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The Role of Carbon Pricing in Accelerating Energy Transition: A Case Study of Indonesia's Industrial Processes and Product Use (IPPU) Sector

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Abstract

Carbon pricing serves as an effective economic instrument to mitigate greenhouse gas emissions while fostering investment in renewable energy by reducing dependence on fossil fuels. This study examines the development of carbon pricing policies to accelerate the energy transition, focusing on the Industrial Processes and Product Use (IPPU) sector. The proposed scheme is based on the Emissions Trading Scheme (ETS), tailored to local regulations and industrial capacities. This research employs a systematic review and content analysis of successfully implemented carbon pricing policies in various countries. While carbon pricing has been applied in the energy and forestry sectors, existing studies often lack specificity regarding emission thresholds or quantified carbon values across different emission sources. The IPPU sector, despite being a significant emitter, remains underrepresented in current policy design and academic literature. The findings indicate that carbon commercialisation supports renewable energy transition projects and increases investment in the electricity sector. This study proposes a carbon credit scheme tailored to the Indonesian wood industry (referred to as Industry X), which has begun integrating biomass and bioenergy to compensate for fossil-based emissions. The novelty of this study lies in its targeted focus on the IPPU sector and the practical application of a carbon pricing framework for industrial decarbonisation. The results suggest that integrating carbon pricing with fiscal incentives and energy regulations enhances industrial competitiveness in transitioning to clean energy. This study provides policy recommendations to improve carbon pricing mechanisms, supporting renewable energy investment and sustainable industrial transformation.

Keywords:
carbon pricing, emissions trading scheme, energy transition, industrial competitiveness, renewable energy investment

1. Introduction

Energy transition is a critical strategy in reducing greenhouse gas (GHG) emissions, particularly from the energy sector, which remains the primary contributor to global emissions. More than just a shift from fossil fuels to renewable energy, this transition involves comprehensive changes in policy, infrastructure, and energy consumption patterns (Alwaaritsy & Romadan, 2025). However, transition efforts require strict regulatory support and a shift toward clean electricity sources to avoid offsetting emissions gains. Therefore, energy transition serves as a fundamental pillar in achieving both national and global emission reduction targets (Nam & Jin, 2021). Moreover, energy transition is not just about swapping fossil fuels for renewables; it’s a much broader shift that requires changes in how we shape policies, build infrastructure, and use energy in our daily lives. Research consistently points to energy efficiency as one of the most impactful ways to address climate change. At the same time, simply electrifying our systems isn't enough; we need to ensure that the electricity itself comes from cleaner sources. In this sense, the energy transition isn't just one option among many; it's the foundation for achieving meaningful emission reductions, both at home and on a global scale (Xu & Yang, 2024).

One of the most widely recognised policy instruments to facilitate environmental investments in the energy transition is carbon pricing (Onabowale, 2025). Research by Xu & Yang (2024) found that carbon pricing, whether implemented through a carbon tax or emissions trading schemes, is a strategic tool that has been proven to be effective in lowering carbon emissions and accelerating the transition toward clean energy (Simpa et al., 2024). Its effectiveness has been empirically demonstrated. Carbon trading has been shown to increase renewable energy generation by up to 73.32%, while carbon taxes have driven increases of 31.79%. The strengths of carbon pricing are its flexibility, economic efficiency, and potential to generate government revenues that can be reinvested into clean energy infrastructure and social equity programs. Carbon pricing serves as a powerful market signal and serves as a bridge between climate ambitions and the realities of the global economy. Globally, carbon pricing has become an increasingly reliable policy instrument to effectively and efficiently reduce GHG emissions. By 2024, carbon-based policies had reached more than 70 mechanisms, either through carbon taxes or emissions trading systems (ETS) (Pan et al., 2024). Leading adopters include the European Union with its progressive EU ETS (Dominioni & Petit, 2025), as well as countries like Sweden, Canada, and Singapore, which have introduced high-rate carbon taxes. In Indonesia, carbon pricing was initiated through Presidential Regulation No. 98 of 2021 on Carbon Economic Value, followed by the launch of carbon trading in the coal-fired power sector in 2023. In addition to emissions trading, the 2021 Law on Harmonisation of Tax Regulations outlines a phased plan for carbon tax implementation. These measures are intended to push high-emitting industries to internalise the external costs of their carbon emissions and support the achievement of Net Zero Emissions (NZE) by 2060. The Indonesian government has prioritised five key sectors for carbon trading: energy, forestry, agriculture, waste, and industrial processes and product use (IPPU).

PWC (2023) discusses the key concepts in carbon pricing implementation as seen in Figure 1. Carbon pricing in Indonesia has been realised by energy (power generation) and forestry (KLHK, 2023). The implementation of the IPPU sector within the carbon trading framework still faces challenges, particularly due to the absence of standardised regulations and methodologies for determining carbon pricing. Among IPPU sub-sectors, the wood industry stands out as a compelling case for study. While its production processes contribute to GHG through the use of non-renewable energy, wood products themselves act as environmentally friendly materials with carbon capture and storage capabilities during their tree phase, thus offering dual roles as both polluters and carbon reducers. Transitioning to renewable energy sources in this sector presents a promising opportunity to gain carbon credits through carbon trading schemes.

