STRANDED ASSET RISK IN COAL-FIRED POWER PLANTS: A REALITY CHECK FOR ENERGY DECARBONISATION GOALS

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Abstract

The decarbonisation of the electricity sector requires a substantial reduction in coal power generation, rising concern over stranded assets. This study conducts a desktop assessment of grey literature and peer-reviewed studies to investigate the influence of plant lifespans and carbon policies implementation against stranded asset risks in coal power plants. Current studies suggest that 77% and 97% of coal reserves and coal power facilities may become stranded under various climate transition scenarios. Although coal power plants typically built for 30 to 50 years of operation, Paris Agreement pathways suggest potential decommissioning after 35 years in a 2°C scenario and about 20 years in a 1.5°C scenario. Germany, China, and Indonesia were chosen as comparative case studies due to different degrees of reliance on coal and decarbonisation policies. Germany faces lower risk due to its aging coal infrastructure and strict phase-out policies, whereas China and Indonesia experiences higher risk due to younger assets and continued coal dependency. Overall, stranded asset exposure is closely connected to plant lifetime and carbon policy implementation.

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Abbreviation:

IEA	International Energy Agency	EU	European Union
GHG	Greenhouse Gas	US	United States
USD	United States Dollar	ETS2	Emissions Trading System 2
eq	equivalence	GCAM	Global Change Analysis Model
CO_2	Carbon dioxide	GDP	Gross Domestic Product
Gt	Gigatonnes	%	Percent
MW	Megawatt	€	Currency sign for the Euro

Keywords:
Energy transition, Plant retirement, Carbon, Policy, Net-zero emission, Climate change

1.0 INTRODUCTION

Coal-fired power plants have become a symbol of the world's modernisation and industrialisation, shaping humanity's direction (Finkelman *et al.,* 2021; Koc & Teker, 2019; Vinogradov, 2016). It has also been a major driver of global energy production during the Industrial Revolution (IEA, 2024; Saletnik *et al.,* 2025). Today, even though renewable energy is growing rapidly, numerous studies highlight coal remain its strategic importance in many national energy mixes, particularly in fast-growing Asian economies (Burney, 2020; Cropper *et al.,* 2021; Cui *et al.,* 2021; Shearer *et al.,* 2017). This is further confirmed by the International Energy Agency (IEA) which coal-fired power plants continue to play a major role in global electricity generation, accounting for just 35% of total power production worldwide (IEA, 2025). However, despite its dominant contribution to the mankind, coal-fired power plants are one of the primary sources of global Greenhouse Gas (GHG) emissions. They are recognised as the largest anthropogenic source of CO_2 emissions, covering for more than 40% of world emissions from fossil fuel combustion as reported by (IEA, 2026). More detailed study by (Filonchyk *et al.,* 2026) estimated that coal-fired power plants emit approximately 13.7 $GtCO_{2eq}$ annually which this is in line with the previous studies (Chen *et al.,* 2023; Guevara *et al.,* 2024; Hassan *et al.,* 2024; Wang *et al.,* 2023). From those series of studies and reporting, it can be observed that coal-fired power plants continue to represent the single largest source of global GHG emissions among all energy mix generations.

Based on this rising trend, the Paris Agreement which has been ratified in 2016 with a global commitment to reduce the annual temperature increase to not more than 2°C (UNFCCC, 2024) and the global energy sector must reach net-zero CO_2 emissions by mid-century (IPCC, 2014). The achievement of these climate targets requires major adjustments in industrial and energy systems, particularly in sectors with high dependence on fossil fuels. Accordingly, the series of studies on the significant challenges to meet Paris Agreement targets which aim to limit global warming to 1.5°C were carried out by (O'Neill, 2018; Rogelj, 2016). They emphasised that all anthropogenic activities must be readjusted (IEA, 2021; Voumik, 2023) where the world's coal production must also decline to about 90% by 2050 (IEA, 2022). Such a rapid transition away from coal will inevitably accelerate the decarbonisation of energy systems and impose substantial structural changes on coal-dependent industries worldwide. Consequently, coal-fired power plants face the risk of stranded assets across multiple stages of the value chain, and beyond technological concerns, encompassing economic and social dimensions (Caldecott *et al.,* 2021). To respond on the progressive risk of stranded asset risk, the Intergovernmental Panel on Climate Change (IPCC) has emphasised on the lifetime factor of coal plants where 50-year lifespans may align with aggregate Nationally Determined Contributions (NDCs) but substantial asset stranding risk persists from both existing and planned capacity. This is because emissions reduction required by 2030 must occur at

