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Techno-economic evaluation of selected decentralised CHP applications based on biomass combustion with steam turbine and ORC processes

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- Case studies: economic assessment
- Sensitivity analysis
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Introduction

- In 2004 the project “Decentralised CHP technologies based on biomass combustion – state of development, demonstration activities, economic performance” had been performed within the IEA Bioenergy Agreement Task 32.
- The main objectives were to gain an overview of technological and economic developments and demonstration activities.
  4 case studies with a capacity range of up to 20 MW_{el} were investigated.
- In the last 10 years the technologies available for small scale biomass CHP systems have developed considerably.
- For this reason an update of the assessment for the most successful CHP technologies has been performed.

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Objectives

- **3 different selected case studies have been investigated:**
  - **Biomass-fired steam turbine plant in Austria (5.7 $MW_{el,gross}$)**
  - **Biomass fired ORC plant in Estonia (2.4 $MW_{el,gross}$)**
  - **Biomass fired Direct Exchange ORC plant in Slovakia (130 $kW_{el,gross}$)**

- **Due to very different plant sizes and local side constraints a direct comparison of the case studies is not meaningful.**

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Case Study 1: Steam turbine plant in Austria

- Start-Up: 2012
- CHP technology - Design:
  - Backpressure steam turbine
  - Steam temperature 525°C
  - Steam pressure 90 bar
  - Heat consumer: district heating network
- Operation mode: Mainly heat controlled
- Manufacturer steam boiler: Weiss GmbH
- Manufacturer steam turbine: MAN Diesel und Turbo
- Technology maturity: commercial

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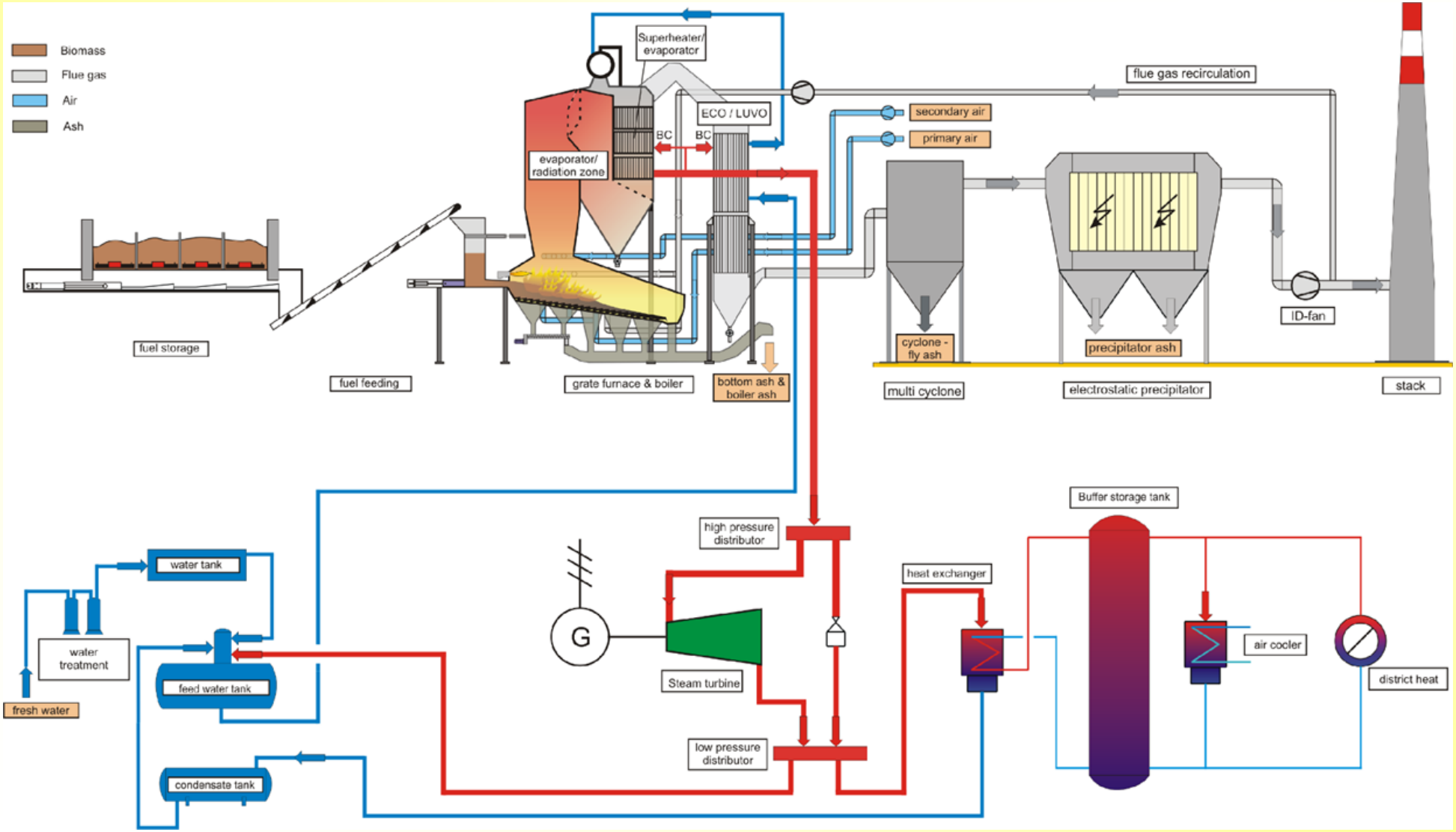
Case Study 1: Steam turbine plant in Austria



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Case Study 2: ORC plant in Estonia

- **Start-Up: 2012**
- **CHP technology - Design:**
  - **ORC split process**
  - **Thermal oil boiler with HT+LT thermal oil circuit**
  - **Thermal oil flow temperature 310°C**
  - **Integrated flue gas condensation unit**
  - **Heat consumer: district heating network**
- **Operation mode: Heat controlled**
- **Manufacturer thermal oil boiler: Polytechnik**
- **Manufacturer ORC: Turboden s.r.l**
- **Technology maturity: commercial**

