Flexible CFPPs to Accommodate Rapid Penetration of Variable Renewable Energy

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CFPPs emissions mitigation initiatives

Coal-fired Power Plant (CFPP)

NZE Target 2060

The GoI has prohibited PLN from including new CFPP in its development plans (although previously planned CFPPs can proceed)

Phase-Out

Retire CFPP earlier than its economic life by purchasing CFPP with lower-cost financing than originally used to construct the plant, thereby allowing the new owners to retire the plant sooner and still earn a reasonable return on their investment

Phase-Down

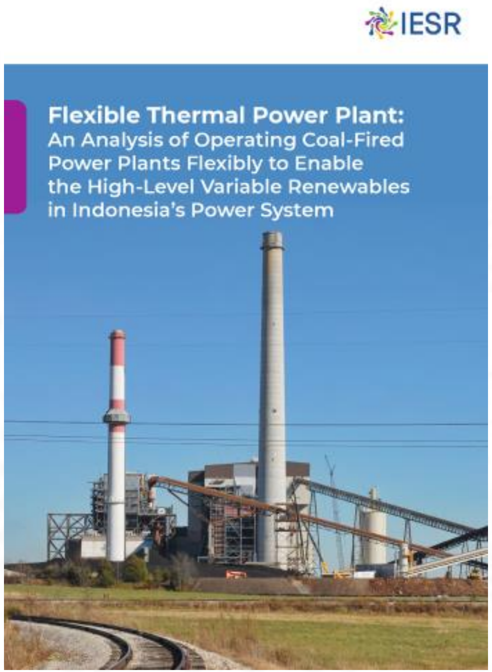
To utilise the economic potential of existing CFPPs, in line with efforts to reduce coal use

Flexibility

- Parallel efforts are ongoing while awaiting the phase-out
- Modifying the CFPP operational to enhance coal power plant flexibility to accommodate VRE integration

Source: analisis IESR dan Castlerock

IESR previous works on flexible CFPPs



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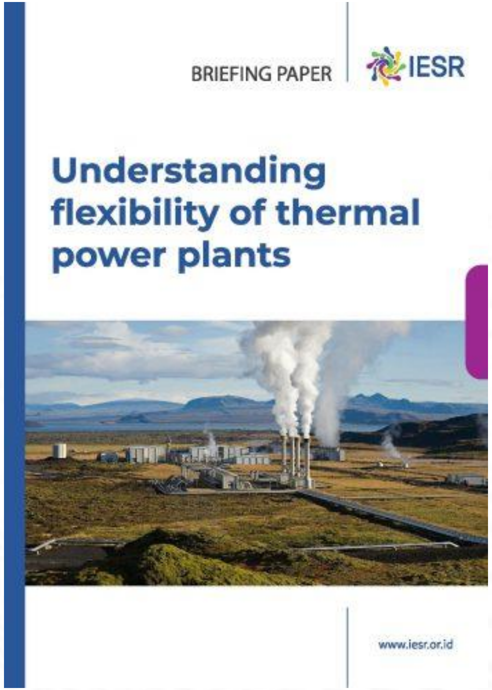

