1.5°C-ALIGNED COAL POWER TRANSITION PATHWAYS IN INDONESIA:

Additional Strategies Beyond the Comprehensive Investment and Policy Plan (CIPP)

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SUMMARY

Indonesia, one of the world's largest coal producers, aims to transition away from coal, boost renewable energy production, and align with global climate goals. To accelerate the coal transition, several financial mechanisms have been developed to facilitate financial resources, including the Energy Transition Mechanism (ETM) led by the Asian Development Bank (ADB) and the Just Energy Transition Partnership (JETP), supported by the International Partners Group led by the U.S. and Japan, with participation from several other G7 countries.

In November 2023, the Government of Indonesia published the first version of the Comprehensive Investment and Policy Plan (CIPP), outlining the country's power sector emissions reduction roadmap and strategies. While the plan was expected to detail how the emissions reduction and renewable targets envisioned by the JETP will be delivered with investment and policies, we find that critical elements of a successful coal power transition are missing from the current version.

To address the gaps, this research develops a comprehensive, high-ambition pathway for Indonesia's coal power transition by combining a global integrated assessment model (GCAM), a power system dispatch model (PLEXOS), and bottom-up analyses. It expands the existing version of the CIPP in several dimensions, including (1) assessing the pathway that is 1.5°C aligned through 2050, (2) covering both on-grid plants and off-grid captive plants, (3) exploring a larger set of transition options for different coal plants, and (4) conducting plant-by-plant assessments to better understand the technical and economic suitability for individual plants, using the best available data.

OUR KEY FINDINGS SHOW THAT:

- Under the 1.5°C aligned transition pathway that covers both on-grid and captive coal power plants, Indonesia's power emissions peak at 382 $MTCO_2$ by 2025, followed by a decrease of 13% by 2030, 50% by 2040, and close to zero by 2050.
- Under this pathway, emissions from captive coal power plants grow substantially – more than double – between 2020 and 2025 due to projects already under construction, accounting for 30% of total coal power emissions in 2025. As a result, on-grid plants deliver more emissions reductions to offset growing captive coal emissions in the near term and contribute to 68% of the cumulative emissions reduction through 2050.
- Under a 1.5°C-aligned scenario, Indonesia's power system undergoes significant transformation. The integration of increasing intermittent renewable energy sources requires deployment of new storage technologies, expanded and improved grid infrastructure, and stable and flexible operation. During the transition to the new system, coal plants shift the role from baseload generation to dispatch service with more flexible, reduced utilization, especially during dry seasons. The generation cost of the power system is expected to decrease by 21% by 2030 and by 75% by 2050.

TRANSITION PATHWAY AND STRATEGIES

FOR CAPTIVE COAL PLANTS:

By canceling the 2.6 GW of projects at pre-construction stages, emissions from captive coal plants peak at 106 $MtCO_2$ in 2025 and achieve limited reductions (2% from peaking) by 2030

In the near term, emissions reductions are mainly achieved by adopting biomass co-firing in eligible plants and by substituting coal capacity with onsite renewable energy (solar), where grid connection in Sulawesi becomes critical to reduce emissions after 2040.

Between 2025 and 2050, the adoption of biomass co-firing at 80 eligible units (13 GW) contributes to approximately half of cumulative emissions reductions, onsite solar substitution at 16 units (2.5 GW) contributes to 26% of total emissions reductions, and grid connection of 34 units (4.8 GW) contributes to 23% of total reductions.

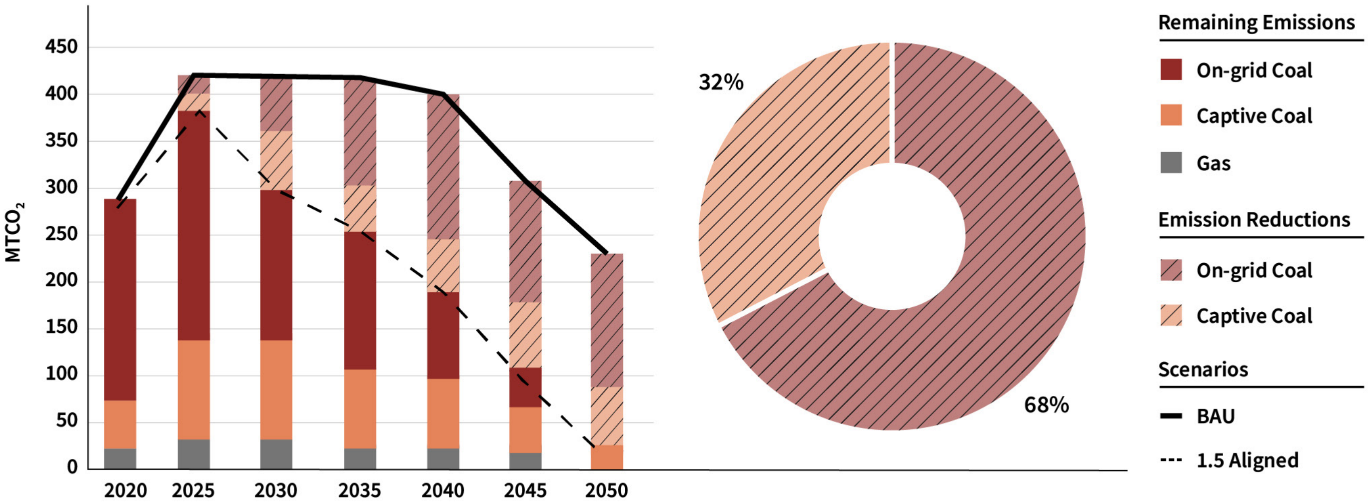
FOR ON-GRID COAL PLANTS:

Emissions from on-grid coal plants peak at 276 MtCO2 in 2025 and achieve a 17% emissions reduction by 2030, following roughly a linear pathway to zero emissions by 2050.

In the near term, emissions reductions are mainly achieved by lowering plant utilization and adopting biomass co-firing at eligible plants; where early retirement (before 30 years) becomes increasingly important post-2035.

Between 2025-2050, early retirement contributes to nearly half (51%) of cumulative emissions reductions, gradually lowering the utilization of 53 units (8 GW) contributes to 38% of the total reductions, and the adoption of biomass co-firing at 103 units (5 GW) and 374 MW stroker plants contributes to 10% of the total reductions.

CO_2 EMISSIONS FROM POWER GENERATION UNDER BAU AND 1.5°C -ALIGNED PATHWAYS, INCLUDING ON-GRID AND CAPTIVE POWER PLANTS, REDUCTIONS BY PLANT TYPE IN EACH PERIOD (BAR) AND OVER 2025-2050 (PIE)



This analysis provides the first detailed transition pathway assessment for captive coal power and the combined transition pathway that covers both on-grid and captive coal power plants in Indonesia. Future efforts should focus on quantifying the costs of all proposed strategies in this report. This includes assessing the retrofitting costs of existing coal plants for flexible operation and the costs of repurposing coal plants for biomass co-firing. Additionally, further analysis is needed to assess aspects such as the onsite solar potential at captive plants locations and the biomass supply available in the country for biomass co-firing.

1. INTRODUCTION

Indonesia is one of the world's largest coal producers, but it has signaled its desire to turn away from coal, increase renewable energy production, and contribute to both domestic and global climate goals. To achieve its goals, Indonesia has several policies and programs in place to decarbonize the power sector. As part of the country's commitment to the Paris Agreement, Indonesia submitted its enhanced Nationally Determined Contribution (NDC) in 2022. The new NDC increased the unconditional emissions reduction target from 29% to 32% below the business-as-usual scenario (BAU), and the conditional target from 41% to 43% below BAU.[1] This includes emissions from land use, land use change, and forestry.

One of the policies Indonesia has adopted to achieve its goals is the Presidential Regulation 112/2022, which mandates that the Ministry of Energy and Mineral Resources (MEMR) lead the process of developing a coal retirement roadmap.[2] The roadmap, which was introduced to interested stakeholders in 2023, is currently under review by government ministries,[1] namely the Ministry of Finance and the Ministry of State-owned Enterprises. It includes a list of proposed[2] coal-fired power plants to be retired, as well as a thorough analysis of both off-grid and on-grid power systems.

Another policy Indonesia has adopted is the Ministry of Finance Regulation (PMK) 103/2023. This regulation establishes a tailored financing framework to accelerate the transition of the electricity sector.[3] The framework, institutionalized as the Energy Transition Platform, offers interested parties blended finance options for selected projects, utilizing resources from authorized sources and the public budget. The platform is administered by PT Sarana Multi Infrastruktur (SMI) and is overseen by a steering committee responsible for supervising the platform's utilization, as mandated by the regulation. SMI has also been appointed as the Energy Transition Mechanism (ETM) Country Platform Manager.