significant faster rate than the decline observed in the global coal projects between 2016 and 2021 to remain on track with the climate targets. This concerns is supported by previous studies conducted by (Edwards *et al.,* 2022; IEA, 2021; IPCC, 2014). From previous studies on the climate change, we found that they deliberately discussed on the significant impact of coal-fired power plants on the increasing amount of CO_2 emissions in the atmosphere. As a result, leading world organisations requested commitment from the countries to restructure their coal dependency and explore renewable energy for which has led to another industrial dilemma in energy sector so called "Stranded Assets".

To address this arising energy dilemma, a number of studies were carried out to deal with the relevant issues. The IEA describes stranded assets as investments that are no longer able to deliver expected economic returns due to changes in market conditions and regulatory frameworks driven by climate-related policies. A stranded asset is defined as the investments that lose value or fail to deliver expected returns before the end of their planned operating life (Bos & Gupta, 2019; IEA, 2013; Miriam, 2020). Respectively, (Ansar, 2013) described stranded assets as assets that experience unexpected or premature write-downs, devaluation, or even transformation into financial liabilities. In the present study, stranded assets are defined as the unexpected loss of value experienced by investors and plant operators when coal-fired power plants become financially unfeasible to operate. Such conditions may generate adverse economic consequences and negative public perception, which can ultimately hinder the progress of decarbonisation efforts. Consequently, stranded assets have emerged as a significant challenge to sustainable energy transition, particularly in developing economies that continue to rely heavily on coal-based power generation.

The significant financial impact of stranded assets on the coal power plant industry is widely discussed and evaluated. (Von Dulong *et al.,* 2023) highlighted earlier warning that stranded assets may lead to substantial financial losses for power plant owners and investors, which can subsequently encourage resistance toward transition policies and decarbonisation measures. Meanwhile, (Bos & Gupta, 2019) investigated the country's economic status and presume that due to the use of outdated technology which may impact to the environment, the developing country may receive higher impact in stranded assets.

A more comprehensive review has been made on the financial impact of stranded assets globally. The detail value amount of the stranded assets was measured and projected to show the significant impact on the global economy as well as national financial ecosystem. According to the IEA's Net-Zero Emissions by 2050 scenario, it is estimated that stranded assets from existing coal- and gas-fired power plants could reach approximately USD 90 billion by 2030, escalating to nearly USD 400 billion by 2050 (IEA, 2021). Comparably, (Kefford *et al.,* 2018) explored the effect of early retirements for coal-fired power plants consistent with a 2°C emissions trajectory and estimated that total stranded investments in China, the EU, India, and the US could exceed USD 500 billion. This is in line with the finding from the International Renewable Energy Agency (IRENA) that the power generation sector is identified as the third highest contributor to environmentally driven stranded asset risks, with projected financial losses estimated at around USD 1.9 trillion.

Apart from the financial impact, the previous study has examined the early retirement, plant lifetime and policy implementation. According to (Rode *et al.,* 2017), early retirement refers to the decommissioning of power generation assets before they reach their anticipated physical or operational plant lifetime. Furthermore, (IEA, 2011) added that the implementation of early retirement strategies for fossil fuel-based power plants, particularly coal-fired facilities, is considered essential for achieving the climate mitigation targets outlined in the Paris Agreement. While these measures can largely reduce emissions, they may also result in significant economic losses and create huge value of stranded assets. Existing studies have shown that decisions on coal-fired power plant retirement are influenced by factors such as plant age, carbon emissions, air pollution, and industry competitiveness (Maamoun *et al.,* 2020; Spencer, 2017).

On policy implementation, (Sen & von Schickfus, 2020) demonstrated that the retirement of coal-fired power plants is closely linked to the stringency of carbon policies, suggesting that stronger decarbonisation measures can accelerate plants phase-out and increase stranded asset exposure during the energy transition. (Zhang, 2016) highlighted that retiring relatively new coal-fired power plants before the end of their intended lifetimes may lead to extensive economic losses and carbon lock-in effects, showing the trade-offs associated with accelerated decarbonisation efforts. The implications become even more significant when considering the findings from (Fofrich *et al.,* 2020), who reported that the early retirement of coal-fired power plants often requires changes in operating schedules and in several cases, the premature shutdown of power plants.

