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Role of Discount Rate and Social Cost of Carbon for Carbon Capture Utilization and Storage Technologies in Thailand's Low Emissions Pathways

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ABSTRACT

In order to meet Thailand's carbon neutrality target by 2050 (CN2050), it has been proposed that state-of-the-art—but costly—CCUS and BECCS technologies be integrated into the country's electricity generation framework. Climate projects are advised to utilize low discount rates and incorporate the social cost of carbon (SCC). This study employed the AIM/Enduse model, a framework developed by Japan's National Institute for Environmental Studies (NIES), to evaluate suitable discount rates and estimate SCC as the carbon pricing for electricity generation employing CCUS and BECCS technologies. Findings indicate that with a fixed discount rate of 3 percent, SCC begins at 63 USD/tCO_2 for achieving the CN2050 target. Conversely, under a declining discount rate scenario - where a 6 percent rate is applied prior to 2037 and then reduced to 3 percent post-2037 - the SCC starts at 21 USD/tCO_2 before 2037 and increases to 63 USD/tCO_2 thereafter. Therefore, it is crucial to apply suitable discount rates and SCC to encourage adoption of costly negative emissions technologies and achieve objectives of the CN2050 targets.

1. THAILAND'S LONG-TERM LOW GREENHOUSE GAS EMISSION DEVELOPMENT STRATEGY

The Paris Agreement is dedicated to strengthening global efforts to combat climate change by aiming to cap the century's temperature rise well below 2°C above pre-industrial levels, with the aspiration of limiting it to 1.5°C [1]. As highlighted by the Intergovernmental Panel on Climate Change (IPCC), a temperature increase exceeding 1.5°C significantly magnifies the risks associated with climate change impacts [2]. To address this, countries are striving to ensure that global warming remains within the 1.5°C threshold. Thailand, as a developing country Party, has revised its Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) submitted to the United Nations Framework Convention on Climate Change (UNFCCC). This strategy articulates Thailand's commitment to achieving carbon neutrality by 2050 (CN2050) and net-zero greenhouse gas emissions by 2065 (NZE2065), aligning with the 1.5°C target [3].

To achieve the CN2050 and NZE2065 goals, Carbon Capture, Utilization, and Storage, called CCUS, and Bioenergy with Carbon Capture and Storage, called BECCS, have been proposed for use in the electricity generation sector, starting in 2040. While CCUS and BECCS are recognized as greenhouse gas (GHG) mitigation technologies, their implementation remains costly. Project developers have found the cost-effectiveness of these technologies unsuitable for immediate adoption, largely due to the influence of discount rates in their analysis. Developing countries like Thailand typically apply a business-oriented 10% discount rate. In contrast, the IPCC advises lower rates of 5% for short-term climate projects and 2% for long-term climate projects [4]. Adjustments in discount rates can significantly impact the evaluation of economic of projects, which must account not only for private costs but also for external costs, particularly "social costs" arising from project implementation.

This research utilizes the Asia Pacific Integrated Model (AIM)/Enduse, created by Japan's National Institute for Environmental Studies (NIES), to identify the optimal discount rate and calculate the SCC for electricity generation. This analysis is designed to promote the adoption of CCUS and BECCS technologies and support Thailand's ambition to achieve carbon neutrality by 2050.

2. TECHNOLOGY TO SUPPORT NET ZERO EMISSION SCENARIOS IN THE ENERGY SECTOR

The Sixth Assessment Report (AR6) of IPCC [5] and the net zero emissions 2050 report [6] emphasize the vital importance of CCUS and BECCS technologies. Both technologies are applied to reduce or eliminate carbon dioxide emissions in various sectors, including electricity generation and industrial sectors. The net zero emissions in global electricity generation would happen in 2040, as reported by the International Energy Agency (IEA). However, CCUS and BECCS technologies are

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expensive. Therefore, the cost of electricity production technologies is a crucial consideration, particularly for CCUS and BECCS technologies.

The version of AIM model, called AIM/Enduse, is a bottom-up model designed with the objective of minimizing total system costs within given constraints, such as greenhouse gas (GHG) emissions levels, carbon taxes, and technology subsidies [7, 8, 9]. This model has been developed by the National Institute for Environmental Studie, and extensively applied at global, national, and activity levels for analyses pertaining to energy and environmental issues [10]. Figure 1 illustrates the schematic diagram of the model. The AIM/Enduse comprises three key parts: (1) primary energy, which in this study refers to fuels utilized for electricity generation; (2) energy technologies, which represent power generation technologies; and (3) energy demand, denoting the required amount of electricity. Additionally, the model accommodates the integration of various constraints, such as emissions targets or policy instruments, to adapt to specific scenarios and objectives.