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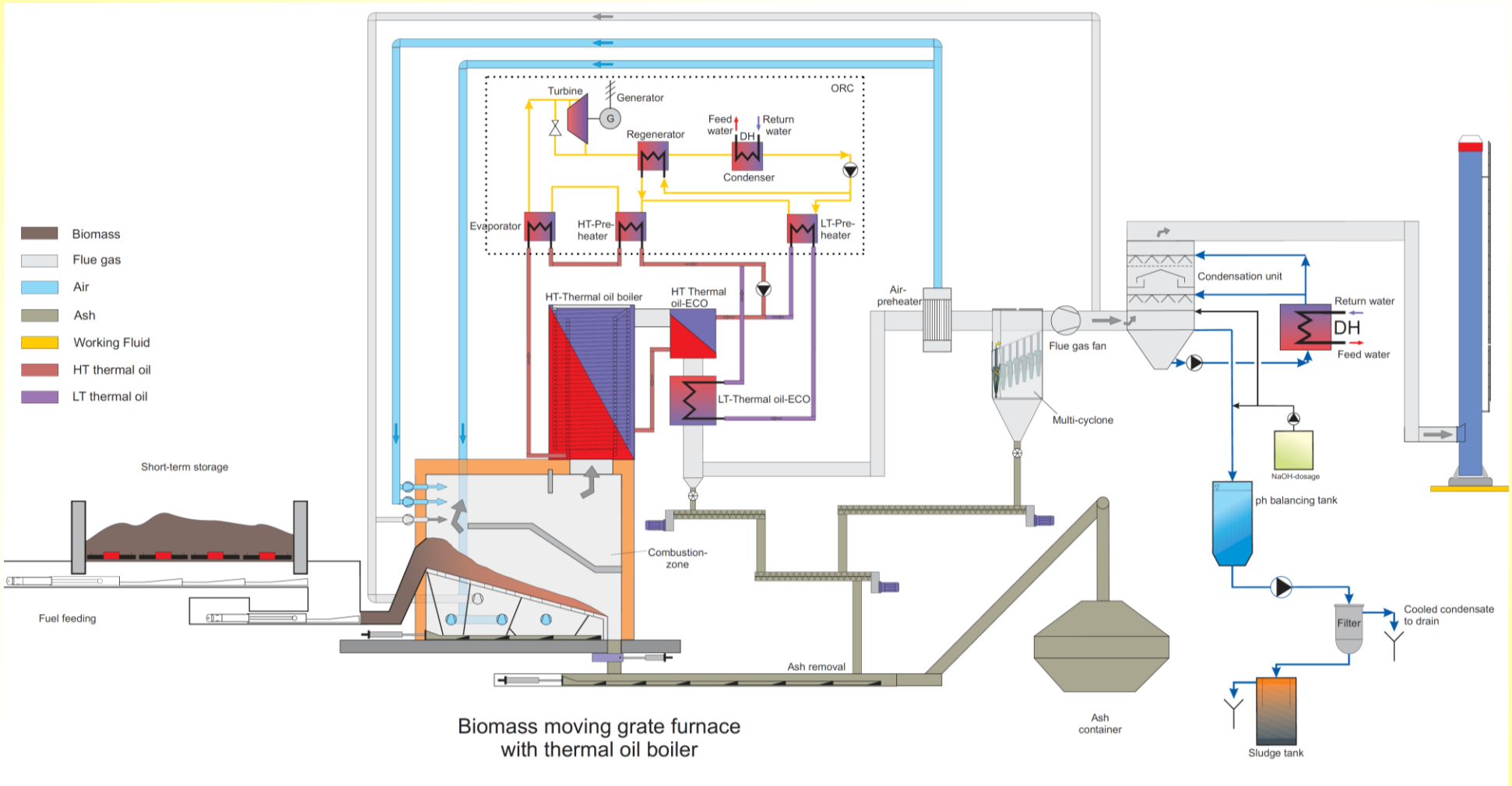
Case Study 2: ORC plant in Estonia



Biomass moving grate furnace
with thermal oil boiler

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Case Study 3: Direct exchange ORC plant in Slovakia

- Start-Up: 2014
- CHP technology - Design:
  - Direct exchange ORC process without an intermediate thermal oil cycle
  - Flue gas temperature entering ORC system: up to 530°C
  - Heat consumer: process heat in saw mill
- Operation mode: Heat controlled
- Manufacturer biomass burner: Fiedler
- Manufacturer ORC: Triogen
- Technology maturity: demonstration (1st year of operation)

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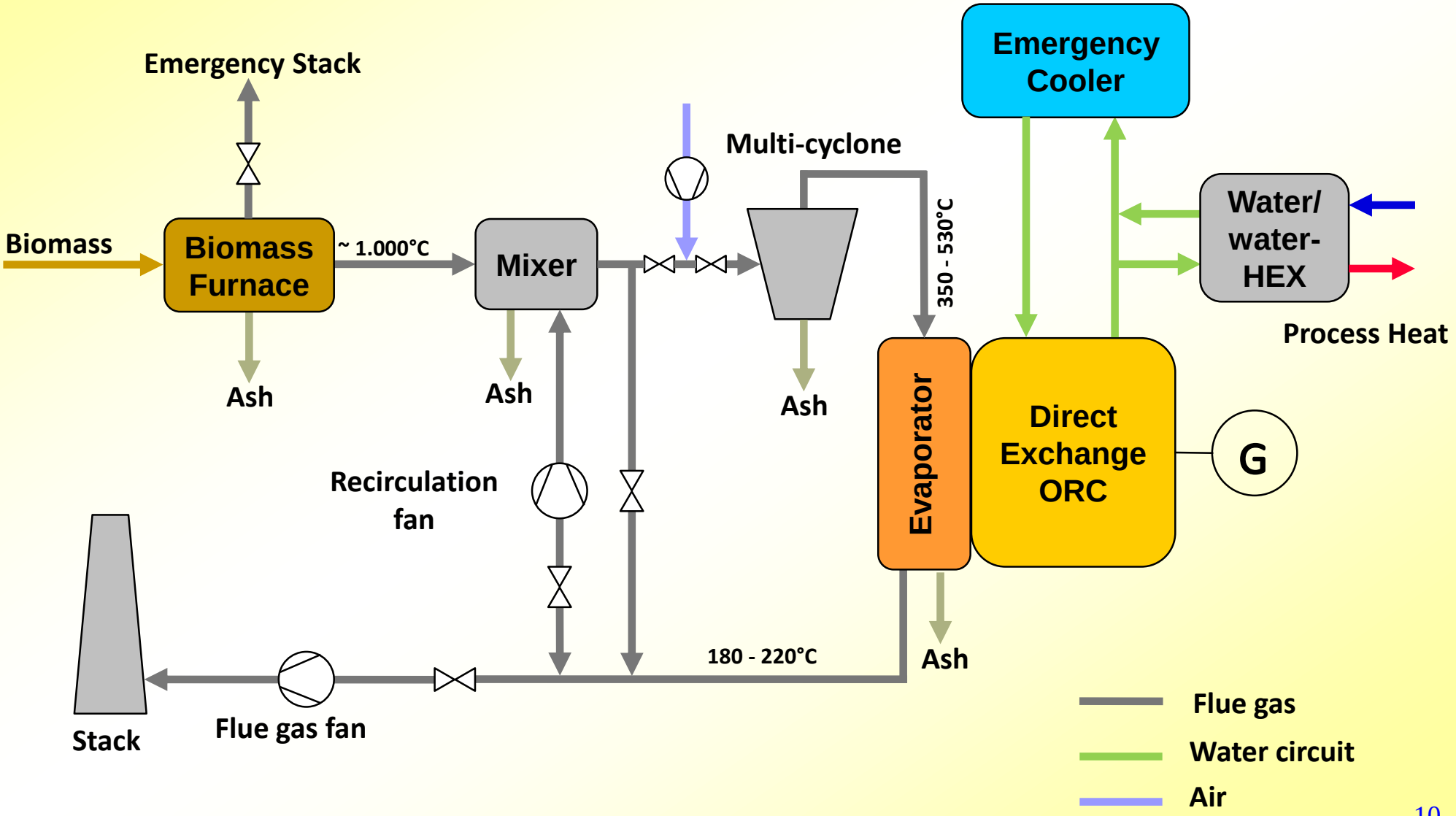
Case Study 3: Direct exchange ORC plant in Slovakia