Several financial mechanisms have been established to support the accelerated coal transition in Indonesia, including the Energy Transition Mechanism (ETM) and the Just Energy Transition Partnership (JETP). The ETM, developed by the Asian Development Bank (ADB), provides funding to country-specific programs that promote the early retirement of coal power plants.[4] As an example, in 2022, ADB signed a memorandum of understanding with an Independent Power Producer (IPP) in Indonesia to expedite the retirement of the Cirebon-1 coal power plant in West Java.[5] Recent developments regarding this asset indicate that progress is being made as expected, with all transactions anticipated to be finalized by the end of the first semester of 2024. The retirement of the asset is planned for 2035, which is 7 years earlier than its power purchase agreement (PPA). The retirement is estimated to cost between $250 and $300 million.[6]

The Just Energy Transition Partnership (JETP) is an agreement between the Government of Indonesia and the International Partners Group, a group composed of several G7 countries and led by the United States and Japan. Signed at the G20 Leaders Summit in 2022, the partnership aims to mobilize $20 billion in public and private financing to support Indonesia's energy transition.[7] The JETP sets several climate targets and plans, including peaking power sector emissions before 2030, capping power sector emissions at 290 $MTCO_2$ in 2030, reaching net zero emissions by 2050, and achieving at least 34% of power sector generation with renewable resources by 2030.[7]

To achieve these targets, Indonesia has launched the JETP strategic and technical roadmap, known as the Comprehensive Investment and Policy Plan (CIPP). The plan presents the energy transition pathway for Indonesia's power sector, outlines the financing requirements for its execution, and provides policy recommendations for its implementation, considering aspects of a just energy transition.[8]

According to the CIPP, the success of Indonesia's decarbonization efforts will largely depend on its deployment of renewable energy. The plan increases the renewable energy target to 44% by 2030 and places significant emphasis on expanding hydropower and geothermal, in addition to traditional sources such as solar and wind energy.[8] Furthermore, the CIPP highlights biomass co-firing as a strategy to decarbonize the power sector, with a goal for biomass co-firing to account for 5-10% of electricity generation in coal power plants from 2030 to 2050.[8] Additionally, the plan proposes an increase in natural gas production, which is viewed as a greener alternative to coal power plants.

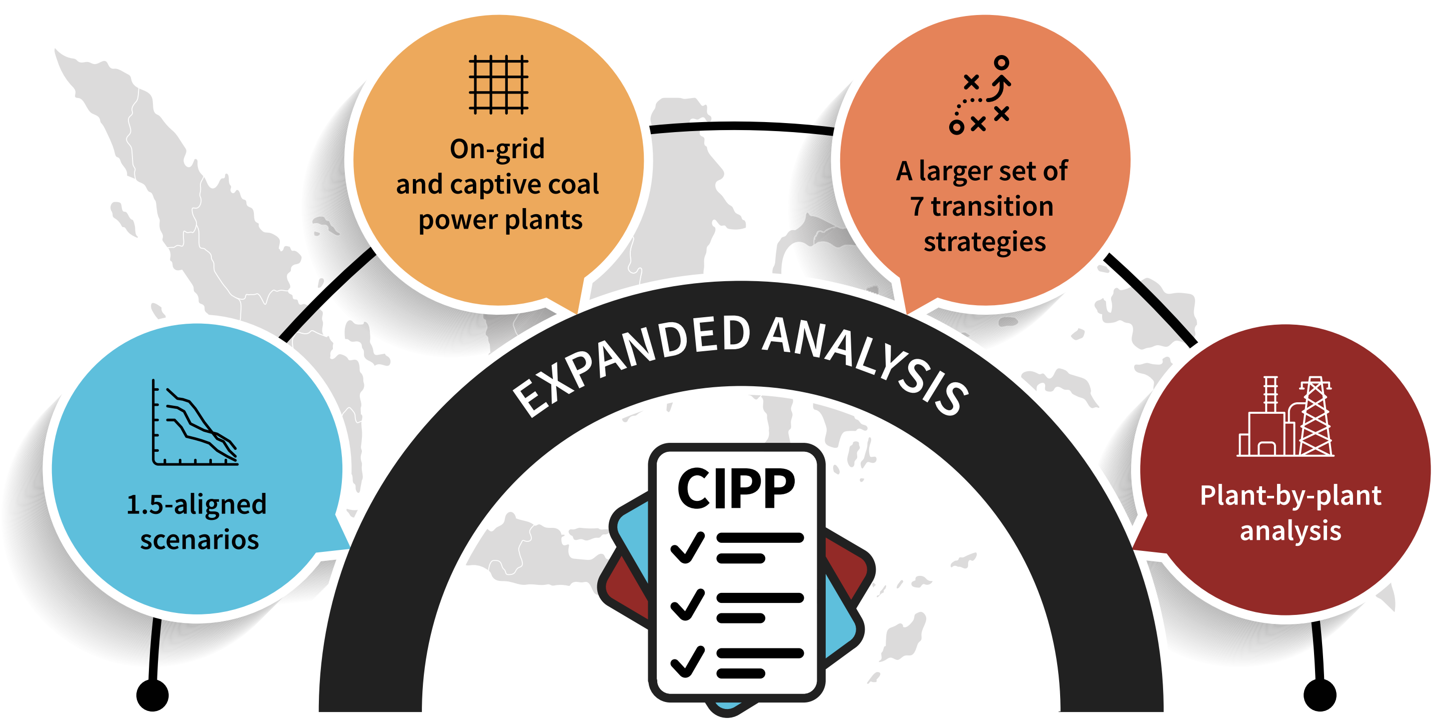
As of today, the CIPP is the most comprehensive analysis of Indonesia's options to decarbonize the power sector. Although it presents a thorough analysis of the country's on-grid fleet, the plan leaves behind relevant aspects that need to be addressed to achieve ambitious climate targets and the decarbonization of the power sector. The plan does not include analysis of off-grid captive power plants, which currently contribute significantly to emissions and are expected to maintain a large share of future emissions. In addition, the plan lacks details on specific strategies to decarbonize the power sector, such as repurposing coal and gas power plants after 2040, and proposes transition pathways that are not aligned with 1.5°C degree global climate targets.

On top of that, Indonesia has shown a reluctance to move away from coal. The country continues to build more power plants, despite President Joko Widodo's 2020 announcement that new coal construction will stop after 2023. Additionally, Indonesia recently announced plans to reduce its renewable energy targets. The current draft of the National Energy Policy would reduce the 2025 renewable energy target from 23% to 17-19%.[9] As one of the top coal exporters, Indonesia must move away from coal in tune with the rest of the world. When coal exports decline, Indonesia must have a plan to cope with the expected loss in revenue.

Considering the above, this report develops a comprehensive, high-ambition pathway for Indonesia's coal power transition that covers both on-grid and off-grid captive plants with a set of concrete strategies through 2050. Specifically, the report expands upon the existing version of the CIPP in several dimensions:

- Assessment of climate ambitious pathways for Indonesia's power sector through 2050
- Definition of a combined 1.5°C aligned pathway for on-grid and captive off-grid coal power plants, as well as specific pathways for each segment.
- Identification of a new set of short, mid and long-term transition strategies for on-grid and captive coal plants, including:
  - Cancellation of units in pre-construction stages (captive)
  - Early retirement before 30 years of operation
  - Lower utilization for dispatch
  - Biomass co-firing
  - Onsite renewable substitution (captive)
  - Grid connection (captive)
  - Carbon Capture and Storage (CCS)
- Plan-by-plant assessment to better understand the technical and economic suitability of each coal unit for each transition strategy, using the best available data.

FIGURE 1. RESEARCH OVERVIEW - A COMPREHENSIVE PLAN FOR 1.5°C-ALIGNED POWER SECTOR TRANSITION BEYOND THE CIPP



Furthermore, the report provides an assessment of the power system's operational performance under ambitious climate pathways, including an analysis for 2030 to depict the implications of decarbonization on the seasonal operation of Indonesia's on-grid power system. Finally, the report offers policy and regulatory recommendations to leverage financial mechanisms for achieving power sector decarbonization, considering factors such as the CIPP financing gap and the potential costs and investment signals necessary for implementation.

