Silesian University of Technology

RESEARCH UNIVERSITY
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Ministry of Science and Higher Education

Coal Repowering in Poland

Łukasz Bartela

<u>Paweł Gładysz</u>

International Partner Conference on Repowering 2023

Coal to X Repowering Towards Energy Transition Pathway

DEsire Team:

NCBR Narodowe Centrum Badań i Rozwoju

Rzeczpospolita Polska

Silesian University of Technology

Ministerstwo Klimatu i Środowiska

EPK

ichtj

INSTYTUT SOBIESKIEGO

DEsire

Main goals of the DEsire project

A plan of decarbonization of the power industry through modernization with the use of III+ and IV generation nuclear reactors

which will be a roadmap for the organization of investment processes aimed at transforming centralized generation systems, considering the criteria of sustainable development

Pilot of the national Cluster of Power Industry Transformation (CPIT)

which will provide organizational support for activities aimed at increasing the effectiveness of various stakeholder groups in the process of transformation of domestic power plants and combined heat and power plants.

Structure of project

PHASE A – finished
Industrial research and development works

- Identification and analysis of the national energy and accompanying infrastructure
- Development of an integrated model for assessing energy and economic aspects
- Organization and security of the process of modernization and operation

PHASE B – on-going
Pre-implementation works

- **Procedures for modernization and three feasiblity studies**
- **Social diagnosis and preparation of analytical materials supporting the implementation of the modernization plan**
- **Preparation for the practical application of the project results**
- **Preparation of the modernization plan**

Genesis of the DEsire project

- works done by the Qvist-Gładysz-Bartela team

C2N

C2N#0 Greenfield

- *NPP is being built near the decommissioned CPP,*
- *no material links between the liquidation and the investment,*
- *it may be beneficial, for example, to transfer the rights to use water intakes, access to transmission lines and workforce.*

C2N#1 Brownfield

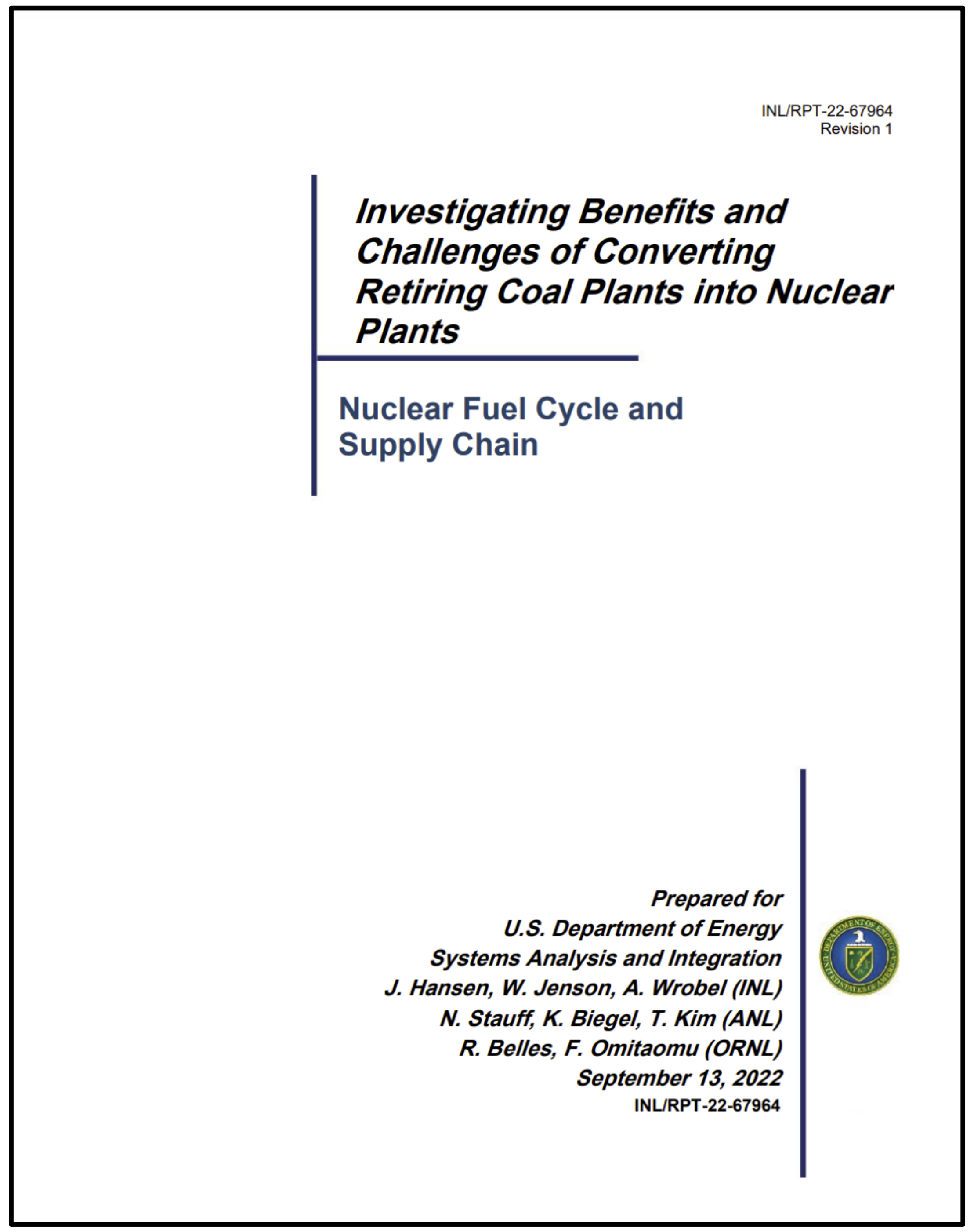
- *NPP is being built in place of the decommissioned CPP,*
- *space and support infrastructure are used,*
- *any type of nuclear reactor may be used.*

C2N#2 Direct

- *NPP is being built in place of the decommissioned CPP,*
- *space, support infrastructure and main infrastructure are used,*
- *direct coupling of the reactor island with the turbine island.*

C2N#3 Indirect

- *NPP is being built in place of the decommissioned CPP,*
- *space, support infrastructure and main infrastructure are used,*
- *direct coupling of the reactor island with the turbine island (steam generator + TES system)*



INL/RPT-22-67964
Revision 1

Investigating Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants

Nuclear Fuel Cycle and Supply Chain

Prepared for
U.S. Department of Energy
Systems Analysis and Integration
J. Hansen, W. Jenson, A. Wrobel (INL)
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September 13, 2022
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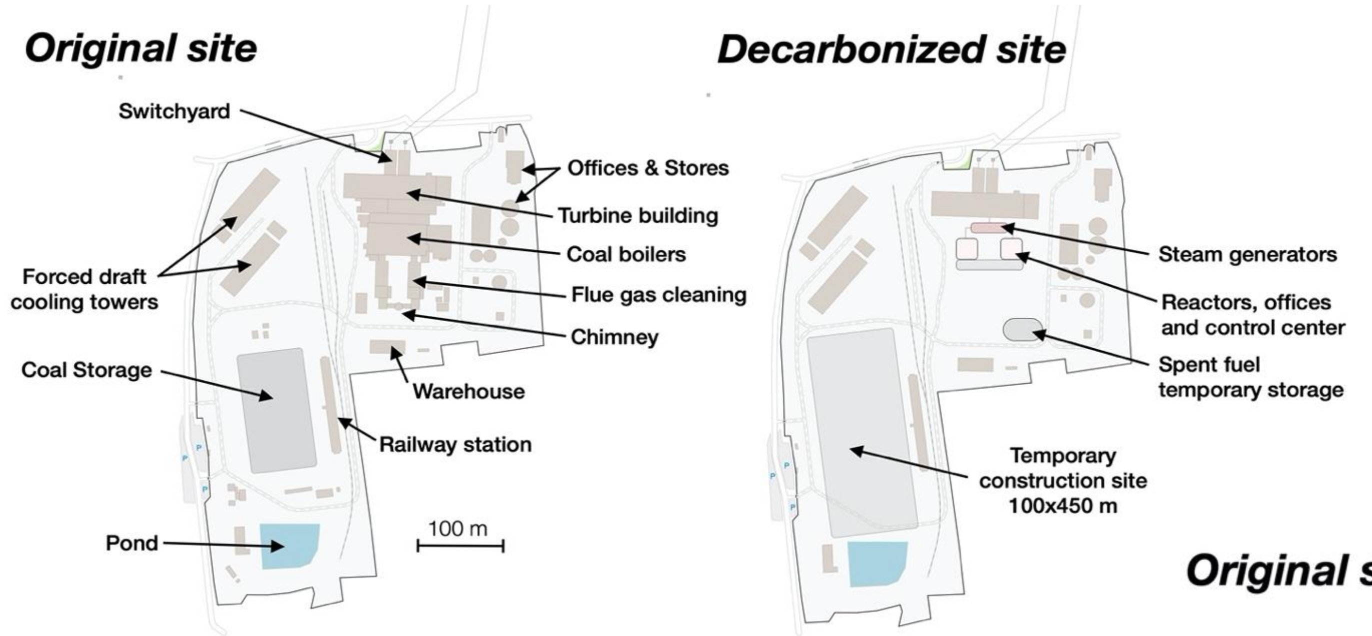
Repurposing

Full Repowering & Partial Repowering



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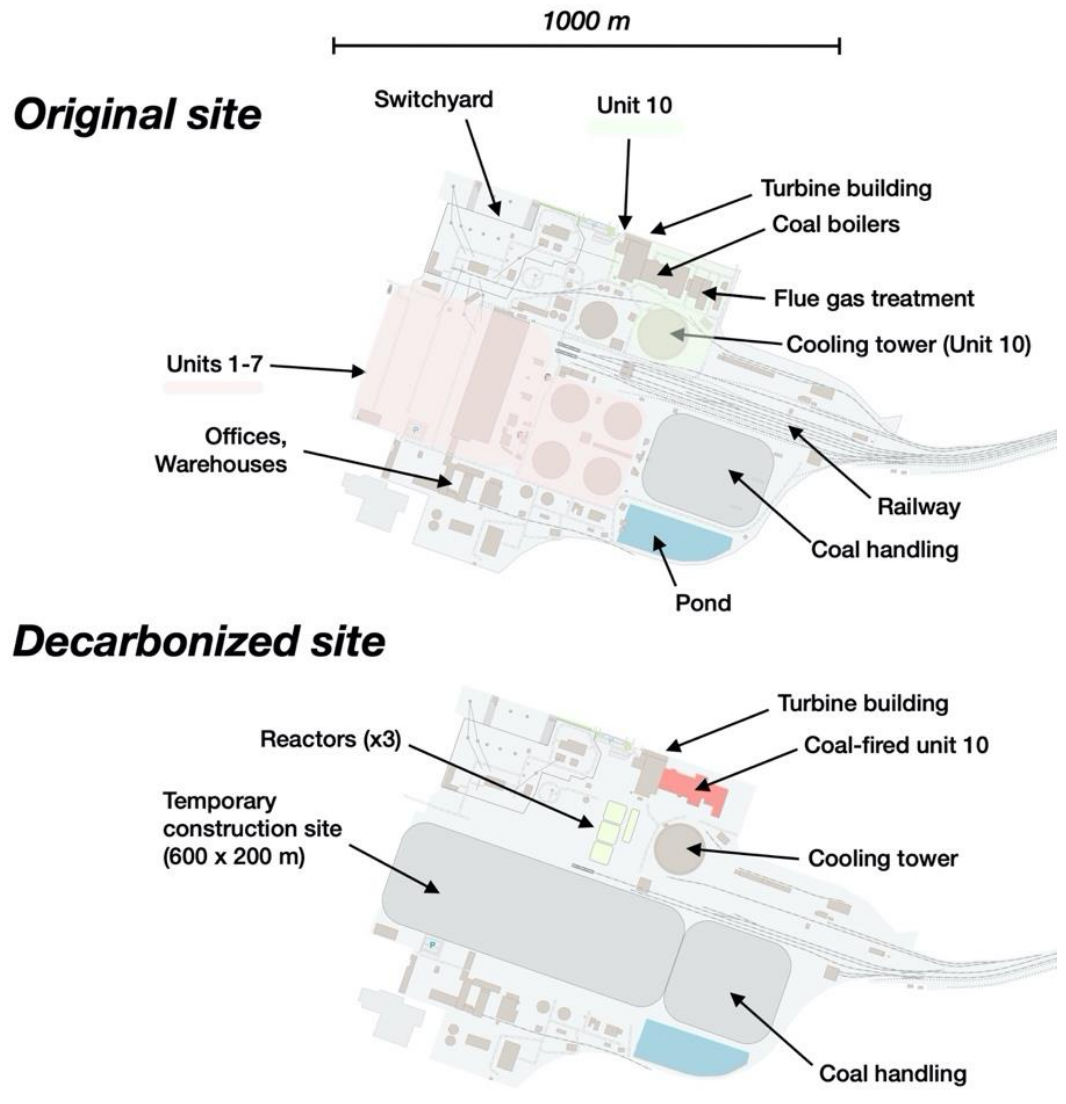

2019 – 2020

EDF ENVIRONMENTAL DEFENSE FUND

Scope:

- **General assessment of Polish energy sector** and options for decarbonization within retrofit of existing units
- Small modular reactors reftrofit **case studies** for three different coal-fired plants in Poland (**Coal-to-Nuclear option**)

2021 – 2022

Quadrature Climate Foundation

Scope:

- **Coal-to-Nuclear** with **Thermal Energy Storage (TES)** option – case study for Łagisza Power Plant and Kairos KP-FHR
- Gas-to-Nuclear option – case studies for (i) reference state-of-the-art NGCC and (ii) specific CHP NGCC located in Poland