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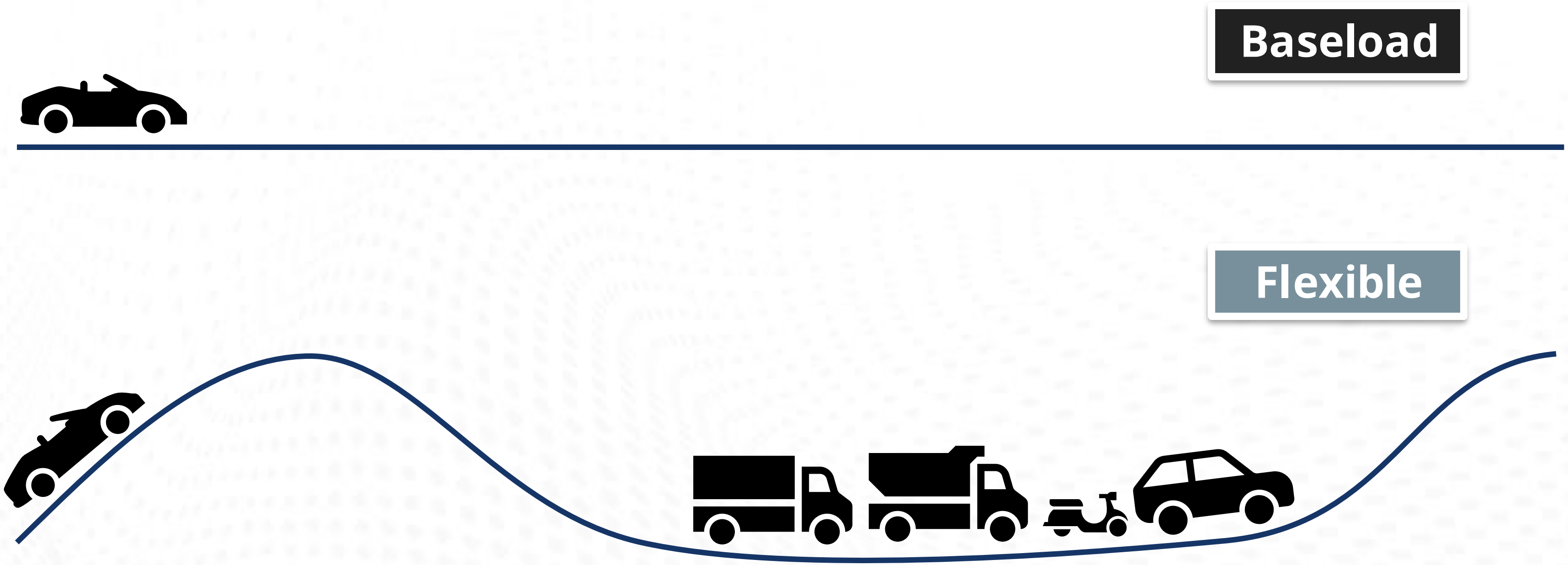
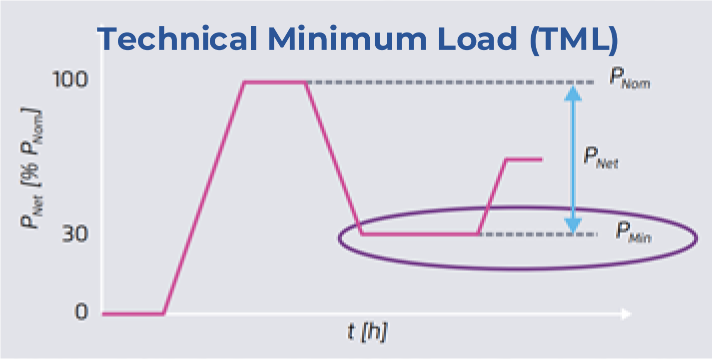
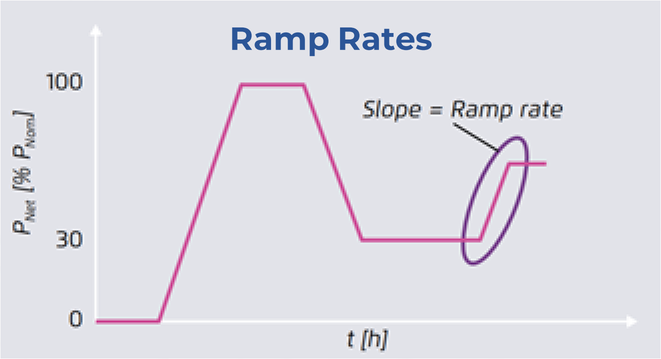
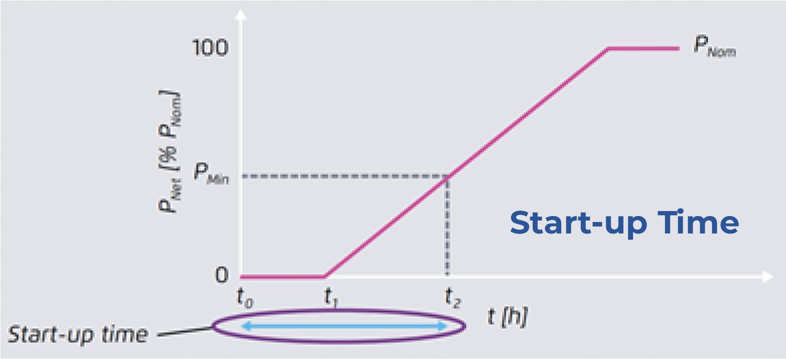
An analogy for CFPP's flexible operation