Therefore, this literature suggests that stranded asset risk is closely associated with plant lifetime and policy implementation. As the decarbonisation policies become more stringent, coal-fired power plants may force to retire earlier than originally intended, leaving less time to recover capital investments. Consequently, the extent of stranded asset exposure is shaped by the interaction between policy requirements and remaining operational lifetime of the existing plants.

Under the United Nations Framework Convention on Climate Change (UNFCCC), countries are broadly classified into Annex and Non-Annex groups according to their historical contributions to GHG emissions, level of economic development, and the capacity to address climate change (UNFCCC, 1992). This classification provides the basis for differentiated responsibilities within the international climate framework. Annex countries generally comprise of developed economies that have adopted more stringent climate commitments and the progressing towards coal phase-out policies. The examples countries include Germany, France, and Italy. In contrast, non-Annex countries encompass a wide range of developing economies with differing energy transition pathways. One important subgroup consists of large industrial economies, such as China and India, where coal continues to

play a vital role in supporting economic growth and electricity generation. The second Non-Annex subgroup represents resource-dependent developing nations that rely heavily on coal extraction and exports to fund their domestic development for those countries like Indonesia, Vietnam, Philippines and Malaysia. Evaluating the completely different pressures faced by these distinct economic profiles highlights the influence of differing climate mandates, domestic demand, and trade dependencies threaten the energy infrastructure.

(Fazeli *et al.,* 2025) expressed the concern that Southeast Asian Nations (ASEAN) are considered the world's third-fastest region for new coal-fired additions after China and India, and the risk of coal-fired power plants becoming stranded assets is significant, especially when taking into consideration the rapid development of renewable power generation and the implementation of carbon pricing schemes. Hence, we found that the fundamental studies should consider these three main country groups which are the Annex as the developed countries, the Non-Annex as the major consumers and the Non-Annex as the major exporters to visualise the reality of stranded assets risk globally.

Research on stranded assets in coal-fired power plants has expanded considerably in recent years with many studies focusing on the financial valuation, early retirement pathways, and the implications of climate policies within individual countries or regions. Some researchers have consistently identified plant lifetime and carbon policy implementation as the important drivers of stranded asset exposure. However, there is still a lack of comparative assessment that evaluates plant lifetime and carbon policy interaction across countries with various levels of coal dependency, economic status, and decarbonisation strategies. Therefore, the purpose of this study is to examine the factors influencing stranded asset risk in coal-fired power plants under ongoing energy transition and decarbonisation efforts. The study is motivated by increasing concerns regarding the financial implications of coal phase-out policies and the challenges faced by countries operating under different transition conditions. Through a synthesis of grey literature and peer-reviewed studies, the research seeks to provide comparative insights into the key determinants of stranded asset risk rather than performing detailed quantitative valuations of stranded assets.

2.0 METHODOLOGY

A qualitative analysis and assessment are performed to synthesise and comparatively interpret stranded asset exposure using evidence from peer-reviewed literature and institutional reports. This paper was conducted through a structured desktop study, drawing on both peer-reviewed literature and authoritative grey literature. The study's flow is shown in Figure 1.

For data collection, relevant peer-reviewed literature was identified from search engines such as *Google Scholar, ScienceDirect (Elsevier)* and *Scopus*, while authoritative grey literature was collected from official reporting from organisations such as the IEA, International Renewable Energy Agency (IRENA), Intergovernmental Panel on Climate Change (IPCC), and UNFCCC. These sources were used as reference points to compare different transition scenarios examined in this study. The search process employed combinations of keywords including "stranded asset risk", "coal-fired power plant", "plant lifetime", "coal phase-out", "carbon policy", "energy transition", "net-zero", and "energy decarbonisation". There were 343 documents detected through these keyword-based searches.

For data analysis, the screening and selection procedures are as follows: Duplicate documents were omitted using EndNote and irrelevant records which were unrelated to fossil fuel sector studies were excluded based on title relevance during the preliminary review stage. Subsequently, 92 studies were selected for the abstract screening with the following criteria: (i) discussed stranded asset exposure associated with coal-fired power plants; or (ii) use of recognised modelling approaches or institutional decarbonisation scenarios that evaluated coal retirement pathways, carbon policies, or climate mitigation strategies; of (iii) examined operational lifetimes or transition risk; or (iv) provided financial, environmental, or policy-related analysis relevant to coal transition. Finally, 74 articles were chosen as the main references for further synthesis processes.