Given the limited research on carbon pricing within the IPPU sector in Indonesia, with the lack of a specific policy, this study proposes a formula for calculating the commercial value of carbon, adapting existing global carbon pricing methodologies. This formula serves as a quantitative framework for evaluating the potential implementation of carbon pricing in Indonesia's industrial sector. Employing a combined approach of systematic review and field-based case studies, the research addresses how carbon pricing mechanisms can be effectively contextualised and integrated into national industrial policy to accelerate sustainable energy transitions. This study also analyses the development and effectiveness of carbon pricing policies in multiple countries, offering a comparative foundation for domestic application. Based on empirical findings, the study estimates the potential financing scale for energy transition initiatives that could be mobilised through carbon pricing instruments. Theoretically, it contributes to the conceptual discourse on carbon pricing in developing countries and provides empirical insight into its application within the industrial sector. Practically, it offers numerical evidence on how carbon pricing could unlock internal financing opportunities for industrial actors. From a policy standpoint, it presents tailored recommendations for designing adaptive and locally relevant carbon pricing strategies.

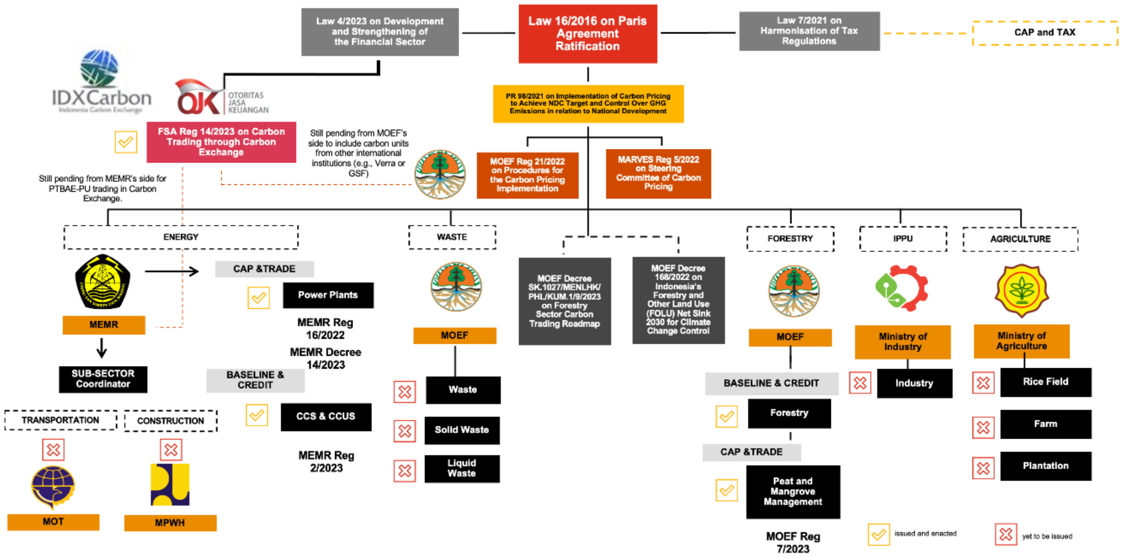

Figure 1. Carbon pricing regulatory framework in Indonesia (PWC, 2023).

2. Methods and Materials

2.1 Research Design

This study adopts a mixed methods approach to explore the potential application of carbon pricing schemes within the wood industry as part of a broader sustainable energy transition strategy. Primary data were collected through field research at a wood-processing company, focusing on the potential for certified carbon credits from ongoing eco-friendly projects. Meanwhile, secondary data were gathered through a systematic literature review, identifying previous studies that specifically examined the effectiveness and challenges of carbon pricing in industrial sectors (Carrera-Rivera et al., 2022). The reviewed literature included theoretical frameworks, policy discussions, and empirical findings, which were used to strengthen the analytical foundation and build evidence-based arguments (Sugiyono, 2019). The insights gained were then analysed to construct the conceptual framework that underpins the empirical evaluation and simulation scenarios in this study.

2.2 Systematic Review

A systematic review is a structured way used by experts to locate, appraise, and summarise evidence from studies to answer specific questions and support practice or policy (Munn et al., 2018). The literature search utilised the Semantic Scholar database to compile reputable academic studies useful for policy framework formulation and identifying best practices from various countries. Additionally, the method helped to collect historical carbon pricing data, serving as the analytical foundation for simulations used in this research. The systematic approach is illustrated in the following diagram.

Figure 2 shows the flow of the systematic review process in selecting relevant articles related to the topic of carbon pricing to support the transition. The process started at the identification stage, where a total of 582 articles were obtained from searching the Semantic Scholar database with the specified search string. No additional articles from other sources were found. The search was conducted to collect data from the last five years until 10 May 2025. After analysing the full text papers, 17 full text articles were included in the study for further analysis. This process reflects the rigorous stages of conducting a transparent and structured systematic literature review.