Flexible operation parameters







Flexible operation means:

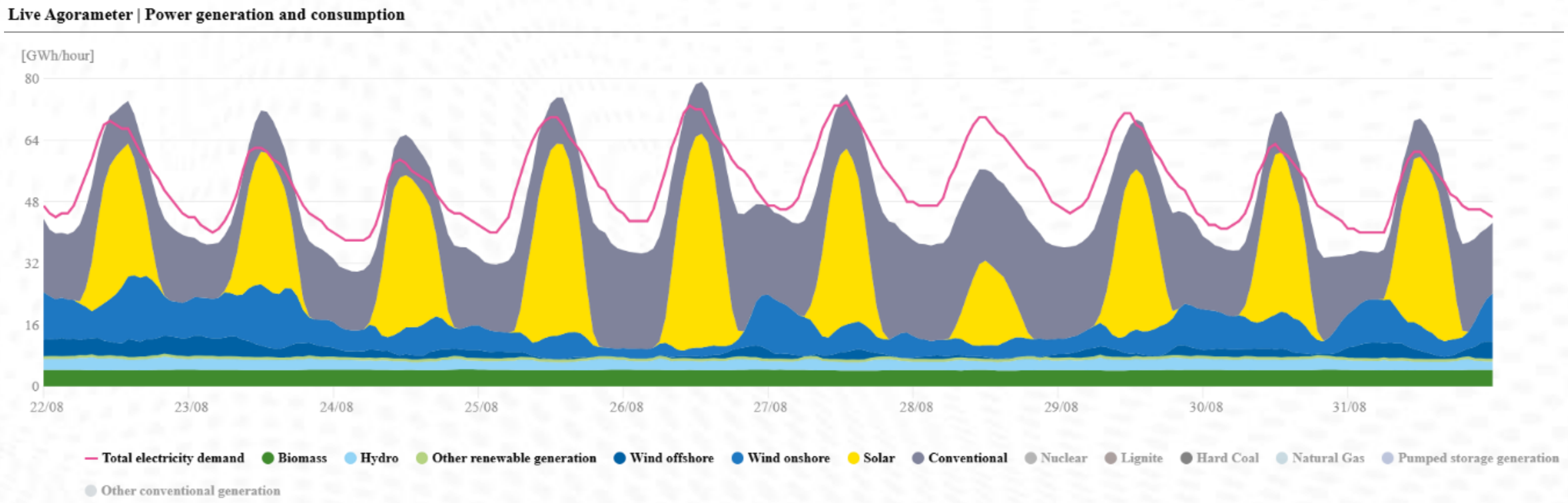
- **Lower** TML
- **Higher** ramp rates
- **Shorter** start-up times

... **relative** to each parameter at design points

Source: Agora Energiewende. (2017). Flexibility in Thermal Power Plants

Drivers for flexible CFPPs

- **Increasing share of renewables**, especially VREs, within the system
- **Lower cost of generation** of the renewables
- **Limited options** for balancing resources
- **Tighter regulations** on emissions and environment



Source: Agora Energiewende, Live Agorameter, 2025

State-of-the-art of CFPPs flexible operation parameters

Technical Minimum Load (TML)

Power Plant Type	Most Used [% PNom]	State-of-the-Art [% PNom]
Hard Coal-Fired	25–40%	25–40%
Lignite-Fired	50–60%	35–50%