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Techno-economic evaluation Methodology

- The techno-economic assessment of the different CHP technologies has been performed based on the VDI 2067 taking capital, consumption, operating and other costs into account.
- For the evaluation of CHP plants the heat and electricity generation costs have been considered independently. For this reason the overall investment as well as operational costs were split in a heat related part based on a virtual hot water boiler with the same thermal capacity as the CHP plant and in a part for the CHP surplus necessary for electricity production.
- A sensitivity analysis has been performed to evaluate the most important influencing factors.

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Techno-economic evaluation
Capacity and production

	Unit	DE-ORC	ORC-EST	ST-A
Nominal conditions				
Fuel energy input CHP plant	[kW_{NCV}]	1.110	14.200	27.860
Electric capacity CHP plant gross	[kW_{el}]	130	2.400	5.700
Electric capacity CHP plant net	[kW_{el}]	90	2.050	5.000
Heat capacity CHP module *	[kW_{th}]	660	9.580	17.000
Total efficiency gross	[%]	71,2	84,4	81,5
Annual conditions				
Full load operating hours CHP	[h/a]	7.500	5.140	7.807
Total fuel energy input CHP (100%)	[kWh_{NCV}/a]	9.028.000	74.830.000	200.000.000
Electricity production gross	[kWh_{el}/a]	975.000	12.336.000	44.500.000
Electric efficiency gross	[%]	10,8	16,5	22,3
Heat production	[kWh_{th}/a]	5.265.000	55.943.000	93.000.000
Thermal efficiency	[%]	58,3	74,8	46,5
Total efficiency gross	[%]	69,1	91,2	68,8
Specific electricity consumption CHP plant	[kWh_{el}/MWh_{th}]	48,0	46,1	29,1
Total electricity consumption CHP	[kWh_{el}/a]	299.520	3.145.000	4.000.000
Energy sold				
Electricity sold	[kWh_{el}/a]	780.780	10.361.000	42.174.000
Heat sold	[kWh_{th}/a]	5.212.350	55.383.570	90.000.000

*** Thermal capacity of flue gas condensation has not been taken into account**

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Techno-economic evaluation
Economic side constraints

Parameter	Unit	DE-ORC	ORC-EST	ST-A
Feed-in tariff	[€/MWh$_{el}$]	110,0	89,9	122,0
Period of feed-in tariff granted	[Years]	15,0	12,0	15,0
Heat price	[€/MWh$_{th}$]	32,0	45,0	55,0
Interest rate	[%/a]	3,0	3,0	4,0
Fuel price	[€/kWh$_{NCV}$]	10,0	12,3	21,5
Hourly rate - personnel costs (CHP related)	[€/h]	10	10	55
Annual working hours (CHP related)	[h/a]	53	1.700	1.700
Hourly rate - personnel costs	[€/h]	10	10	45
Annual working hours	[h/a]	130	4.900	5.100
Electricity price (own needs)	[€/kWh$_{el}$]	70	125	120
Investment costs total	[€]	860.000	12.830.000	24.770.000
Investment subsidy	[€]	-	2.720.000,0	2.317.500