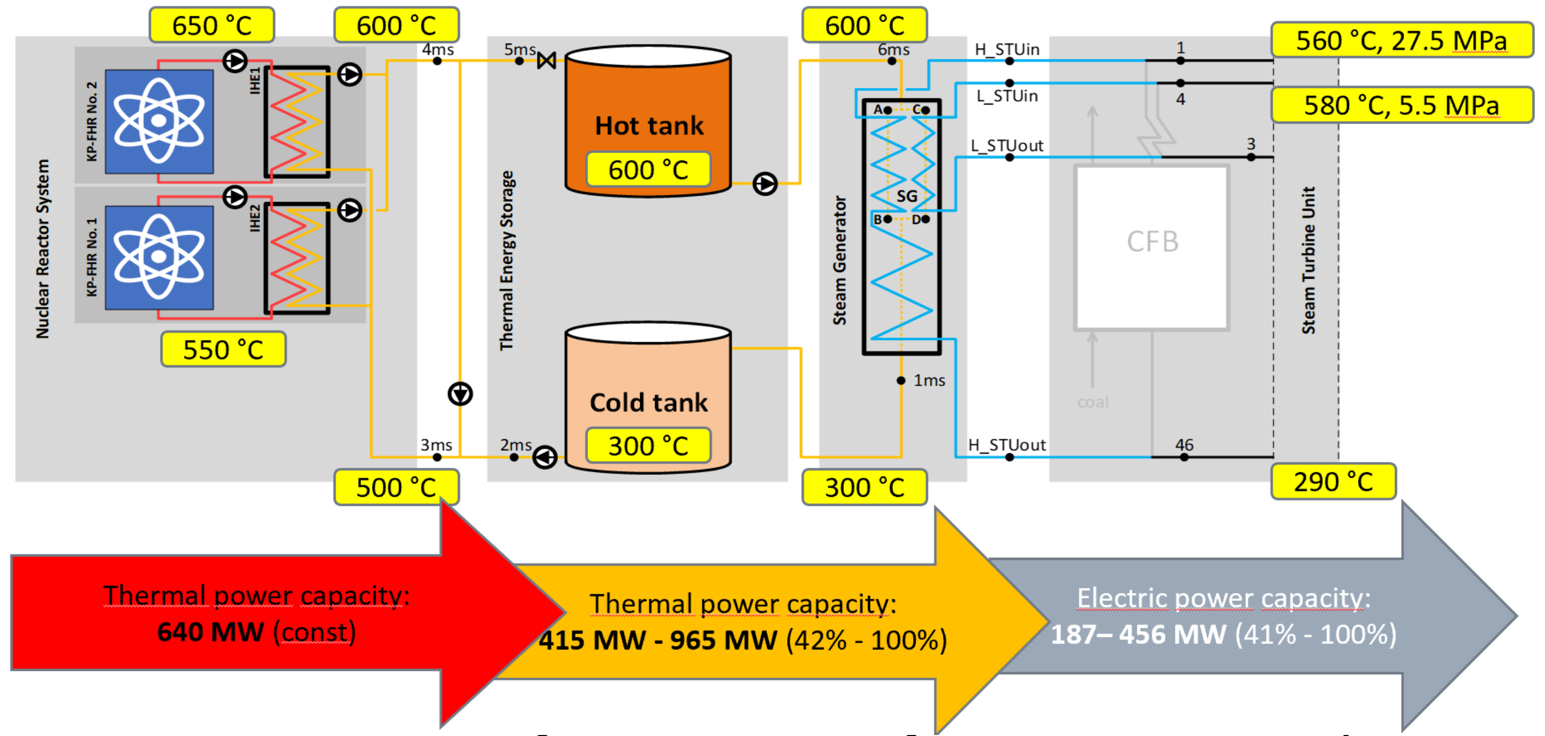

Fig. Diagram of integration of SMR system with TES at Łagisza unit

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DEsire

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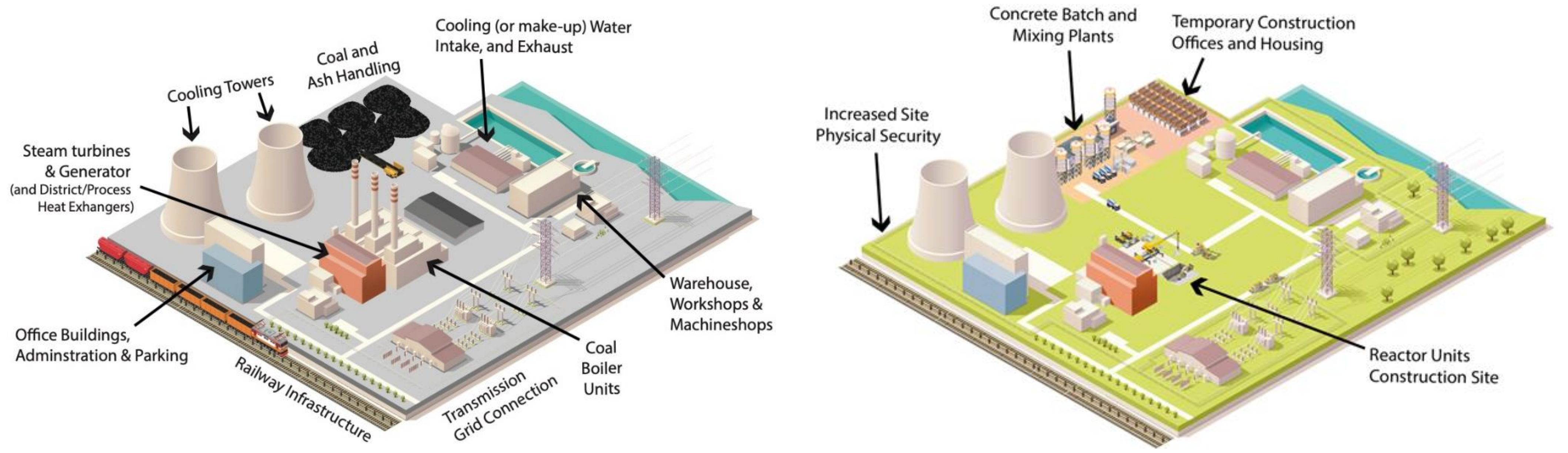

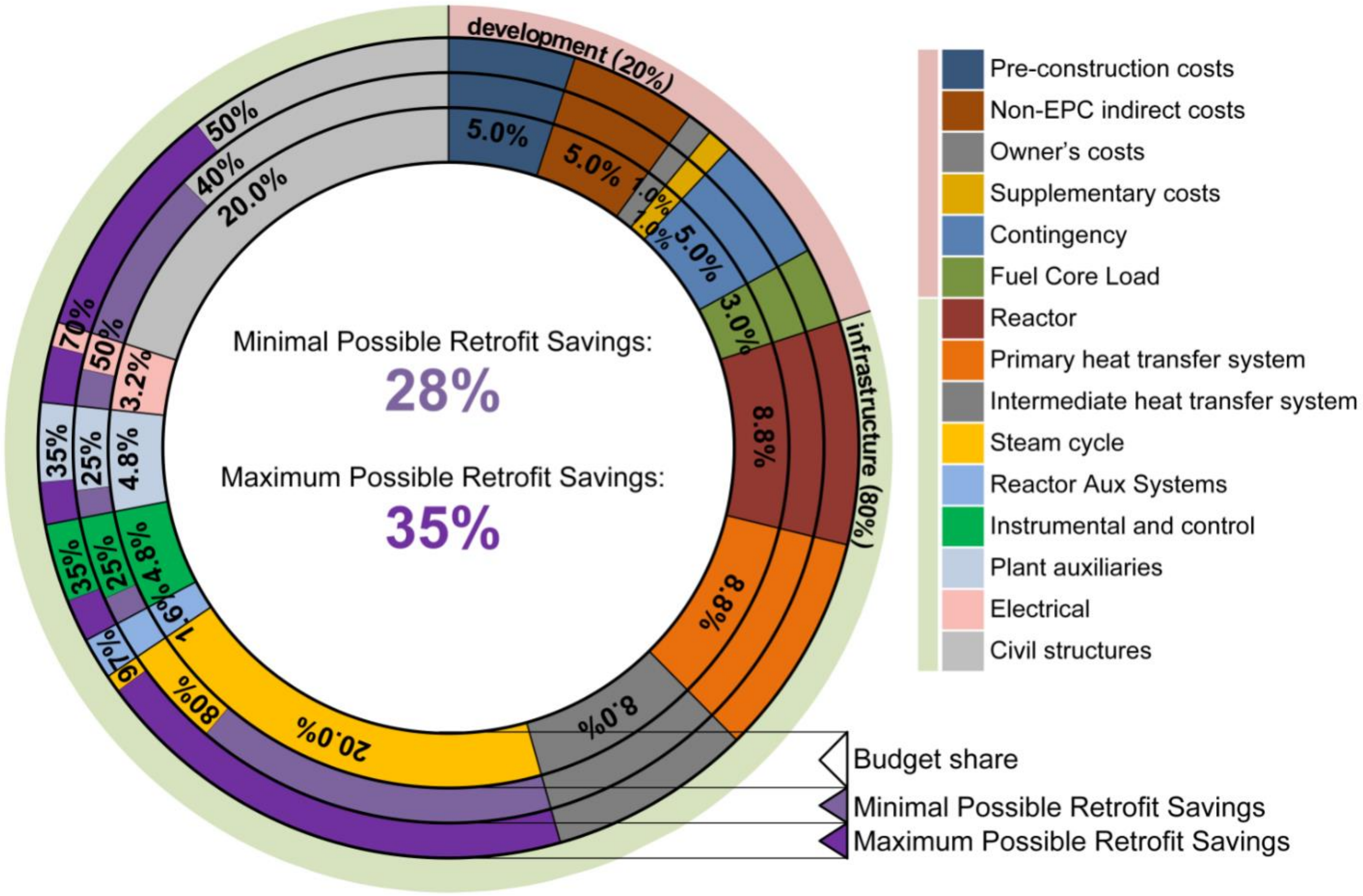

Fig. Possible investment savings due to the use of the existing infrastructure of the coal-fired power unit

Total capital investment cost (*TCIC*) = overnight capital cost (*OCC*) + interests during construction (*IDC*)

$$TCIC_{RET} = OCC_{GF}(1 - RS) + IDC_{RET}$$

RS – **retrofit savings in direct retrofit (C2N#2)** option for Łagisza power plant were estimated to be **up to**:

- **97% for steam cycle**,
- 35% for instrumental, controls and other plant auxiliaries,
- 70% for electrical side,
- 50% for civil structures.

Genesis of the DEsire project

- works done by the Qvist-Gładysz-Bartela team

$$\Delta NPV = \sum_{\tau=1}^{n} \frac{(NCF_{RET,\tau} - NCF_{REF,\tau})}{(1+r)^{\tau}} - TCIC_{RET}$$