Ramp Rates

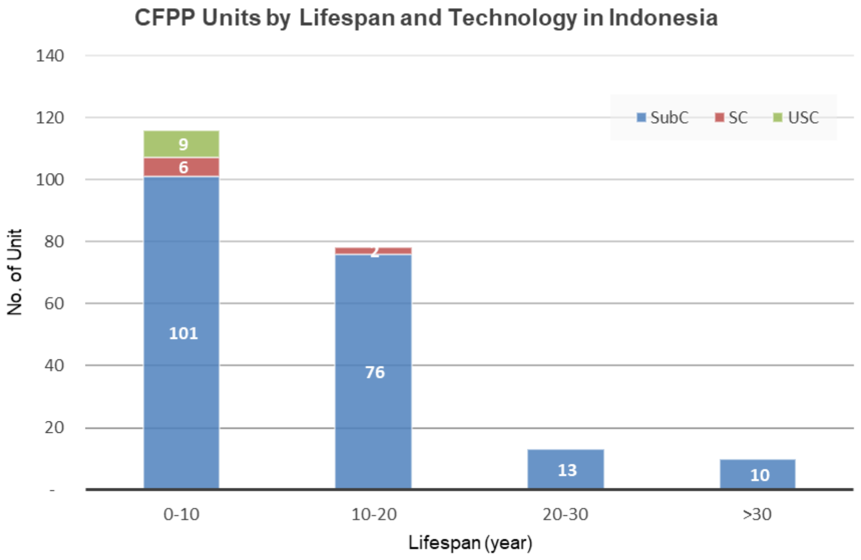
Power Plant Type	Most Used [%/min]	State-of-the-Art [%/min]
Hard Coal-Fired	1.5–4%	3–6%
Lignite-Fired	1–2%	2–6%

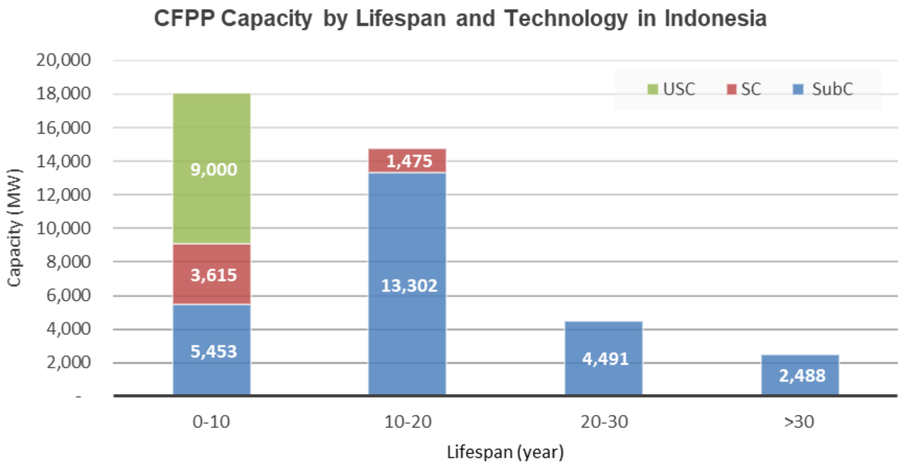
Start-up Time

Power Plant Type	Most Used	State-of-the-Art
Hard Coal-Fired	2.5 – 3 hours (Hot start) 5 – 10 hours (Cold start)	80 minutes – 2.5 hours (Hot start) 3 – 6 hours (Cold start)
Lignite-Fired	4 – 6 hours (Hot start) 8 – 10 hours (Cold start)	1.25 – 4 hours (Hot start) 5 – 8 hours (Cold start)