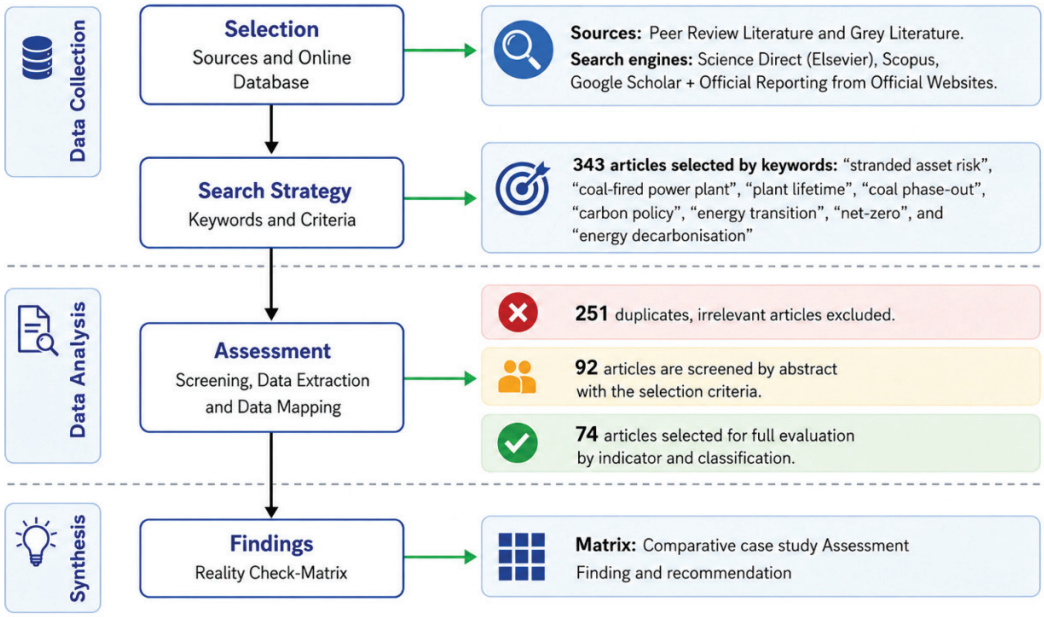

Figure 1: Flow of study

For the synthesis, we assess all finalised grey literature and peer-reviewed articles to identify the major factors contributing to stranded asset risk in coal-fired power plants worldwide. Special consideration is given to plant lifetime and carbon policy due to

their frequent association with stranded asset exposure in the literature. The review further examines whether these factors consistently emerge as key determinants of stranded asset risk across different transition contexts. In addition, peer-reviewed studies are analysed to explore national attributes, including coal dependency, economic status, and decarbonisation strategies, may influence the magnitude of stranded asset exposure.

Therefore, this study evaluates the influence of plant lifetime and carbon policy implementation under the different transition conditions. Equally important, this study examines the coal dependency, economic status, and decarbonisation strategies influence stranded asset exposure across different national contexts. Based on these considerations, three countries were selected as comparative case studies that represent significantly different national attributes and provide comparative insights into the influence of plant lifetime and carbon policy on stranded asset risk.

The literature was synthesised into two analytical pillars, namely plant lifetime and carbon policy implementation which form the basis of the subsequent comparative assessment. The assessment considers indicators such as average plant age, coal contribution to national electricity generation, coal phase-out commitments, carbon pricing mechanisms and policy enforceability. To ensure the transparency, classifications were benchmarked against values reported in the literature. The finding of the study is a set of structured statements aimed to guide the understanding of stranded asset risks under different national attributions. The limitation of the present study is its dependency on secondary data and scenario-based conditions. The estimated stranded asset values cannot be directly compared with those reported in other studies. This is due to the differences in assumptions which may be regarded as other factors such as discount rates, carbon pricing and asset boundaries. Therefore, the findings presented in this study should be interpreted as indicative comparative exposure patterns rather than definitive financial valuations.