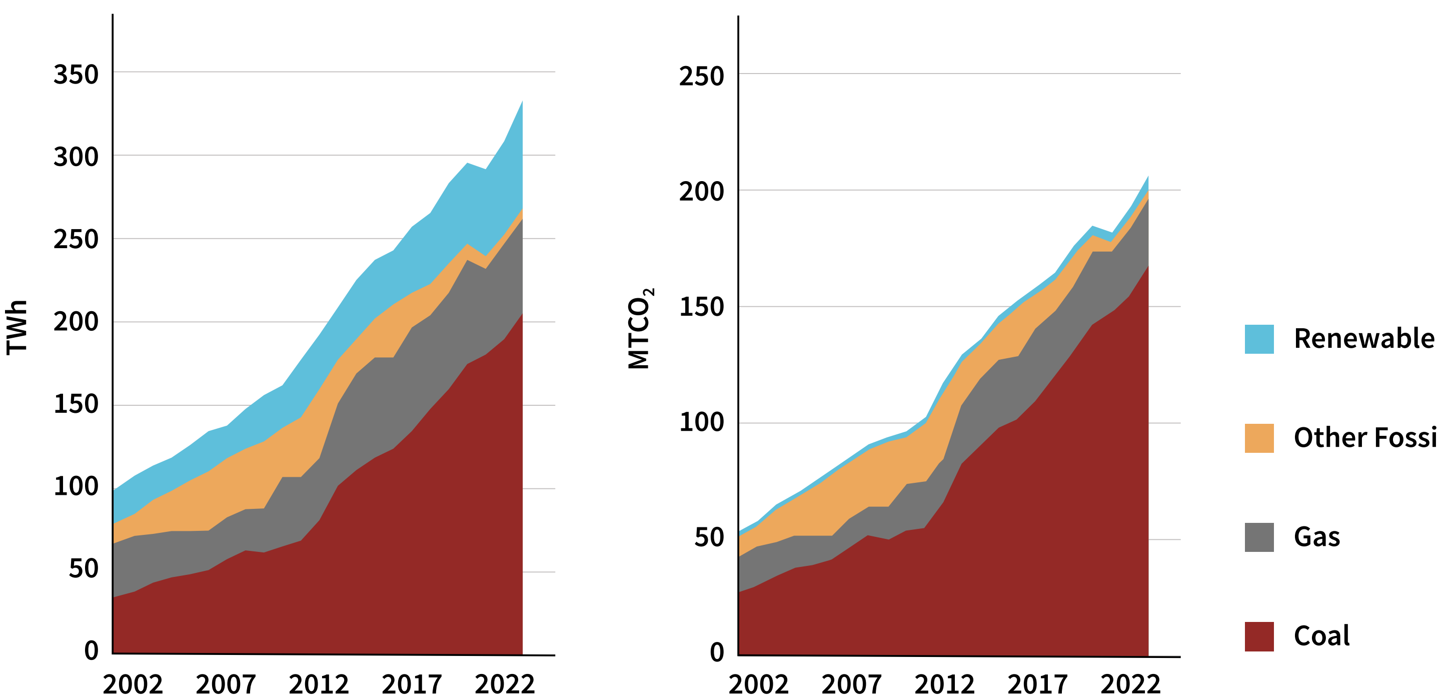
2. CURRENT STATUS OF INDONESIA'S POWER SECTOR

A. RAPID INCREASE IN COAL POWER GENERATION AND SLOW DEPLOYMENT IN RENEWABLES

As of 2022, Indonesia's power system had an installed capacity of 84 GW. Renewable power plants constituted 15% of this capacity, while coal, gas, and other fossil fuel power plants made up 53%, 24%, and 9%, respectively.[10] In 2022, coal-fired power plants produced 62% of the electricity in the interconnected system, while gas plants contributed 17%. Wind and solar plants made up less than 1% of electricity generation.[10]

Electricity demand has grown 60% over the past decade,[10] leading to a significant expansion of the power plant fleet, with coal power capacity more than doubling during this period. Low-carbon technologies such as wind and solar have also increased during the last decade by more than 60%. Hydro and biomass capacity increased 61% and 57%, respectively, from 2012 to 2022.[10]

FIGURE 2. INDONESIA POWER GENERATION (LEFT) AND EMISSIONS FROM POWER SECTOR BY FUEL (RIGHT)



Data Source: Ember - Electricity Data Explorer

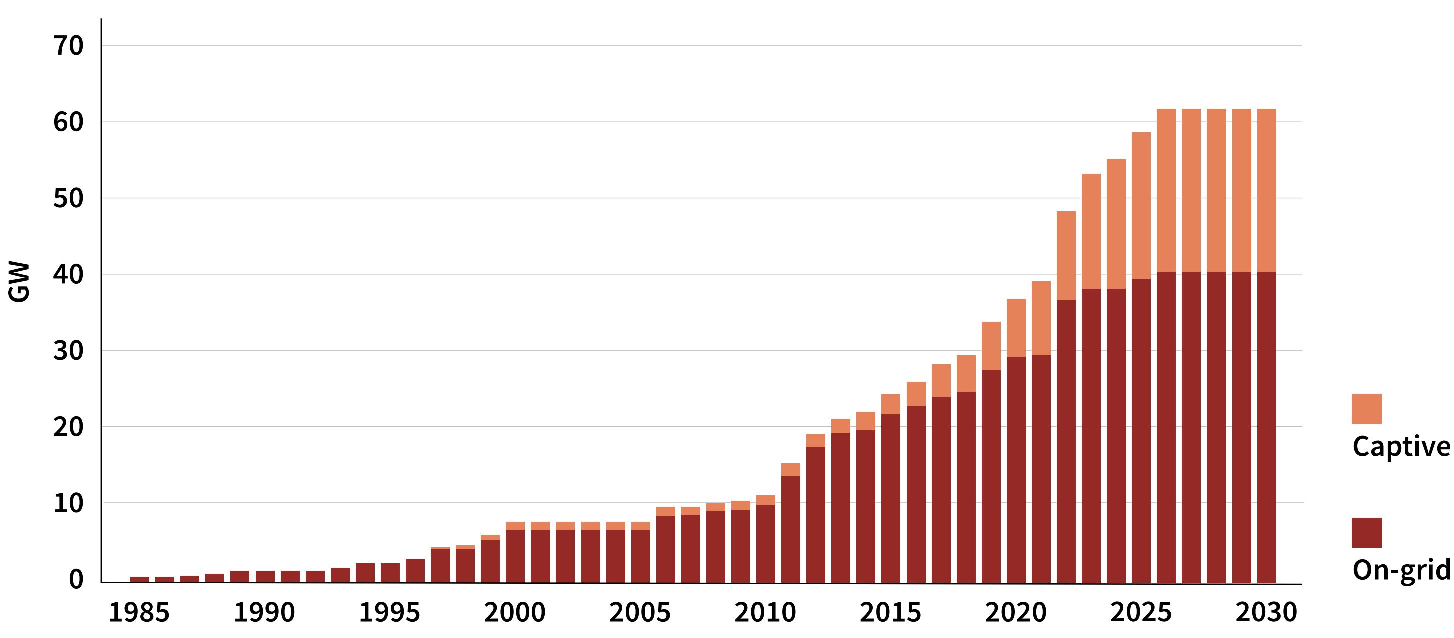
Coal-fired power plants are responsible for the majority of power sector emissions. According to Ember (n.a.), in 2022 coal generation contributed to 82% of the sector's emissions, while gas generation made up 13%.[10] Emissions from the power sector have increased 60% during the last decade, reaching their highest recorded value in 2022.[10]

B. EMERGING CHALLENGES FROM THE POWER SECTOR

One of the main challenges of decarbonizing Indonesia's power sector is the growth of captive coal-fired power plants driven by economic and industrial demands.[11] Captive power plants in Indonesia are mainly located in industrial clusters or facilities, where they are required to provide a reliable service that adjusts to the industries' operational needs.[11] Indonesia's geographical characteristics, continuous electricity demand growth, and historical underinvestment in power generation and transmission infrastructure have led industries to rely on their own power plants to fulfill their energy requirements.[11]

Although Indonesia has banned the development of new coal-fired power plants (Presidential Regulation No. 112 of 2022), captive plants are exempt from this provision. As of 2023, Indonesia has 15 GW operating captive coal power plants, representing 28% of the total installed coal capacity.[12] After 2025, with the 6 GW under construction projects coming online, captive coal will account for 34% of total installed coal capacity. 80% of the captive coal installed capacity in the country was built after 2016.[12]

FIGURE 3. OPERATING COAL-FIRED POWER CAPACITY BY ON-GRID AND CAPTIVE COAL (2024 ONWARDS ARE ESTIMATES BASED ON CONSTRUCTION PROJECTS)