Source: analisis IESR dan Castlerock

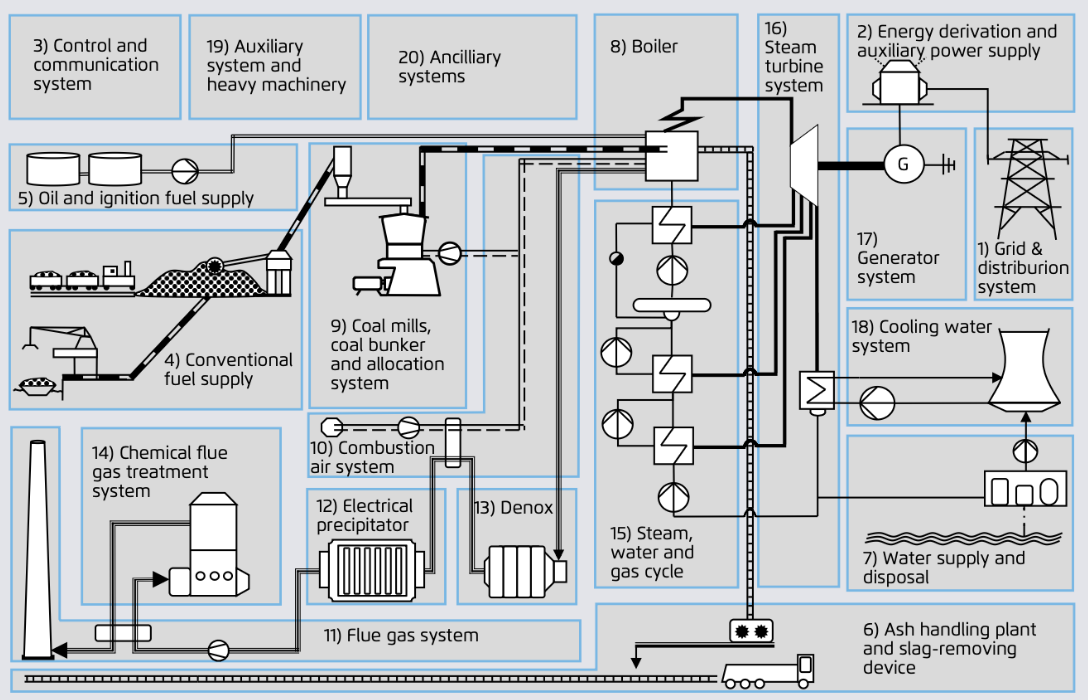
CFPPs characteristics in Indonesia - age, capacity, and steam cycle technology





