Journal of Technology and Policy in Energy and Electric Power
Volume 1, Number 2, June 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v1i2/115

Research Article

A Comparative Analysis Of Carbon Pricing Schemes On The Cost Of Reducing Carbon Emissions In The Java, Madura And Bali Regional Power Generation Sector

Disa Amalia Zaini[1*], Widodo Wahyu Purwanto[1]
[1]Department of Interdisciplinary Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia
Corresponding author:** ***Disa Amalia Zaini, amaliyadisa@gmail.com

CITATION

Author Name. (2025). Article title. *Journal of Technology and Policy in Energy and Electric Power*. 1:2. https://doi.org/10.33322/jtpeep.v1i2

ARTICLE INFO

Received March 30, 2025
Accepted May 14, 2025
Available online June 29, 2025

Abstract: This study conducts a comparative analysis of carbon pricing schemes on reducing carbon emissions in the electricity sector in Java, Madura and Bali (Jamali). The method used is a quantitative simulation of the cost of reducing carbon emissions in the Jamali generation system for three carbon price scenarios: Emission Trading System (ETS), Cap and Tax (CT), and abatement cost (AC). The results show that with a carbon pricing scheme for emission reduction as much as the cost of carbon pricing requires, regardless of the technology, every increase in carbon tax by 1 USD/ton CO_2 results in an increase in electricity prices. In contrast, the cost of emission reduction analysis shows that in the initial phase of tariff implementation, the carbon mitigation cost for the carbon tax scheme is around USD 45 million and USD 137 million for the emissions trading scheme (ETS), to reduce emissions by approximately 22 million tons of CO_2. However, this value increases significantly by the end of the policy period, with estimates reaching USD 6 billion per ton of CO_2 for the carbon tax scheme and USD 4 billion per ton of CO_2 in the ETS framework, to achieve the emission reduction target of 48 million tons of CO_2. Meanwhile, the NZE and NZE-CAP scenarios reduce emissions intensity to 0.844 tons of CO_2 per MWh and 0.781 tons of CO_2 per MWh, respectively, with abatement costs of USD 67/ton CO_2 and USD 70/ton CO_2.

Keywords: power generation, carbon price, emission reductions, costs

1. Introduction

Global climate change caused by greenhouse gas emissions has become the urgent challenge of this century. The IPCC asserts that to limit warming to 1.5°C, global greenhouse gas emissions must peak before 2025 and be reduced by about 43% by 2030, with the goal of achieving carbon neutrality by mid-century. Indonesia has set ambitious emission reduction targets in its Nationally Determined Contribution (NDC). In its 2022 Enhanced NDC, Indonesia committed to reduce emissions by 31.89% unconditionally and up to 43.2% with international assistance by 2030 compared to a *business-as-usual* scenario [1]. The energy sector, particularly power generation, is a major contributor to total national carbon emissions. The Java-Madura-Bali (Jamali) region as the centre of electricity demand in Indonesia, which is mostly fossil fuel power plants, in 2020, coal accounted for 68% of existing electricity production [2]. Therefore, efforts to reduce emissions from the Jamali power generation sector will determine the success of achieving national climate change targets.

Currently, a policy instrument that is considered capable of driving emissions reductions is a carbon price. A carbon price, which charges a fee per ton of CO_2, can encourage a reduction in fossil fuel consumption and a shift to clean energy technologies. The development of carbon trading and carbon taxes continues to be seen in various countries. By 2020, there were 30 carbon taxes and 31 emissions trading schemes (ETS) worldwide, covering twenty-two percent of global emissions [4]. Currently, carbon trading and carbon taxes are on the rise with 38 countries implementing carbon taxes and 31 countries implementing emissions trading schemes (ETS) and some implementing both [5].

Various countries have implemented carbon pricing mechanisms, either through carbon taxes or emissions trading schemes, and empirical evidence shows that these policies are effective in reducing emissions growth rates. Previous research has found that the implementation of carbon pricing reduces the growth rate of national CO_2 emissions by around 1-2% compared to a scenario without carbon pricing, mainly through emissions reductions in the electricity generation sector [6]. The Chinese government provides free CO_2 emission quotas to power generating units, tailored to their capacity and technology. If their CO_2 emissions exceed the free quota, power unit owners must purchase CO_2 emissions from the carbon market [7]. Based on research conducted by R. Best et al, the effect of carbon pricing on the growth rate of CO_2 emissions during 1997-2017 in 142 countries, found that countries with carbon prices had 2% lower emissions growth [8]. Furthermore, research by S. Sen et al, found that an increase in energy/carbon taxes by €1/tCO_2 would reduce fossil fuel demand by 0.73% [9]. Various policy methods have been implemented to reduce CO_2 emissions in the power sector, economists and international organizations strongly recommend carbon pricing as a cost-effective instrument to achieve specific reduction targets. Some developed and developing countries, such as Sweden, implemented a carbon tax in 1991 with a price of 26.07 US dollars per ton of CO_2, which gradually increased to 123.07 US dollars per 2 tons of CO_2 by 2022. By implementing a carbon price, Sweden managed to reduce its greenhouse gas emissions by 35 percent by 2020 [10]. These findings emphasize the role of carbon pricing in the world in contributing to emissions reductions in the sector.