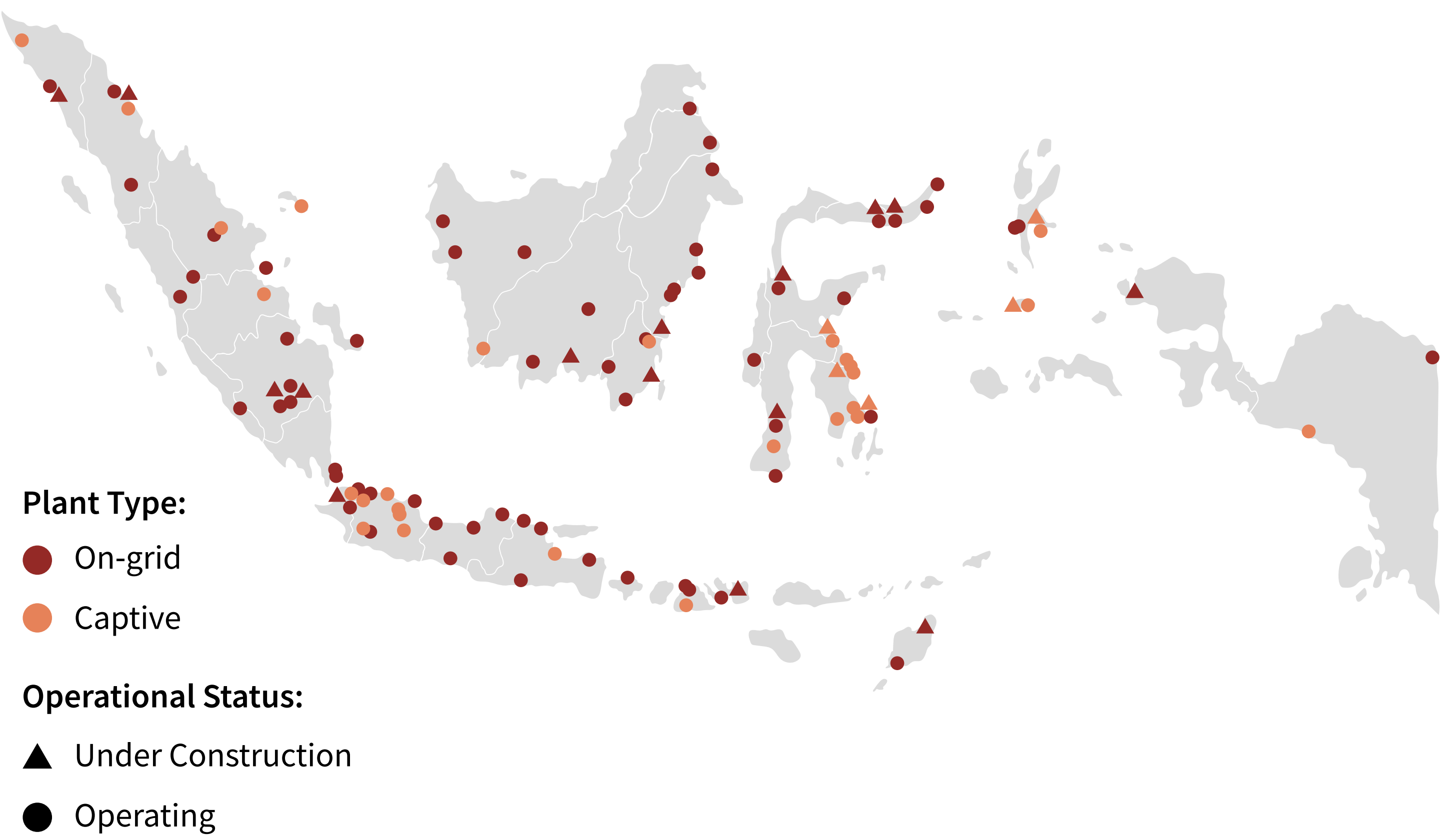


Data Source: Global Coal Plant Tracker, Global Energy Monitor, January 2023 and January 2024

According to Zhu et al (2023), there are two major challenges to the early retirement or phasing out of captive coal power plants in Indonesia. First, captive capacity is expected to grow to align with the government's economic growth model, which includes the expansion of industrial parks and the mining of critical minerals.[11] Second, the substitution of coal-fired power plants with renewable energy or low-carbon alternatives is sometimes not cost-effective, and faces problems such as land utilization preferences and the availability of resources.[11]

The decarbonization of Indonesia's interconnected power system presents significant challenges too, primarily due to the prominent role of on-grid coal power plants. Coal remains the primary fuel for power production, accounting for 62% of total electricity generation in 2022.[10] Moreover, the country boasts 40 GW of installed coal capacity, which has nearly doubled in the last 10 years and represents over 50% of the nation's total on-grid power capacity.[10, 13] Additionally, with an average age of just 9 years,[13] on-grid coal power plants still have a considerable remaining useful life. These characteristics highlight the potential economic impact and energy security implications of decisions regarding the operation of existing coal capacity.

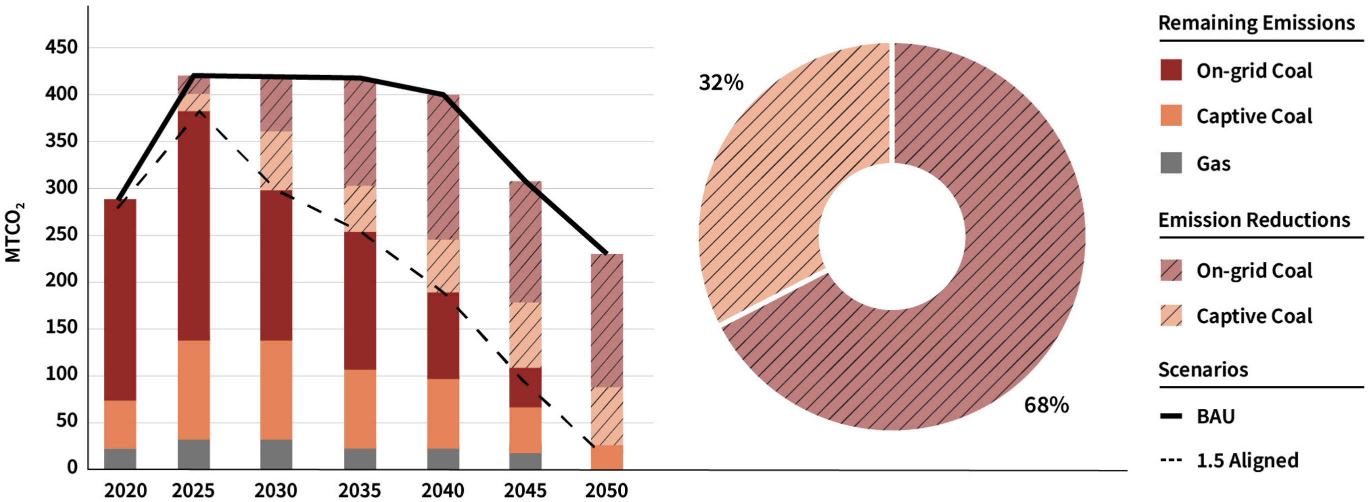
FIGURE 4. DISTRIBUTION OF ON-GRID AND CAPTIVE COAL POWER PLANTS



3. A 1.5°C -ALIGNED PATHWAY BEYOND CIPP

A. COMBINED PATHWAYS INCLUDING ON-GRID AND CAPTIVE PLANTS

FIGURE 5. CO_2 EMISSIONS FROM POWER GENERATION UNDER BAU AND 1.5°C -ALIGNED PATHWAYS, INCLUDING ON-GRID AND CAPTIVE POWER PLANTS, REDUCTIONS BY PLANT TYPE IN EACH PERIOD (BAR) AND OVER 2025-2050 (PIE)



In light of the challenges Indonesia faces in decarbonizing its power sector, as well as the progress made by the CIPP, and the available financial mechanisms to support these efforts, it is important to explore more ambitious alternatives to enhance emissions reduction efforts, aligning with the global 1.5°C -degree climate target.

By using plant-level data from the Global Coal Plant Tracker database (2023 and 2024) and conducting a comprehensive plant-by-plant analysis, this report introduces more ambitious strategies than those presented in the CIPP to decarbonize the on-grid sector, and proposes alternative approaches to phase out or replace captive coal power plants.

For this analysis, two emission scenarios were defined: Business as Usual (BAU) and a 1.5°C -aligned scenario. The BAU pathway incorporates Indonesia's operating on-grid and captive coal power capacity, along with under-construction power plants. In this scenario, emissions peak in 2025 at 420 $MTCO_2$, remain fairly constant through 2040, and then gradually decrease to 229 $MTCO_2$ by 2050, representing a 46% reduction from the 2025 peak. (Refer to the Technical Appendix for more details).

The 1.5°C -aligned scenario, consistent with the global 1.5°C -degree target, aims to peak power sector emissions at 382 $MTCO_2$ by 2025 and achieve net-zero emissions by 2050. Based on the emissions goals set for the power sector in Indonesia's JETP, specific targets are set for the on-grid and captive segments, with emissions expected to decrease by 13% from 2025 to 2030, 50% by 2040, and close to zero by 2050.

By 2030, two-thirds of emission reductions are projected to be attributed to actions in the on-grid segment, with the remaining third corresponding to decreasing emissions from captive plants. This trend is anticipated to continue, with 68% of emission reduction attributed to the on-grid segment from 2025 to 2050, while the remaining reduction is explained by reductions in captive plants.

B. TRANSITION STRATEGIES AND 1.5°C -ALIGNED PATHWAY FOR CAPTIVE COAL POWER PLANTS

To achieve the 1.5°C aligned scenario, various strategies were analyzed on a plant-by-plant basis for the captive segment. These strategies include cancellation, biomass co-firing, grid connection, carbon capture and storage (CCS), and renewable substitution. Initially, the strategy of cancellation entails the elimination of approximately 2.6 GW of captive power plants that are either announced or in pre-permit status according to the GCPT database (2024). This approach prevents the emission of roughly 18 $MTCO_2$, emissions not included in Figure 6, as the BAU scenario only considers plants that are operating or under construction.

The other decarbonization strategies (biomass co-firing, grid connection, CCS, and renewable substitution) are anticipated to reduce captive emissions by 2% by 2030, 29% by 2040, and 76% by 2050 compared to the 2025 peaking levels.

By 2030, 74% of emission reduction will be due to biomass co-firing, and 26% will be from renewable substitution. By 2040, biomass co-firing is projected to account for 66% of emission reduction, while renewable substitution will contribute the remaining 34%. Furthermore, by 2050, 54% of the reduction will be attributed to grid connection, 30% to renewable substitution, 7% to biomass co-firing, and 10% to the adoption of CCS on biomass co-firing units.

Overall, emission reduction from 2025 to 2050 will be 283 $MTCO_2$. Biomass co-firing will explain 47% of all emission reductions from 2025 to 2050, while renewable substitution will represent 26%, grid connection 23%, and BECCS deployment 4%.