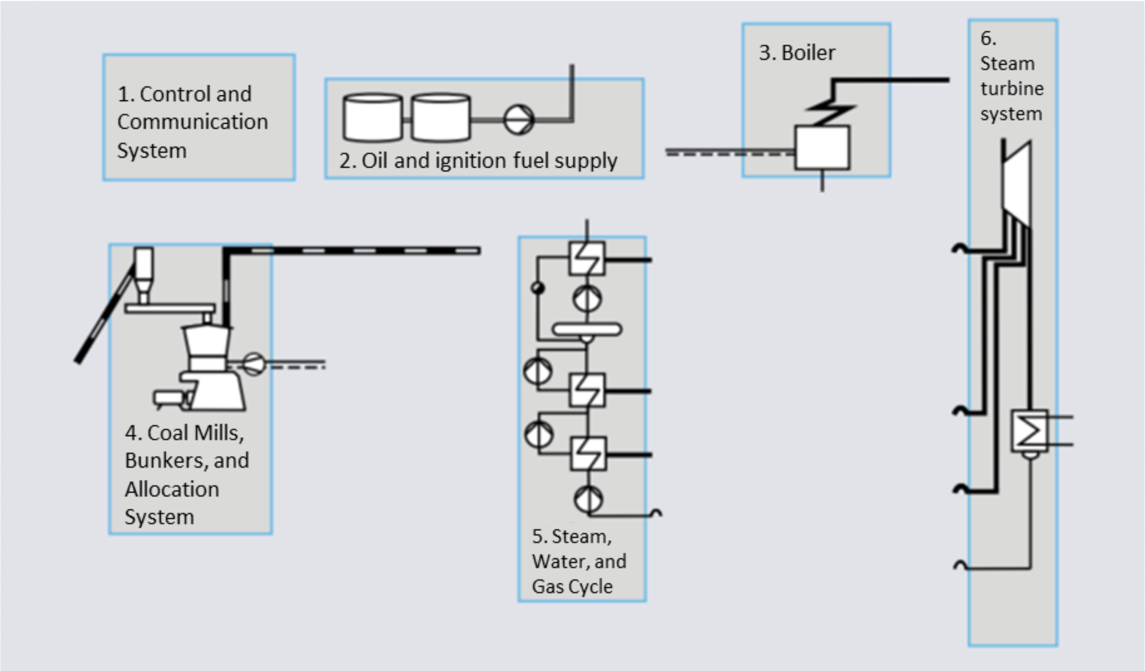
Source: analisis IESR dan Castlerock

Typical subsystems found in a CFPP



Source: Agora Energiewende. (2017). Flexibility in Thermal Power Plants

Recommended subsystems to be retrofitted for CFPPs flexible



Source: Agora Energiewende. (2017). Flexibility in Thermal Power Plants

No.	Retrofit Options	Subsystems	Subcritical (500 MW)	Supercritical (750 MW)	Flexibility Objective*
1	Gas bypass to keep air heater warm	• Steam, Water & Gas Cycle	$1.50M	$3.00M	IRT, RML
2	Improved APH basket life with traveling APH blowers (to remove deposits before cycling down)	• Steam Turbine System	$1.00M	$1.00M	IRT, RML
3	Improved flame proving equipment for burners	• Control & Communication • Oil and Fuel Supply for Ignition • Boiler	$1.00M	$1.50M	IRT, RML, RST
4	Improved vibration sensing & monitoring	• Control & Communication • Boiler	$2.50M	$3.50M	IRT, RML, RST
5	New valve operators (full arc / sliding pressure)	• Steam, Water & Gas Cycle • Steam Turbine	$1.80M	$4.00M	IRT, RML, RST
6	Improved APH basket life with advanced materials (for wet flue gas cycling)	• Steam Turbine System	$2.00M	$2.00M	IRT, RML

***Notes:**

- **RML = Reduced Minimum Load; IRT = Increased Ramping Rate; RST = Reduced Start-up Time**

Source: analisis IESR dan Castlerock, as quoted from Venkataraman, S. et al., Cost-Benefit Analysis of Flexibility Retrofits for Coal and Gas-Fueled Power Plants, NREL/SR-6A20-60862, 2014. https://docs.nrel.gov/docs/fy14osti/60862.pdf

Flexibility scenario tested

80% CF

- Baseload Operation
- No shares of renewable
- Optimum Emission Factor

65% CF

- Moderate Flexibility
- Medium shares of renewable
- Small increase of Emission Factor
- Not require investment
- Higher O&M cost
- Provide avoided carbon tax

Flexible without retrofit

40% CF

- Aggressive Flexibility
- High shares of renewable
- Highest Emission Factor
- Need significant investment
- Highest O&M cost
- Provide avoided carbon tax

Flexible with retrofit

Source: analisis IESR dan Castlerock

First study CFPP case: Subcritical, 575 MW, 28 y/o

Parameter	Units	Baseload (CF 80%)	Flexible without Retrofit (CF 65%)	Flexible with Retrofit (CF 40%)
Annual Electricity Generation	MWh/yr	4,029,600	3,274,050	2,014,800
Total O&M	USD/yr	35,714,400	34,728,407	32,843,310
Additional O&M	USD/yr	-	1,736,420	6,568,662
CAPEX Retrofit	USD	N/A	N/A	9,800,000
If Carbon Tax Applied:				
Annual Emission Produced	tCO_2e/yr	4,041,689	3,283,872	2,020,844
Specific Carbon Emission Cap	tCO_2e/MWh	0.911		
Max. Emission Cap	tCO_2e/yr	3,670,966	3,670,966	3,670,966
Taxable Emission	tCO_2e/yr	370,723	N/A	N/A
Domestic Carbon Tax Rate: **1.88 USD/tCO_2e**				
Annual Carbon Tax Paid	USD/yr	695,106	N/A	N/A
Potential Avoided Carbon Tax Annually	USD/yr	N/A	**695,106**	**695,106**
International Carbon Tax Rate: **19 USD/tCO_2e**				
Annual Carbon Tax Paid	USD/yr	7,043,741	N/A	N/A
Potential Carbon Tax Avoided Annually	USD/yr	N/A	**7,043,741**	**7,043,741**