The Indonesian government demonstrates its commitment to reducing carbon dioxide emissions through the Value of Carbon Economy (NEK) policy stipulated in Presidential Regulation No. 98 of 2021. This policy regulates emission reduction mechanisms, including carbon trading with a cap-and-trade system, where businesses are required to comply with the emission limits set through PTBAE-PU. Regulatory support is also provided through POJK Number 14 of 2023 and SEOJK 12/2023 which regulate carbon trading procedures on the stock exchange. In addition, a carbon tax instrument was adopted through the EITI Law Number 7 of 2021 as a fiscal effort to encourage carbon emission control in related sectors. Carbon tax as a fiscal instrument is considered to be able to influence the control and reduction of carbon emissions. The CPP Law has set a carbon tax rate of IDR 30.00 per kilogram of CO_2 equivalent. The implementation plan for the implementation is gradually starting with the steam power plant (PLTU) sector. Meanwhile, the ETS price in Indonesia is currently in the range of Rp96,000-Rp144,000 (equivalent to 6-9 USD/ton CO_2). It becomes an interesting discussion if currently the emissions produced by coal power plants, especially in the Jamali region, still exceed the set limit (*cap)*, so that power plants must be charged a carbon price. Research by Indra, et al using the PowerGen-ABM model tool states that the emission reduction target will increase the cost of electricity generation in Indonesia on average in 2028 from 65.3 USD / MWh in the power plant expansion plan to 68.3 USD / MWh [12]. Previous research included carbon prices as a cost externality that must be borne by energy producers so as to encourage the transition to new energy in the Riau region [13]. Research by Perkasa et al to analyse the impact of rising fuel costs on the Jamali electricity system on the implementation of a carbon price scheme using jROS (Joint Resource Optimization and Scheduler) with the results of implementing a carbon price scheme (*cap and trade*) is more profitable with a difference in additional fuel costs for the Java-Bali system of IDR 75.67 billion [14]. In addition, carbon pricing will affect the value of electricity prices. Carbon taxes can also disproportionately increase costs for households and businesses. In low- and middle-income countries, where a large proportion of the population is economically dependent on the government and lacks reliable energy access, a small increase in electricity prices can severely undermine public support for carbon pricing policies [14]. This is also an important area to discuss. Thus, some of the research questions that are the focus of this study are:

a. What is the carbon cost for Jamali power plants to meet the emission limits set by the ETS and CT schemes, without changes in generation technology?
b. What is the carbon cost (abatement cost) of implementing a change in generation technology?
c. How does carbon taxation affect electricity prices?

To answer this question, an economic analysis was conducted by calculating the amount of current emissions projected up to 2030 and calculating the cost of the carbon price that must be paid to achieve the set emission reduction target.

2. Methodology

This study used a quantitative techno-economic simulation with a focus on the power generation sector in the Jamali region. The model comparatively identified several carbon pricing policies on the cost of carbon emission reduction and their influence on the value of the cost of production or Levelized Cost of Electricity (LCOE). In general, the simulation is carried out by projecting Jamali electricity production from 2024 to 2030, then setting an emission reduction target, then calculating the total reduction in carbon emissions generated and the cost of reducing carbon emissions with 3 schemes: carbon price ETS, Cap and Tax (CT) and emission reduction with generation expansion planning (GEP) with changes in technology portfolio towards cleaner energy.

The emission reduction target based on the *cap* limit is calculated only for coal-fired power plants with the emission intensity value adopting the emission intensity of Java, Madura and Bali in the 2021-2030 RUPTL according to Table 1.

Table 1. Jamali Emission Intensity Target

Year	Emission Intensity (ton CO2/MWh)
2021	0,894
2022	0,882
2023	0,87
2024	0,858
2025	0,846
2026	0,834
2027	0,822
2028	0,810
2029	0,798
2030	0,788

Annual electricity production using the following formula:

$$E_{i,t} = P_{i,t} \times CF \times T \quad (1)$$

with:

$E_{i,t}$: electricity production of technology *i* in year *t* (MWh/year)
P_i : installed capacity of technology *i* (MW)
CF : Capacity Factor
T : number of operating hours in a year

Emissions are calculated using the following formula:

$$Em_{i,t} = E_{i,t} \times \varepsilon_i \quad (2)$$

with:

$Em_{i,t}$: CO_2 emissions from power generation technology *i* in year *t* (tons CO_2 per year)

$E_{i,t}$: electricity production from technology *i* year *t* (MWh per year)
ε_i : emission factor for power generation technology *i* (tons CO_2/MWh)

Reduction emission cost is calculated using the following formula:

$$C_{\mathrm{i,t}}^{carbon} = Em_{i,t} \times N_t \quad (3)$$

with:
$C_{\mathrm{i,t}}^{carbon}$: reduction emissions cost for power generation technology *i* in year *t* (USD per year)
N_t : carbon price in year *t* (USD/ton CO_2)