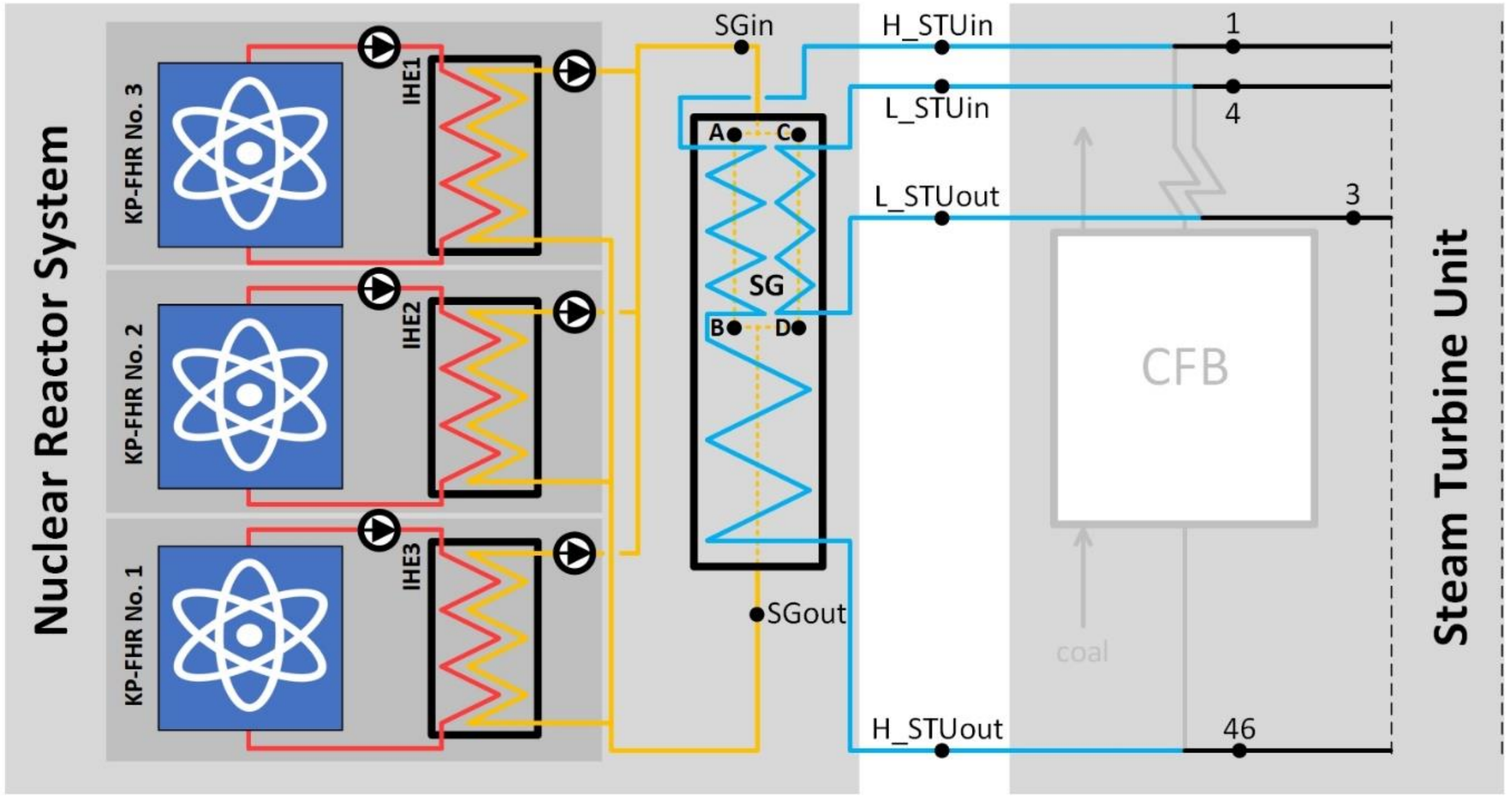

Fig. Diagram of integrations of SMR systems with a 460 MW Łagisza unit

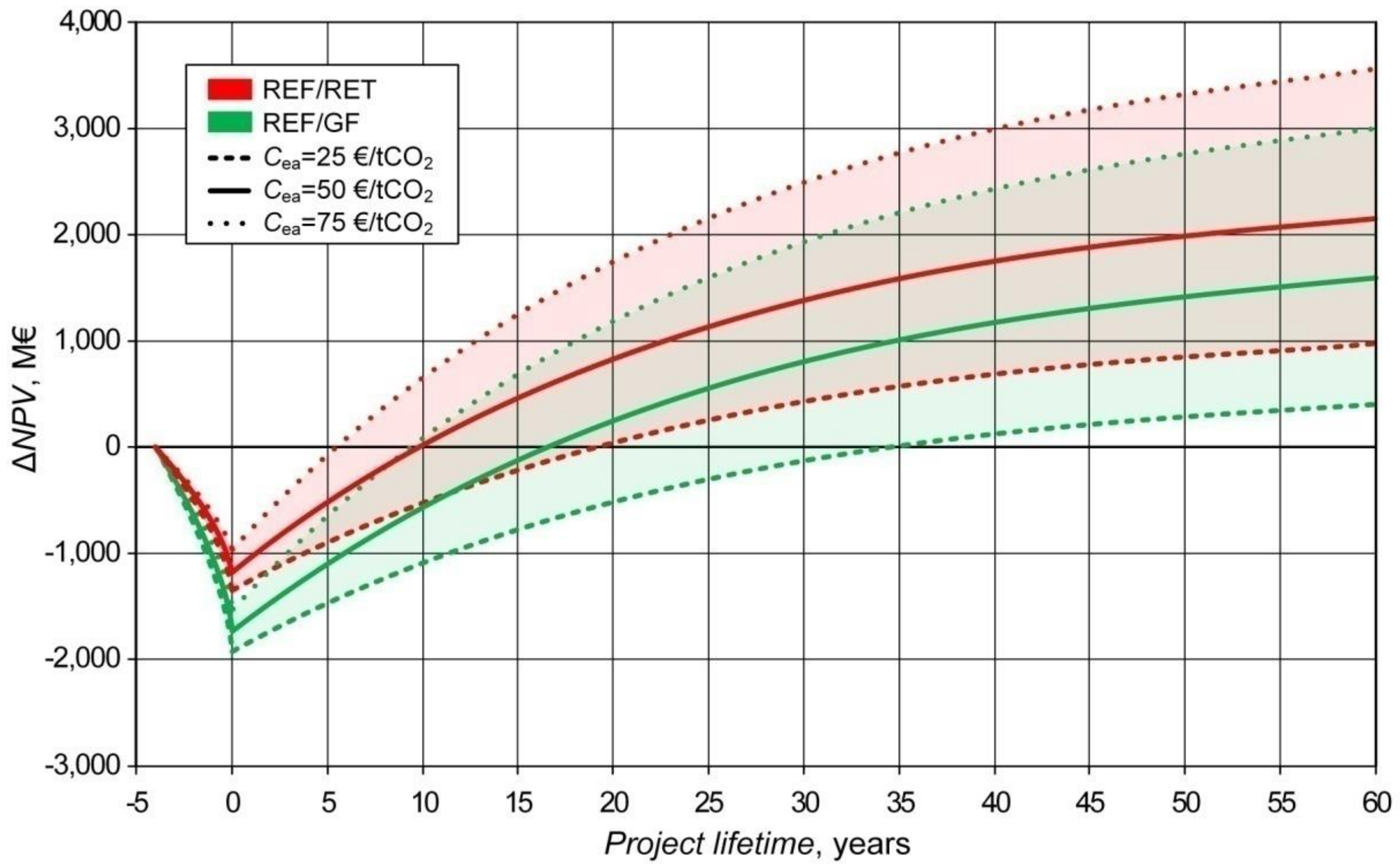

Fig. ΔNPV as a function of project lifetime for the GF and RET investment pathways for Łagisza unit

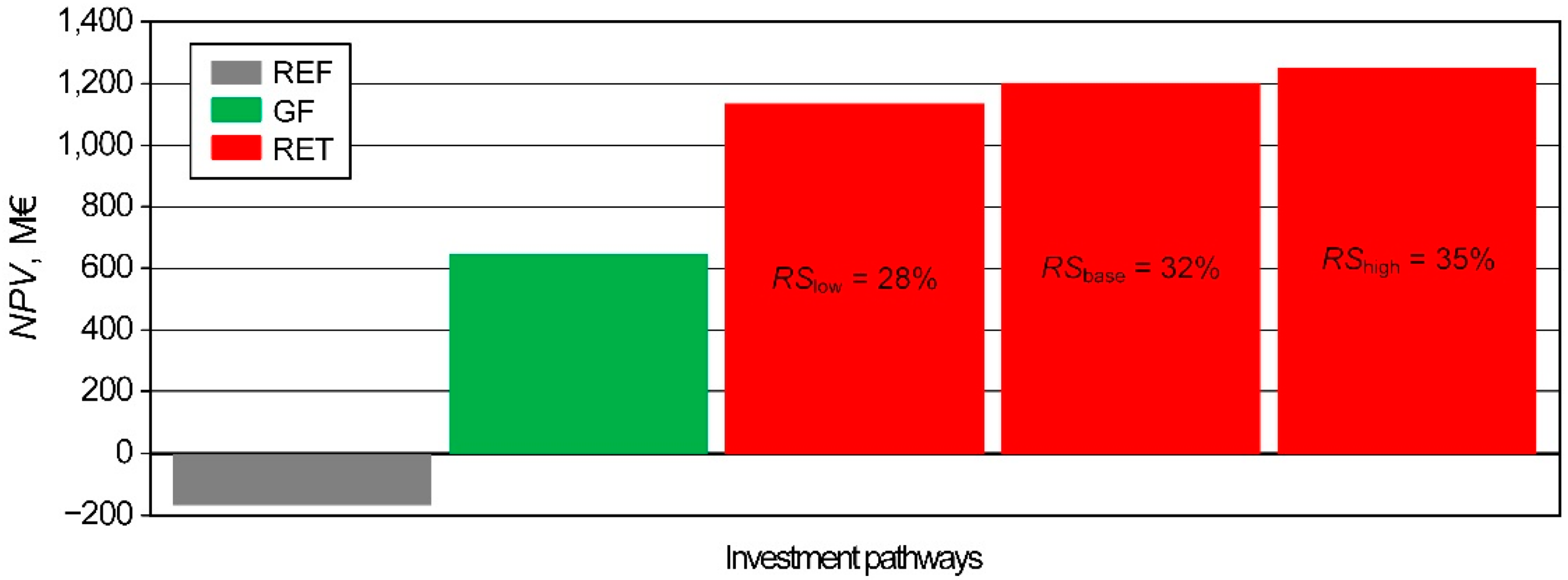

Fig. ΔNPV for base assumptions for three investment pathways (retrofit investment pathway for three different values of retrofit savings) for Łagisza 460 MW unit

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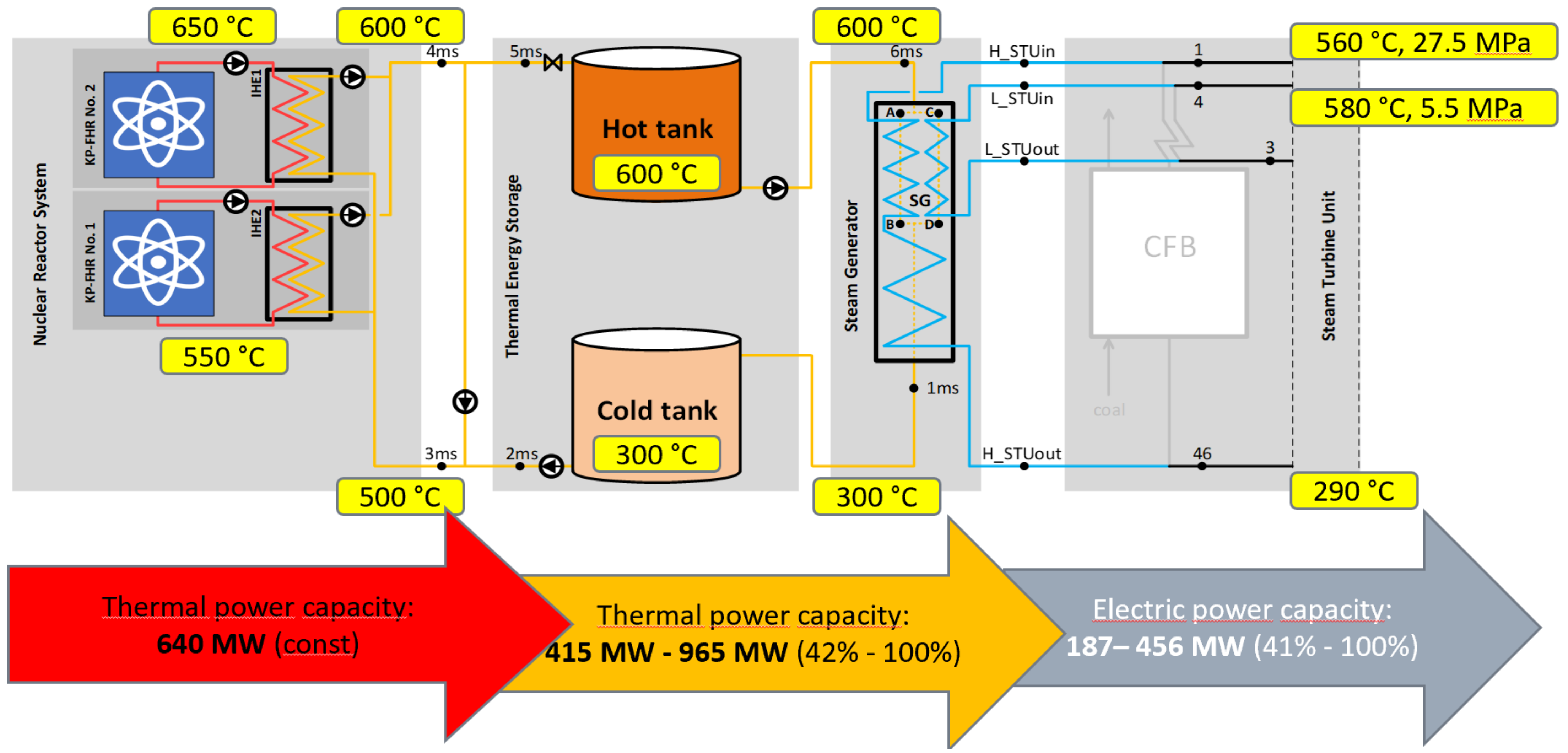
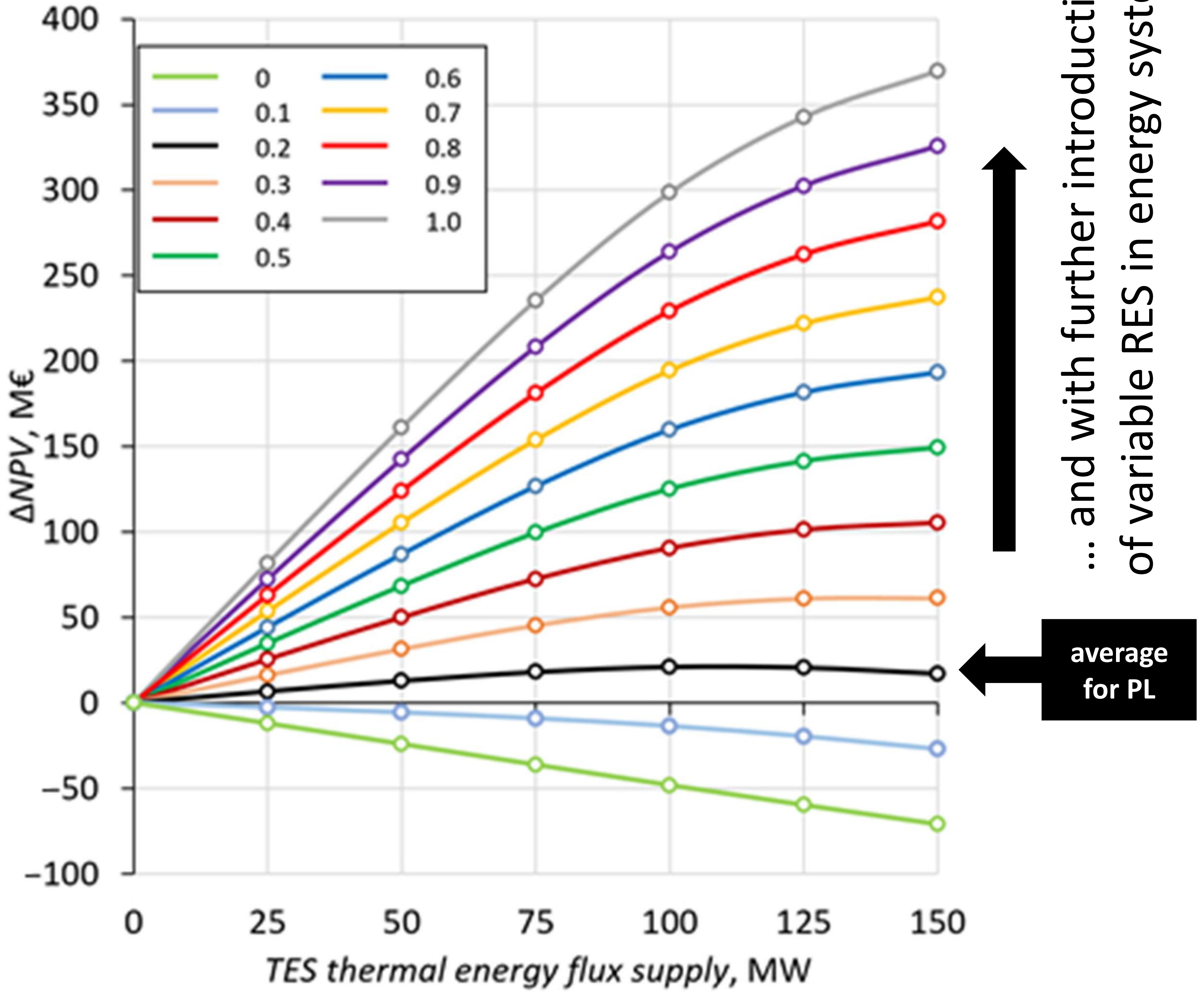
Fig. Diagram of integration of SMR system with TES at Łagisza unit