FIGURE 6. CO_2 EMISSIONS FROM CAPTIVE POWER GENERATION UNDER BAU AND 1.5C-ALIGNED PATHWAYS, REDUCTIONS BY TRANSITION STRATEGY IN EACH PERIOD (BAR) AND OVER 2025-2050 (PIE)

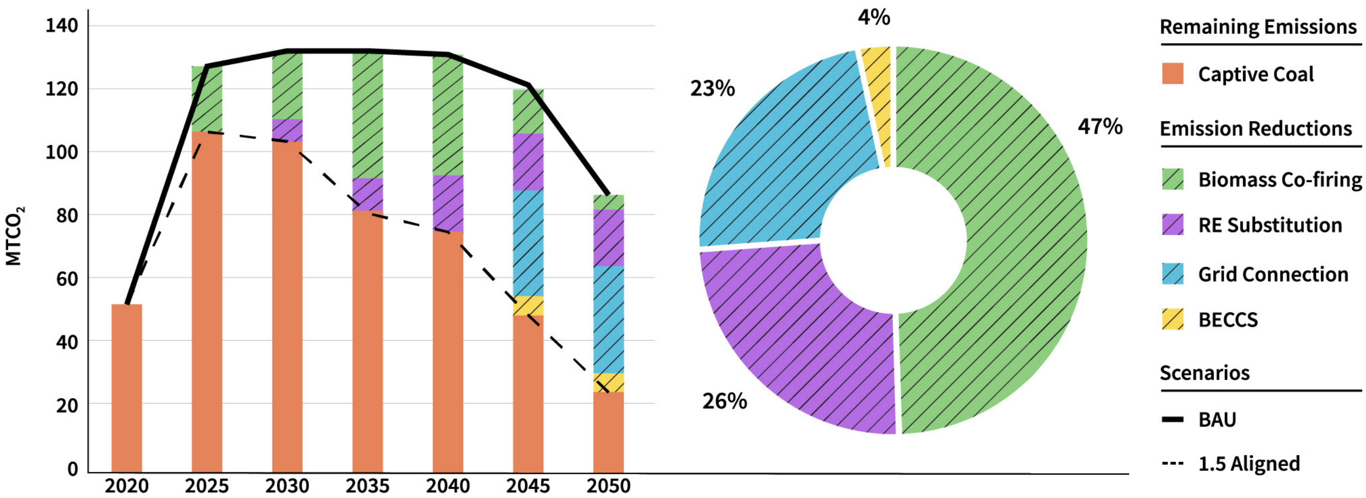


TABLE 1. SUMMARY OF 1.5°C -ALIGNED DECARBONIZATION STRATEGIES FOR CAPTIVE COAL POWER PLANTS

	UNITS	CAPACITY (GW)	KEY PLANT-LEVEL RESULTS
Cancellation of Pre-Construction Projects	5	2.6	Cancellation of announced and pre-permit projects.
Biomass Co-firing	80	13	Substitution of 30% of coal used for electricity production with biomass in eligible plants.
Renewable Substitution	16	2.5	Incorporation of 11.2 GW of solar capacity by 2040 in eligible industrial parks.
Grid Connection	34	4.8	Connection to the transmission grid of captive coal power plants in Central, South, and Southeast Sulawesi.
Carbon Capture and Storage (CCS)	1	1.1	Adoption of CSS technology in biomass co-firing plant in North Kalimantan.

Biomass Co-firing

Through the biomass co-firing strategy, 80 eligible coal units (13 GW) (refer to the Technical Appendix) are expected to substitute 30% of the coal used for electricity production, on a thermal basis, with biomass. The co-firing share for eligible plants is assumed to remain constant throughout the period and was estimated based on co-firing ratios successfully achieved at plants with identical boiler technology in other countries and PLN ratio targets.[17–21]

This strategy results in plant-level emissions reductions of 27% in 2025, 32% by 2030, and 56% by 2040, compared to their potential CO_2 emission peaking levels in 2025 when no other strategies are considered. Total emissions reductions from this option decrease from 2030 onwards as biomass co-firing plants are retired upon reaching 30 years of operation, some units are substituted with renewables, some are adopted for BECCS, and some plants located in the Sulawesi region become connected to the grid. The cumulative reduction of this strategy is equivalent to 132 $MTCO_2$ during the 2025-2050 period.

Renewable Substitution

The renewable substitution strategy involves the gradual replacement of 2.5 GW of coal capacity with 11.2 GW of solar capacity by 2040. This approach assumes that captive industrial parks that have publicly expressed their interest in building renewable power plants will replace existing coal units to accommodate new renewable projects. Overall, this strategy assumes that by 2030, 4.2 GW of solar capacity will replace 980 MW of existing or under-construction coal units, while in 2035, 6.5 GW of renewable plants are expected to replace 1.5 GW of coal capacity.

As a result of this strategy, 16 coal units from five captive power plants will retire before reaching 30 years of operation (see Technical Appendix for more details), leading to a reduction in emissions from these plants by 8% by 2030, 12% by 2035, and 20% by 2040 when compared to 2025 values. This reduction is equivalent to a total decrease of 72 $MTCO_2$ from 2030 to 2050.

Grid Connection

The grid connection strategy takes into account Indonesia's plan to construct approximately 2040 km of transmission lines in Sulawesi in the next few years.[8] With this new infrastructure, 4.8 GW (34 units) of coal capacity in Central, South, and Southeast Sulawesi is expected to connect to the grid by 2045, resulting in a reduction of emissions from the captive segment by 34 $MTCO_2$ in 2045 and 2050.

All of the plants expected to connect to the grid are eligible for biomass co-firing. Consequently, this strategy reduces the effects of the biomass co-firing strategy by approximately 40% in 2045, as can be observed in Figure 6. Additionally, this strategy assumes that Sulawesi plants connected to the grid will retire by 2050, and the captive demand from their industrial parks will be supplied predominantly with renewable sources.

Carbon Capture and Storage

Finally, the CCS strategy involves the adoption of CCS technology on one eligible 1.1 GW biomass co-firing unit currently under construction in North Kalimantan (refer to Technical Appendix). The analysis assumes that CCS captures 90% of CO_2 released, resulting in a reduction of 6 MTCO2/year in 2045 and 2050, allowing for negative emissions. This strategy is responsible for 5% and 7% of emissions reductions in 2045 and 2050, respectively.

C. TRANSITION STRATEGIES AND 1.5°C -ALIGNED PATHWAY FOR ON-GRID POWER PLANTS

To achieve the 1.5°C aligned scenario, more ambitious strategies than those presented in the CIPP report were considered for the on-grid segment. Even though the CIPP proposes a pathway that peaks emissions by 2025, and decreases them to reach 250 $MTCO_2$ by 2030, and approximately 20 $MTCO_2$ by 2050, the plan is deficient in two critical areas. First, it lacks sufficient strategies and clear information to adhere to its own suggested pathways. Secondly, it lacks ambitious strategies necessary to align with a 1.5°C scenario that reaches 230 $MTCO_2$ by 2030, and complete decarbonization by 2050.

According to the CIPP, strategies to decarbonize the on-grid power sector include the early retirement of 1.7 GW of coal capacity (660 MW by 2035 and 1.050 GW by 2037), reducing the utilization of coal power plants from 70% in 2022 to 50% by early 2040, incentivizing co-firing of biomass (5-10% of annual generation from coal plants between 2030 and 2050), and repurposing coal and gas power plants after 2040.[8] However, despite these concerted efforts, policies are projected to reduce emissions by just 43 $MTCO_2$ by 2030 and 88 $MTCO_2$ by 2040, revealing a distinct gap in achieving the CIPP proposed pathway, and a more ambitious 1.5 aligned scenario.

TABLE 2. COMPARISON OF EMISSION PATHWAYS BETWEEN CIPP AND THIS ANALYSIS FOR THE ON-GRID SECTOR, 2025-2050 MTCO2

	EMISSIONS UNDER BAU CIPP	EMISSIONS REDUCTIONS BY LOWER UTILIZATION UNDER CIPP	EMISSIONS REDUCTIONS BY BIOMASS CO-FIRING UNDER CIPP	EMISSIONS UNDER CIPP TARGET	1.5C-ALIGNED SCENARIO (THIS ANALYSIS)
2025	294	10	0	275	275
2030	316	29	14	250	230
2035	316	56	14	210	173
2040	288	75	13	175	115
2045	202	51	8	125	58
2050	13	0	0	20	0

This underscores the need for further action to bridge this disparity and advance towards the desired emissions trajectory. In this regard, more ambitious goals for lower utilization, biomass co-firing, and early retirement are necessary, along with the implementation of additional measures such as the adoption of CCS in eligible plants. Utilizing information from the GCPT for Indonesia in 2023, a plant-by-plant analysis was conducted to identify which coal units could be eligible for any of the mentioned strategies and to quantify the potential emission reductions associated with each one.

Through the implementation of these supplementary strategies, emissions in the power sector could align with the 1.5°C scenario, peaking by 2025 (at 276 $MTCO_2$) and subsequently reducing by 17% by 2030 and 58% by 2040, ultimately achieving complete decarbonization by 2050.

By 2030, 75% of expected reductions will be due to lower utilization, while the remaining 25% will result from biomass co-firing. Moving forward to 2040, 53% of emission reduction will be attributed to lower utilization, 38% to early retirement, and 9% to biomass co-firing. By 2050, all emissions will be reduced, due to the early retirement of the remaining operating coal and gas units by that year.

Overall, adoption of these strategies could lead to 612 $MTCO_2$ of emission reductions from 2025 to 2050. Of this reduction, 51% is attributed to the early retirement of coal units, while 38% is attributed to lowering the utilization of coal plants, 10% to biomass co-firing, and 1% to the adoption of CCS.

