narva City Heat Economy Development Plan 2023-2032 and AS Narva Soojusvork, Enerfit Press Release May 2024

Narva (Estonia): District heating generation mix and transformation

The Narva DH system historically relied on shale oil and biomass. Fossil fuel heat generation will likely be replaced by additional biomass.

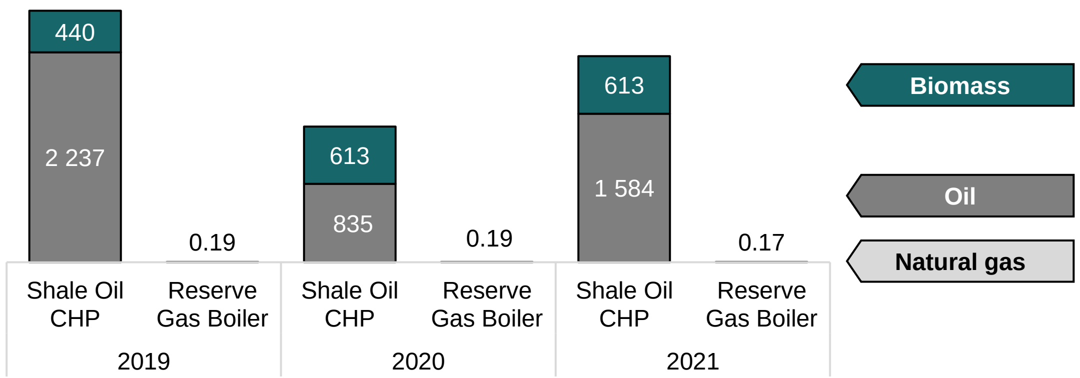
Historically, the Narva district heating system relied on shale oil, but due to falling gas prices it has transitioned to natural gas (after 2022).

- The Narva district heating system is supplied by the 160 MW Narva Baltic Power Plant CHP which runs on shale oil. The shale oil CHP operates at the market price of electricity, i.e. at times of low electricity prices, the heat for the city of Narva is produced by the stand-by power plant.[1]
- The reserve boiler plant has three 80 MW gas boilers. This results in a total of 400 MW thermal capacity.
- Due to falling gas prices the shale oil plant has been temporarily decommissioned in 2024, as it could not run profitably. It is planned to add the plant as reserve capacity.[2]

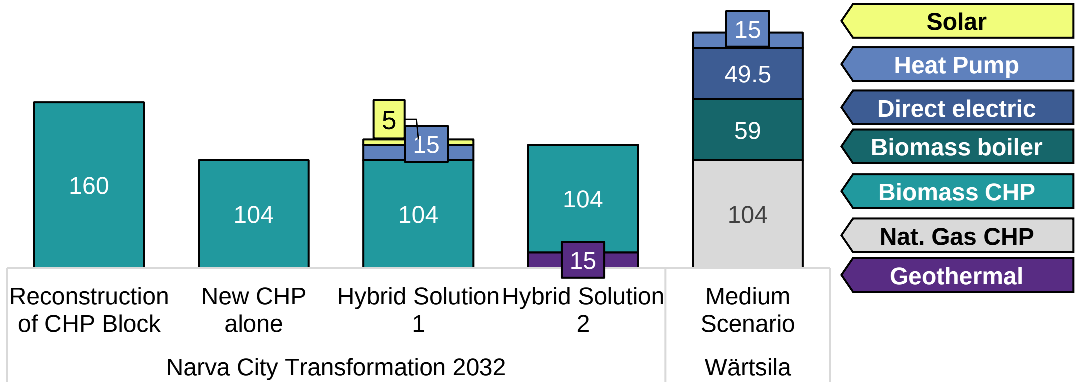
Studied transitions scenarios include the replacement of the fossil fuel district heating with either biomass or a hybrid solar and heat pump solution.

- The city of Narva commissioned a district heating development plan for 2032 for the decoupling of the district heating from shale oil. The study found that the cheapest option would be the reconstruction of the Baltic Power Plant (biomass), followed by a new cogeneration plant with hybrid solutions (solar and heat pumps) and a new cogeneration plant (biomass).[1]
- The Wärtsila modelling suggests that an alternative solution could rely on a 104 MW natural gas CHP, biomass and electric boilers, a heat pump and heat storage. [3]

Narva district heating fuel use, 2019-2021 [GWh][1]



Narva district heating transition scenarios, 2032 [MW][1,3]



Abbreviation: CHP … combined heat and power plant, DH … district heating.
Source: Compass Lexecon analysis based on [1] Energex (2023) Narva City Heat Economy Development Plan 2023-2032 [2] Enerfit Press Release May 2024 [3] Wärtsila Narva Heat Portfolio Modelling

Narva (Estonia): District heating generation mix and transformation

Wärtsilä's modelling showcases that besides the options presented in Narva's heat development plan, there is the alternative of adding gas engines to the generation mix.