Deviation index – module of the relative deviation of electricity prices occurring in the energy valley and during the peak demand period relative to the average price

*Fig. ΔNPV as a function of TES thermal energy flux supply for the eleven values of **deviation index** (from 0 to 1, with step 0.1).*



Coal-to-Nuclear classification – DEsire project

C2N

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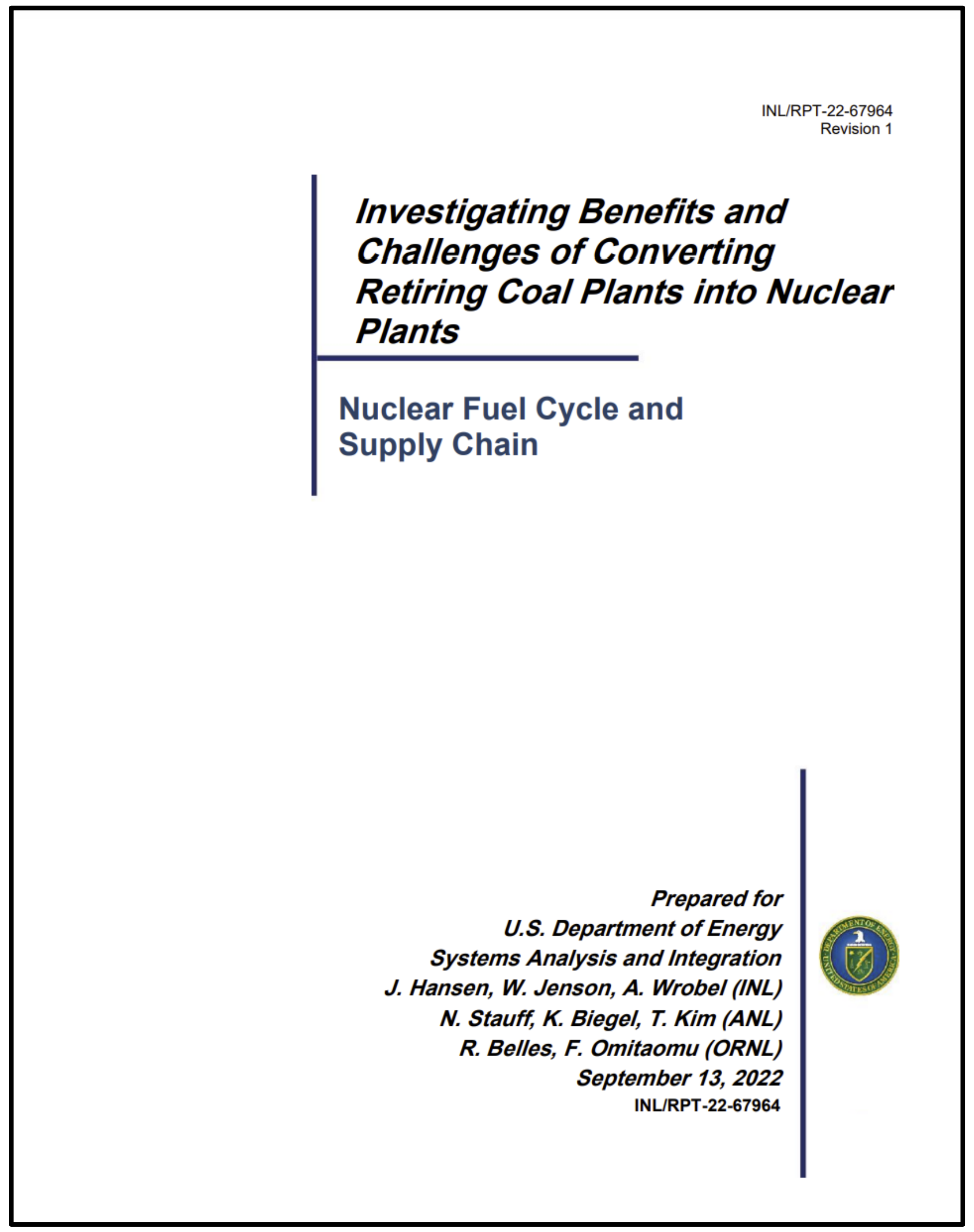
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Repurposing

Full Repowering & Partial Repowering

Locations

- locations indicated in the **Polish Nuclear Power Programme** (strategic government document)
- locations analyzed in the **DEsire project**
- cluster of conventional coal-fired power plants in **Silesia-Malopolska region** (ca. 8.5 GW_{el})

Coal-to-Nuclear
repowering / repurposing
as part of a
Just Transformation of Coal Regions

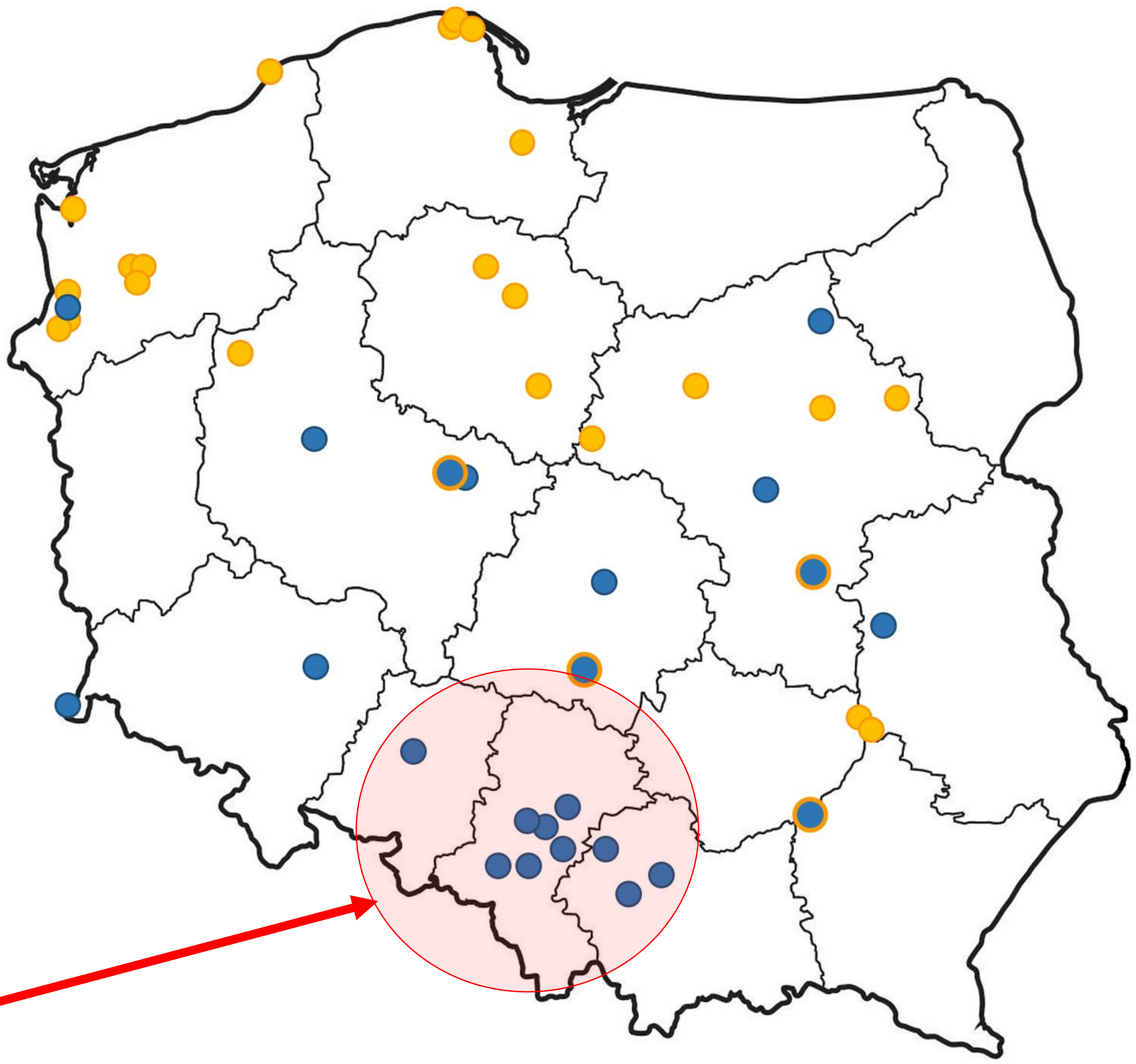
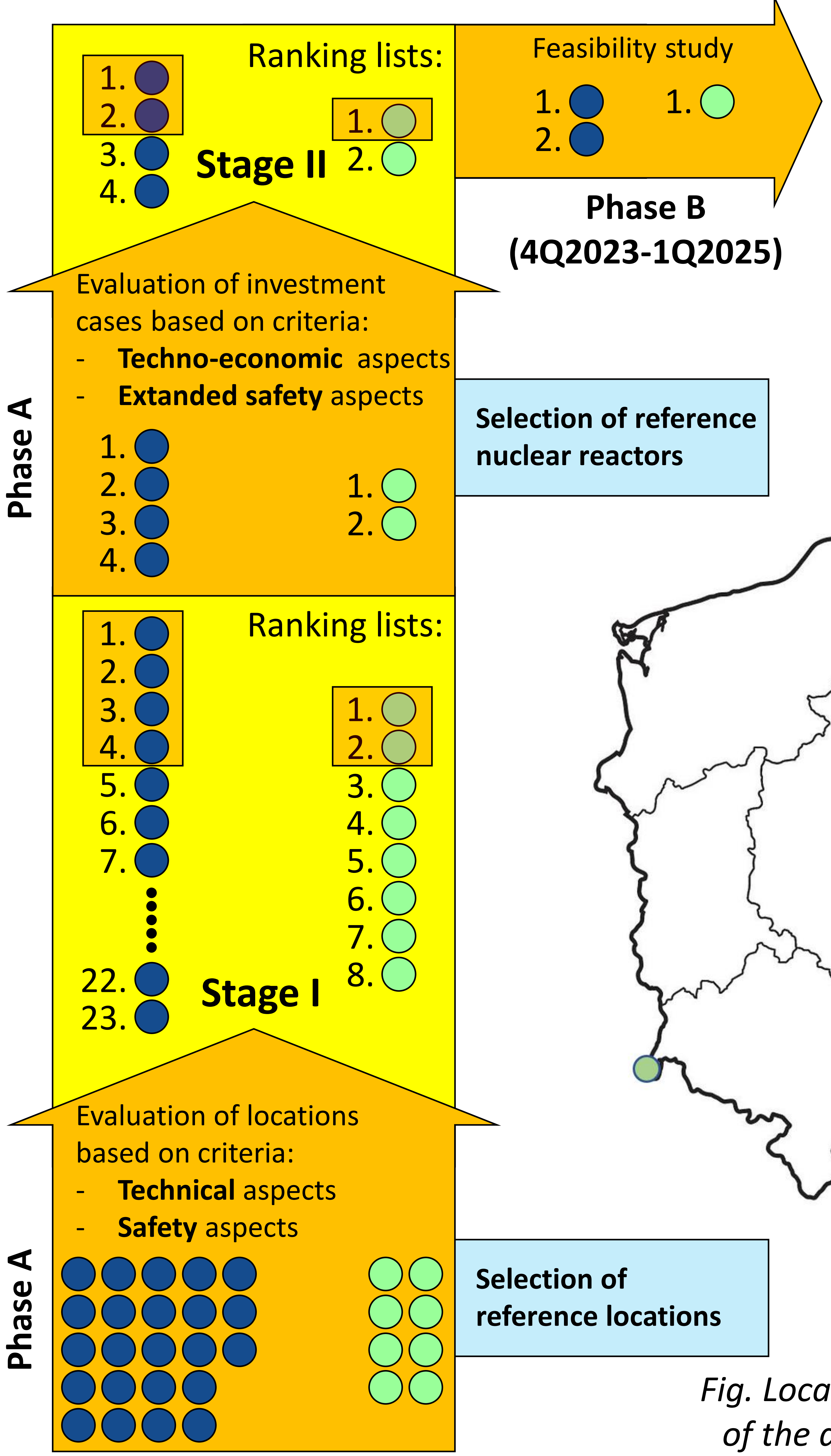
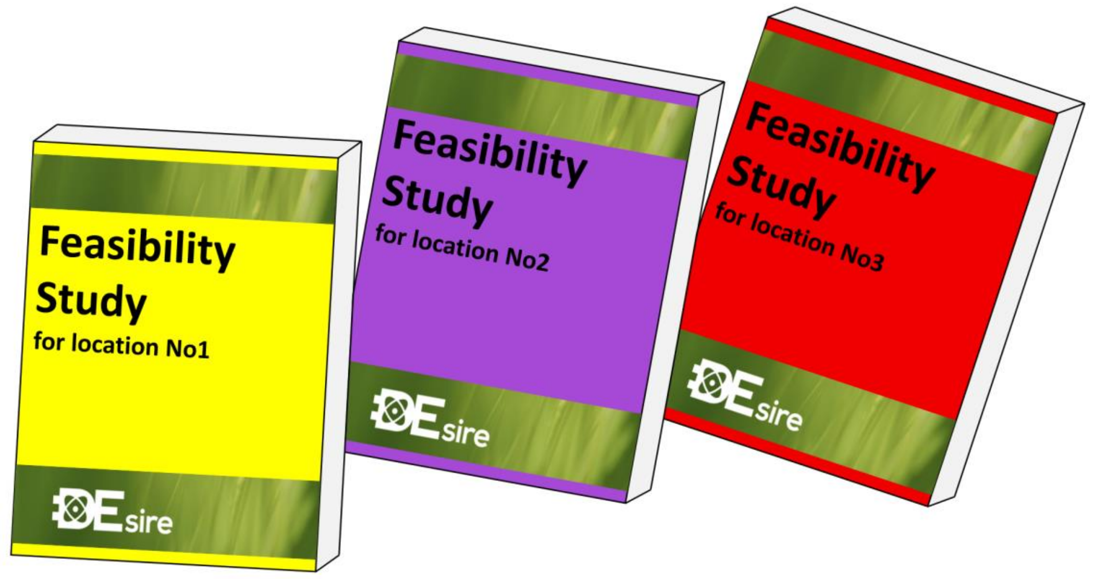