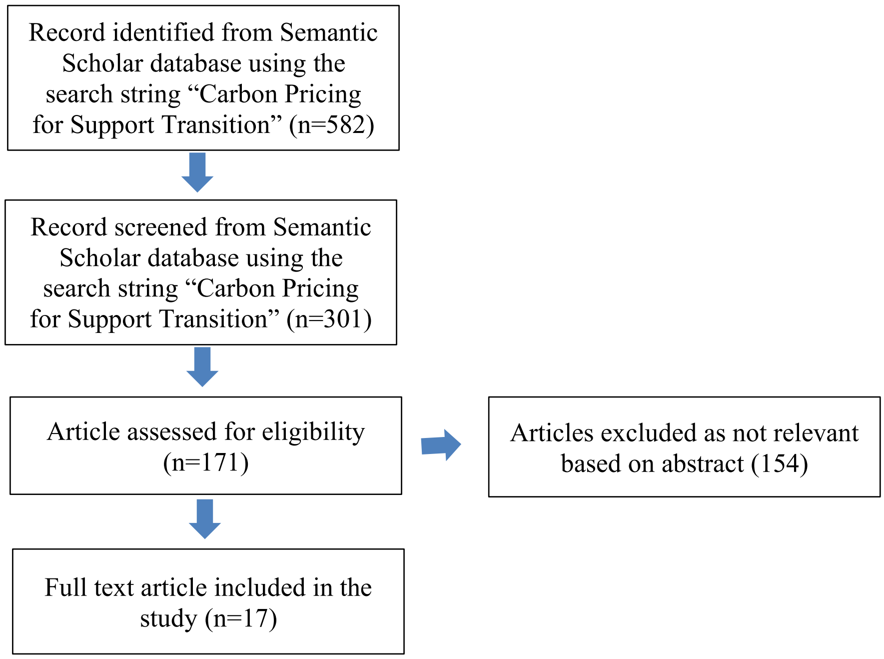

Figure 2. PRISMA diagram of a systematic review of research.

2.3 Case Study

This case study was conducted at a wood manufacturing company that processes timber into semi-finished materials. The company has implemented sustainability practices aligned with the triple bottom line framework. Field data collected reflects both its production capacity and its contribution to low-carbon development. Interestingly, although the production process emits greenhouse gases, the company also has the potential to earn certified carbon credits, given the role of its wood products in carbon locking and its adoption of clean energy practices—such as using biomass and converting waste into wood pellets for bioenergy. This case study aims to evaluate how well the company is prepared to face carbon pricing regulations and whether the resulting financial incentives could support further clean energy initiatives, especially as the facility still relies on fossil fuels to operate heavy equipment. By estimating the emissions that have been reduced through biomass substitution and the implementation of the zero-waste principle, the company can calculate the potential value of carbon credits based on carbon price scenarios that apply nationally and internationally. Income from carbon trading can be allocated to renewable energy projects, particularly towards the construction of solar panels in industrial areas.

3. Results and Discussions

3.1. The Urgency of Carbon Pricing and Its Development in Supporting the Global Energy Transition

Transitioning our energy systems plays a vital role in tackling the growing challenge of GHG emissions, especially since the energy sector continues to be the largest source of these emissions worldwide. However, energy transition is not just about swapping fossil fuels for renewables; it is a much broader shift that requires changes in how we shape policies, build infrastructure, and use energy in our daily lives. Research consistently points to energy efficiency as one of the most impactful ways to address climate change. Nevertheless, without firm and consistent regulations to guide the process, even the best-intentioned energy policies may fall short. At the same time, simply electrifying our systems is not enough; we need to ensure that the electricity itself comes from cleaner sources. In this sense, the energy transition is not just one option among many; it is the foundation for achieving meaningful emission reductions, both at home and on a global scale (Yang & Li, 2024).

Carbon pricing is a mechanism for imposing a monetary cost on carbon emissions, which is done through two main approaches: carbon taxation and ETS (Thisted & Thisted, 2020).The main objective of these policies is to internalize the external costs of GHG, such as environmental damage and climate change impacts (Digitemie & Ekemezie, 2024). By putting a price on carbon emissions, carbon pricing provides an economic incentive for businesses and communities to reduce their carbon footprint. This policy not only encourages greener behaviour but also helps accelerate the transition to a low-carbon economy, where economic development goes hand in hand with climate crisis mitigation efforts (Rosenbloom et al., 2020).

The position of carbon pricing is increasingly urgent as a global climate strategy. In enterprise-level energy transition management, carbon pricing is one of the most important emerging strategies. The effectiveness of carbon pricing depends not only on the size of the internal carbon tariff but also on the strategic design involving internal incentives and reinvestment.

Internal incentives for carbon pricing refer to voluntary mechanisms used by companies to put an economic value (price) on the carbon emissions they produce in business operations. This is implemented by creating a synthetic comparison model of similar companies that did not adopt the policy, in order to measure the effectiveness of the policy in reducing carbon emissions, and to establish statistical correlation (Qin et al., 2023). Reinvestment is a policy that reallocates these revenues to low-carbon projects such as energy efficiency, green infrastructure, and green research and development (Wilkowska et al., 2024).

Integrating secondary investment and internal profit sharing can yield the best performance in terms of emission reductions, goodwill accumulation, and long-term systemic profits. Systemic profit generation involves structural adjustments to the economy and industrial sector in response to carbon pricing or other climate policies (such as carbon taxes, cap-and-trade, or emissions standards), with the aim of lowering carbon intensity and transforming production structures towards lower emissions (Berthe et al., 2023). The findings confirm that the success of carbon pricing is strongly influenced by active organizational engagement, integration into corporate sustainability strategies, and adaptability to market dynamics and short-term decision-making psychology. Thus, carbon pricing serves not only as an emissions accounting tool, but also as a strategic management instrument that strengthens organizational synergies and corporate resilience to climate change risks (Yanfei et al., 2023).

Studies have shown that when designed well, carbon pricing can significantly reduce emissions. For example, in British Columbia, a carbon tax is imposed on the consumption and purchase of fossil fuels, with a tax rate set at USD50 per ton (Liu, 2023). The resulting tax varies depending on the type of fuel used. This policy reduced per capita fuel consumption by 16 %. Across the covered sectors, emission reductions can reach 2–4 % per year (Adu & Denkyirah, 2024). In addition, carbon pricing encourages innovation and investment in clean technologies and accelerates the energy transition to more sustainable sources. While economic interventions through green investments and policies can have a tangible impact on emissions reductions, they require time and predictive policy planning (Kwilinski et al., 2024).