The addition of carbon pricing to the LCOE of power plants is calculated using the following formula:

$$LCOE_{\mathrm{i},t}^{A} = LCOE_{i,t} + C_{\mathrm{i,t}}^{carbon} \quad (4)$$

with:
$LCOE_{\mathrm{i},t}^{A}$: LCOE for generation technology *i* in year *t*, including carbon pricing (USD/MWh)
$LCOE_{i,t}$: LCOE for generation technology *i* in year *t* (USD/MWh)
$C_{\mathrm{i,t}}^{carbon}$: carbon price in year *t* (USD/ton CO_2)

Abatament Cost is calculated using the following formula:

$$AC_t = \frac{C_{\mathrm{t}}^{sc}\ (USD) - C_{\mathrm{t}}^{BAU}(USD)}{E_{\mathrm{t}}^{BAU}\ (ton\ CO2 - E_{\mathrm{t}}^{sc}} \quad (5)$$

dengan:
C_{t}^{sc} : total generation cost under the scenario in year *t* (USD)
C_{t}^{BAU} : total generation cost under the baseline in year *t* (USD)
Em_{t}^{sc}: total emissions generated under the baseline in year *t* (tons CO_2)
Em_{t}^{BAU} : $total$ emissions generated under the baseline in year *t* (tons CO_2)

The objective function in the GEP simulation uses TIMES:

TCt,y= Annualize ICt,y+ FOMt,yCapacityt,y+FCt,y+VOMt,y× Energy Prodt,y (6)

where:
TC = total cost (USD)
t = generation technology t
y = year y
IC = investment cost (USD/MW)
FOM = fixed operation and maintenance cost (USD/MW)
VOM = variable operation and maintenance cost (USD/MWh)
FC = fuel cost (USD/MWh)
Capacity= generating capacity t (MW)
Energy Prod = total electricity production of technology t in year y (MWh)

1. Simulation Scenario Design

This study uses 3 (three) emission reduction cost scenarios. The carbon tax and ETS scenarios are the main scenarios to see the cost of carbon to achieve emission reduction targets. The next scenario is technological changes to the supply of electrical energy to achieve the emission reduction target (*abatement cost)*.

Table 2. Simulation Scenario

No.	Scenario Name	Regulatory Mechanism	Key Parameters
1	CT (Carbon Tax)	3 levels of carbon price, PLTU annual emission cap	Carbon tax rate (USD/ton), PLTU emission cap
2	ETS	3 levels of carbon price, PLTU annual emission cap	carbon price (USD/ton), PLTU emission cap
3	AC (Abatement Cost Scenario)	*least cost optimization,* NZE scenario	Abatement cost (USD/ton), emission reduction target, technology analyzed

Based on the *World Bank's carbon* pricing *dashboard,* carbon prices for carbon tax schemes vary widely based on each country's policies.

Developed countries have implemented carbon taxes at high rates, while developing countries are still at low rates due to fiscal policy constraints. Based on reference from the *World Bank's carbon pricing dashboard*, this study uses three carbon tax and ETS tariff scenarios. The selection of these tariff ranges is intended to represent variations ranging from realistic minimum policies in the short term to ecologically ambitious high tariffs. The carbon price of 2 USD/ton CO_2 corresponds to Indonesia's initial actual policy, while the other carbon prices refer to the *world bank's* carbon price trajectory. The ICPF recommends for developing countries a value of 50 USD/ton CO_2[15] . For each tariff scenario, the model calculates the changes in power plant operating costs due to the carbon price and the costs incurred to reduce CO_2 emissions.

Table 2. Carbon Price Scenarios

Year	**Carbon Tax Scenario (USD)**		
	Low	Medium	High
2024	2	2	2
2025	5	11,65	23,5
2026	8	21,3	45
2027	11	30,95	66,5
2028	14	40,6	88
2029	17	50,25	109,5
2030	20	60	130

Tahun	ETS (USD)		
	Low	Medium	High
2024	6	6	6
2025	7,5	13,35	21,5
2026	9	20,7	37
2027	10,5	28,05	52,5
2028	12	35,4	68
2029	13,5	42,75	83,5
2030	15	50	100,0

Global carbon price trajectories show that developed countries tend to apply high tariffs from the start, such as Sweden reaching USD 137/ton CO_2, Norway around 90 USD/ton CO_2, and France setting EUR 44.6/ton CO_2 before being stopped due to social pressure [16]. In contrast, developing countries generally start low and increase gradually, e.g. Colombia starts at USD 5/ton CO_2 with plans to increase to USD 10, and Singapore from USD 5/ton CO_2 to USD 15-25 by 2030 [16]. Based on this pattern, it is recommended that the carbon price scenario for Indonesia be simulated based on the current price and then gradually increase to 130 USD/ton CO_2 by 2030.

The abatement cost analysis in this study was conducted by comparing two main approaches to achieving the Net Zero Emission (NZE) target in the electricity generation sector, namely the NZE scenario based on system optimization modelling and the NZE scenario with an explicit cap on carbon emissions. The selection of the two scenarios is based on the need to understand the trade-off between cost efficiency and certainty of achieving emission reduction targets. The main consideration in conducting this comparative analysis is to identify differences in the marginal cost of emission reductions (USD/ton CO_2) between the two scenarios, as well as to assess the impact of policies on the choice of low-carbon technologies adopted.