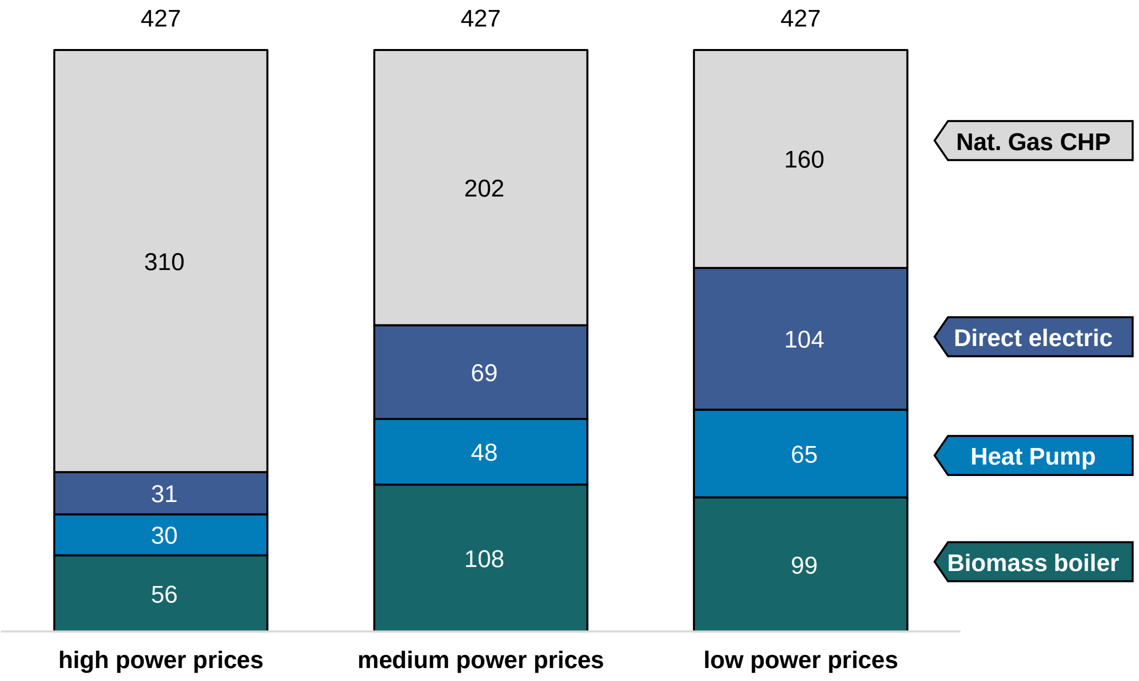
A combination of electricity-consuming and electricity-producing assets allows to adjust the heat generation mix dynamically depending on power prices.

- When power prices are high, the natural gas CHP can combine generating electricity market revenues with supplying heat to the DH system.
- Conversely, in a scenario of low power prices, a larger share of the heat would be produced by electricity-consuming technologies.
- In light of a possible lack of dispatchable capacities beyond 2027 , the inclusion of gas CHPs could also improve security of supply in the electricity sector.[2]

Hurdles to implementation[3]

- In the tender for a new heat-generating asset, the **lowest heat generation cost** will be selected. This favours biomass boilers over gas CHPs.
  - Importantly, this method does not fully account for advantages of gas CHPs beyond heat generation cost. The CHP would also generate power market revenues and provide flexibility to the power system
- There is **regulatory uncertainty around obtainable heat revenues**: at the time of FID, the investor would not know the heat price it would receive.

Wärtsilä Modelling: Illustrative generation mix in different power price scenarios[1] [GWh]



Underlying power price curves are outputs of Wärtsilä's fundamental power market model in two extreme climate years and one average climate year assuming generation capacities as reported in ENTSO-E ERAA 2022.

Abbreviation: CHP … combined heat and power plant, DH … district heating, FID … final investment decision.

Source: Compass Lexecon analysis based on [1] Wärtsila Narva Heat Portfolio Modelling [2] NECP Estonia [3] Insight from stakeholder interviews.

13.

About Compass Lexecon and the EMEA Energy Practise

About Compass Lexecon

COMPASS LEXECON
part of: FTI CONSULTING

- One of the world's leading economic consulting firms, Compass Lexecon provides corporations, governments and law firms with clear analysis of complex issues.
- We have been involved in a broad spectrum of matters related to economics and finance – providing critical insight in legal and regulatory proceedings, strategic decisions and public policy debates. Our experience and expertise apply to virtually any question of economics, in virtually any context of the law or business, and in any industry.
- We have more than 500 professionals worldwide and more than 90 professionals in Europe – based in Brussels, Berlin, Düsseldorf, London, Madrid and Paris.