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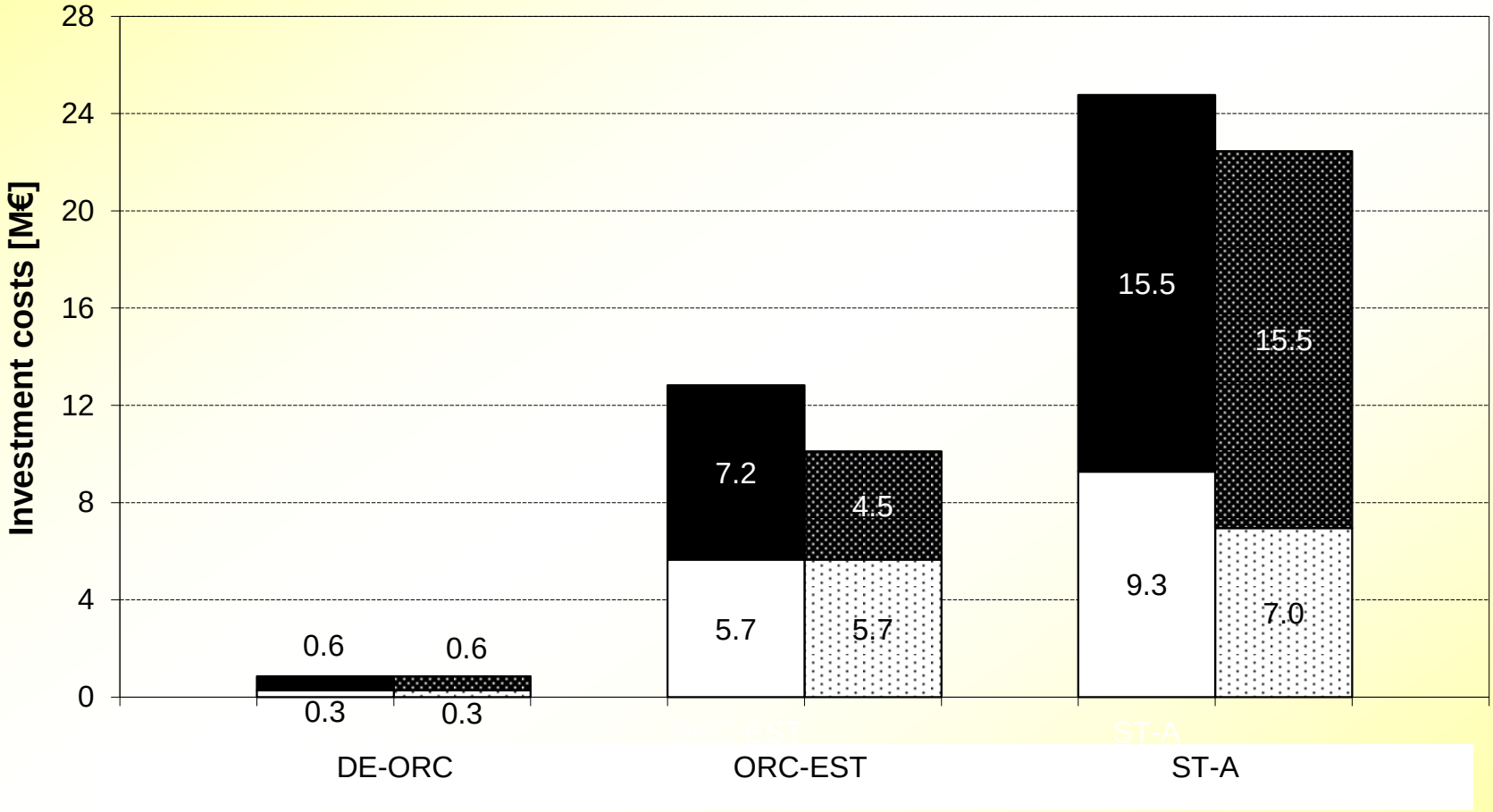
Techno-economic evaluation
Total investment costs



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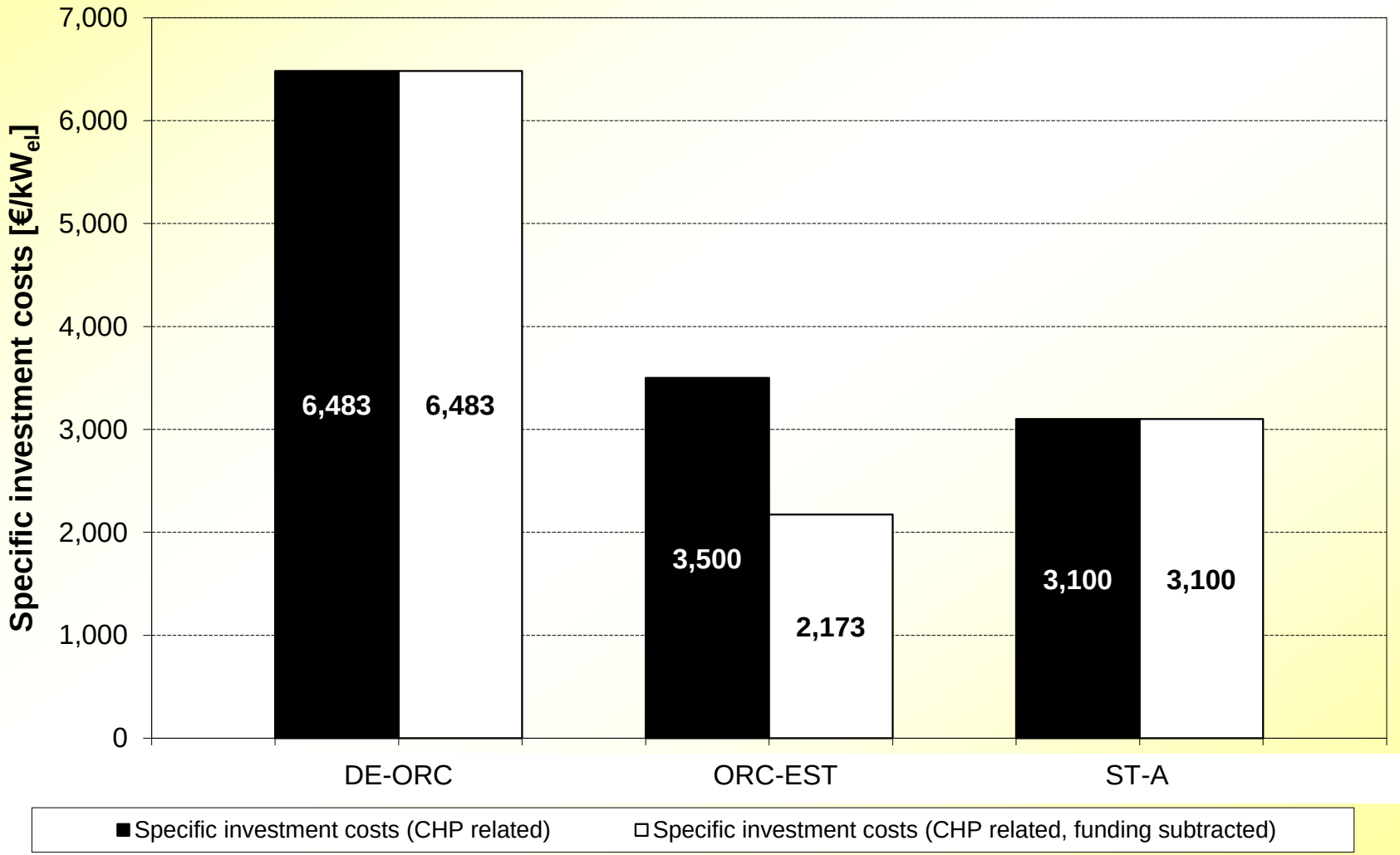
Techno-economic evaluation
Specific investment costs CHP related