2. Data and Assumptions

Based on the Decree of the Minister of Energy and Mineral Resources number: 14.K/TL.04/MEM.L/2023 that the emission limits currently set apply to coal-fired power plants grouped by generating capacity. The power plant in this model uses historical data from the company as follows:

The parameter data used is sourced from technical assumptions of power plants and demand projections in the Jamali region, including installed capacity, capacity factor (CF), efficiency. The model incorporates key generation technologies such as coal-fired power plants (subcritical, supercritical, ultra-supercritical and Pembngk to see the impact of high carbon tax. Data was obtained from Indonesia's Directorate General of Electricity and the Danish Energy Agency's 2021 report, Technology Data for Indonesia's Power Sector. The investment value per coal plant technology in Indonesia until 2030 is assumed in Figure 2.

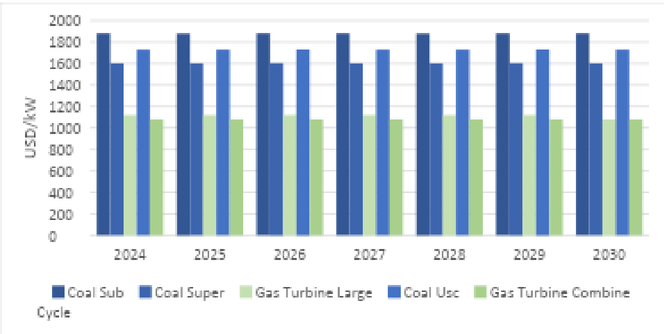


Figure 2. Power Plant Investment Costs [17]

Journal of Technology and Policy in Energy and Electric Power
Volume 1, Number 2, June 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v1i2/115

This simulation uses specific emission factors for each generation technology used based on the Ministry of Environment and assumptions from previous research. Emission factors are used to obtain the emission value of each energy produced. The emission factor of coal power plants has the highest value, meaning that it can produce the largest emissions. Emission factors for various power generation technologies can be seen in Figure 2.

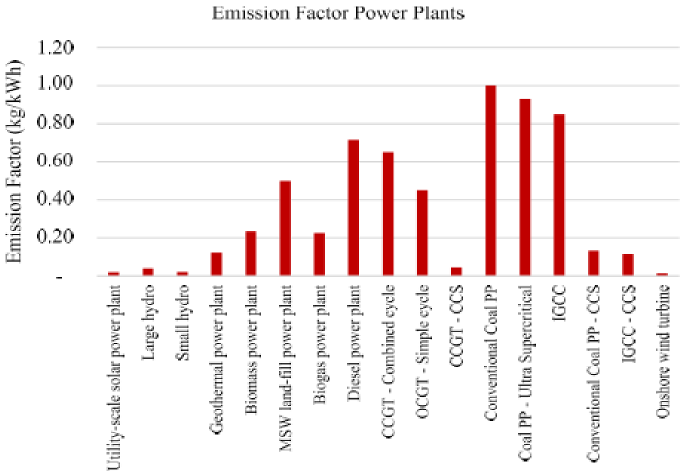


Figure 3. Power plant emission factors[18]