The European Union demonstrates that a jump in carbon prices across sectors can significantly reduce emissions. However, it also risks lowering Gross Domestic Product (GDP) due to rising energy costs and the potential for "carbon leakage" (the transfer of emissions to countries with less regulation). These findings suggest that investment in renewable energy has a critical role to play in mitigating the negative impacts of carbon pricing policies. In a scenario involving renewable energy investments, the decline in GDP is reduced by only 0.4 %, while emissions are reduced by 24 %. In contrast, if these investments are not considered, the economic impact of carbon pricing becomes more pessimistic. In addition, the implementation of a carbon border adjustment mechanism (CBAM) has proven effective in reducing carbon leakage. However, it may add inflationary pressures and slightly reduce economic growth due to increased industrial import costs. The CBAM mechanism findings strengthen the argument that carbon pricing policy needs to be accompanied by investment support and trade policy safeguards to ensure that the energy transition does not add excessive economic burden (Delgado-Téllez et al., 2025).

In this context, carbon pricing mechanisms can accelerate the energy transition, especially when combined with green bonds instruments as an effective financing tool to support renewable energy projects and climate change mitigation, by offering economic incentives for the public and private sectors. With carbon pricing, either in the form of carbon taxes or fiscal incentives, investments in green bonds are directed towards projects that directly reduce carbon dioxide (CO_2) emissions. Countries with good governance and strict emissions policies tend to be more successful in leveraging green bonds to support the energy transition.

For policymakers and investors, a good carbon pricing policy can provide clear incentives to invest in clean energy (Shu et al., 2017). On the other hand, if such policies are not carefully designed, they can exacerbate negative economic impacts and influence investment decisions less efficiently. This research reveals that carbon risk has become a determining factor in investment decision-making, with carbon pricing policies playing a central role. A carbon price, whether in the form of a carbon tax or an emissions trading system, provides a strong signal against sectors that have a high exposure to carbon emissions, encouraging investors to shift to more environmentally friendly sectors, such as renewable energy. At the same time, the application of carbon risk management strategies through tools such as carbon footprint analysis and carbon value-at-risk allows investors to more accurately assess potential losses due to climate policies. The empirical case shows that investments in green energy and low-carbon technologies are increasingly becoming the top choices in investors' portfolios, reflecting a sea change in the investment universe towards the energy transition (Hu, 2024).

In the BRICS (Brazil, Russia, India, China, South Africa) countries, there is a strong link between Foreign Direct Investment (FDI), technological innovation, and increased use of renewable energy in efforts to reduce carbon emissions. FDI has the potential to make a positive contribution to the energy transition, especially if focused on sectors that support environmental sustainability (Rehan et al., 2025). However, the high ecological footprint indicates that natural resource management is still not optimal and faces major challenges. Therefore, energy transition policies need to be complemented by strategies that encourage innovation, expand the application of clean energy, and more strictly regulate resource-intensive sectors such as mining to align with decarbonization targets. In the global south, especially BRICS, targeted FDI through appropriate policies can accelerate the transition to a low-carbon economy without hampering growth (Hieu & Hai, 2023). However, the trade-off between economic expansion and sustainability remains real, reflected in the increasing ecological footprint, which calls for a more circular approach to development. Overall, the success of the energy transition depends on synergies between carbon pricing policies, renewable energy incentives, CBAM mechanisms, and green investments, with coordination across sectors and countries and increased public awareness to mitigate political resistance and uneven social impacts.

The interrelationship between green innovations, environmental taxes, renewable energy consumption, and economic growth plays a complex role in influencing environmental quality, particularly CO_2 emissions in OECD countries. The adoption of green innovations, as well as increased renewable energy consumption, contributes significantly to reducing CO_2 emissions. Policy interventions are needed that not only promote economic growth but also steer it toward a more sustainable path through the implementation of carbon taxes, strengthening the green innovation ecosystem, and accelerating the clean energy transition. Climate change mitigation efforts cannot rely on one approach alone, but must combine fiscal instruments, technology policies, and energy system transformation in an integrated manner (Kafeel et al., 2024). The results of the search for the development of carbon pricing are summarised in Table 1.