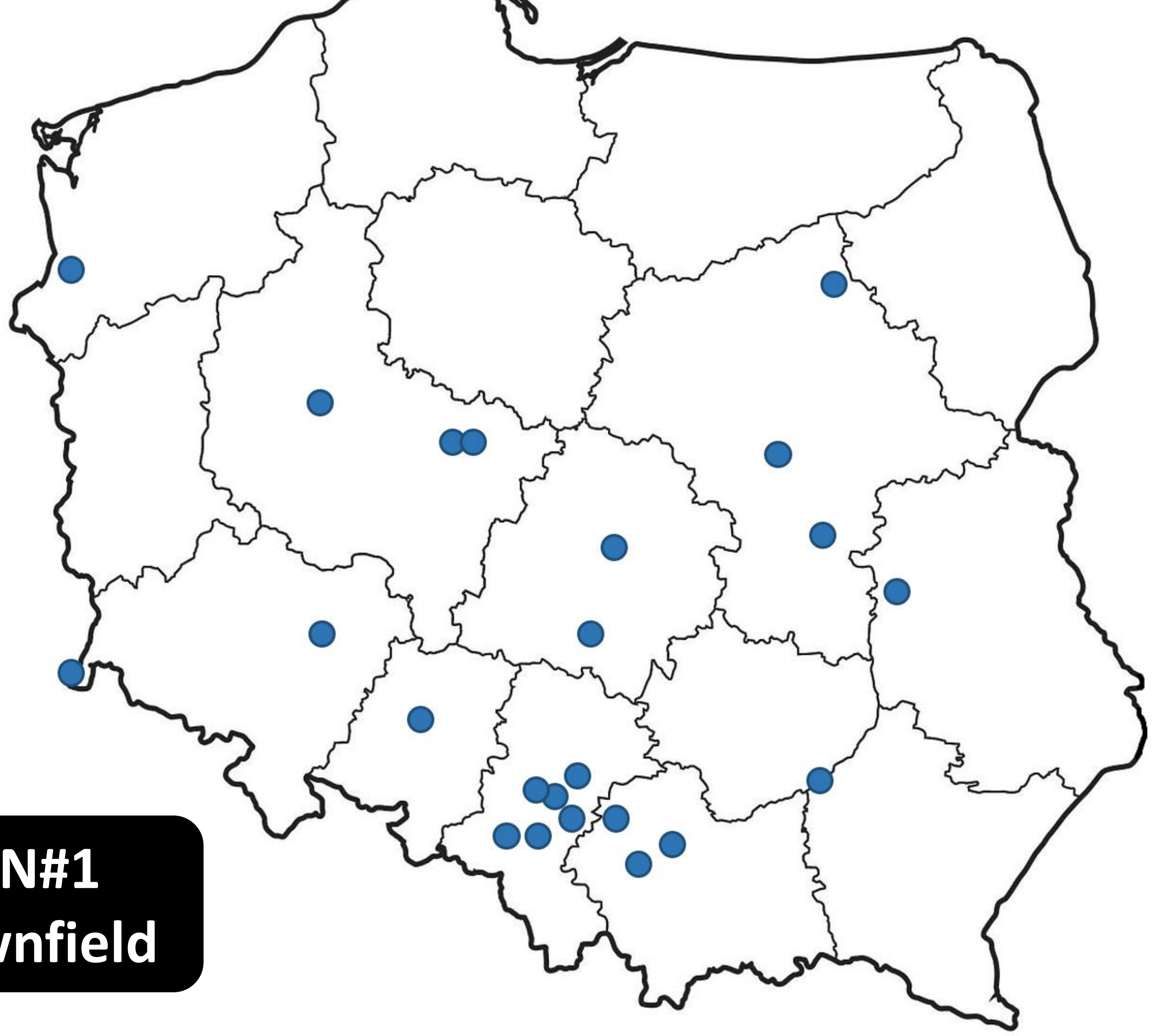
Fig. Locations indicated in the Polish Nuclear Power Programme and analyzed in the DEsire project

Locations





23 locations:



C2N#1 Brownfield

Fig. Locations of CPPs selected for the assessment of the brownfield C2N conversion pathway potential

8 locations:

C2N#2 Direct

Fig. Locations of CPUs selected for the assessment of the direct C2N conversion pathway potential

Locations

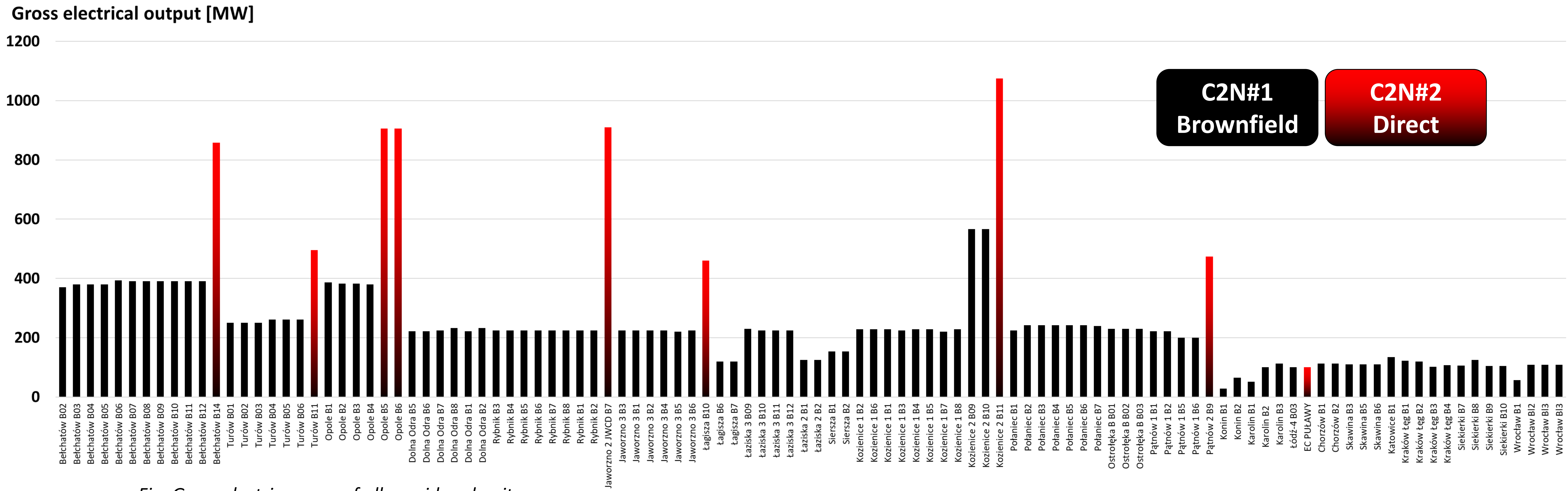


Fig. Gross electric power of all considered units

Stage I – evaluation criteria

C2N#1 Brownfield | **C2N#2 Direct**

- different **weighting factors** for evaluation criteria depending on the pathway (C2N#1 vs C2N#2)
- final conclusions based on **unified approach**
- first step for **CtNRL** (Coal-to-Nuclear Readinnes Level)

Technical aspects:

- power output **infrastructure** (electrical grid capacity)
- access to transport **infrastructure** (sea, railroad, highways)
- assess to **cooling water** (sea, lakes, rivers)
- **area availability** (dates, complexity)
- **demand for heat** (district heating systems, industrial heat demand)

Safety aspects:

- **formal requirements** and recommendations imposed by international and national organizations on the design and operation of nuclear power systems (e.g. seismic activity, floods, mineral deposits, selected types of facilities)
- potential **nuclear hazards** to the personnel of the unit and the **local population** (e.g. population density)
- applied solutions for **reactor protection systems**, steam turbine thermal cycle, and auxiliary infrastructure (technology advancement, redundancy of safety systems)
- management of **spent nuclear fuel and radioactive waste** (management technology/facilities, enrichment of nuclear fuel)

Stage II – evaluation criteria

C2N#1 Brownfield | **C2N#2 Direct**

- **independent** safety and techno-economic studies
- final conclusions based on **expert assessment**
- detailed studies for site-specific features (including the same area for safety, just **more detailed and in-depth studies**)

Economic aspects:

- **CO_2 emissions** and EU-ETS costs to be avoided
- actual **on-site infrastructure** to be reused (electrical grid, cooling systems)
- existing coal-unit **projected lifetime**
- **complexity of integration** with existing steam turbine and other systems
- potential **investment savings** compared to greenfield
- partial costs offset by means of **heat production**

Extended site- and nuclear reactor-specific safety aspects:

- **formal requirements** and recommendations imposed by international and national organizations on the design and operation of nuclear power systems (e.g. seismic activity, floods, mineral deposits, selected types of facilities)
- potential **nuclear hazards** to the personnel of the unit and the **local population** (e.g. population density)
- applied solutions for **reactor protection systems**, steam turbine thermal cycle, and auxiliary infrastructure (technology advancement, redundancy of safety systems)
- management of **spent nuclear fuel and radioactive waste** (management technology/facilities, enrichment of nuclear fuel)

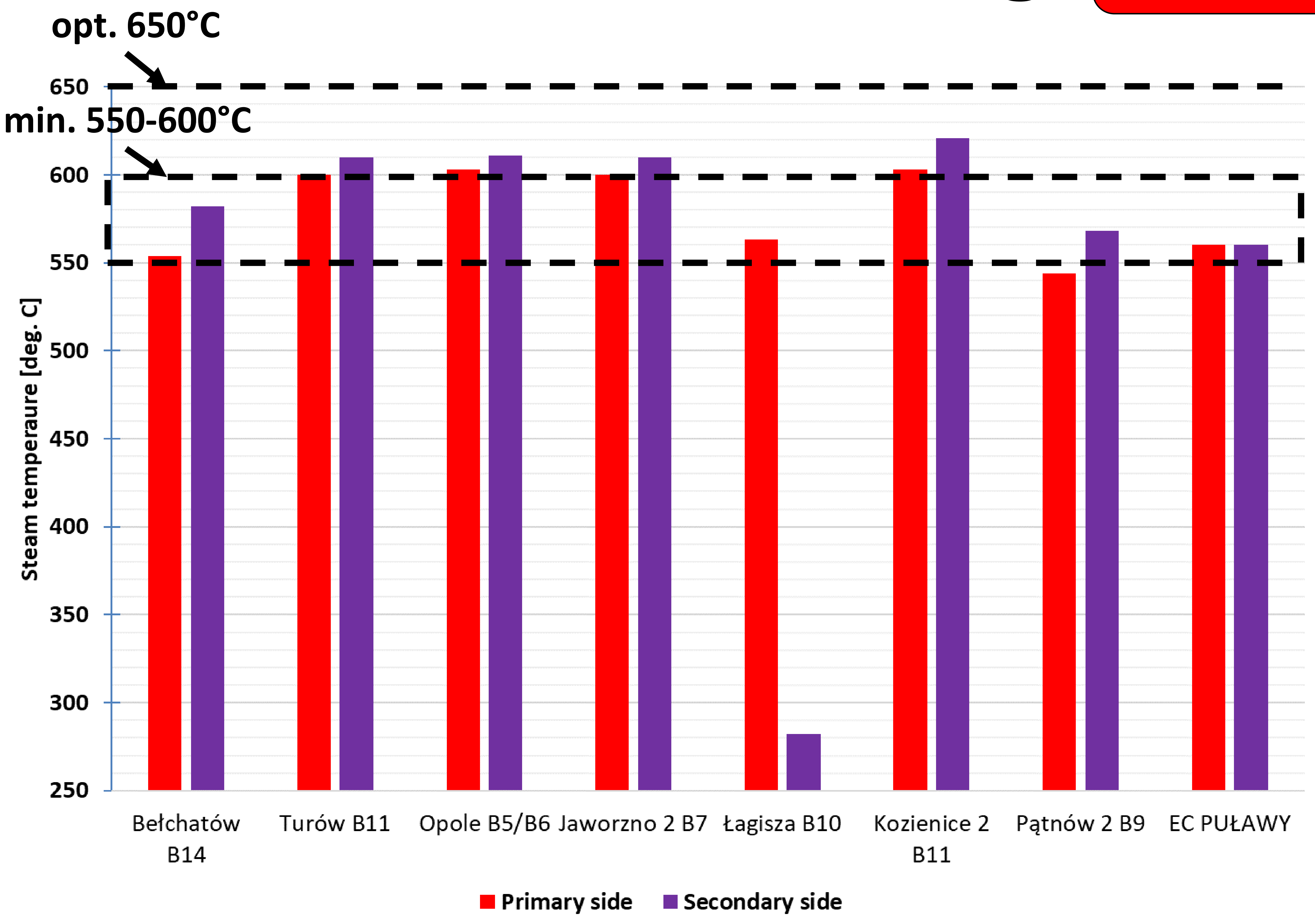
Reactors matching

C2N#1 Brownfield

Provider	Name	Type of reactor	**Electrical power** (gross / net)	**Status** (in operation / in construction)
Westinghouse (USA)	**AP-1000**	**pressurized water reactor (PWR)**	**1250 / 1150 MW**	**4 / 2**
KHNP (South Korea)	**APR1400**	**pressurized water reactor (PWR)**	**1420 / 1350 MW**	**4 / 6**
EDF (France)	**EPR**	**pressurized water reactor (PWR)**	**1720 / 1600 MW**	**3 / 3**
EDF (France)	EPR-1200	pressurized water reactor (PWR)	c.a. 1200 MW	0 / 0
KHNP (South Korea)	APR1000	pressurized water reactor (PWR)	c.a. 1000 MW	0 / 0