3. Results and Discussion

1. Carbon Emissions generated

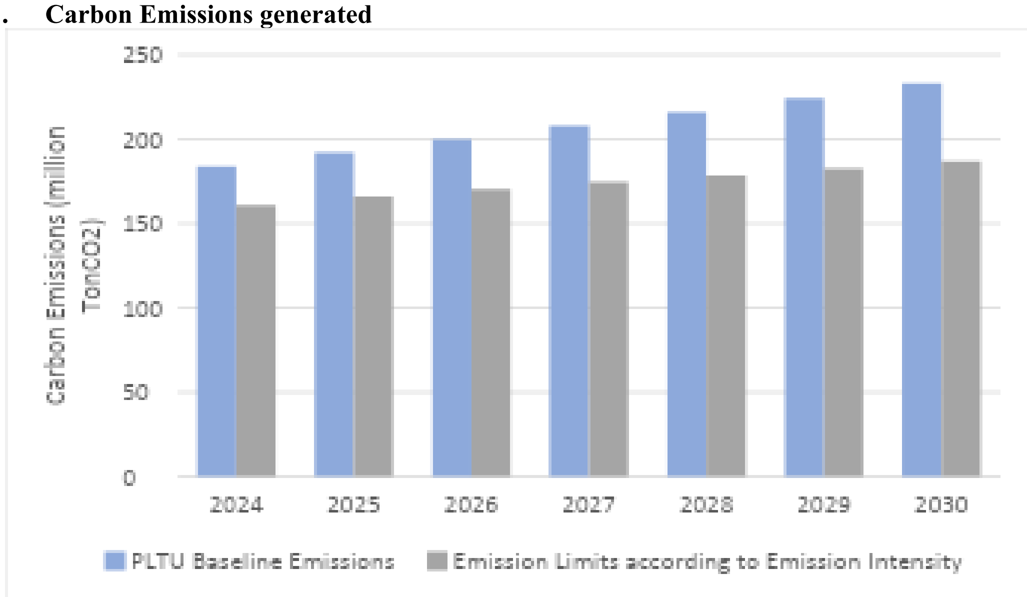


Figure 5. Carbon emission and emission limitation of power plant

Based on the target of reducing emission intensity to 0.788 tonsCO_2/MWh in 2030, the projected emission reduction each year is shown in Figure 5. The results of the model calculations carried out that PLTU emissions from 2024 to 2030 continue to increase. In 2024 with emissions of around 187 million tons of CO_2 to more than 237 million tons of CO_2 in 2030. Figure 5 illustrates the emission limits where from these limits there are emissions that must be controlled. By doing a *cap,* it can control the increase in emissions every year. In this simulation, with emissions increasing every year, the target is to reduce a larger percentage of emissions, from around 12% in 2024 to 22% in 2030. This simulation shows that current emissions in the power generation sector are still above the predetermined limit, so steps are needed to reduce carbon emissions in order to meet

Journal of Technology and Policy in Energy and Electric Power
Volume 1, Number 2, June 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v1i2/121

the emission reduction target in accordance with the ENDC commitment. In Indonesia, the *cap* framework serves as the foundation for carbon pricing in Indonesia.

2. Carbon Tax and ETS Scenario Results

The results of the calculation without carbon tax show that the emissions of the power generation sector in Jamali tend to increase with energy growth. The total carbon emissions of Jamali's power plants are projected to be around 183 million tons of CO_2 and this number rises to around 232 million tons of CO_2 by 2030. The increase of more than 25% in the 2024-2030 period occurs mainly due to the addition of fossil generation capacity to meet growing electricity demand. The emission intensity of electricity generation in Jamali in the baseline at around 0.99 tons of CO_2 per MWh without significant change until 2030, indicates no significant shift towards low-carbon energy sources in this scenario. Under the *business-as-usual* (BAU) trend, the Jamali region will continue to be the dominant emitter and reach emission levels far above the emission reduction ambition required under the 2030 national climate target framework.

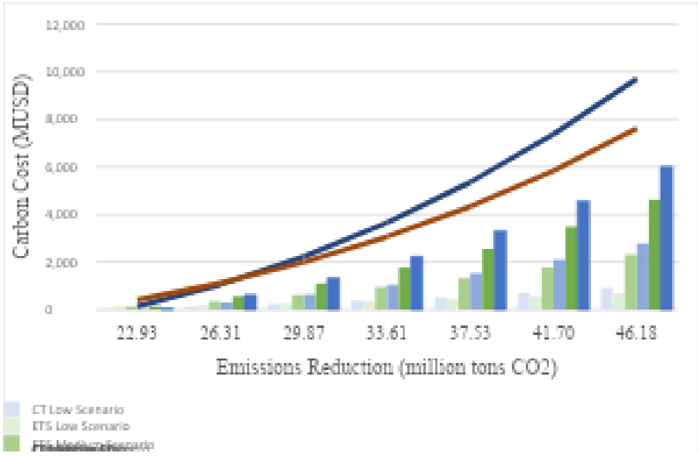


Figure 6. Carbon cost of emission reduction

Figure 6 shows the carbon price in the low, medium and high scenarios. These values show the amount of costs that the coal power generation sector will have to incur as a result of the expected emission reductions through the implementation of a progressive carbon price. The value of the carbon tax paid is calculated by multiplying the volume of carbon emissions that exceed the emission limit. In other words, the larger the emission reduction target (or the tighter the cap), and the higher the carbon price, the greater the cost to businesses.

Both the carbon tax (CT) and emissions trading system (ETS) schemes show a significant upward trend in costs over time, showing the projected carbon costs for emissions reductions from 2024 to 2030. All scenarios still have relatively low cost values in 2024 because they use the current base price, but in subsequent years, especially the CT High and ETS High scenarios, there is a large increase. This is based on all scenarios with the current CT and ETS values applied in Indonesia. The calculation simulation results show that the cost required for the low, medium, and high scenarios is only about 45 million USD in 2024. However, by 2030, the cost increases to more than 923 million USD for the low scenario, 2.9 billion USD for the medium scenario, and 6.3 billion USD for the high scenario. Despite the implementation of efficiency policies or emission intensity targets, the annual increase in emission volume caused by electricity demand growth is still dominated by coal-fired power plants. This cost spike is a direct consequence of the increase in emission volume. While the higher-tariff carbon tax scenario provides a strong price signal to encourage the transition to lower-emitting technologies, it also puts power companies under significant economic pressure, potentially resulting in higher electricity tariffs for consumers. This suggests that the higher the emissions reduction target, the greater the costs to the generation sector. The carbon tax scheme tends to generate higher costs in the *high scenario* than the ETS because it has reference to the highest price range internationally. These two schemes are relatively the same because they are currently still using the *cap* scheme before being subject to carbon tax or required to purchase carbon quotas. Previous research in China states that if the level of carbon quota is too high, then

Journal of Technology and Policy in Energy and Electric Power
Volume 1, Number 2, June 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v1i2/115

the ETS mechanism will lose more [20]. Previous research states that a carbon tax, while providing price certainty, can lead to higher economic costs than a more market and flexible ETS [20].