3.0 RESULTS AND DISCUSSION

3.1 Stranded Asset

Stranded assets may result from unforeseen or unanticipated shifts in (i) the regulatory environment (Blumstein, 1994; Price, 1998; Rozenberg, 2014; Spencer, 2017) (ii) market conditions, including price volatility (Auger *et al.,* 2021; De Silva, 2017; Linquiti & Cogswell, 2016; Wang *et al.,* 2025) (iii) technology advancements (Fay, 2015; Stern, 2012) (iv) financial contexts, including trade-offs and market volatility (Ansar, 2013; Auger *et al.,* 2021; Bertram, 2015; Crew, 1999; Narayanan *et al.,* 2021); and (v) environmental risks (Ansar, 2013). In the case of coal-fired power plants, such premature retirement can create stranded assets or extended and unexpected declines in market value (Hansen, 2022; Linquiti & Cogswell, 2016; Mercure, 2018) under decarbonisation pressures. This is predicted to cause approximately 77 to 97% of coal reserves, as well as existing coal plants, to be stranded (Firdaus & Mori, 2023; IRENA, 2017). (Edwards *et al.,* 2022) demonstrated that global coal capacity would rise by 503 GW, increasing stranded assets by 55%, which equates to about USD 520 billion. Primarily, stranded assets pose risks for countries, producers, investors, and consumers who have committed capital to those assets (Bos & Gupta, 2019).

From the literature, we can demonstrate that stranded assets have become an increasingly important issue within global energy transition discussions, particularly in coal-dependent sectors exposed to decarbonisation pressures. The findings also emphasise coal-fired power plants are highly vulnerable to premature retirement due to regulatory changes, market uncertainty, technological transition, and environmental commitments. The risk is especially significant in developing economies with rapidly expanding coal infrastructure, where long-term investment recovery may become increasingly uncertain under accelerated climate transition pathways.

3.2 The Influence of Plant Lifetime on Stranded Asset Risk

According to the IEA, advanced economies must phase out unabated coal-fired power plants by 2030, while emerging markets must stop by 2040 (IEA, 2021). To visualise the scenario, (Cui *et al.,* 2019) provided a more detailed assessment by combining unit-level plant data with an integrated assessment model to determine retirement schedules consistent with Paris Agreement goals, as shown in Figure 2. Their analysis indicated that under a 2 °C pathway, coal-fired power plants should retire after approximately 35 years of operation, while under a 1.5 °C pathway, operational lifetimes are further reduced to around 20 years. In contrast, maintaining conventional operational lifetimes of approximately 50 years would delay alignment with climate targets until around 2070. (Cui *et al.,* 2019) emphasised there is a significant gap between the conventional investment expectations of coal-fired power plants and the shorter operating periods required under decarbonisation pathways. Coal-fired power plants are usually design with the assumption that capital costs will be recovered over several decades of operation. When retirement happen sooner than expected, the opportunity to recover these investments becomes more limited and the risk of asset devaluation increase. This issue is particularly relevant for countries operating relatively young coal plants, where a considerable share of assets may still be within the investment recovery stage when retirement is needed. As a result, plant lifetime acts as important role in shaping stranded asset exposure and should be considered aligned with climate policy objectives when assessing transition risks.

3.3 The Impact of Carbon Policy on Stranded Asset Risk

According to (Energy, 2025), carbon policy is referring to a set of government regulations and initiatives designed to reduce or mitigate the GHG emissions while ensuring that energy remains affordable and reliable. Strong measures such as net-zero commitments, carbon pricing schemes, and a coal phase-out plan can raise the risk of asset stranding by accelerating the retirement of existing operations (Cui *et al.,* 2019; Energy, 2025; IRENA, 2017; Johnson *et al.,* 2015; Kefford *et al.,* 2018). The (IEA, 2021) emphasises that a major energy transformation which requires an average yearly decline of about 7% in coal-use demands will significantly increase the risk of stranded coal assets.