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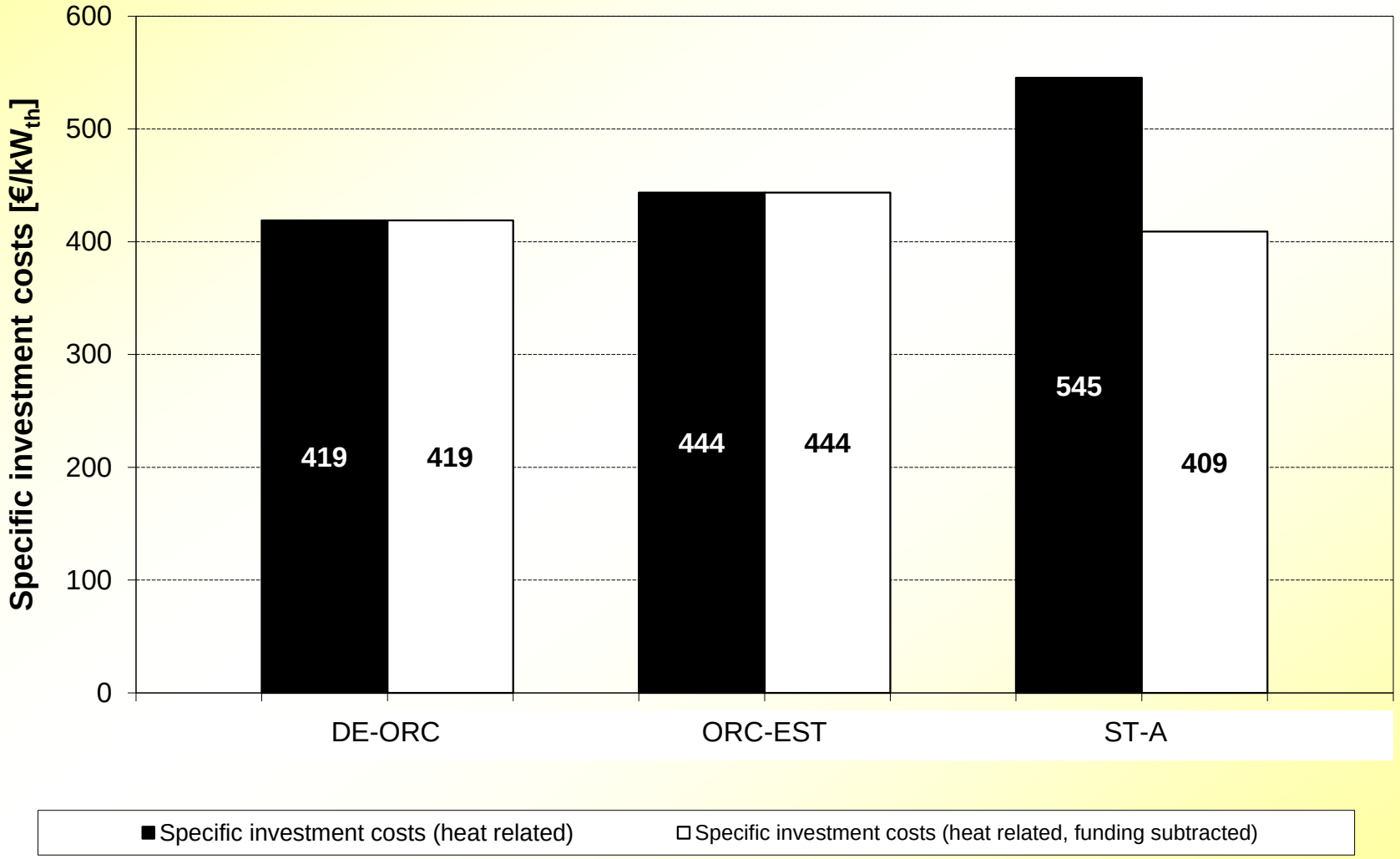
Techno-economic evaluation
Specific investment costs heat related



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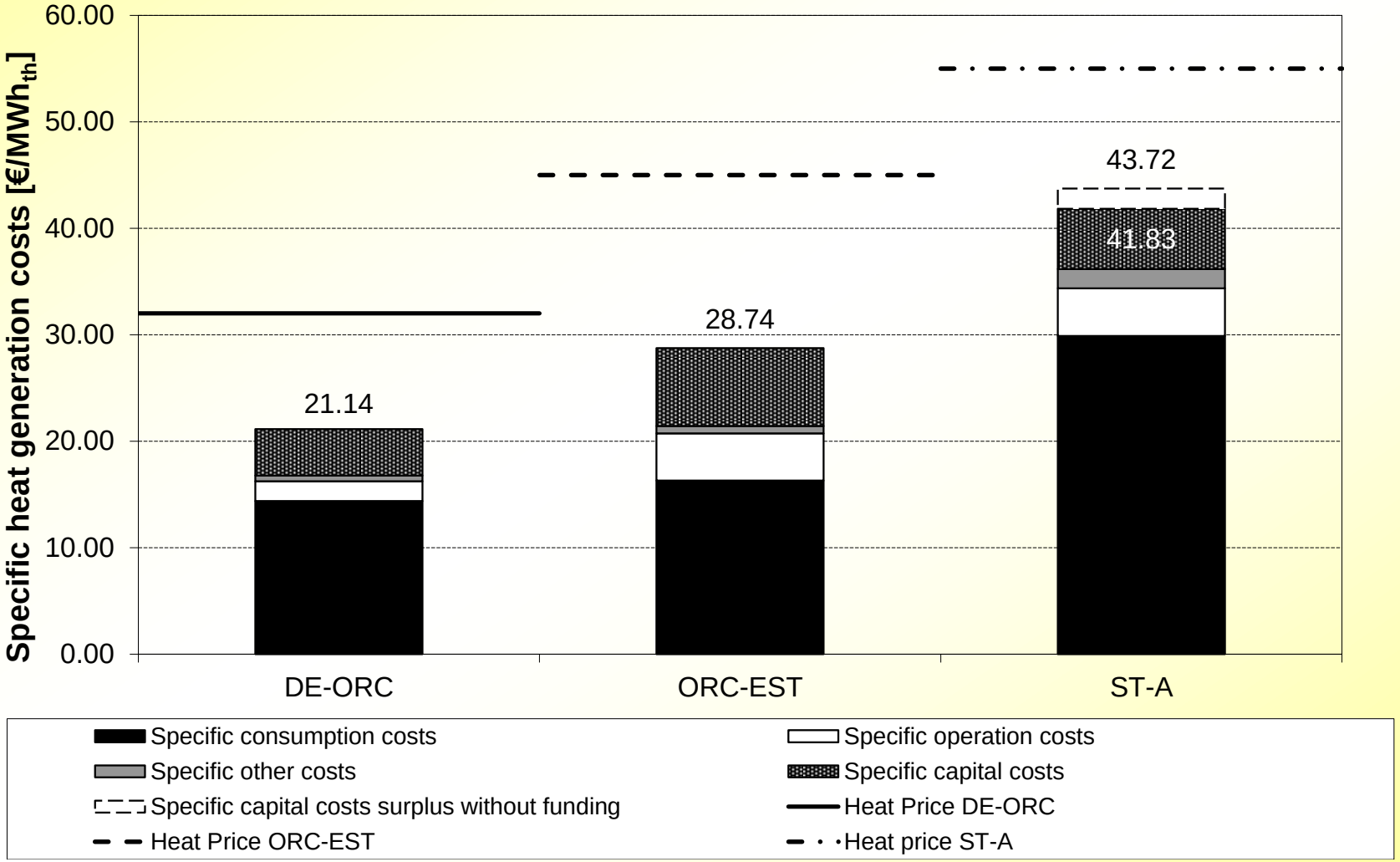
Techno-economic evaluation
Specific heat generation costs