On the other hand, it shows that ETS systems are more responsive to market dynamics and low-carbon technologies, although the design of the carbon market cap and mechanism largely determines its success [21]. Therefore, when choosing between CT and ETS in Indonesia, it is necessary to consider the efficiency of emission reduction as well as fiscal capability and market readiness. The simulation values illustrate that policy design must balance economic efficiency and mitigation objectives. It also shows that realistic phasing of implementation is necessary to avoid overburdening the power generation sector.

The high cost of carbon pricing is thought to alter mitigation by shifting to cleaner technologies. A previous study in China using an input-output model for the Chinese economy found that the electricity generation sector recorded the largest reduction in emissions due to a carbon tax [27]. Previous research suggests that countries that implement a carbon price experience a 1-2% reduction in the growth rate of emissions compared to countries without such a policy [8].

4. **Abatement Cost**

The NZE scenario is a scenario for reducing carbon emissions to zero by 2060. This scenario is combined with setting an emissions cap in accordance with Figure 7.

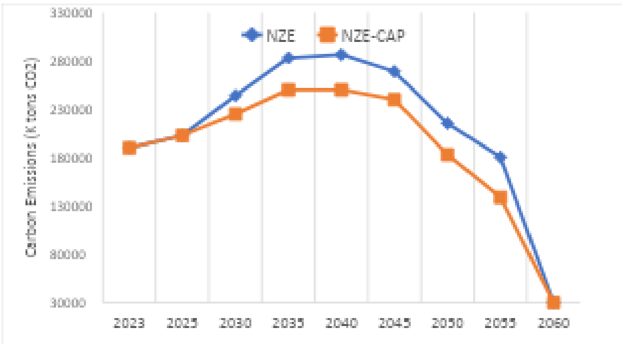


Figure 7. Simulated Carbon Emissions of NZE and NZE-CAP Scenarios

The simulations show that carbon emissions in the NZE scenario rise to a peak around 2040 before declining significantly in 2024 and again in 2060. Meanwhile, in the NZE-CAP scenario, emissions tend to be more in line with the cap. Based on the results of the TIMES simulation, the two scenarios produce different portfolios that influence the difference in the cost of producing electric energy. Production costs are similar at the beginning of the period, but starting in 2050, production costs in the NZE-CAP scenario jump more sharply than in NZE, indicating the additional costs that must be incurred to reduce emissions more aggressively. The difference in production costs each year is the basis for calculating the abatement cost, which is the additional cost required for each unit reduction in CO_2 carbon emissions in the NZE-CAP scenario compared to NZE.

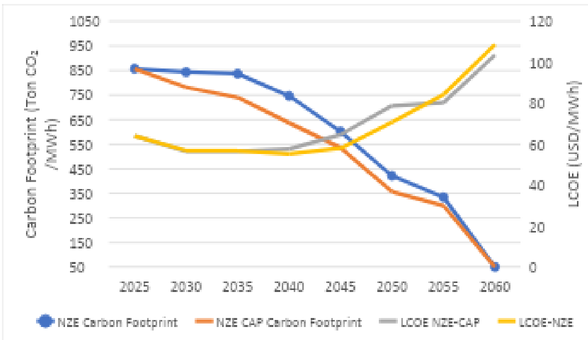


Figure 8 shows that the increasing stringency of carbon emission reduction targets, especially after 2045, is followed by a significant increase in the Levelized Cost of Electricity (LCOE). In the early stages of the

https://doi.org/10.33322/jtpeep.v1i2/121

transition, achieving emission reductions can still be achieved with relatively stable electricity costs, reflected by the LCOE value which tends to stagnate in the range of 50 USD/MWh throughout the period 2025 to 2040. However, after passing the inflection point around 2045, the steeper emission reductions are positively correlated with a spike in LCOE, which even reaches more than 100 USD/MWh in 2060.

1. CO_2Abatement Cost (USD/tonCO_2)

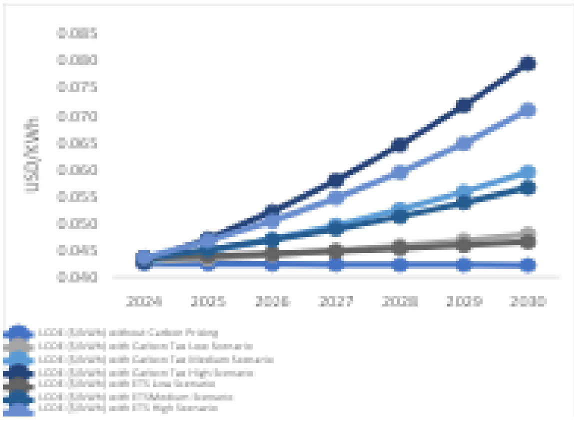
Scenario	2025	2030	2035	Average
NZE	74.74	67.42	67.93	70
NZE-CAP	74.74	72.34	76.38	74.48

The abatement cost calculation results of the two scenarios show that both scenarios have similar abatement cost values. The abatement cost in the NZE-CAP scenario is higher because the emission suppression in this scenario is higher, which affects the production cost. An increased abatement cost value indicates that further decarbonization efforts require higher costs if the emission reduction target is higher.