Facts and Figures

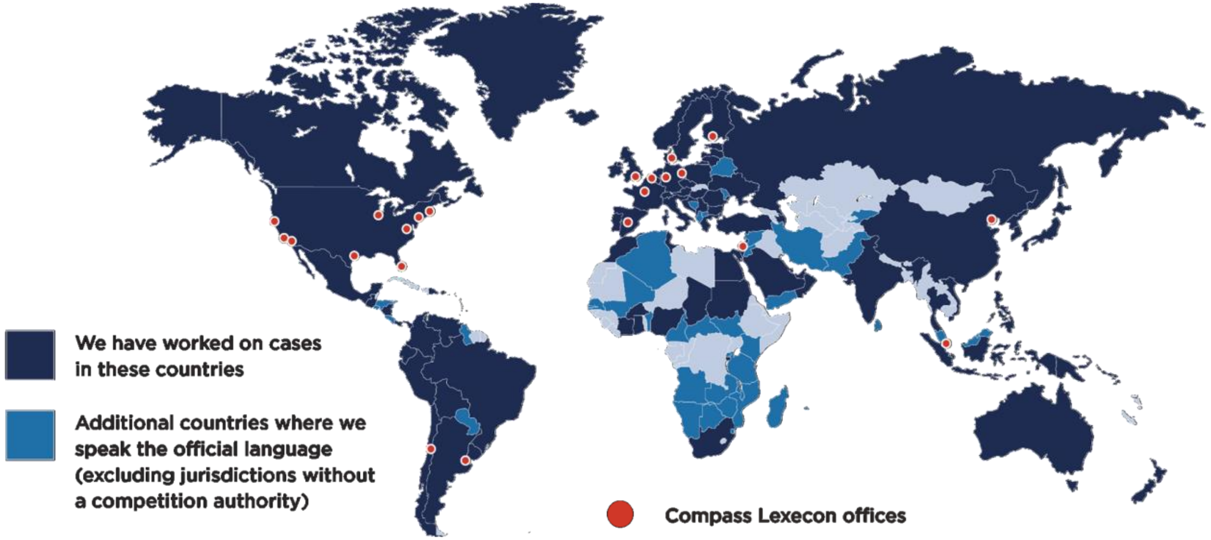
850+	**Economists**	200+	**Ph.D.** economists
23	**Offices** worldwide	2	**Nobel Prize** winners
182	**Merger-related** matters advised on in the last 12 months	84%	**Of the Fortune 100 companies** advised
319	**Antitrust litigation** matters advised on in the last 12 months	90+	**Jurisdictions** in which we have advised clients

Services

- Accounting litigation services
- Antitrust, competition and M&A
- International litigation & arbitration
- Intellectual property
- Valuation & financial analysis
- Market or sector inquiries
- State aid
- Damages
- Econometric analysis
- Economic and financial regulation

Sectors

- **Energy**
- Healthcare
- High Technology
- Pharmaceuticals
- Telecommunications
- Financial services
- Transportation
- International Trade
- Internet
- Entertainment & media



Source: Compass Lexecon

Compass Lexecon's senior energy experts in Europe[1]

We have a team of 100+ experienced energy sector consultants in offices across Europe

London
Joe Perkins
Jason Mann
Stuart Amor
Nicholas Brooks
Martina Lindovska
Boaz Moselle