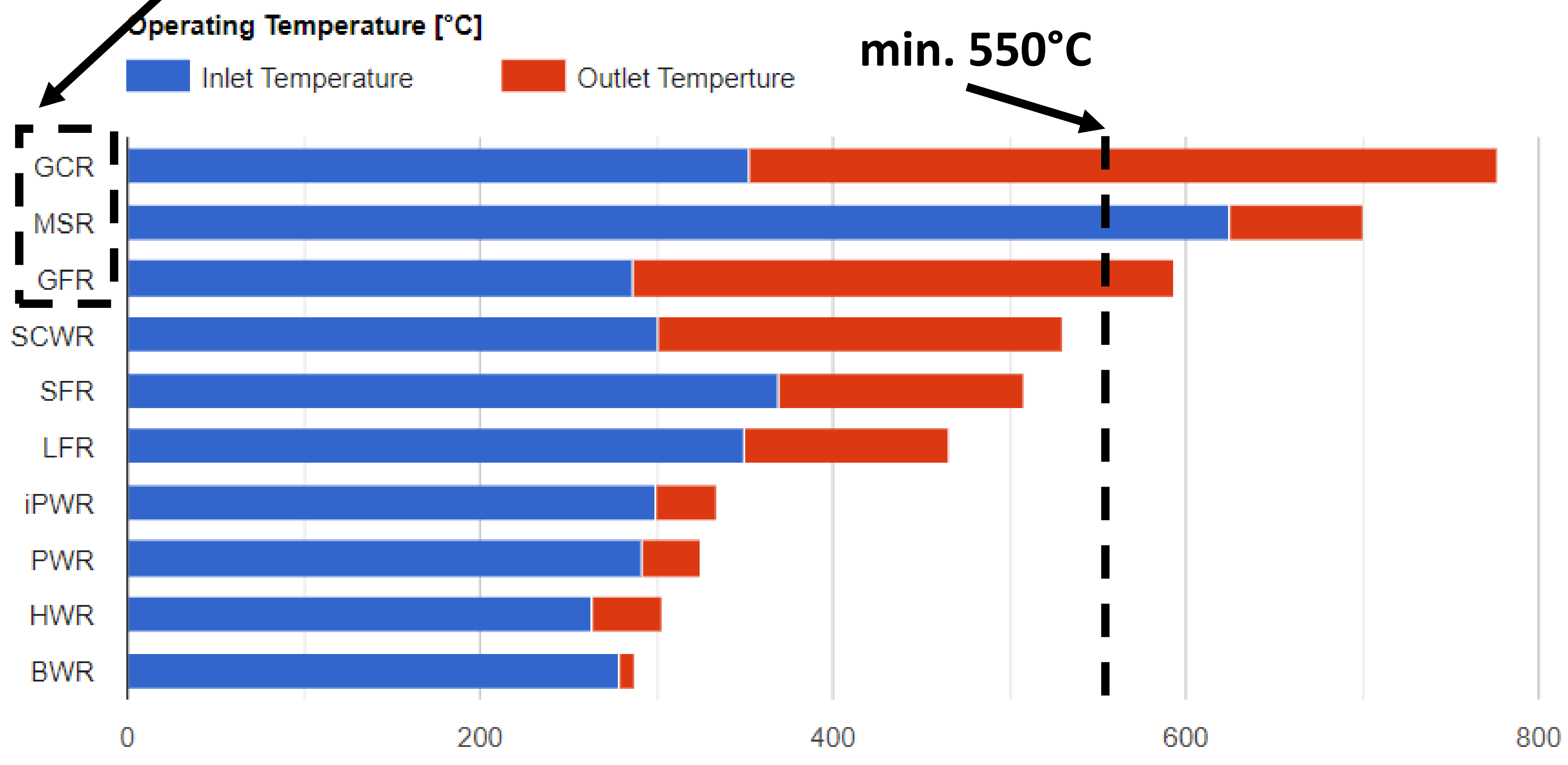
Reactors matching

C2N#2
Direct



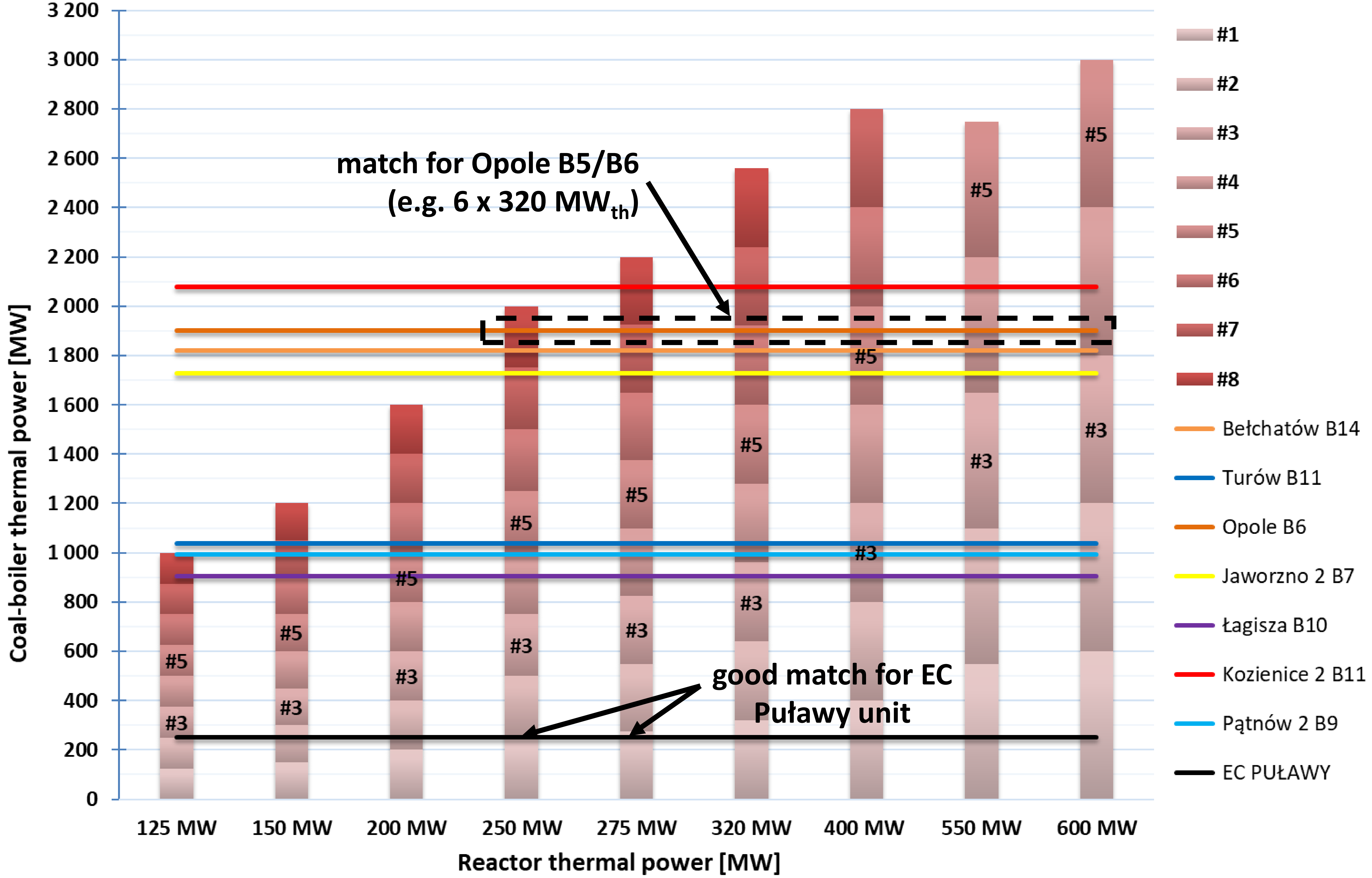
Preselection of SMRs:

- **GCR** (gas cooled reactors);
- **GFR** (fast gas-cooled reactors);
- **MSR** (molten salt reactors).



Reactors matching

C2N#2
Direct



Selection of SMRs:

- we do not consider reactors smaller then **250 MW$_{th}$**;
- for prelimiary selected units, we would need to install **4 – 6 reactors**;
- **500 MW$_{el}$ class units** (Turów B11, Pątnów 2 B9 and Łagisza B10) might be more attractive due to lower number of reactors needed.

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Reactors matching

C2N#2 Direct

Name	Country	Type	Moderator	Coolant	Fuel	Reactor thermal power	Coolant outlet temperature	Status and predictive dates	
HTR-PM	**China**	**GCR**	graphite	helium	8,5% LEU	**2x250 MW**	**750°C**	**in operation**	**2022**
SC-HTGR	**USA**	**GCR**	graphite	helium	14,5% HALEU	**625 MW**	**750°C**	**preliminary design**	**2033**
GTHTR300	Japan	**GCR**	graphite	helium	14% HALEU	600 MW	950°C	basic design	2040s
IMSR400	**Canada**	**MSR**	graphite	fluoride salts	<5,0% LEU	**440 MW**	**700°C**	**detailed design**	**2031**
ITMSF	Japan	**MSR**	graphite	fluoride salts	2,0% LEU	450 MW	704°C	basic design	b/d
ThorCon	USA	**MSR**	graphite	molten salts	<5,0% LEU	557 MW	704°C	basic design	2028
KP-FHR	**USA**	**MSR**	graphite	molten salts	19,7% HALEU	**320 MW**	**650°C**	**conceptual design**	**2026 demo**
LFTR	USA	**MSR**	graphite	molten salts	^{233}U Th	600 MW	650°C	conceptual design	b/d
MCSFR	USA	**MSR**	-	chloride salts	15% HALEU	125/500/ 1000/3000	750°C (950°C)	conceptual design	2030