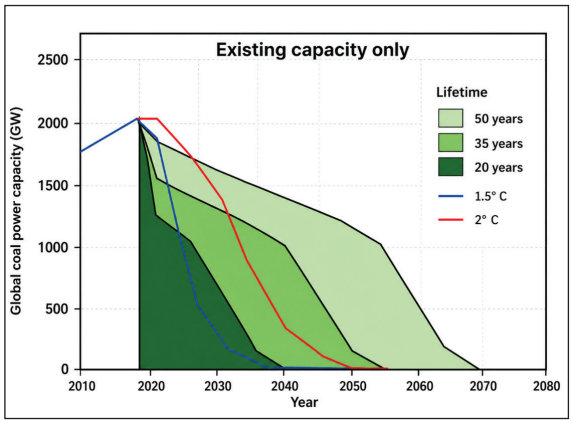

Figure 2: Operational lifetime limits for coal power plants

A recent multi-model analysis in the United States developed by (Bistline *et al.,* 2025) found that from the government's perspective, stringent climate policies could significantly affect public finances. By 2050, revenues from carbon pricing and subsidies for carbon removal are projected to total about 0.1 to 3.7 percent of Gross Domestic Product (GDP). This situation highlights that carbon policy is for a climate mitigation tool and also as a financial signal that shapes overall market outlooks. Studies highlighted that transparent and credible policy signals can guide investors, reduce uncertainty and lower the transition risks related to stranded assets in coal plants (IPCC, 2014). Additionally, (Chai *et al.,* 2023) further emphasised that carbon pricing policies can strengthen market signals and influence both asset valuation and retirement planning.

The literature suggests that policy clarity and enforcement level play an important role in shaping stranded asset exposure. Countries with legally binding and transparent transition frameworks are generally associated with the lower levels of uncertainty rather than those relying on evolving or non-binding policy mechanisms. These findings reinforce the role of carbon policy as the second analytical pillar of this study. Together with plant lifetime, carbon policy provides an important basis for the understanding stranded asset risk under different energy transition conditions.

3.4 Stranded Asset Risk - A Reality Check Assessment

Plant lifetime and carbon policy implementation form the two analytical pillars of stranded asset risk examined in this study. In order to conduct a reality check across the full spectrum of stranded asset exposure, a purposive sampling approach was adopted based on the UNFCCC classification. Purposive sampling is defined as the intentional selection of specific units (eg. individuals, cases, or events) based on their relevancy to the research question that enables the researchers to gain deep insights into complex phenomena (Omid *et al.,* 2024). The selection criteria and the country classifications are presented in Table 1.

According to Table 1, Germany represents an advanced Organisation for Economic Cooperation and Development (OECD) economy with mature climate legislation and ageing coal infrastructure (Breitenstein, 2020; Ideas, 2024; IPCC, 2022; Markewitz *et al.,* 2018; Scott, 2025). China represents a major coal dependent emerging economy characterised by large-scale coal infrastructure and evolving transition commitments (Asia, 2023; Zhang, 2021; Zhang *et al.,* 2022). Indonesia represents a developing coal exporting economy with relatively young coal plant, high fiscal dependence on coal revenues, and evolving policy frameworks (Asia, 2024; Reyseliani *et al.,* 2024). This gives in-depth perspectives on the national level realities of stranded asset exposure.

- **Germany**

As shown in Table 2, stranded asset risk in Germany reflects the interaction between binding legislation, market dynamics and the ageing profile of its coal plants. As a Party listed under Annex I, II and OECD country, Germany has adopted some of the world's most ambitious coal phase-out measures (UNFCCC, 2025). For instance, the Coal Phase-out Act mandates a complete coal exit by 2038, with the possibility of accelerating the phase-out to 2030, and this pathway is strengthened by the EU ETS2 carbon-pricing mechanism (Scott, 2025). The average age of Germany's coal fleet estimated at 40 to 45 years (Markewitz *et al.,* 2018) leads to the retirement schedules broadly aligning with technical lifetimes which helps reduce systemic exposure. (Breitenstein, 2020) provided a more detailed study by applying a Monte Carlo simulation to test different scenarios. Their results showed that stranded asset values of €0.4 billion (≈USD 0.44 billion) under the 2038 pathway and €14.3 billion (≈ USD 15.6 billion) if the exit is carried forward to 2030 (Breitenstein, 2020). The analysis also highlighted that carbon pricing and renewable feed-in change the merit order, which is gradually eroding profitability for lignite and hard coal plants. It also discussed compensation mechanisms proposed by the Coal Commission which the estimates are vary and the legal basis for such payments may subject to differing interpretations. Overall, the German case demonstrates that the stranded asset risk can implicate beyond power generation, including effects on the financial sector through changes in utility share prices.