Second CFPP study case: Supercritical, 813 MW, 13 y/o

Parameter	Units	Baseload (CF 80%)	Flexible without Retrofit (CF 65%)	Flexible with Retrofit (CF 40%)
Annual Electricity Generation	MWh/yr	5,697,504	4,629,222	2,848,752
Total O&M	USD/yr	50,497,056	49,102,948	46,437,584
Additional O&M	USD/yr	-	2,455,147	9,287,517
CAPEX Retrofit	USD	N/A	N/A	15,000,000
If Carbon Tax Applied:				
Annual Emission Produced	tCO_2e/yr	5,253,099	4,268,143	2,626,549
Specific Carbon Emission Cap	tCO_2e/MWh	0.911		
Max. Emission Cap	tCO_2e/yr	5,190,426	5,190,426	5,190,426
Taxable Emission	tCO_2e/yr	62,673	N/A	N/A
Domestic Carbon Tax Rate: **1.88 USD/tCO_2e**				
Annual Carbon Tax Paid	USD/yr	117,511	N/A	N/A
Potential Carbon Tax Avoided Annually	USD/yr	N/A	**117,511**	**117,511**
International Carbon Tax Rate: **19 USD/tCO_2e**				
Annual Carbon Tax Paid	USD/yr	1,190,778	N/A	N/A
Potential Carbon Tax Avoided Annually	USD/yr	N/A	**1,190,778**	**1,190,778**

Benefits from the perspective of system operator, in this case PLN

Case Study	Reference Price	Cost of generation (USD/year)		
		CF 80%	CF 65%	CF 40%
Subcritical 575 MW	DMO	**209.539.200**	**(4.608.855)**	**(12.290.280)**
	International market price	**239.864.918**	(21.093.967)	(56.250.580)
Supercritical 813 MW	DMO	**346.620.920**	**(17.092.512)**	**(45.580.032)**
	International market price	**396.785.893**	(12.330.171)	(32.880.455)

The calculation above assumed the energy loss due to the flexible operation is replaced by solar PV

Source: analisis IESR dan Castlerock

Another benefit...

Scenario	CFPP 100 MW	CFPP 600 MW
High solar irradiance	354.000.000 IDR	2.120.000.000 IDR
Low solar irradiance	265.000.000 IDR	1.590.000.000 IDR

- Reduce the start-up/shutdown → Reduce High Speed Diesel (HSD)
- Assumptions:
  - HSD price: 10.600 – 14.150 IDR/litre
  - HSD usage during start-up:
    - CFPP100 MW: 25.000 litre
    - CFPP 600 MW: 150.000 litre.

Source: IESR. (2022). Flexible Thermal Power Plant: An Analysis of Operating Coal-Fired Power Plants Flexibly to Enable the High-Level Variable Renewables in Indonesia's Power System

Recommendations

- **Phased Emission Reduction:**
  - Supplementary strategy to CFPPs phase-out.
  - Low-utilization high-value operations.
- **Leverage Flexibility for Grid Stability:**
  - Ancillary services becomes critical in a high VRE-share system.
  - CFPPs, through retrofitting and operational adjustments, could fit in the role, ensuring grid adequacy and security.
- **Manage Financial and Regulatory Hurdles:**
  - A review and amendment of existing PPAs is necessary.
  - The most opportune time for these investments is after debt repayments have been completed and higher tariffs can be negotiated to recover costs.
- **Prioritize Older and Less Efficient Units:**
  - Focus on subcritical and supercritical CFPP units as they make up the majority of Indonesia's fleet.
  - Already at a stage where flexibility upgrades are most relevant and cost-effective.

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Thank you

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