Stage I and II results

C2N#1 Brownfield

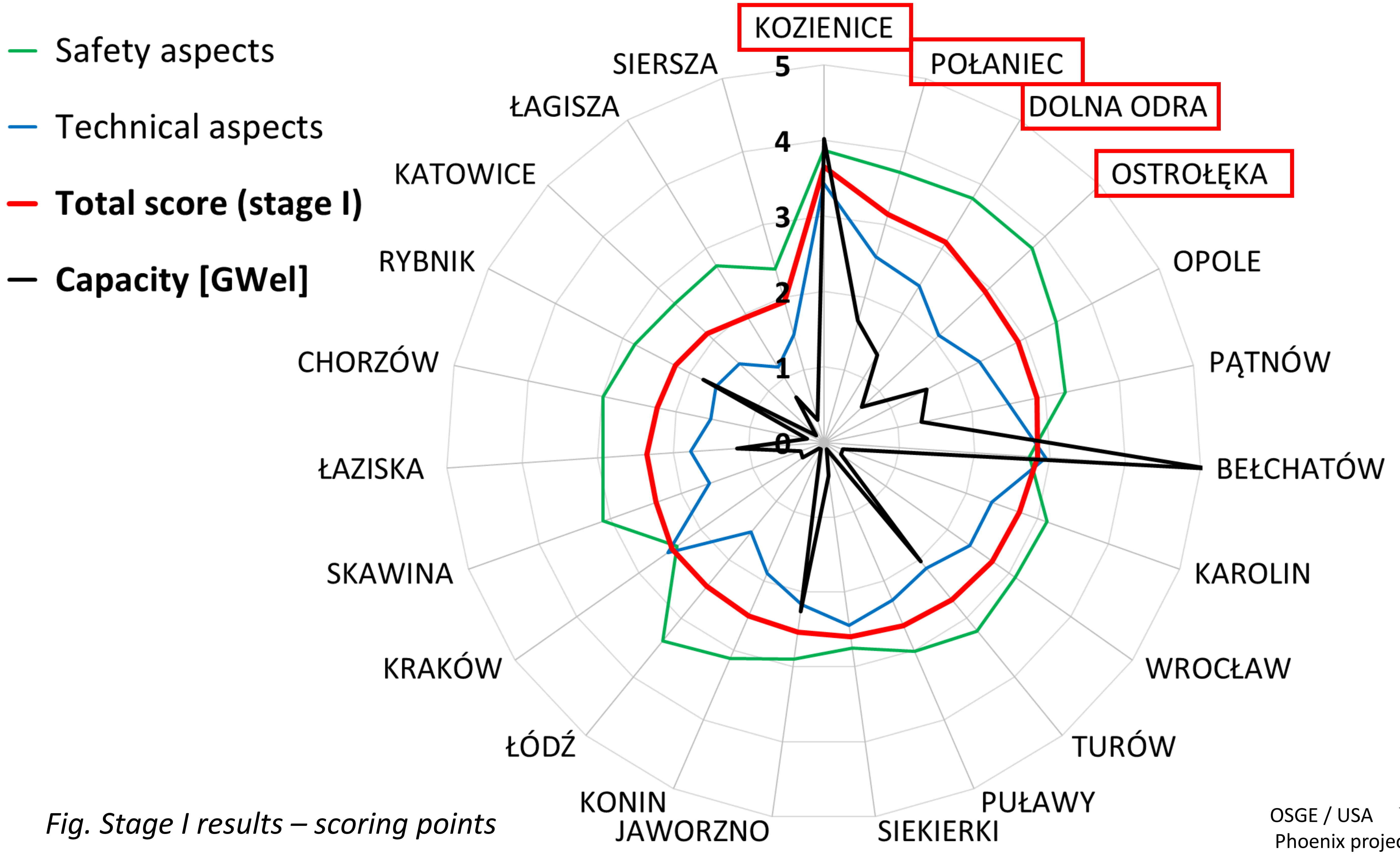
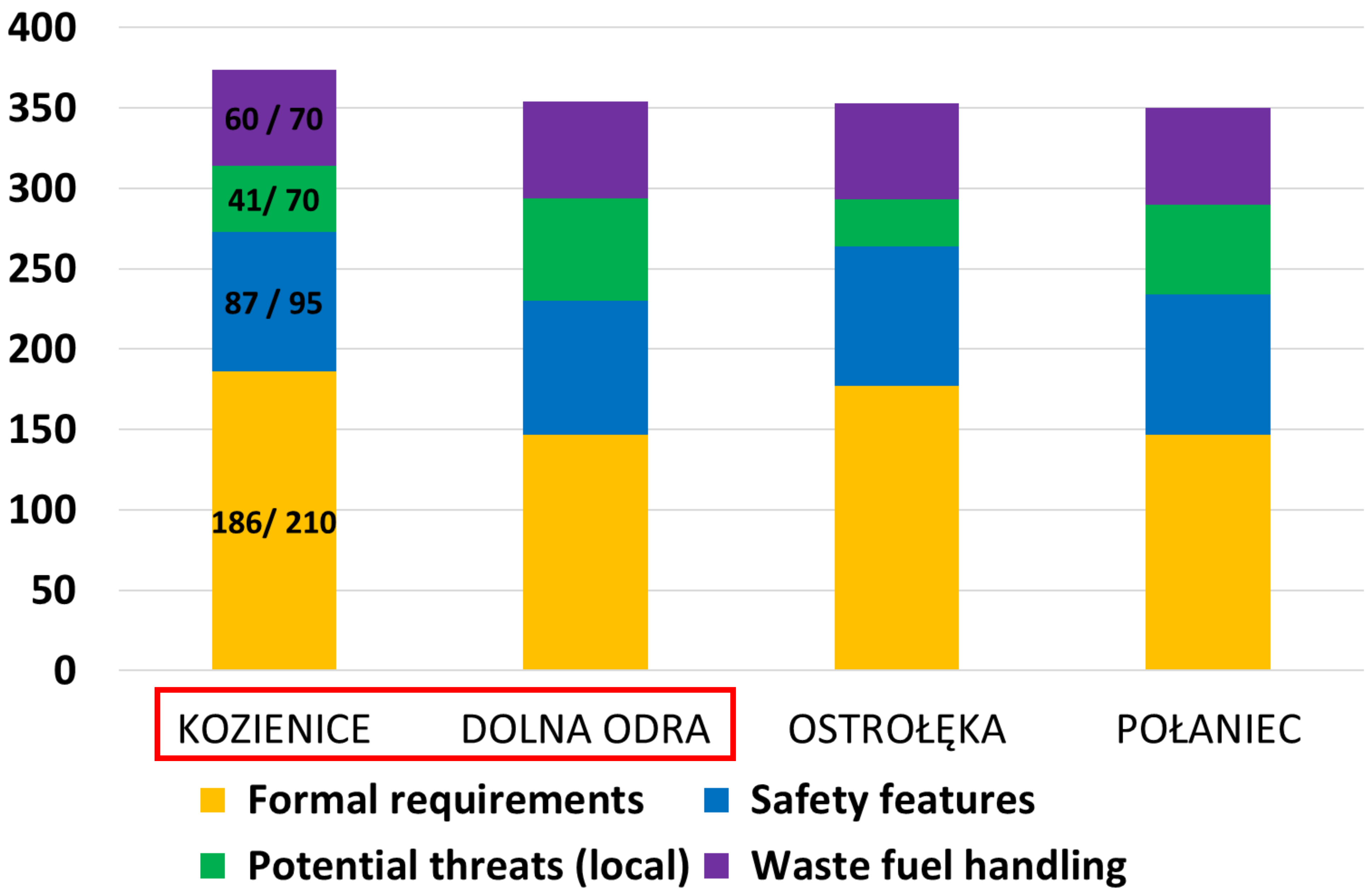


Fig. Stage I results – scoring points

OSGE / USA ★
Phoenix project

Fig. Stage II results – extended safety features points



Tab. Stage II results – TEA summary

Location	Current capacity [GW_{el}]	Estimated NPP capacity [GW_{el}]	Estimated CAPEX savings	Avoided emissions [kg CO_2/MWh]
KOZIENICE	**4.02**	(2.30 – 3.20) **2.70**	**high** (above 20%)	**872**
DOLNA ODRA	**1.35**	(1.15 – 1.60) **1.35**	**moderate** (15% - 20%)	**977**
POŁANIEC	**1.66**	(1.15 – 2.30) **1.60**	**moderate** (15% - 20%)	**907**
OSTROŁĘKA	**0.69**	(1.15 – 1.35) **1.15**	**moderate** (15% - 20%)	**840**

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Stage I and II results

C2N#2
Direct

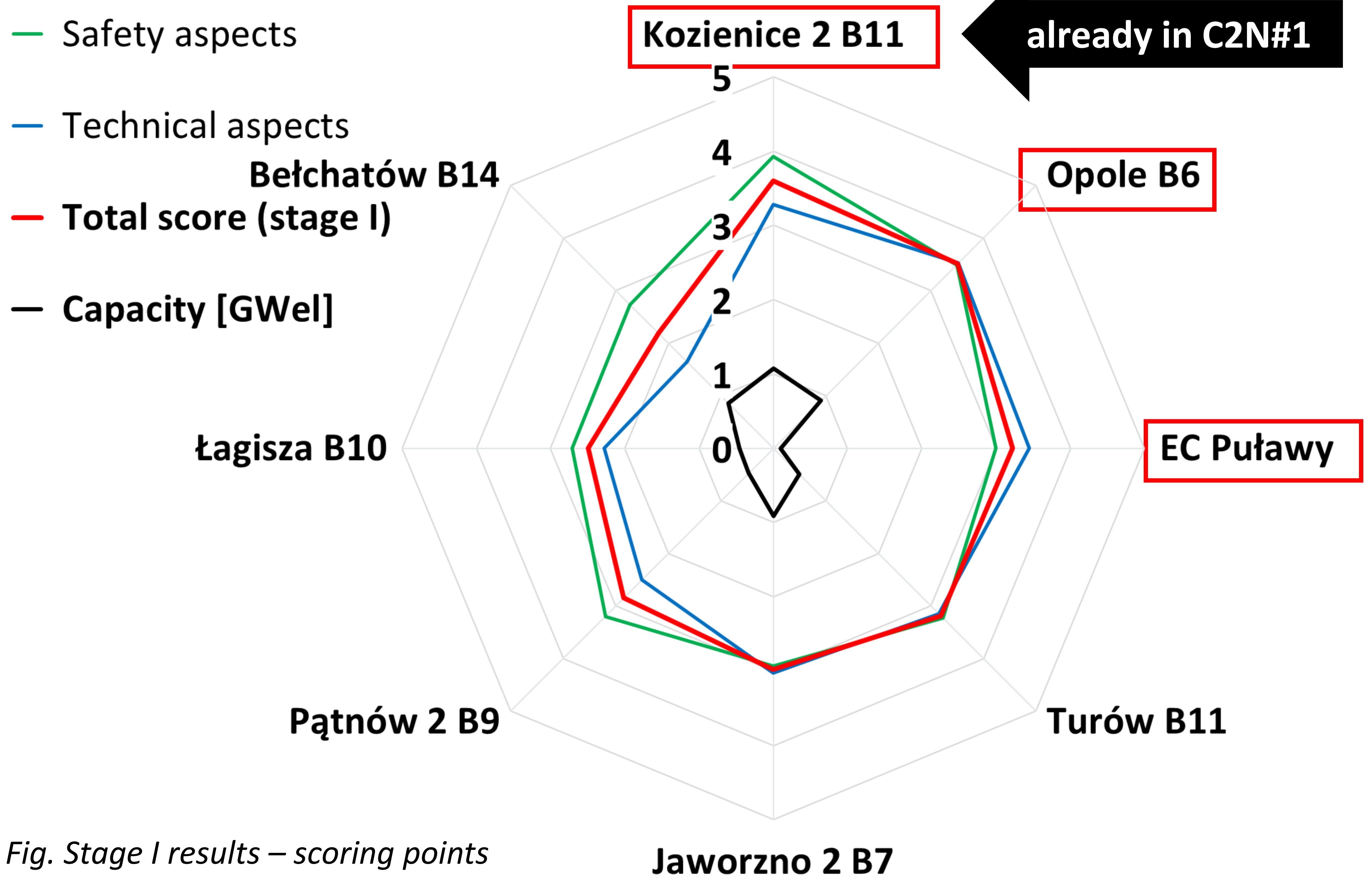
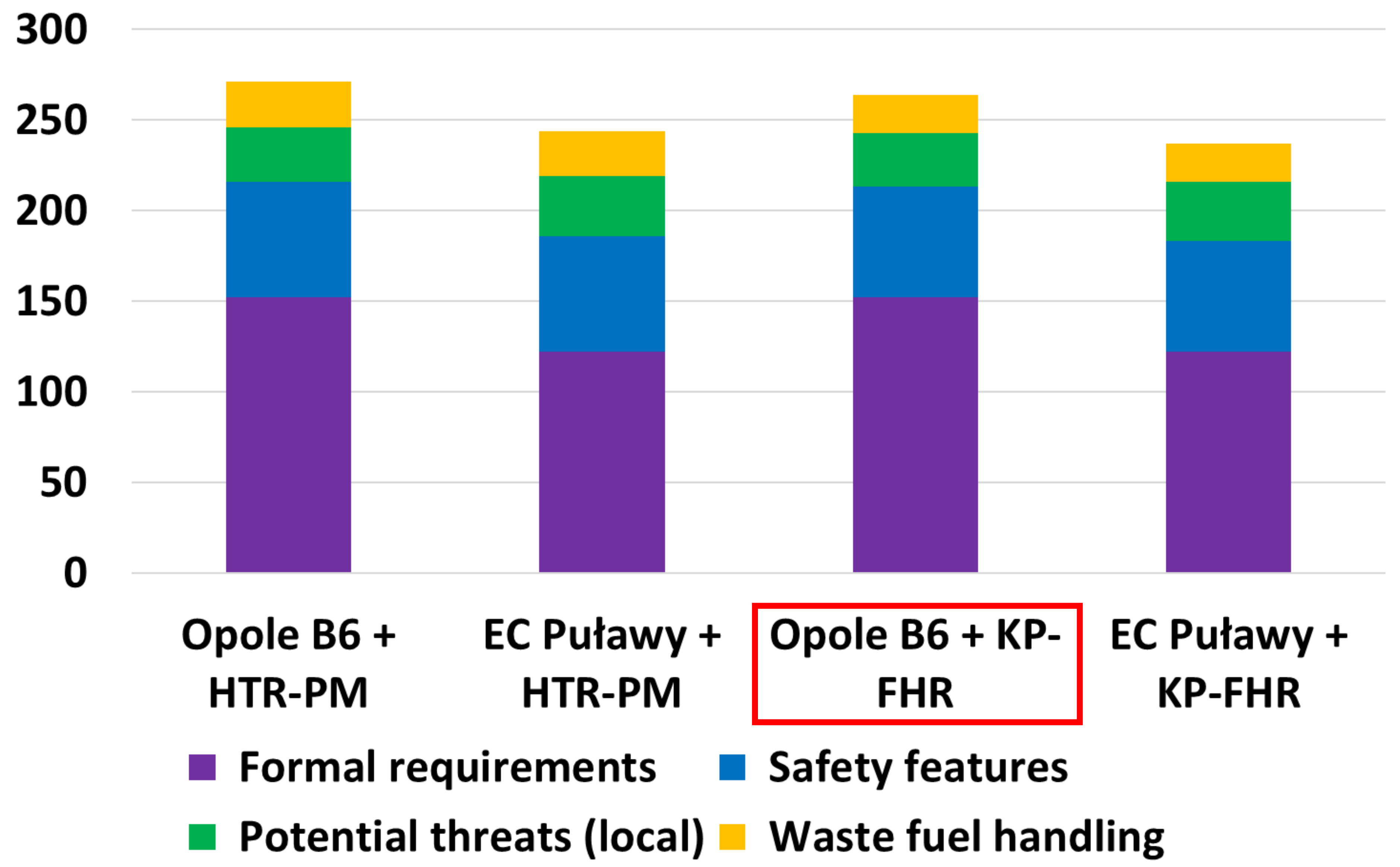


Fig. Stage I results – scoring points

Fig. Stage II results – extended safety features points



Tab. Stage II results – TEA summary

Location	Current capacity [MW_{el}]	Type of reactor	Integration complexity	Estimated CAPEX savings	Avoided emissions [kg CO_2/MWh]
Opole B6 (and B5)	905	6 x KP-FHR	**low** (dedicated HRSG)	**high** (above 30%)	**695**
Opole B6 (and B5)	905	4/5 x HTR-PM	medium	moderate (20% - 30%)	695
EC Puławy (CHP unit)	100	0.5 x HTR-PM	medium	moderate (20% - 30%)	n/a

Locations

C2N#1
Brownfield

23 locations:

Bełchatów
Chorzów
Dolna Odra (1.3 GW_{el})
Jaworzno
Katowice
Karolin
Konin
Kozienice (2.7 GW_{el})
Kraków
Łagisza
Łaziska
Łódź
Opole
Ostrołęka (0.7 GW_{el})
Pątnów
Połaniec (1.6 GW_{el})
Puławy
Rybnik
Siekierki
Siersza
Skawina
Turów
Wrocław