Table 1: Selection criteria for comparative case study

Selection Criteria			Selected Country
Economic Status (UNFCCC Tier)	**Coal Dependency**	**Carbon Policy**	
Annex 1 & II OECD (Industrialised Donor)	Less Dependency (about 20%) (Old/Legacy Plant)	100% Phase-out by 2038 (Legally binding mandate)	Germany
Non-Annex 1 (Developing Giant)	Biggest coal consumption (58% global coal consumption) (Mature Plant)	Net-Zero by 2060 (Emissions peak before 2030)	China
Non-Annex 1 (Developing Exporter)	Biggest coal exporter (over 450+ million tonnes annually) (Young/Expanding Plant)	Net-Zero by 2060 (Backed by the $20B JETP aid pact)	Indonesia

Source: IEA (2025), Global Energy Review 2025, IEA, Paris https://www.iea.org/reports/global-energy-review-2025, Licence: CC BY 4.0

Table 2: Stranded asset risk assessment for Germany

Parameter	Comparative Indicator	Ref	Key Finding
Country Classification	• Annex I, II OECD, coal ~21.9% of the power mix.	(Ideas, 2024)	Aligning phase-out timelines with asset standard ageing helps limit systemic risk, though faster retirements can raise expenses.
Plant lifetime (Pillar 1)	• Average plant age 40–45 years. • Older plants.	(Markewitz *et al.,* 2018)	
Carbon policy (Pillar 2)	• Net Zero by 2045. • Legally binding thru the Climate Change Act. • Coal Phase-Out Act mandates an exit 2038, with an accelerating option 2030. • Backed by the EU ETS2 carbon pricing mechanism.	(IPCC, 2022; Scott, 2025)	
Stranded asset value*	• €0.4 billion (≈USD 0.44 billion) under the 2038 plan; • €14.3 billion (≈USD 15.6 billion) if accelerated to 2030.	(Breitenstein, 2020)	
Tools	• Based on a Monte Carlo simulation.		

**The reported values are based on the published studies and reflect different scenario assumptions and the methodological approaches. They are intended to illustrate relative exposure trends rather than provide definitive or directly comparable valuations.*

Table 3: Stranded asset risk assessment for China

Parameter	Comparative Indicator	Ref	Key Finding
Country Classification	• Non-Annex, coal is >60% of electricity.	(Asia, 2023)	The level of exposure is significant but moderated through government control of coal supply.
Plant lifetime (Pillar 1)	• Technical lifetime ~30 years • Relatively young plant.	(Zhang *et al.,* 2022)	
Carbon policy (Pillar 2)	• Net Zero by 2060, • But not legislated. • National ETS 2021: limited coverage and price levels.	(IPCC, 2022)	
Stranded asset value*	• USD 9.3–35 billion under 2 °C scenario, assuming minimum 30 years' operating lifetime.	(Zhang, 2021)	
Tools	• Based on the Global Change Assessment Model (GCAM) with plant-level data.		

The combination of legally binding phase-out policies and ageing coal assets appears to reduce exposure in relation to countries with younger coal plants. However, accelerating retirement timelines may increase the transition costs and generate additional financial uncertainty.

- **China**

China is grouped as a non Annex country as shown in Table 3. It continuously depends heavily on coal, which supplies more than 60% of its electricity (Asia, 2023). Even though a national net zero target was announced for 2060 (IPCC, 2022), but an official phase-out has not been legislated. The national ETS introduced in 2021 yet still limited in scope and price signals (IEA, 2024). Moreover, the China's coal plants are comparatively young with an average age of around 30 years (Zhang *et al.,* 2022). Hence, this increases the risk of stranding if plants lifetimes are shortened. (Cui *et al.,* 2019) used the GCAM with plant-level data to quantify operational lifetime limits under Paris-aligned scenarios. The results showed that plant lifetimes must be reduced up to 35 years for the 2 °C goal and 20 years for the 1.5 °C goal, far below the historical average of 50 years. Under a 2 °C scenario, the related stranded asset exposure is estimated at USD 9.3 to 35 billion (Zhang, 2021). Their finding highlighted that if all planned projects proceed and plant operating lifetime are shortened by 5 to 10 years, the risk of stranded assets would increase substantially.

These gaps translate directly into the stranded asset risk where plants built today could operate for decades except, they are forced into early retirement. Although government intervention through coal reserve systems and mandated supply contracts helps maintain the market stability (IEA, 2024), it does not eliminate the underlying exposure associated with relatively young coal assets and non-binding decarbonisation commitments. Overall, the China case highlights a considerable level of stranded asset exposure arising from the combination of relatively young coal plants and an evolving policy framework, although government control of coal supply continues to moderate part of the risk.