When compared to the CIPP strategies, the more ambitious lower utilization strategy increases emissions reductions by 43% by 2030 and by 40% by 2040. Similarly, a more aggressive early retirement plan more than triples the reduction of emissions considered in the CIPP for this strategy, moving from 7.5 $MTCO_2$ to 37 $MTCO_2$ in 2035 and from 12 $MTCO_2$ to 59 $MTCO_2$ in 2040. Finally, Carbon Capture and Storage (CCS) and additional biomass co-firing beyond what is assumed in the CIPP can further reduce emissions by 7 $MTCO_2$ by 2045, significantly enhancing the likelihood of achieving climate goals.

FIGURE 7. CO_2 EMISSIONS FROM ON-GRID GENERATION UNDER BAU AND 1.5C-ALIGNED PATHWAYS, REDUCTIONS BY TRANSITION STRATEGY IN EACH PERIOD (BAR) AND OVER 2025-2050 (PIE)

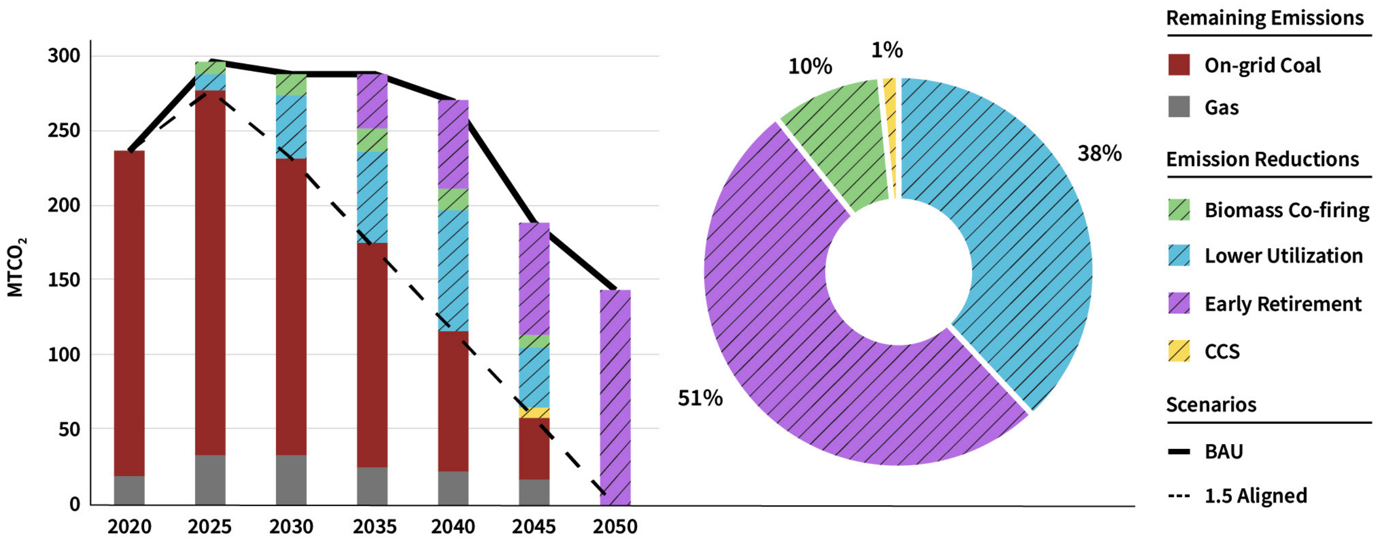


TABLE 3. SUMMARY OF 1.5°C -ALIGNED DECARBONIZATION STRATEGIES FOR ON-GRID COAL POWER PLANTS

	UNITS	CAPACITY (GW)	KEY PLANT-LEVEL RESULTS
Lower Utilization	53	8	Eligible flexible plants are expected to operate at 40% by 2030 and 2035, 35% by 2040, and 30% by 2045.
Early Retirement	105	25	3.8 GW of low-hanging fruit and 1.7 GW identified by the CIPP are expected to retire by 2035-2037. Additional 3.5 GW, 4.8 GW and 11 GW should retire by 2040, 2045, and 2050, to achieve climate targets.
Biomass Co-firing	102	5	Biomass co-firing ratio should ramp from 5% in 2024 to 57% by 2030. Stoker plants (374 MW) are expected to complete the transition to full biomass conversion by 2035.
Carbon Capture and Storage (CCS)	4	1.8	Adoption of CSS technology in plants located in South Sumatra. CCS is expected to capture 90% of the CO_2 released.

Lower Utilization

Through the plant-by-plant analysis and the application of a screening methodology to identify units with the attributes to provide flexibility services, new capacity factors were estimated for on-grid coal power plants, consistent with the 1.5°C -aligned scenario. In total, 53 units (8 GW) were classified as flexible power plants, expected to operate with lower capacity factors and respond to power system needs at a faster pace (see Technical Appendix). To achieve the expected emissions reductions, these flexible coal units must reduce their utilization to 40% in 2030 and 2035 and further decrease to 35% by 2040, and 30% by 2045, until retirement by 2050.

The remaining coal units (39 units, 23.5 GW) that are not classified as flexible plants or are eligible for biomass co-firing will reduce their utilization in values similar to those proposed in the CIPP. By 2030 and 2035, these plants must operate at over 60%. By 2040, the utilization rate must decrease to 55%, and by 2045 to 50%. This lower utilization, as shown before, will reduce emissions significantly, and will allow Indonesia to get closer to their mid-century climate goals.

The strategy of lower utilization accounts for 75% of on-grid emission reductions in 2030, and 53% in 2040 (see Figure 7). Through this strategy, 249 $MTCO_2$ can be prevented from 2025 to 2050.

Early Retirement

A more ambitious early retirement plan than the one proposed in the CIPP is necessary to meet the 1.5°C -aligned scenario. In addition to the 1.7 GW foreseen in the plan for 2035 and 2037, approximately 23.2 GW of coal power plants must face early retirement by 2050. Through a plant-by-plant analysis and utilizing the findings of Cui, R., et al. (2022), additional early retirements are required in 2035, 2040, 2045, and 2050.

By 2035, 3.8 GW (23 units) must be retired to align with the 1.5°C -degree scenario for that year. These units correspond to the low-hanging fruit units identified by Cui, R., et al. (2022), who evaluated Indonesia's on-grid power plants using technical, economic, and environmental indicators. Plants classified as low-hanging fruit received scores lower than the median in each of the dimensions that the authors analyzed[14] (see Technical Appendix for more details).

In 2040, 3.5 GW (11 units) of additional coal power capacity must be retired from the power system to achieve the 1.5°C emission pathway. These units are not eligible for biomass co-firing and lack the technical attributes necessary to provide flexibility services. Ranging from 150 to 660 MW, they are located in different provinces such as South Sumatra, East, West and Central Java, and Banten. By the time they are scheduled for retirement, they will have operated for approximately 29 years.

By 2045, 4.8 GW (6 units) of coal units with the same characteristics mentioned earlier should retire from the power system. These units are located in Banten and Central Java and, on average, will be 27.3 years old at retirement. Finally, by 2050, 11 GW (61 units) of coal capacity must retire to achieve carbon neutrality. The average age of retirement for these plants will be 26.7 years.

Overall, considering that all coal units must retire by 2050 to achieve the climate targets, the average age of retirement of all coal plants, including the ones that are proposed for early retirement, will be 28.9 years. About 50% of units (representing 40% of coal capacity) will retire at 30 years of operation, while only 3% of units (3% of coal capacity) will retire before reaching 20 years of operation.

The early retirement of coal fired power units will prevent the emission of 311 $MTCO_2$ from 2035 to 2050. This strategy provides 38% of emission reductions in 2040 and 100% of emission reductions in 2050, as seen in Figure 7.

Biomass Co-firing

All plants in the GCPT (2023) database were evaluated to determine biomass co-firing suitability. Aspects including boiler type, distance from the nearest biomass processing plant, and the type of feedstock processed were considered to select units for co-firing. In total, 103 units (5GW) were selected, with a biomass co-firing ratio projected to ramp from 5% in 2024 to 57% by 2030. Additionally, stoker plants (42 units with a total capacity of 374 MW) complete the transition to full biomass conversion by 2035.

The biomass ratio selected for the year 2030 was calculated based upon the CIPP's biomass target, which states that "bioenergy contribution to energy mix in 2030 is 8%, with 3% coming from cofiring".[8] Under a ranking system that disqualifies less suitable plants and selects a relatively smaller fraction of the fleet for co-firing (PLN planning identifies nearly 19 GW of on-grid capacity for co-firing by 2025 alone), a highly ambitious 2030 ratio target results.[21]

Co-firing results in emission reductions of 22% in 2025, 40% by 2030, and 40% by 2040 when compared to the potential CO_2 emission peaking levels among on-grid plants in 2025. Raising the biomass ratio at stoker plants increases emission reduction from this strategy by 3% from 2025 to 2050. This cumulative reduction is equivalent to 60 $MTCO_2$ during the 2025-2050 period.