Table 1. Systematic review: carbon pricing to support energy transition

Author	Scopes	Objective	Key Findings	Policy Implications
Best & Burke (2020)	Global / OECD and non-OECD countries	Assess the effectiveness of carbon pricing policies in changing national energy mixes and encouraging the transition to renewable energy.	• Carbon pricing contributes to a reduction in coal usage by up to 3%. • It encourages a measurable increase in the share of renewable energy sources, including biomass, waste, wind, and solar. • Although national energy mixes exhibit decadal inertia, significant shifts are achievable with appropriately calibrated carbon price signals.	• Reinforces the strategic role of carbon pricing in industrial sector decarbonisation and energy efficiency improvements. • Highlights the relevance of exploring carbon pricing mechanisms within the wood industry as part of broader energy transition strategies.
Vormedal et al. (2020)	Global (Major Oil Companies)	Investigate the motivations and economic interests driving major oil companies' support for carbon pricing policies, and assess their implications for the energy transition.	Major oil companies tend to support moderate carbon pricing schemes, primarily due to their economic interest in expanding natural gas operations.	• Suggests that energy companies may leverage carbon pricing to reinforce their market dominance while aligning with energy transition goals. • Supports integrating market economy dynamics into broader carbon pricing and energy transition frameworks.
Koh et al. (2021)	Developing countries	Analyse the impact and benefits of carbon pricing in facilitating the energy transition in developing countries.	Carbon pricing mechanisms generate fiscal revenue that can be channelled into clean energy projects.	• Demonstrates how carbon pricing can create fiscal space for investment in renewable energy infrastructure. • Supports the integration of climate policy with economic resilience strategies in developing countries..
Wolfram et al. (2021)	United States – light-duty vehicle sector	Examine the influence of carbon pricing-particularly on indirect emissions-on the adoption of electric vehicles (EVs) and the energy transition in the vehicle sector.	EV adoption leads to a direct reduction in tailpipe emissions.	Demonstrates how comprehensive carbon pricing frameworks can accelerate the decarbonisation of the transport sector.
Foggia & Beccarello (2022)	Global / Europe, the Americas, Asia	Assess the efficiency and synergy between mandatory ETS and voluntary white certificate schemes (WhC) in promoting energy efficiency and reducing GHG.	• The integration of ETS and WCP enhances the flexibility and overall effectiveness of energy efficiency policies. • The economic value of these interventions is highly sensitive to fluctuations in gas markets and carbon prices. • Under certain market conditions, White	• Highlights the importance of synergising mandatory and voluntary market-based instruments in the energy and industrial sectors. • Suggests that flexible policy frameworks can be tailored to sector-specific contexts, such as

			Certificates may offer greater value than ETS. • Combined implementation strengthens corporate energy management and decarbonisation strategies.	the wood-based veneer industry, especially in volatile carbon and energy markets.
Wang et al. (2022)	Global, with a focus on China	Analyse the design of renewable energy policies with imperfect carbon pricing condition, particularly within ETS.	Feed-in-Tariffs (FITs) are more effective in reducing emissions but less effective in stimulating renewable energy production compared to Renewable Portfolio Standards (RPS).	• Highlights the need for integrated policy design that aligns renewable energy incentives with carbon pricing frameworks. • Suggests that policy effectiveness should be evaluated not only in terms of emissions reduction but also in terms of energy production and socio-economic welfare.
Ding (2022)	Japan	Examine the impact of rising fossil fuel prices on household living costs in Europe, and provide policy recommendations addressing the energy crisis and energy transition.	Significant regional disparities in Carbon Pricing Transfer Rate (CPTR) across Japan affect electricity pricing.	• Highlights how carbon pricing mechanisms can shape energy sector dynamics and influence the pace of clean energy transition. • Underscores the need for fair and efficient policy adjustments, particularly in countries pursuing net-zero targets.
Ari et al. (2022)	Europe	Assess the impact of rising fossil fuel prices on household living costs and provide policy recommendations in the context of the energy crisis and transition.	Surging fossil fuel prices in 2022 are estimated to raise household living costs by approximately 7%.	• Highlights the critical role of carbon pricing in supporting the energy transition and achieving emissions reduction targets. • Emphasises the need for policies that mitigate the social impact of high energy prices while maintaining momentum toward decarbonisation. • Stresses the importance of balancing energy security with long-term sustainability goals.
Barbier, (2023)	G7 countries	Analyse how carbon pricing can support the energy transition within the framework of G7 international policy.	Advocates for the elimination of fossil fuel subsidies to ensure energy prices reflect their true external costs.	• Highlights the strategic link between carbon pricing, global climate diplomacy, and energy transition efforts. • Provides insight into internationally coordinated policy approaches to accelerate clean energy development.

Putri et al. (2024)	Global / Countries in Europe, the Americas, and Asia	Evaluate the role of carbon taxes in advancing a low-carbon economy and supporting the development of a green fiscal system.	• Carbon taxes effectively reduce CO_2 emissions by sending price signals that influence energy consumption and production behaviour. • Applied across multiple sectors: industrial, energy, household and transportation. • Delivers a double dividend: emissions reduction and increased state revenues. • Calls for an integrated global system to ensure policy uniformity and fairness. • Promote social inclusiveness and resource efficiency.	• Serves as an alternative or complementary policy framework to market-based mechanisms such as the ETS. • Highlights the importance of incorporating pricing instruments into mitigation strategies for sectors like the veneer industry. • Support alignment with broader energy transformation and environmental fiscal policies, particularly in the forestry and manufacturing.
Ranteala et al. (2024)	Global / multi-country literature review	Analyse the effectiveness of carbon pricing policies-carbon tax and ETS-in fostering a comprehensive low-carbon economy.	• Carbon pricing internalises the external costs of CO_2 emissions, incentivising shifts in consumption and production behaviour. • While it may increase product prices, it also accelerates resource efficiency and innovation in environmentally friendly technologies. • Integration with other mitigation strategies is essential to maximise impact and avoid political resistance. • Regular evaluation is necessary to ensure policy effectiveness and support a just transition. • Carbon taxes and ETS are recognised as cornerstone instruments in global climate policy.	• Offers a conceptual and strategic foundation for developing carbon pricing mechanisms in the industrial sector, including veneer production. • Can inform the design of fair and comprehensive policy interventions that align with technological innovation and energy efficiency goals in the forestry sector.
Gangoda wilage (2024)	Indonesia (industrial case study)	Analyse the economic impact and industrial adaptation strategies in response to carbon tax policies in Indonesia.	• Carbon tax presents a significant burden for SMEs, whereas large companies demonstrate greater adaptive capacity. • Common adaptation strategies include energy efficiency improvements, diversification of energy sources, and policy advocacy. • The government needs to implement progressive tariff structures, innovation incentives, and regulatory support to foster proactive	• Highlights the necessity of integrating fiscal policy with innovation support to ensure the effectiveness of carbon pricing within energy transition strategies. • Stresses the importance of fair, adaptive policy design to maintain industrial sustainability and encourage inclusive transformation.