$\sum$ 92 units
$\sum$ 22.4 GW_{el}

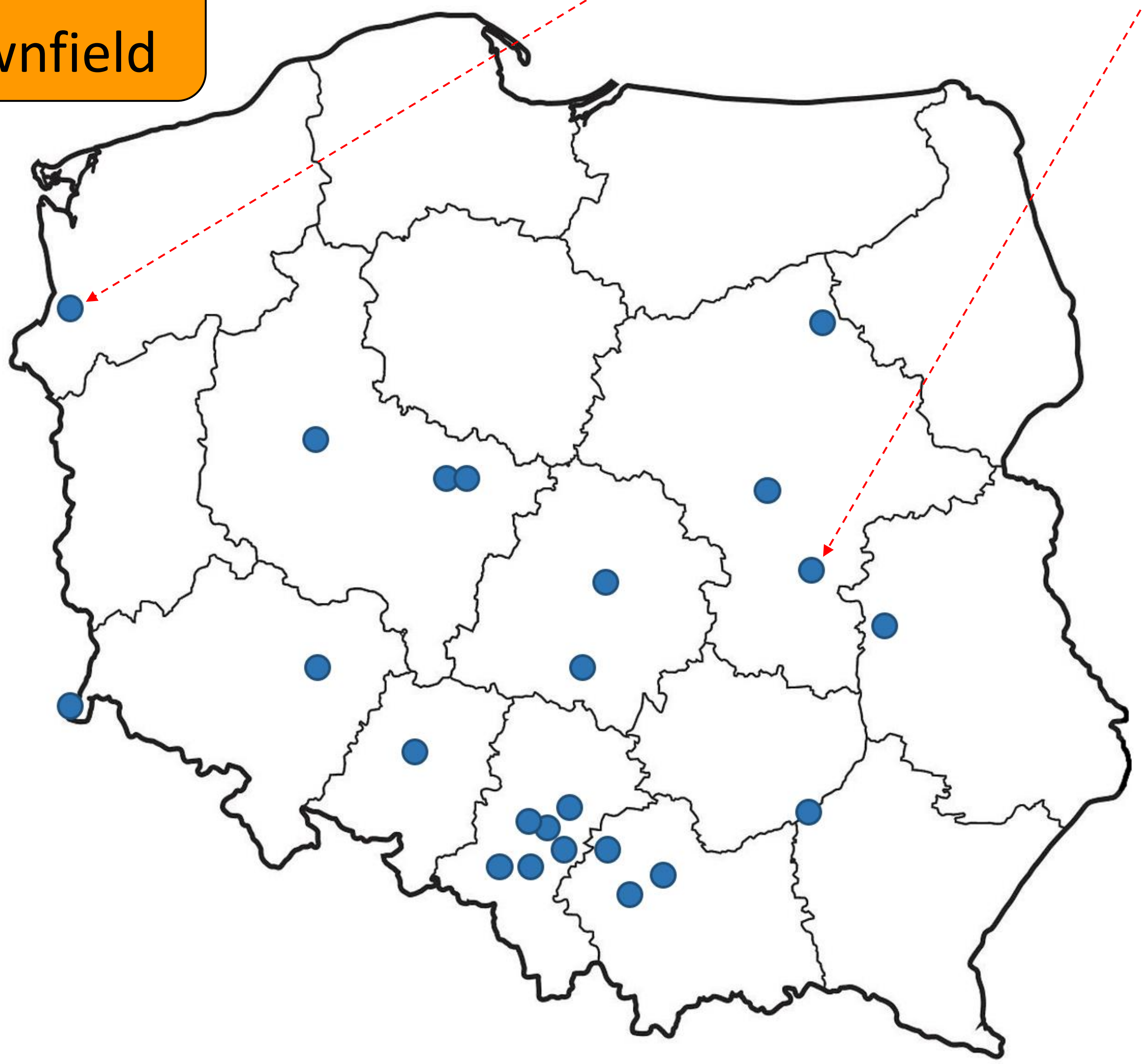


Fig. Locations of CPPs selected for the assessment of the brownfield C2N conversion pathway potential

C2N#2
Direct

8 locations:

Bełchatów
Jaworzno
Kozienice
Łagisza
Opole (905 MW_{el})
Pątnów
Puławy (100 MW_{el})
Turów

$\sum$ 9 units
$\sum$ 6.2 GW_{el}

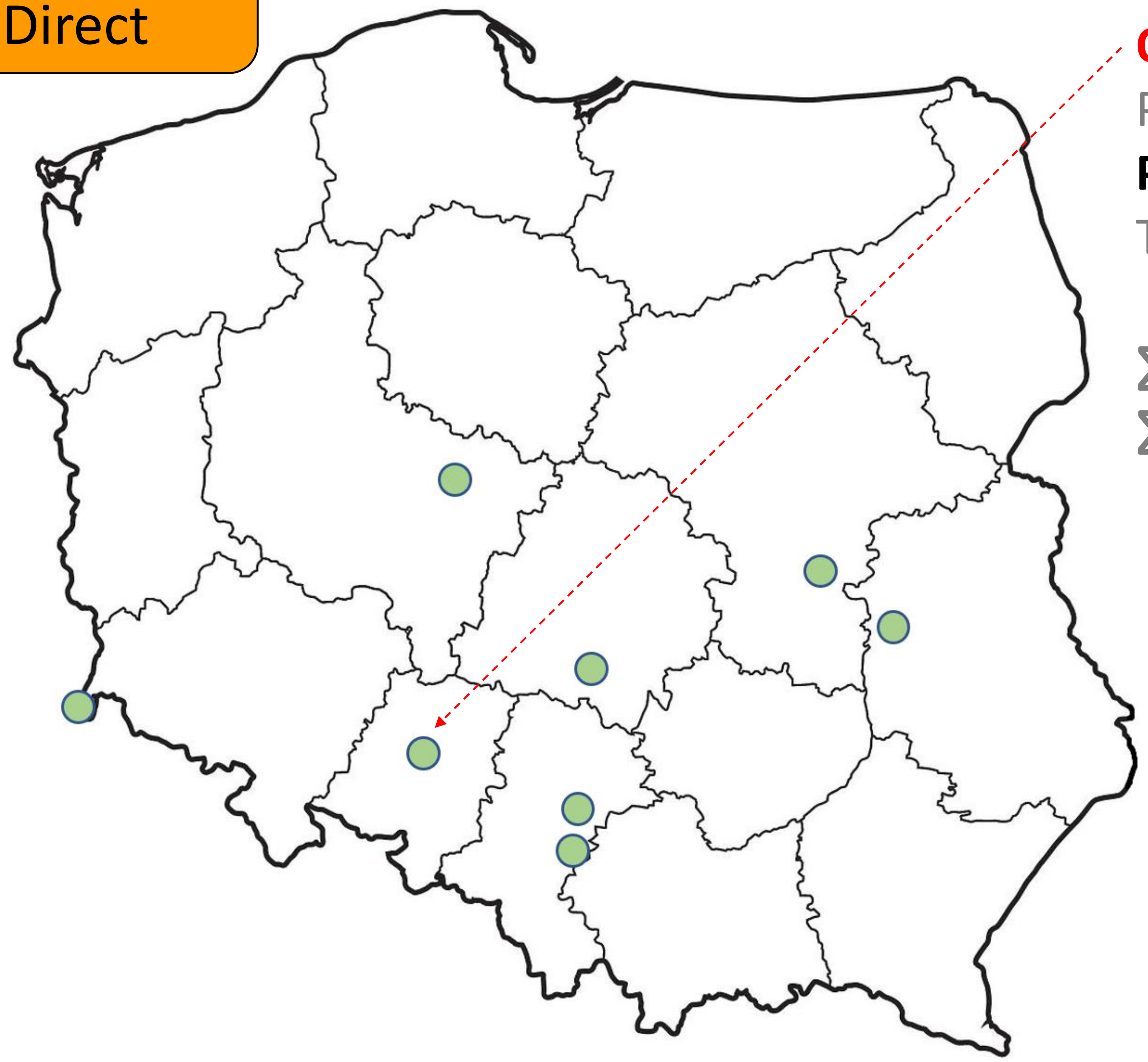


Fig. Locations of CPUs selected for the assessment of the direct C2N conversion pathway potential

Summary

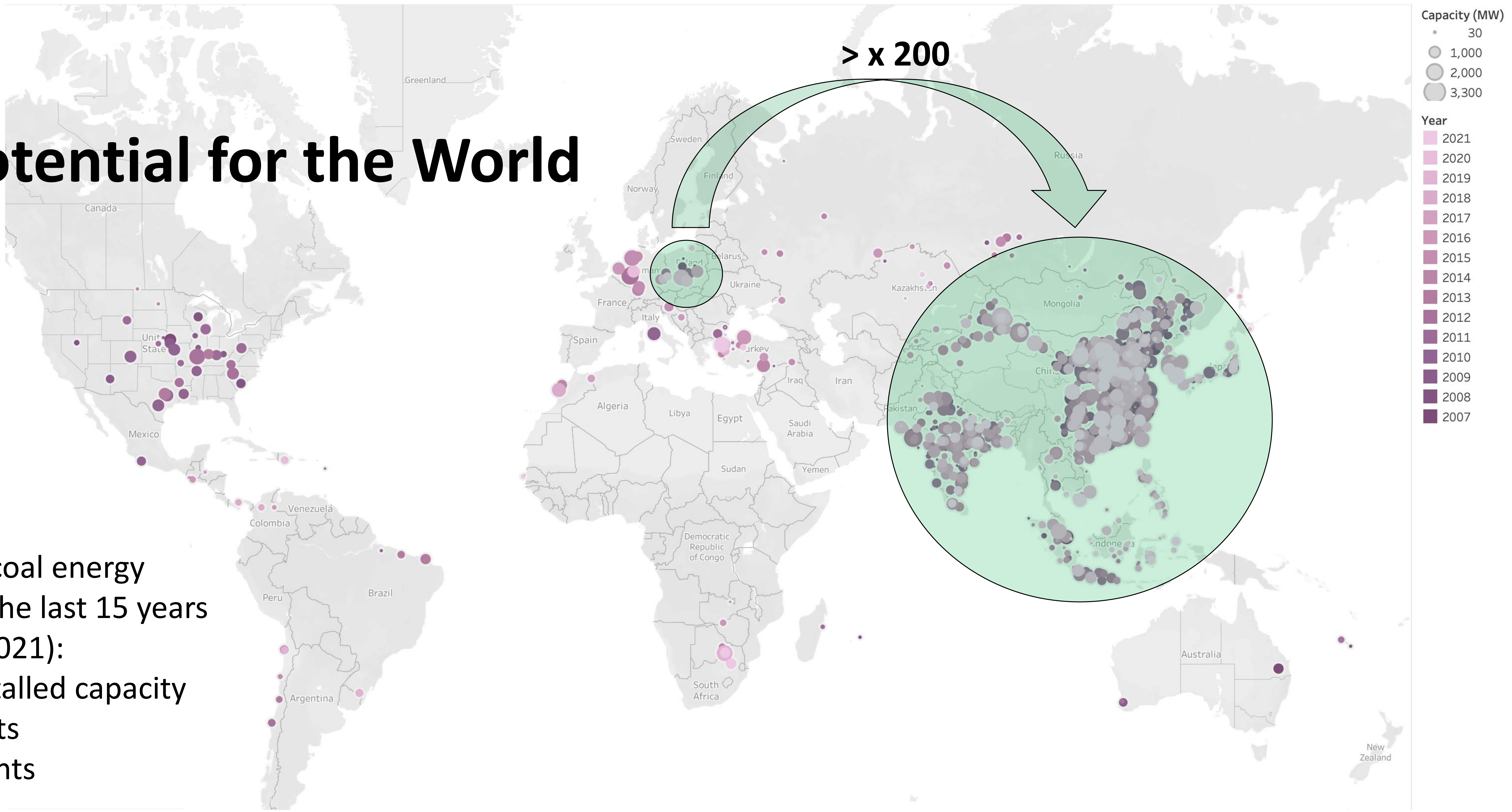
Technical and economic considerations:

- **both** C2N#1 (brownfield) and C2N#2 (direct) **pathways are suitable for Poland**, with several highly-scored power plants and specific coal-fired units
- critical technical aspects are associated with **cooling systems** and – for direct integration with SMRs – **matching and combining of the reactors thermal output with the replaced coal-boilers**
- potential **investment savings reported between 18.7% and 35.5%**, depending on specific location, type of integration and considered reactor type

Safety and public relevance (acceptance):

- similar challenges as for greenfield investments in terms of nuclear safety, although some **site-specific obstacles needs to be acknowledged**
- nuclear energy for coal-fired power plant locations could help **maintain the economic activities in those regions**, utilizing the existing workforce and infrastructure

Potential for the World



Investments in coal energy
in the world in the last 15 years
(from 2007 to 2021):
1350 GW of installed capacity
3400 power units
1300 power plants

Follow-up in DEsire project

Clustering activities:

- **dedicated seminars** for Polish and international C2N stakeholders planned starting from Q1 2024 (events every 2-3 months)
- **C2N International Forum** in Poland in March 2025
- **study visits** of DEsire team to technology vendors and project developers around the world
- **technical dialog** as part of the planned feasibility studies

Public outreach:

- **public acceptance study** for C2N pathways of decarbonization
- scope of **re-training programme** for coal-fired power plant operators and personnel
- social media and **local community outreach** activities in Poland
- **politician outreach** as part of the proposed energy mix of Poland by 2050 studies

DEsire Team:

Silesian University of Technology

Ministerstwo Klimatu i Środowiska

THANK YOU!

website:

https://projektdesire.pl/en

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Selected publications

- Qvist, S.; Gładysz, P.; Bartela, Ł.; Sowiżdżał, A. Retrofit Decarbonization of Coal Power Plants—A Case Study for Poland. *Energies* **2021**, *14*, 120. https://doi.org/10.3390/en14010120

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