Carbon Capture and Storage

The CCS strategy involves the adoption of CCS technology in four eligible units, equivalent to 1.8 GW, in the province of South Sumatra (see Technical Appendix). These units are expected to operate at 50% of their capacity, and the deployment of CCS is assumed to capture 90% of the CO_2 released, resulting in a reduction of 7 MTCO2 emissions in 2045. This reduction represents 5% of the total emission reductions for that year.

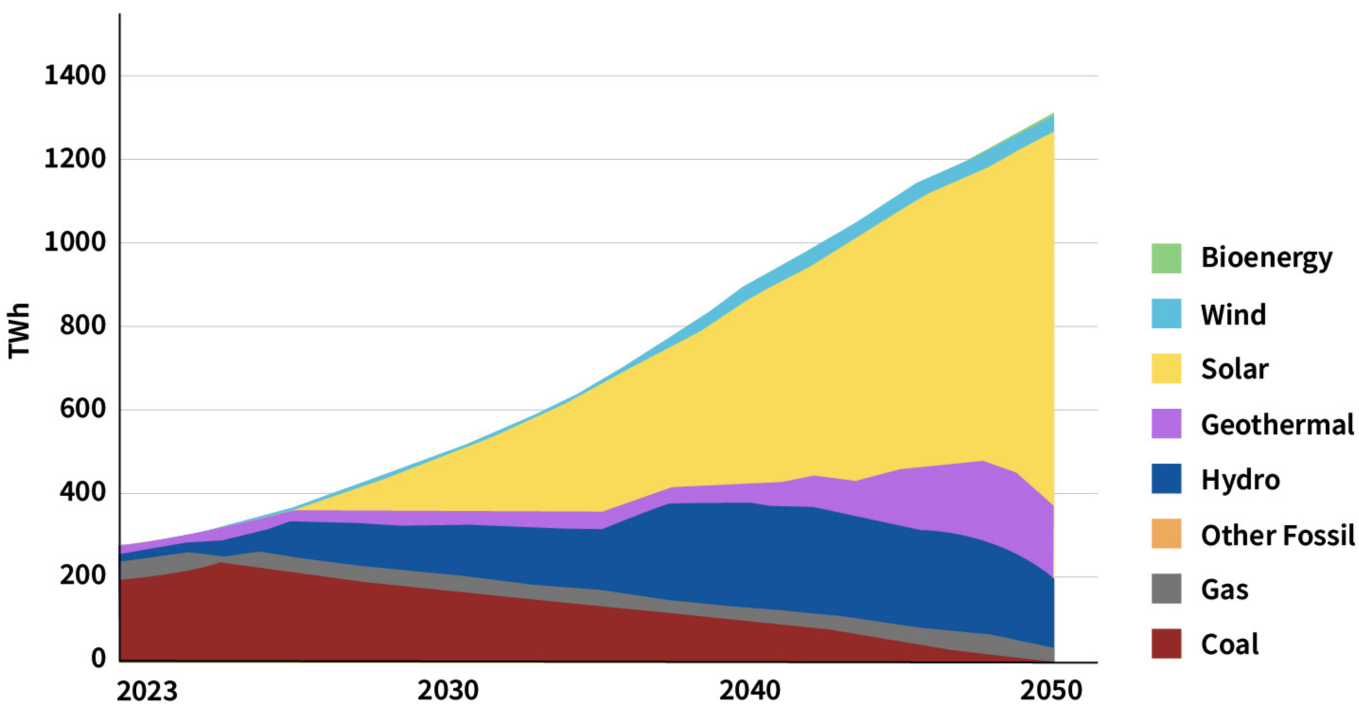
Emissions from Gas Power Plants

Emissions from gas-fired power plants were estimated for both operating and under-construction units, using plant-by-plant data and emissions methodology from GEM (2024).[22] By 2023, there were 4.3 GW under construction, while 12.35 GW were already operating with natural gas or LNG. Similar to coal-fired power plants, gas plants are assumed to retire after 30 years of operation. By 2050, it is projected that the remaining 5.9 GW of gas plants will phase out that year.

D. POWER SYSTEM OPERATION UNDER A 1.5°C-ALIGNED SCENARIO

Indonesia's electricity generation mix undergoes a major transition in the 1.5°C-aligned scenario. Currently dominated by fossil fuels, this share will progressively decrease in favor of low-emission generation sources (see Figure 8). By 2030, renewables will displace unabated fossil fuels to comprise two-thirds of the total generation, with fossil fuels making up only a few percent by 2050. In the long term, utility-scale solar photovoltaics (PV) will be the most significant renewable contributor, supported by hydropower, bioenergy, onshore wind, and geothermal energy.

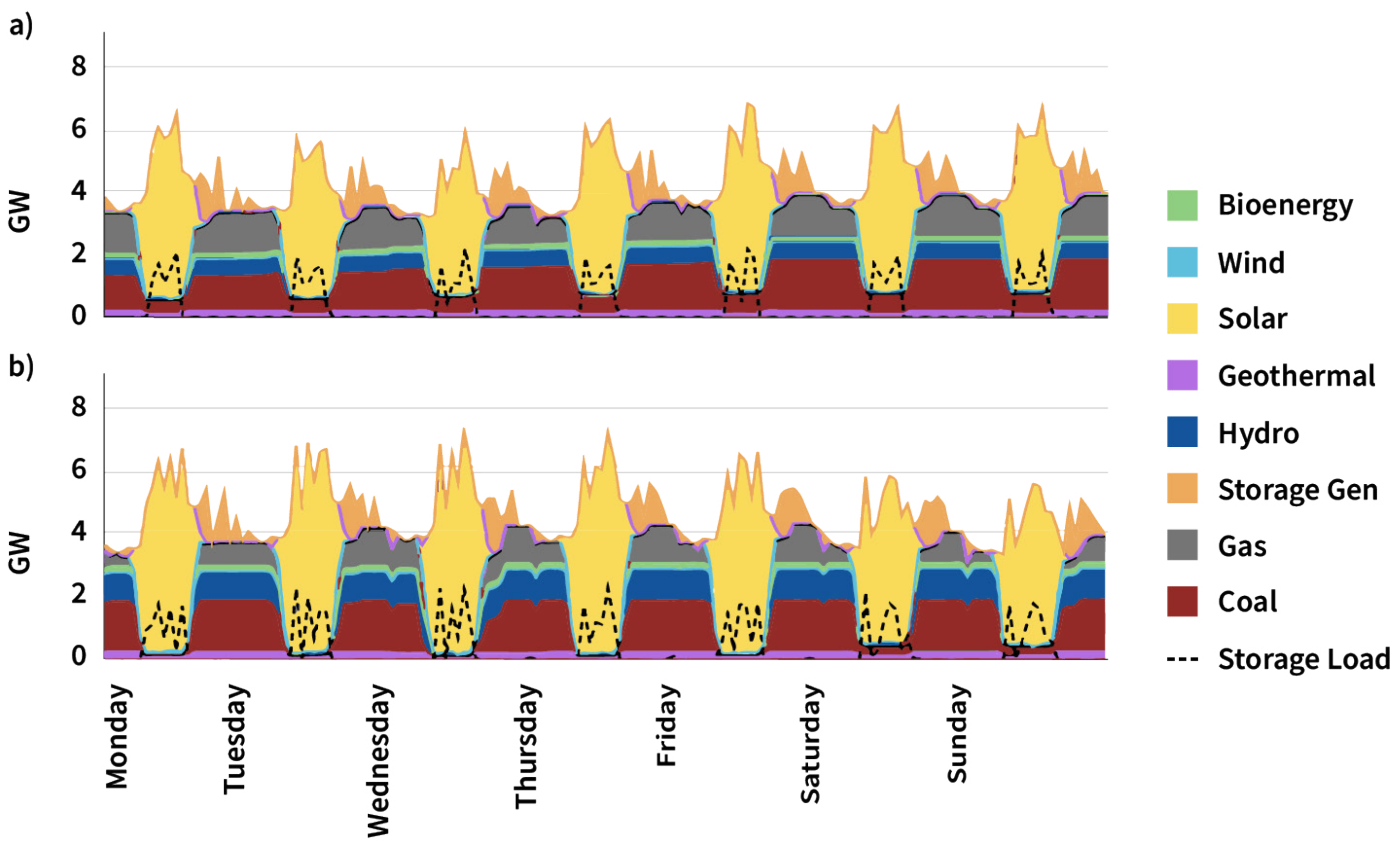
FIGURE 8. INDONESIA POWER GENERATION BY FUEL IN 1.5°C-ALIGNED SCENARIO, 2023-2050



Indonesia's power system is characterized by independent transmission systems across its islands, except for the Java-Madura-Bali system, which is interconnected. The system primarily comprises 150kV transmission lines, although some high-voltage lines are present in the Java-Madura-Bali and Sumatra systems.[23] In terms of planning, PLN uses minimum reserve margin as reliability criteria. Minimum reserve margin of 35% is imposed in developed regions such as the Java-Madura-Bali system, and higher minimum reserve margin (40%) in other systems.[23]

The load profile and operational parameters vary depending on the weekday and season (dry/wet). During the dry season, demand is higher throughout the day, due to higher needs of cooling, when compared to the wet season. Furthermore, the seasonal variability affects the generation of hydropower plants, currently the prominent renewable energy source, with high generation occurring during wet season.