			participation rather than passive compliance.	
Okedele et al. (2024)	Cross-country analysis - major economies (Canada, the EU)	Evaluate the effectiveness of diverse carbon pricing schemes in reducing global emissions.	High carbon prices are empirically linked to significant reductions in CO_2 emissions,	Supports the development of adaptive and integrative carbon pricing policies tailored to national contexts.
Wei et al. (2024)	Simulation model--carbon trading scheme context	Analyse how three actors (power plants, high energy-consuming companies, consumers) adapt to carbon pricing policy and social dynamics	Large emissions quotas reduce motivation for transition.	Emphasises the importance of integrating behavioural and social dimensions into carbon pricing frameworks.
Hughes & Landry (2024)	Canada	Examine public responses and resistance to Canada's carbon pricing system, and analyse its socio-economic impact across provinces.	Canada's carbon pricing system combines carbon fees with revenue returns.	Highlights the importance of addressing economic and social inequality in carbon pricing implementation.
Nurhayati et al. (2024)	Indonesia, Sweden, Finland	Analyse Indonesia's carbon tax policy in supporting emission reduction and energy transition goals, and compare it with established frameworks in Sweden and Finland.	Indonesia is committed to achieving NZE by 2060 and introduced a carbon tax on coal-fired power plants starting in 2022.	Lessons from Sweden and Finland underscore the importance of long-term consistency, public trust, and reinvestment of tax revenues into clean energy and social equity programmes.
Samosir et al. (2025)	Indonesia - Coal-fired power plant sector	Assess the effectiveness of carbon pricing in shifting the national energy mix and encouraging renewable energy adoption.	• Carbon pricing has led to a measurable reduction in coal consumption (up to 3%) and a corresponding increase in renewables (biomass, waste, wind, solar). • The national energy mix exhibits strong inertia due to historical and infrastructural factors, but targeted carbon price incentives can catalyse meaningful change.	• Demonstrates the strategic role of carbon pricing in influencing industrial behaviour and accelerating the energy transition. • Suggests potential for applying carbon pricing to the wood industry and other resource-based sectors as part of a broader transition strategy.

Various studies show that carbon pricing policies such as carbon taxes and ETS consistently contribute to supporting the energy transition towards a cleaner and lower-emission system. These policies encourage a reduction in coal use (Best & Burke, 2020; Samosir et al., 2025), fund clean energy projects in developing countries (Koh et al., 2021), and accelerate the adoption of electric vehicles in the transport sector (Wolfram et al., 2021). The effectiveness of such policies increases when combined with other instruments, such as feed-in tariffs, renewable portfolio standards, and energy certificate schemes (Foggia & Beccarello, 2022; Song et al., 2022). In the context of developed countries and the G7, the elimination of fossil fuel subsidies is a strategic step towards ensuring that energy prices reflect external costs (Barbier, 2023). Meanwhile, studies in Japan and Europe highlight the challenges of distributing the economic burden to households due to rising energy prices (Ari et al., 2022; Ding, 2022).

In addition, from the perspective of industry and socio-political actors, responses to carbon pricing policies vary. Large oil companies support moderate policies in order to strengthen natural gas expansion (Vormedal et al., 2020). Meanwhile, industry players in Indonesia are adapting through energy efficiency, diversification, and policy advocacy (Gangodawilage, 2024; Nurhayati et al., 2024). Global literature also show that high carbon prices are effective in reducing emissions and encouraging environmentally friendly innovation (Putri et al., 2024; Ranteala et al., 2024; Okedele et al., 2024). However, the long-term success of such policies depends heavily on fair design, support for innovation, and integration with energy transition strategies and sustainable fiscal policies.

Determining the appropriate carbon price level to reduce emissions is based on existing global standards to ensure the overall effectiveness of climate policies and prevent carbon leakage. Broadly speaking, there are two types of EU ETS carbon pricing instruments: cap-and-trade and carbon taxes. Based on research conducted by Okedele et al. (2024) referencing the World Bank Group database, the recommended carbon price is USD158.8, with an average of USD20–80. Meanwhile, according to the carbon market range applied by the International Carbon Action Partnership, the carbon price should be GBP 100.34, with an average of GBP 57.24 per tonne of CO_2.

In Indonesia, the strategic role of carbon pricing in encouraging the clean energy transition has been applied to geothermal power plant project investments. Heryan & Sudrajad (2024) examined the impact of implementing a carbon trading scheme on the financial performance indicators of a 110 MW geothermal power plant project. The results show that the scheme increases the net present value of the project by 13.58%, shortens the payback period from 8.37 to 7.67 years, and raises the modified internal rate of return by 0.31%. Heryan & Sudrajad (2024) provided empirical evidence that carbon market-based policy instruments are not only effective in reducing GHG emissions, but also in improving the economic viability of renewable energy projects. Carbon pricing has become a key instrument in internalising the external costs of GHG emissions into economic decisions. It has been implemented by various countries to achieve global climate targets.