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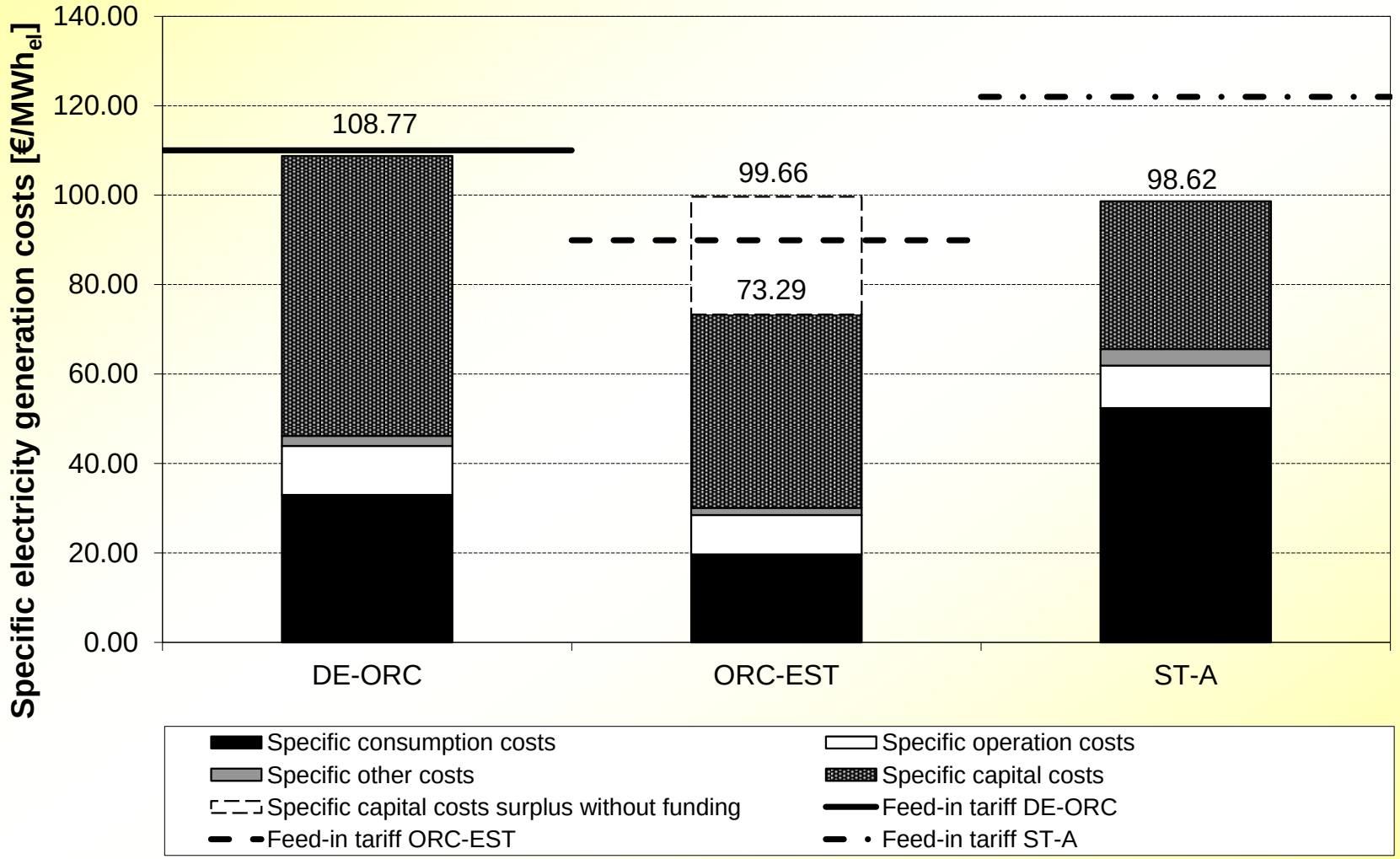
Techno-economic evaluation
Specific electricity generation costs