- **Indonesia**

Indonesia also grouped as a Non Annex country. They produces about two-thirds of its electricity from coal and remains the world's largest exporter of thermal coal (UNFCCC, 2025) as shown in Table 4. The national pledge to reach net zero by 2060 but is not legally binding (IPCC, 2022). The carbon pricing instruments are still evolving despite international support through the Just Energy Transition Partnership (JETP) (Asia, 2024). The coal plant is very young with an average age of less than 15 years (Asia, 2024). This indicates that early retirements would strand assets long before their technical lifetimes. (Reyseliani *et al.,* 2024) used the VEDA TIMES optimisation model to simulate the decarbonisation pathways with and without a coal plant phase-out. Their study estimated USD 9 billion stranded in power plant assets, with USD 63 billion in untapped reserves and USD 799 billion in upstream losses (Reyseliani *et al.,* 2024). These values highlighted the scale of exposure beyond the power sector which extending to mining revenues and regional fiscal stability. For example. East Kalimantan and South Kalimantan derived up to 35% of revenues from coal which make them highly exposed. Their study also highlighted that Indonesia's dependence on Carbon Capture and Storage (CCS) is critical in decarbonisation scenarios which bring up questions on feasibility and cost. Meanwhile, gas security is another concern as phase-out pathways increase dependence on imported natural gas between 2035 and 2050. Indonesia's scenario

Table 4: Stranded asset risk assessment for Indonesia

Parameter	Comparative Indicator	Ref	Key Finding
Country Classification	• Non-Annex, the world's largest thermal coal exporter, uses coal for ~ two-thirds of electricity.	(UNFCCC, 2025)	The combination of young plants, high coal dependence and evolving policy instruments puts Indonesia within the elevated exposure category.
Plant lifetime (Pillar 1)	• The average plant age is under 15 years. • Very young compared to a typical 40-year lifespan.	(Asia, 2024)	
Carbon policy (Pillar 2)	• Net Zero pledge by 2060. • Policy-based and not legally binding. • Carbon pricing mechanisms are still developing despite Just Energy Transition Partnership (JETP) support.	(Asia, 2024; IPCC, 2022)	
Stranded asset value*	• Stranded assets are estimated at USD 9 billion in power assets, USD 63 billion in untapped reserves, and USD 799 billion in upstream losses.	(Reyseliani *et al.,* 2024)	
Tools	• Based on the VEDA TIMES optimisation model.		

shows stranded asset risk in developing, coal-producing countries is intensified by young plants, fiscal dependence and evolving policy frameworks which put them in the elevated exposure category.

Overall, the stranded asset risk is difference across countries and is shaped by the characteristics of national coal plants as well as the policy frameworks that govern the energy transition. In Germany, the ageing coal plants combined with legally binding phase-out policies contribute to limit the exposure, even though accelerated retirement pathways may increase transition costs. In China, relatively young coal plants and continued reliance on coal contribute to significant exposure, despite government intervention that help to moderate part of the risk. In Indonesia, the combination of young coal plants, highly dependence on coal-related activities, and evolving policy mechanisms laid the country at a comparatively higher level of exposure. While these classifications are illustrative rather than definitive, they emphasise the importance of aligning the retirement planning, policy implementation, and financial considerations to support the long-term decarbonisation goal.

4.0 CONCLUSION

This study examined stranded assets risk associate with operational lifetime and carbon policy implementation across national contexts. The findings conclude that stranded asset risk is strongly influenced by the correlation between operational lifetime and policy-driven retirement requirements. The comparative assessment discloses that exposure varies according to national conditions. Germany displays relatively lower exposure due to its ageing coal assets and legally binding phase-out commitments. China faces significant exposure because its coal plants have an average age of 30 years, while coal remain a major source of electricity generation. Indonesia demonstrates an elevated exposure also due to its younger coal plant, continued reliance on coal-related economic activities, and developing policy framework.

For industry stakeholders, plant retirement planning should aligned with plant age profiles and national decarbonisation targets to reduce the risk of unrecovered investments. For policymaker, transparent and consistent carbon policy implementation is important for providing transition certainty and supporting long-term investment planning. This study is limited by reliance on published literature and differences in modelling assumptions, system boundaries, and scenario conditions. Future research should focus on Malaysia, examining stranded asset exposure under decarbonisation pathways, considering coal dependency, plant age profile and evolving energy transition policies. ■

AUTHORS' CONTRIBUTIONS

Nor Syuriaty Jaafar	Conceptualisation, Methodology, Writing - Original draft preparation
Noor Fatina Emelin Nor Fadzil	Writing - Reviewing and Editing
Norhuda Abdul Manaf	Writing - Reviewing and Editing

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