3.2. Case Study IPPU: Industry X

Industry X is a wood processing company that is not only productivity-oriented but has also integrated environmentally friendly approaches into its operations. Industry X has adopted several technologies and production practices that support sustainability principles. One concrete step is the use of biomass as fuel for the boiler, which is used to generate heat energy in the wood drying process. The use of biomass replaces dependence on fossil fuels and reduces carbon emissions. In addition, the company has developed a wood pellet-based bioenergy unit, which is not only an internal alternative energy source but also has potential as a renewable energy commodity in the market. Furthermore, Industry X has implemented the principle of net zero waste, which is a production process that uses all wood waste as fuel or additional raw materials, so that no waste is discharged into the environment.

With this approach, Industry X has the potential to earn carbon credits, as it successfully reduces emissions from production activities and the use of fossil fuels, especially in the operation of heavy equipment and drying systems. Industry X's potential contribution to emission reduction opens up great opportunities within carbon trading schemes. The industrial area where Industry X operates has high sunlight intensity, so it has great potential to be developed as an alternative source of electrical energy. Energy from these solar panels can be used for the operation of production machinery, thus reducing dependence on electricity from the conventional grid, which is still largely based on fossil energy. These two approaches help Industry X understand its potential contribution to emissions reductions and the economic opportunities to support energy transition projects that can be obtained through carbon trading mechanisms. In addition, the scheme can also serve as a strategic basis for future sustainability reporting and green investment planning.

To measure the carbon credit potential of Industry X, we formulated a mathematical calculation scenario based on operational field data and a thorough review of scientific literature, as no standard formula is currently available, meaning carbon credits must be tailored to each specific industry. Although grounded in empirical data, this scenario has limitations, as it assumes a constant emission factor. It serves as a strategic estimation tool that will require adjustments as technology and regulations evolve. To assess its carbon credit potential, the following two calculation schemes were applied.

3.2.1 Scheme 1: Carbon Offset from Total Production Allocation

The first scheme focuses on calculating total carbon units based on the percentage of production output allocated to three product categories: wood products (60%), bioenergy (25%), and biomass (15%). The calculation starts by summing the total available wood stock from the previous year with the amount of wood used during the current year and then subtracting the remaining stock at the end of 2023 (see Table 2). From this data, we obtained an estimate of the volume of wood production in cubic meters (m^3), which was then converted into tons of CO_2 emissions offset through environmentally friendly production management (see Tables 3, 4, and 5). This scheme emphasizes the full utilisation of production outputs, if all contribute to carbon offset.

Table 2. Wood productivity data during 2023.

Material (Timber)	Product A (Veneer) in m^3	Product B (Plywood) in m^3	Product C (Wood working) in m^3	Total in m^3
Stock 2022	382.74	3,643.86	2,865.43	6,892.03
Log usage	16,938.00	39,978.25	18,439.77	75,356.02
Stock 2023	825.96	4,747.86	4,670.65	10,244.47
Total				72,003.58

Table 3. Carbon offset project (CO_2 tonnes) based on wood productivity.

Parameter	Formula	Wood Product	Bioenergy	Biomass
Material (%)	-	60%	25%	15%
Volume (m^3)	% × wood product 2023	43,202.15	18,000.89	10,800.54
Density (ρ) (kg/m^3)	-	400.00	640.00	640.00
Mass (m) (tonnes)	V × ρ	17,280.86	11,520.57	6,912.34
Conversion factor (tCO_2/ tonnes of mass)	-	0.50	0.0726	0.0618
Emissions (tCO_2)	m × Conversion Factor	8,640.43	836.60	427.30

Table 4. Industry's carbon footprint measurement.

Emission mass (tCO_2e)	759.03
Emission reduction	2.5%

Table 5. The value of carbon credits for first scheme.

Carbon Mass (tCO_2e)	Formula	Value	Notes
Emission reduction target (tCO_2)	Emission × 2.5%	18.98	The company has a CO_2e deficit of 18.98 tCO2e
Industry's carbon cap	tCO_2e - emission reduction target	740.05	Emissions > carbon cap → deficit Emissions < carbon cap →surplus
Carbon offset project	Σ tCO_2 carbon offset	9,904.33	The total value of CO_2 tons from Wood Products, Bioenergy, and Biomass. This carbon offset project is a reduction in the emission deficit to calculate carbon units
Carbon Unit (SPE-GRK)	Carbon offset - emission deficit	9,885.35	Based on POJK 14 of 2023, 1 carbon unit is stated in 1 ton of CO_2 emitted in the period of the year
Value (IDR)	Carbon unit x IDR 77,000	761,172,123.06	Trading price on the Indonesian carbon exchange on September 27, 2023

3.2.2 Scheme 2: Carbon Offset from Remaining Wood Stock.

In the second scheme, the focus is only on the wood stock still available at the end of the year, as shown in Tables 6–9. This means that only unsold wood products are considered to retain potential carbon credit value. Products that have already been sold are assumed to have released their carbon value outside the company system. Thus, the calculation of carbon units in this scheme is more conservative and only considers the remaining stocks that are still under the company control. While this scheme results in fewer carbon units, it offers a more cautious valuation aligned with actual carbon retention within the company. The two schemes present different strategic approaches. Scheme 1 provides a broader assessment by recognising carbon offsets across the entire product lifecycle. Scheme 2 offers a conservative estimate based strictly on company-held stock. Both frameworks support Industry X in evaluating its emissions reduction potential and exploring opportunities in Indonesia's carbon market, particularly under POJK 14 of 2023. These schemes also serve as references for sustainability reporting and green investment planning, enabling Industry X to align its environmental achievements with financial benefits.

Table 6. Wood productivity data during 2023.