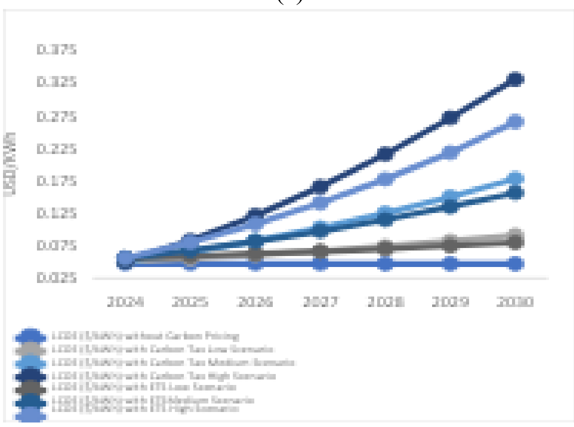
5. Increase in electricity price due to carbon cost

In the LCOE calculation, investment, operation and maintenance (O&M), fuel, and additional carbon costs are taken into account. The carbon price per scenario increases gradually from year to year according to the international carbon price on the *World Bank* carbon *pricing dashboard.*

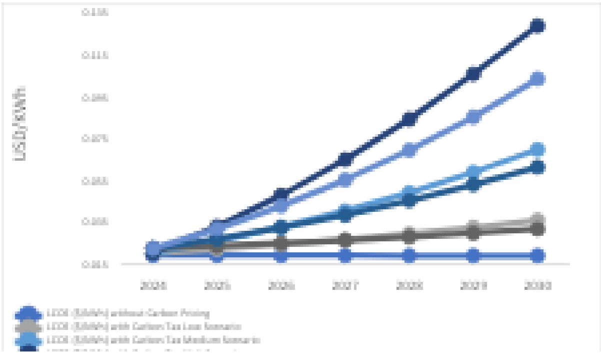
When a carbon price policy is implemented, the externality cost of emissions becomes part of the total generation cost calculation, which has direct implications for the increase in LCOE value, especially for fossil-based plants.



(a)



(b)



(c)

Figure 4.6 PLTU LCOE with Carbon Price
(a) Subcritical PLTU (b) Supercritical PLTU (c) Ultrasupercritical PLTU

Based on the simulation results in the figure, all types of power plants experience a significant increase when a carbon price is applied, either through a carbon tax or Emissions Trading System (ETS) mechanism. LCOE without a carbon price shows a relatively stable trend reflecting the projected natural increase in operational and fuel costs. Simulation results in 2030, the LCOE of Subcritical PLTU without carbon price remains below 0.06 USD/kWh. This reflects that without carbon price intervention, the cost of electricity generation from fossil technologies remains within the current economic range, even though it does not take into account the resulting environmental externalities.

In Subcritical PLTU technology, the initial LCOE without carbon is in the range of 0.044 USD/kWh. In the CT High scenario, the LCOE value increases to 0.084 USD/kWh in 2030 while for supercritical PLTU it has a very drastic increase to 0.0245 USD/kWh despite having a lower emission factor than Subcritical PLTU. When the carbon price scenario is applied, both through carbon tax and ETS, there is a significant jump in LCOE, especially in the high scenario. In the high carbon tax scenario, the LCOE of Subcritical PLTU can reach a price increase of almost 100% in 2030 from the price in 2024, which means it is more expensive than the scenario without a carbon price. This is in line with previous findings of [22] which states that the implementation of ETS in China can reduce emissions but cannot ignore the economic impact, especially for industries that produce more emissions. A more moderate increase in LCOE is seen in the ETS scenario, indicating that ETS is more flexible in incentivizing emission efficiency and can reduce the cost burden if designed with the right price allocation or flexibility [21].

4. Conclusions

This Study Has Analyzed The Comparative Impact Of Different Carbon Pricing Schemes Namely, Carbon Tax And Emissions Trading System (ETS) On Emission Reduction Costs And Electricity Generation Expenses In The Jamali Power Sector. The Results Demonstrate That, While Both Carbon Pricing Mechanisms Can Contribute To Significant Reductions In Carbon Emissions, The Associated Costs, Particularly The Marginal Abatement Cost, Increase Substantially As Emission Reduction Targets Become More Ambitious. Furthermore, The Implementation Of Carbon Pricing Is Shown To Directly Affect The Levelized Cost Of Electricity (LCOE), With The Effect Being More Pronounced For Fossil Fuel-Based Power Plants. These Findings Underscore The Critical Importance Of Designing Carbon Pricing Policies That Not Only Achieve Emission Reduction Targets, But Also Consider Economic Efficiency, Fiscal Capacity, And Market Readiness. The Insights Generated From This Analysis Provide Valuable Guidance For Policymakers In Formulating Effective, Balanced, And Sustainable Energy Transition Strategies For Indonesia's Power Sector.

REFERENCES

[1] Indonesia, "Enhanced Nationally Determined Contribution." Indonesia, 2022.

[2] "NERACA ENERGI NASIONAL 2020_1709787739."