Berlin
Anton Burger
Ljobomir Mitrasevic

Copenhagen
Sergey Khodja-mirian

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Petr Spodniak
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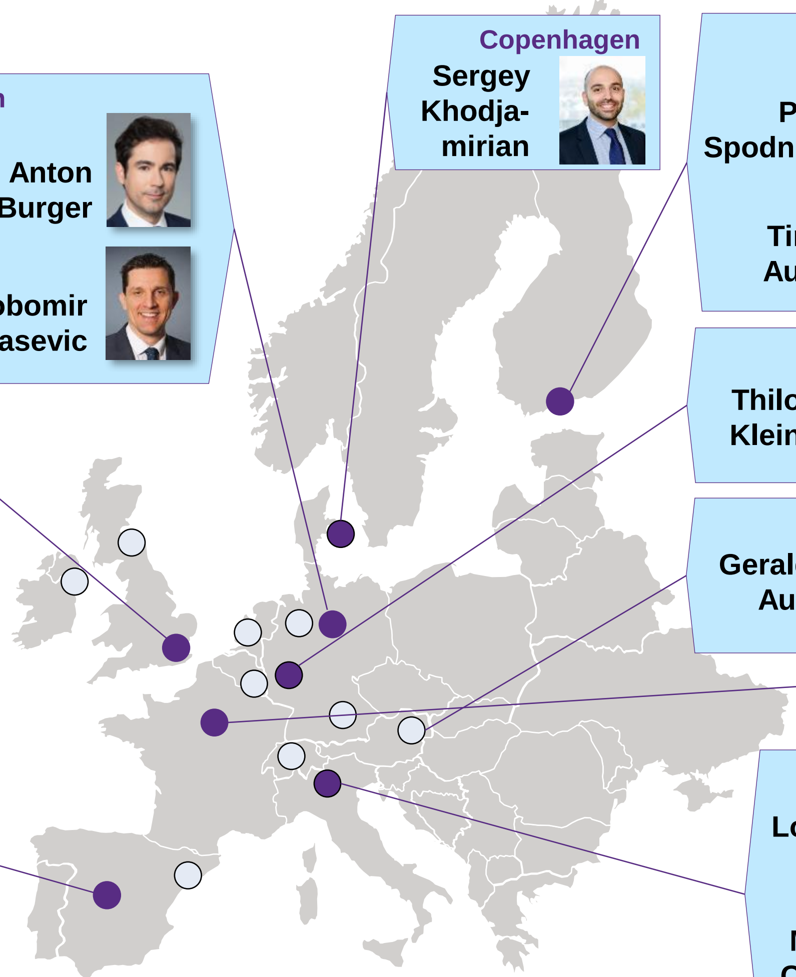
Charles Verhaeghe
Guillaume Duquesne
Hermano Oliveira
Emmanuel Grand
Yves Le Thieis
Dmitri Perekhodtsev



- Main Compass Lexecon energy offices
- Other Compass Lexecon or FTI offices

Notes: [1] incl. experts from our parent company FTI Consulting
Source: Compass Lexecon

Compass Lexecon's EMEA Energy Practice Expertise – Overview

Sectors:
- Electricity
- Gas
- Emissions
- District Heating & Cogeneration (CHP)

1 Market outlooks & analysis
- Market price projections
- Tailor made modelling
- Market analysis
- Valuation of market assets
- Policy impact assessment

2 Energy market regulation
- Network regulation & incentives
- Renewable support
- Market design for power and gas markets
- Regulatory review and impact assessment
- Third party exemptions for electricity and gas infrastructure
- Gas storage regulation

3 Strategy
- Policy action recommendations
- Strategy in regulated industries
- New technologies
- Strategy review
- Transition management

4 Transactions
- Regulatory & commercial due diligences
- Deal valuation
- M & A support
- Expert reports for financing

5 Emissions & environmental economics
- Zero emission scenarios
- Carbon market expertise
- Power-to-gas and hydrogen

6 Competition & State Aid
- State Aid
- Investigations of market abuse and competitive behavior
- Mergers and acquisitions
- Competition issues for natural gas storage and LNG terminals

7 Contract design
- Contract valuation
- PPA negotiation
- Long-term contract renegotiation
- Procurement review

8 Litigation, arbitration and disputes
- Gas supply contract arbitration
- RES support revisions
- Damage quantum analysis
- Power Purchase Agreement (PPA) arbitration
- Energy charter treaty and investor-state arbitration

COMPASS LEXECON

Source: Compass Lexecon

Overview of Compass Lexecon's Modelling Expertise

We have developed comprehensive proprietary models spanning the entire energy system.

COMPASS LEXECON Modelling Expertise

Electricity

Power Market Model

Dispatch

Co-optimisation

Capacity expansion

Ancillary Services Model

Modelling of reservation and activation

- FCR
- aFRR
- mFRR

Gas and LNG

Gas Market Model

LNG Model

- LNG Supply/ Demand
- LNG Shipping
- Netback Optimisation
- Small-scale LNG

Green Gases

PtX Model

- Project profitability
- State aid requirements

Biomethane Model

Price scenarios per biomethane fraction for key EU markets

Regulatory framework
Assessing the impact of regulatory changes

Emissions (CO_2)

Carbon Market Model

Modelling
Supply & demand of emission certificates, and resulting **equilibrium price**

Regulatory framework
Assessing the impact of regulatory changes (e.g. revision of the emission cap and supplied volume of certificates) on the market

(District) Heating

District Heating Model

- Dispatch of existing assets
- Optimal asset park expansion

Heating Market Model

- Evolvement of demand
- Simulation of heat technology evolvement

Source: Compass Lexecon

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