Material (Timber)	Product A (Veneer) in m^3	Product B (Plywood) in m^3	Product C (Woodworking) in m^3	Total in m^3
Stock 2022	382.74	3,643.86	2,865.43	6,892.03
Log usage	16,938.00	39,978.25	18,439.77	75,356.02
Stock 2023	825.96	4,747.86	4,670.65	10,244.47
Total				72,003.58

3.3 Challenges

While the goal of achieving energy independence is very attractive, financial constraints remain a major challenge. Therefore, alternative strategies, such as demand-side management, grid interaction agreements, and innovative financing models, are needed to reduce the high initial costs associated with large-scale energy storage solutions. The success of energy communities also depends on local policies regarding electricity sharing and implementation costs, which need to be considered in further analysis.

The design and implementation of energy communities in urban areas emphasise the importance of renewable technology integration, optimisation of local energy consumption, and the use of time-of-use pricing to drive energy savings. By utilising the potential of renewable resources and energy storage technologies, energy independence can be enhanced to reduce environmental impacts. However, once again, financial challenges and the need for innovative financing models must be addressed to realise a sustainable and economically efficient energy transition (Mavlutova et al., 2023).

Table 7. Carbon offset project (CO_2 ton) based on renewable energy.

Parameter	Formula	Wood Product	Bioenergy	Biomass
Material (%)	-		25%	15%
Volume (m^3)	% × wood product 2023	10,244.47	18.000,89	10.800,54
Density (ρ) (kg/m^3)	-	400.00	640.00	640.00
Mass (m) (tonnes)	V × ρ	4,097.79	11,520.57	6,912.34
Conversion factor (tCO_2/ tonnes)	-	0.50	0.0726	0.0618
Emissions (tCO_2)	m × Conversion Factor	2,048.89	836.60	427.30

Table 8. Industry's carbon footprint measurement.

Emission mass (tCO_2e)	759.03
Emission reduction	2.5%

Table 9. The value of carbon credits for the second scheme.

Carbon Mass (tCO_2e)	Formula	Value	Notes
Emission reduction target (tCO_2)	Emission × 2.5%	18.98	The company has a CO_2e deficit of 18.98 tCO2e
Industry's carbon cap	tCO_2e - emission reduction target	740.05	Emissions > carbon cap → deficit Emissions < carbon cap → surplus
Carbon offset project	Σ tCO_2 carbon offset	3,312.79	The total value of CO_2 tons from Wood Products, Bioenergy, and Biomass. This carbon offset project is a reduction in the emission deficit to calculate carbon units
Carbon Unit (SPE-GRK)	Carbon offset - emission deficit	3,293.82	Based on POJK 14 of 2023, 1 carbon unit is stated in 1 ton of CO_2 emitted in the period of the year
Value (IDR)	Carbon unit x IDR 77,000	253,623,888.33	Trading price on the Indonesian carbon exchange on September 27, 2023

Although carbon pricing is widely recognised as an effective and efficient tool for reducing emissions and attracting investments in clean energy, there are major challenges related to the socio-economic impacts of carbon pricing, which could exacerbate the economic burden for vulnerable groups, especially due to their dependence on conventional energy. Therefore, to achieve an effective energy transition, carbon pricing policies should be designed by integrating transition incentives with social safeguards, such as redistribution of carbon revenues and strengthening synergies between clean energy policies (Savin et al., 2024).

Renewable energy investment and production are increasingly important topics in the context of the global energy transition. Many previous studies have examined various factors that influence renewable energy investment and production strategies, especially those related to quota systems and green energy certificates. An understanding of the structure of the renewable energy market and the dynamics between stakeholders is essential to formulate effective policies and support the sustainable development of renewable energy. Government, energy suppliers, industry, and users are the main parties involved in the renewable energy chain of interests (Gangodawilage, 2024).

4. Conclusions

This research shows that carbon pricing policies have evolved significantly and play a crucial role in supporting sustainable energy transitions across various countries. Analysing international practices in carbon pricing through a literature review, it is found that carbon pricing approaches, whether through carbon tax schemes or emissions trading systems, can effectively incentivise industrial companies to improve energy efficiency, adopt low-carbon technologies, and design more environmentally friendly business strategies. Field findings from the case study of the wood industry in Indonesia, particularly Industry X, demonstrate that the internal implementation of carbon economic value can create funding opportunities for energy transition projects. By quantifying carbon units from the production of wood, biomass, and bioenergy, the company shows potential to generate revenue through carbon trading mechanisms. These funds can be strategically allocated, for instance, to develop renewable energy infrastructure such as solar power plants, thereby reinforcing the industry's contribution to national decarbonisation goals.

However, this study has several limitations. First, it is a preliminary investigation that primarily relies on secondary literature and a single industry case study. This limitation is largely due to the lack of a formal carbon pricing policy in the specific industrial context studied, which restricts access to broader empirical data. As such, the findings may not fully capture the diversity and complexity of industrial responses in other sectors or policy environments. Second, the analysis of carbon unit calculations and potential trading revenues is based on hypothetical estimations rather than verified financial data or active market transactions. To address these limitations, future research should incorporate multi-sectoral case studies, gather primary field data, and apply modelling tools to simulate various carbon pricing scenarios and their economic implications. In conclusion, while carbon pricing policies function not only as environmental instruments but also as effective fiscal and economic tools, their success depends on context-specific design. Indonesia should integrate these policies into its national fiscal framework, offer green investment incentives, and provide tailored support to high-emission industrial sectors with strong mitigation potential. By doing so, carbon pricing can become a foundational pillar in Indonesia's roadmap toward an equitable and sustainable energy transition.

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