[3] "Indonesia establishes the legal framework for a domestic emissions trading system." Accessed: May 20, 2025. [Online]. Available: https://icapcarbonaction.com/en/news/indonesia-establishes-legal-framework-domestic-emissions-trading-system#:~:text=mechanism,Bali%20electricity%20grid

[4] World Bank, *State and Trends of Carbon Pricing 2020*. Washington, DC: World Bank, 2020. doi: 10.1596/978-1-4648-1586-7.

[5] World Bank, *State and Trends of Carbon Pricing 2023*. Erscheinungsort nicht ermittelbar, 2023.

[6] International Energy Agency, *The Potential Role of Carbon Pricing in Thailand's Power Sector*. OECD, 2021. doi: 10.1787/3e6a4d8a-en.

[7] M. Li, H. Gao, A. Abdulla, R. Shan, and S. Gao, "Combined effects of carbon pricing and power market reform on CO2 emissions reduction in China's electricity sector," *Energy*, vol. 257, p. 124739, Oct. 2022, doi: 10.1016/j.energy.2022.124739.

[8] R. Best, P. J. Burke, and F. Jotzo, "Carbon Pricing Efficacy: Cross-Country Evidence," *Environ. Resour. Econ.*, vol. 77, no. 1, pp. 69–94, Sep. 2020, doi: 10.1007/s10640-020-00436-x.

[9] S. Sen and H. Vollebergh, "The effectiveness of taxing the carbon content of energy consumption," *J. Environ. Econ. Manag.*, vol. 92, pp. 74–99, Nov. 2018, doi: 10.1016/j.jeem.2018.08.017.

[10] Ministry of Finance Government of Sweden, "Sweden's carbon tax."

[11] P. Perkasa, Z. Umardi, and Z. H. Natalia, "Impact of The Increase in Fuel Cost for Jawa Madura Bali Electricity System Due to Carbon Tax Implementation Plan in 2022," in *2023 4th International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, Denpasar Bali, Indonesia: IEEE, Aug. 2023, pp. 123–126. doi: 10.1109/ICHVEPS58902.2023.10257354.

[12] M. Indra Al Irsyad, A. Halog, R. Nepal, and D. P. Koesrindartoto, "Economical and environmental impacts of decarbonisation of Indonesian power sector," *J. Environ. Manage.*, vol. 259, p. 109669, Apr. 2020, doi: 10.1016/j.jenvman.2019.109669.

[13] A. Rokhmawati, A. Sugiyono, Y. Efni, and R. Wasnury, "Quantifying social costs of coal-fired power plant generation," *Geogr. Sustain.*, vol. 4, no. 1, pp. 39–48, Mar. 2023, doi: 10.1016/j.geosus.2022.12.004.

[14] "undp-carbon-tax-in-an-evolving-carbon-economy-digital-version."

[15] I. Parry, "Proposal for an International Carbon Price Floor Among Large Emitters," *Staff Clim. Notes*, vol. 2021, no. 001, p. 1, Jun. 2021, doi: 10.5089/9781513583204.066.

[16] Vereinte Nationen, Ed., *United Nations handbook on carbon taxation for developing countries*. New York: United Nations, 2021.

[17] K. Athanasiou, "Indonesian Technology Catalogue 2024".

[18] F. A. Kamandika and S. Dhakal, "Impact of carbon price on Indonesia's power sector up to 2050," *Carbon Neutrality*, vol. 2, no. 1, p. 27, Sep. 2023, doi: 10.1007/s43979-023-00066-4.

[19] Institute for Essential Services Reform (IESR), "Indonesia Energy Transition Outlook 2023." Institute for Essential Services Reform (IESR), 2022.

[20] X. Hu, Z. Yang, J. Sun, and Y. Zhang, "Carbon tax or cap-and-trade: Which is more viable for Chinese remanufacturing industry?," *J. Clean. Prod.*, vol. 243, p. 118606, Jan. 2020, doi: 10.1016/j.jclepro.2019.118606.

[21] R. Rafaty, G. Dolphin, and F. Pretis, "Carbon Pricing and the Elasticity of CO2 Emissions".

[22] B. Lin and Z. Jia, "Impacts of carbon price level in carbon emission trading market," *Appl. Energy*, vol. 239, pp. 157–170, Apr. 2019, doi: 10.1016/j.apenergy.2019.01.194.

[23] "IRENA_Renewable_power_generation_costs_in_2023.pdf."

[24] International Energy Agency, "Net Zero by 2050 - A Roadmap for the Global Energy Sector".

[25] F. Kesicki and P. Ekins, "Marginal abatement cost curves: a call for caution," *Clim. Policy*, vol. 12, no. 2, pp. 219–236, Mar. 2012, doi: 10.1080/14693062.2011.582347.

[26] A. Vogt-Schilb and S. Hallegatte, "Marginal abatement cost curves and the optimal timing of mitigation measures," *Energy Policy*, vol. 66, pp. 645–653, Mar. 2014, doi: 10.1016/j.enpol.2013.11.045.

[27] A. Zhao *et al.*, "Effects of Carbon Tax on Urban Carbon Emission Reduction: Evidence in China Environmental Governance," *Int. J. Environ. Res. Public. Health*, vol. 20, no. 3, p. 2289, Jan. 2023, doi: 10.3390/ijerph20032289.