FIGURE 9. SULAWESI PRODUCTION SIMULATION IN A 1.5°C-ALIGNED SCENARIO FOR A TYPICAL WEEK DURING THE DRY SEASON (A) AND WET SEASON (B), IN 2030



In a 1.5°C-aligned scenario, the integration of variable renewable energy sources will require a flexible operation and the introduction of new technologies to ensure power system reliability. Consequently, some coal plants traditionally operating as baseload will need to provide flexibility services alongside conventional flexible sources such as hydro and gas plants. Additionally, storage systems will be essential for compensating changes in the system's voltage and frequency. Coal and gas dispatch is expected to continue varying according to the season. For example, in Sulawesi, by 2030 dry season coal and gas generation are projected to increase by 15% and 50%, respectively, to compensate for reduced hydro generation and to meet higher demand, thereby increasing generation costs and emissions during that season (Figure 9). These results are consistent with the lower utilization strategy proposed to decarbonize the on-grid power sector.

In a high ambition scenario, the power system is projected to maintain reliable operation at minimal cost, even with the retirement of coal power plants before reaching 30 years of operation. Furthermore, by 2030 and 2050, the power generation cost is expected to decrease by 21% and 75%, respectively, compared to 2023 levels. To further mitigate the impact of the energy transition on power system costs, coal-to-renewable projects could be promoted. Achieving this goal will require Indonesia to establish a clear high-level policy direction and implement substantial changes in regulations related to PLN's procurement processes, power purchase agreements, and tariff regulations for bundled projects.

4. DISCUSSION AND POLICY RECOMMENDATIONS

Indonesia has established policies and regulations, along with international financial cooperation, to begin decarbonizing its power sector and achieve its climate targets. The country has set measures to prevent the development of new coal power plants and offers financial alternatives to promote the development of renewable power plants. In addition, Indonesia benefits from international mechanisms such as the ETM and the JETP, which provide financial resources to support the energy transition. These resources contribute to the phaseout of existing coal power plants, grid improvement and expansion, and execution of renewable power projects.

As part of the JETP, Indonesia presented the Comprehensive Investment and Policy Plan (CIPP) last year. The CIPP outlines the energy transition pathway for Indonesia's power sector, details its financial requirements, and provides policy recommendations that take into account a just transition framework. While the plan represents a significant step toward decarbonization, its selected emission pathways and strategies could be more ambitious and aligned with a 1.5°C scenario. Additionally, the plan does not include analysis of off-grid captive decarbonization pathways, and lacks details on the repurposing of the on-grid coal power plants on an asset-level after 2040.

Considering these gaps, this report goes beyond the proposals in the CIPP and advocates for more ambitious strategies to decarbonize Indonesia's power sector, encompassing both the on-grid segment and captive coal power plants.

Our key findings show that under the 1.5°C-aligned transition pathway that covers both on-grid and captive coal power plants, Indonesia's power emissions peak at 382 $MTCO_2$ by 2025, followed by a decrease of 13% by 2030, 50% by 2040, and close to zero by 2050. Under this pathway, emissions from captive coal power plants more than double between 2020 and 2025 due to projects already under construction, accounting for 30% of total coal power emissions in 2025. As a result, on-grid plants must deliver more emissions reductions to offset growing captive coal emissions in the near-term and contribute to 68% of the cumulative emissions reduction through 2050.

In the case of captive coal plants, emissions peak at 106 $MtCO_2$ in 2025, assuming the cancellation of 2.6 GW of projects at pre-construction stages, and achieve limited emissions reduction (2% from peaking) by 2030. In the near term, emissions reductions are mainly achieved by adopting biomass co-firing in eligible plants and by substituting coal capacity with onsite renewable energy (solar), where grid connection in Sulawesi becomes critical to reduce emissions after 2040. Between 2025 and 2050, the adoption of biomass co-firing at 80 eligible captive coal units (13 GW) contributes to approximately half of cumulative emissions reductions. Onsite solar substitution at 16 units (2.5 GW) contributes to 26% of total emissions reductions, and grid connection of 34 units (4.8 GW) contributes to 23% of total reductions.

For on-grid coal plants, emissions peak at 276 $MtCO_2$ in 2025 and achieve a 17% reduction by 2030, following roughly a linear pathway to zero emissions by 2050. In the near term, emissions reductions are mainly achieved by lowering plant utilization and adopting biomass co-firing at eligible plants. Early retirement (before 30 years) becomes increasingly important after 2035. Between 2025 and 2050, early retirement contributes to nearly half (51%) of cumulative emissions reductions from BAU for on-grid plants. Gradually lowering the utilization of 53 units (8 GW) contributes to 38% of the total reductions, and the adoption of biomass co-firing at 103 units (5 GW) and 374 MW stroker plants contributes to 10% of the total reductions.
In addition, under a 1.5°C-aligned scenario, Indonesia's power system undergoes significant transformation. The integration of increasing intermittent renewable energy sources requires the deployment of new storage technologies, expanded and improved grid infrastructure, and stable and flexible operations. During the transition to the new system, coal plants shift from baseload generation to providing dispatch services with more flexible, reduced utilization, especially during dry seasons. The generation cost of the power system is expected to decrease by 21% by 2030 and by 75% by 2050.

According to the CIPP report, the investment required to achieve the 2030 targets proposed in the plan is estimated at 97 US$ billion.[8] These resources will cover over 400 priority projects,[23] financing grid development, phase-out of coal power plants, and the deployment of renewable energy. Overall, 50% of the resources are allocated for investment in dispatchable clean technologies such as geothermal and hydropower, while 26% is designated for variable renewable plants, and 20% for transmission infrastructure. The early retirement of coal plants represents just 2% of the entire plan.[8]

Considering the $20 billion awarded by the JETP to finance the CIPP, there remains an 80% financing gap. Following the recommendations of the Climate Policy Initiative (2023), to cover this gap, the Government of Indonesia must continue promoting green finance frameworks within the country, and seek additional international funding.[24] Some initiatives under development that could particularly help Indonesia phase out coal plants include the Coal to Clean Credit Initiative (CCCI) and the Energy Transition Accelerator (ETA).[24] These initiatives aim to reduce emissions in the power sector through the use of carbon credits and private investment.

Furthermore, following the recommendations of Cui, R., et al. (2022), Indonesia should establish a strong long-term policy for coal power plant retirement, as reflected in the currently reviewed roadmap draft for PR 112/2022. In addition, policies that govern the retrofitting and repurposing of coal power plants should also be prepared due to their complementary roles in the emissions reductions, as shown in this report.

Considering that the pathways analyzed in this report cover the next 25 years, the measures established by the government should inform stakeholders of the risks involved and provide adequate incentives to transform the power sector. Engagement with coal power plant owners must also be carried out early in the process, regardless of the interventions considered by the government for certain assets, to minimize possible adverse consequences. Most importantly, the energy policy defined to achieve more ambitious climate targets should be coherent with long-term development, climate action, and sectoral plans, including considerations of a just transition and overall welfare.[14]

In particular, to develop the more ambitious strategies proposed in this report, Indonesia's energy sector must establish a favorable governance and innovative regulations. In this regard, as mentioned by Cui, R., et al. (2022), the country should form a national task force dedicated to designing and implementing measures that promote the repurposing and retirement of coal power plants in both on-grid and captive segments.[14] Additionally, the country should consider adopting special tax incentives to encourage the replacement of coal power plants with renewable plants in industrial parks, prioritizing the dispatch of units that transition to biomass co-firing, renegotiating existing contracts between PLN and independent power producers (IPPs), particularly those whose projects are facing difficulties to reach completion, and creating a contract-based mechanism for flexibility services to provide financial signals to investors and accelerate necessary transformations.

To assess the suitability of the proposed strategies, future efforts should focus on accurately quantifying the costs of all approaches. For early retirement, costs must be estimated for each plant, taking into account the terms of their PPAs, useful life, and retirement age. A more thorough analysis is needed for lower utilization, including the costs of retrofitting existing plants and adjusting their existing PPAs. Reform on policies that favor fossil fuels and hamper the renewable adoption stipulated in the JETP CIPP should also be considered, and a plan for its implementation should also be carried out.

In the case of biomass co-firing, a detailed assessment of retrofit needs, technical feasibility, and cost, alongside current and future biomass pricing, availability, storage and transport, and sustainability is crucial to evaluating the viability of this strategy. The ratios selected reflect PLN co-firing goals[21] (in the case of the 2030 goal for captive plants) and CIPP ambition[8] (the on-grid segment co-fires at a ratio necessary to achieve the plan's total co-firing target using a smaller fraction of the fleet). Operational plants[25] and literature[17-20] demonstrate that these ratios are technically achievable, but highly ambitious - these ratios have not yet been used at this scale. Beyond technical retrofits, procuring sufficient biomass at the speed and scale necessitated in this strategy may prove difficult, and could shift power emissions to land. Biomass procurement should prioritize use of existing waste residues and intensification of degraded land over plantation expansion, so as to not induce land use change, ramping up emissions in another sector.[26, 27]

Furthermore, the costs of implementing CCS in the five eligible plants identified for this option should be assessed, considering the available technologies and storage options and capacity by region. Finally, evaluating the grid connection and renewable plant substitution in the captive segment is essential for a successful energy transition. Information from the CIPP can serve as a valuable resource for estimating the approximate costs of these strategies.

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