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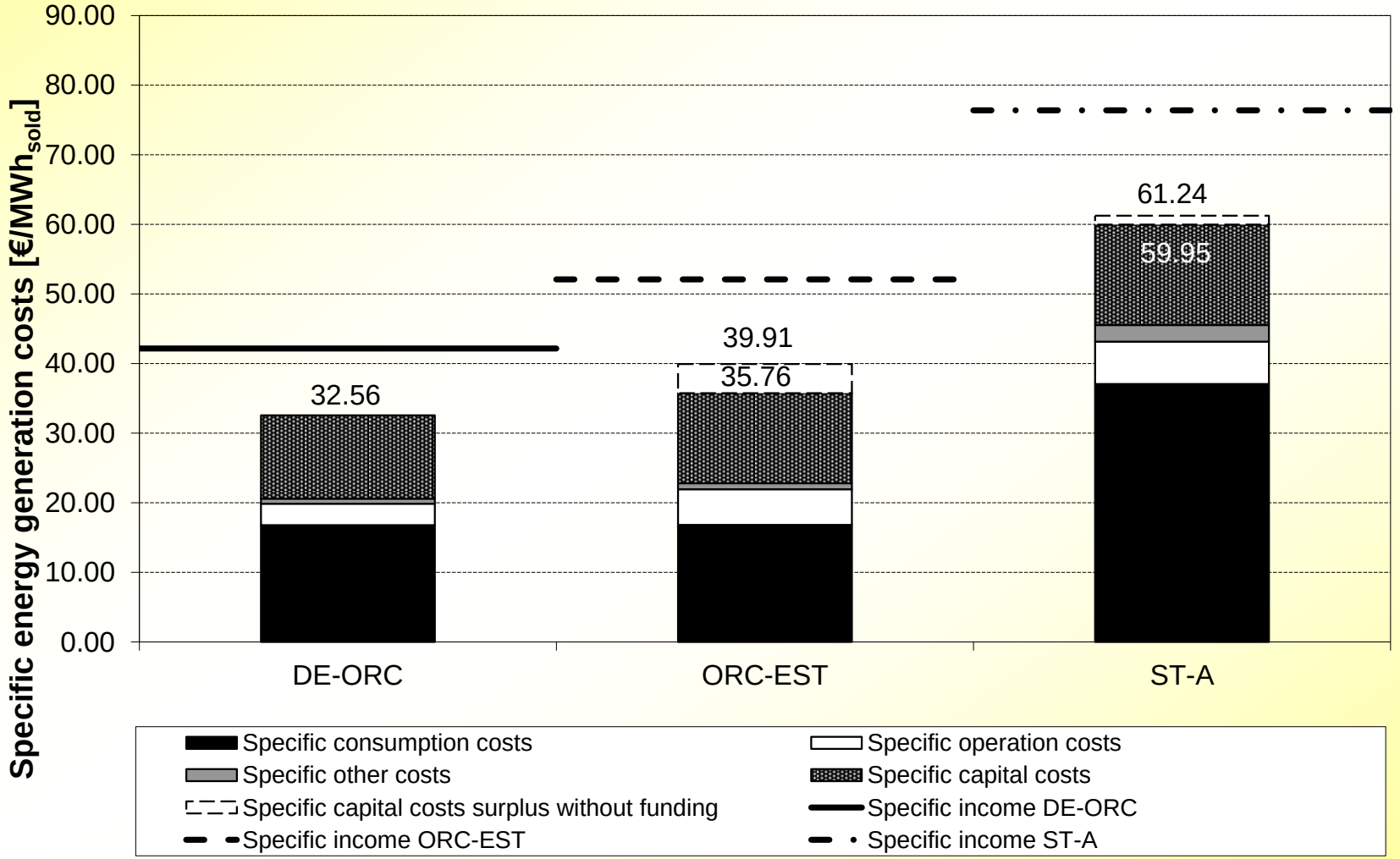
Techno-economic evaluation
Specific total energy generation costs



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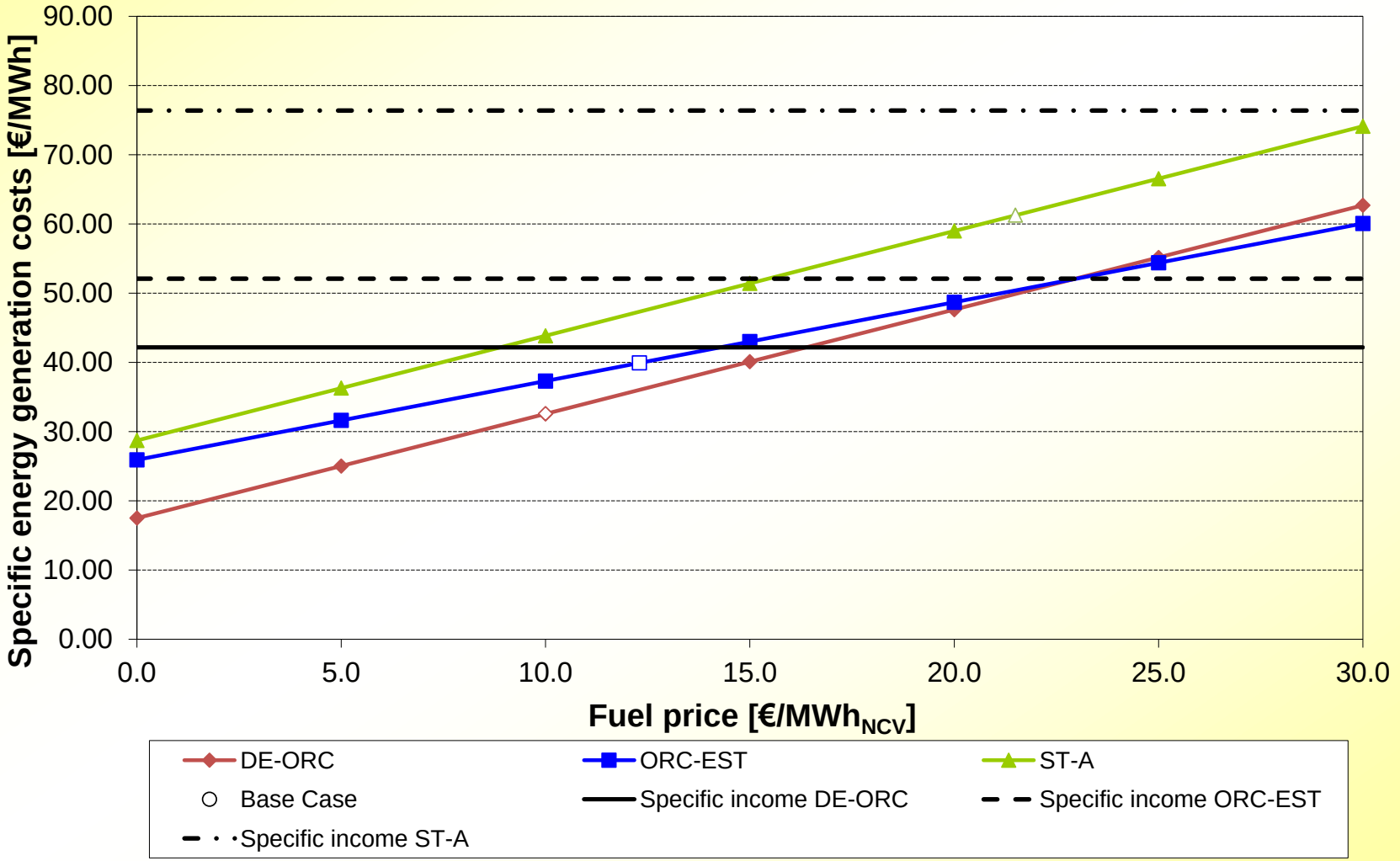
Sensitivity analysis
Fuel price



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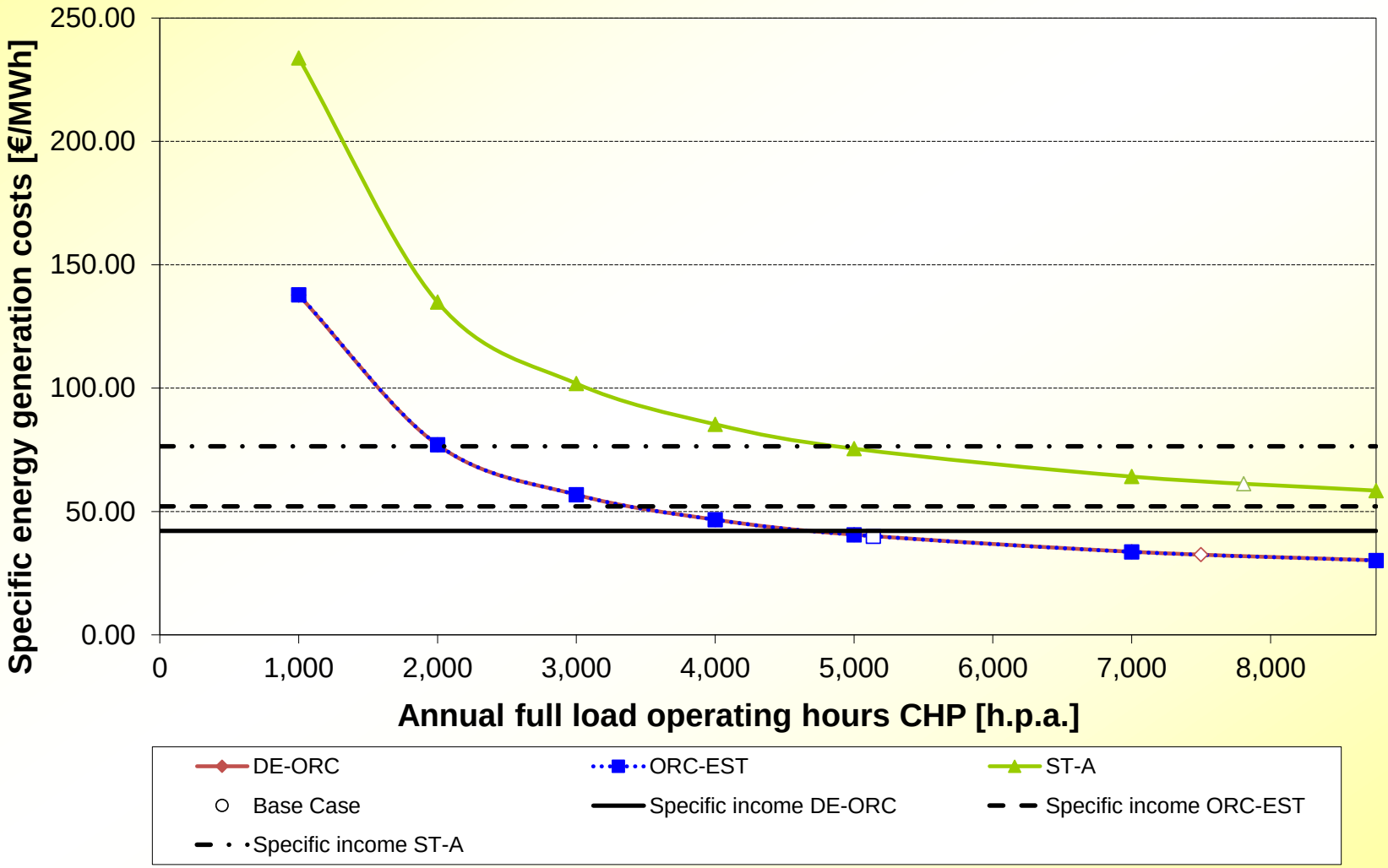
Sensitivity analysis
Full load operating hours



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Conclusion and recomendation (I)

- All three CHP plant investigated can be operated economically The results, however, should not be directly compared due to different local economic framework conditions.
- Overall annual efficiencies achieved are between 69 and 91%, whereas gross electric efficiencies vary between 11 and 22%.
- For steam turbine and conventional ORC plants the potential for further increase of nominal efficiencies is limited but a proper design and system integration is essential. For the direct exchange ORC a potential for further technological improvement exists and should be used with increased operational experiences.
- The specific CHP related investment costs vary between 6,500 €/kW_{el} (direct exchange ORC; 130 $kW_{el,gross}$) and 3,100 €/kW_{el} (steam turbine; 5,700 $kW_{el,gross}$) outlining the economy-of-scale-effect.

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Conclusion and recomendation (II)

- The specific electricity generation costs vary between 99 €/MWh$_{el}$ (steam turbine) and 109 €/MWh$_{el}$ (direct exchange ORC).
- The specific energy generation costs are in a range of 33 €/MWh (direct exchange ORC) and 61 €/MWh (steam turbine)
- The most important influencing variables for the energy generation costs are the full load operating hours and the fuel price.
- > 5,000 – 6,000 full load operating hours are recommended for the investigated decentralised CHP plants in heat controlled operation.
- Feed-in tariffs and investment subsidies suited for the plant size and application are, however, necessary to enable an economic operation of decentralised CHP plants.

Thank you for your attention

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