Regarding the cost optimization function in AIM/Enduse model, the electricity generation model requires technical information, including electricity generation technology, initial cost, O and M cost, lifetime, efficiency, fuel price, energy demand and emissions factor. This study adopts existing electricity generation technologies as specified in the Power Development Plan 2018 Revision 1 of Thailand (PDP2018 Rev.1) and plans the integration of CCUS and BECCS technologies starting post-2040. Technical specifications for electricity generation are sourced from the IEA and the International Renewable Energy Agency (IRENA), detailed in Tables 1 and 2. Fuel prices are applied as constants: coal and lignite prices, based on IEA reports, are set at 28 and 65 USD/toe, respectively [11]. Similarly, the IEA estimates that natural gas costs approximately 577 USD/toe, while diesel is priced at around 1,398 USD/toe. Fuel emission factors are extracted from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2 [19].

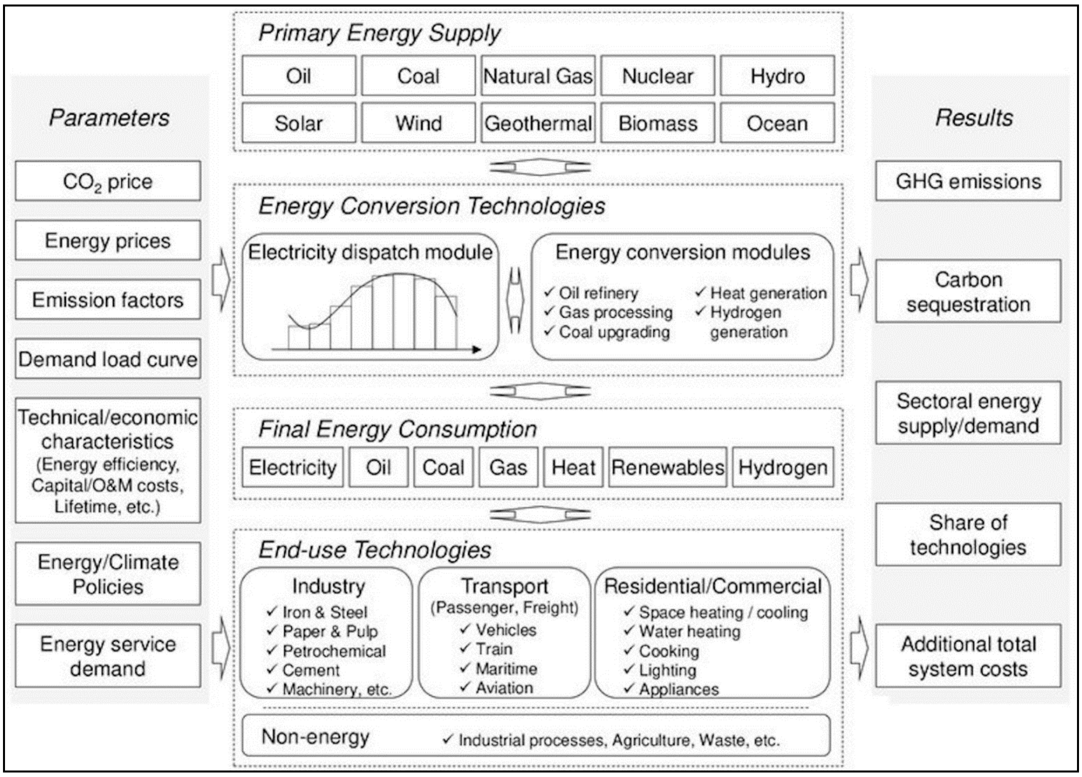

Fig. 1. The concept of the AIM/Enduse model [20].

3. THE DISCOUNT RATE AND SOCIAL COST FOR NET ZERO EMISSIONS IN THAILAND

3.1 The Discount Rate

In economics, monetary value diminishes over time, meaning future costs and benefits are worth less than their present counterparts. This change is influenced by the "discount rate," which adjusts monetary values across different time periods, enabling comparison at a common point in time. Additionally, the discount rate reflects the "opportunity cost" associated with a resource or investment. The application of a discount rate significantly determines the role of government, the type of project implemented, and resource allocation to the next generation. Some projects are less cost-effective today, but they will make great economic benefits in the future, especially for climate change projects.

A high discount rate indicates that future benefits are deemed less valuable than those in the present, which undermines the long-term advantages of climate change initiatives. Consequently, a lower discount rate is advised when conducting economic analysis of climate change projects. Developed countries generally apply lower rates than developing nations. Discount rates are generally applied in two forms: (1) a constant discount rate [21], and (2) a declining discount rate [22]. Interestingly, the IPCC-AR4 advocates for the use of the declining discount rate method.

Table 1. Costs of electricity generation technology.

Fuel	Electricity generation technology	Initial cost (1,000USD/MW)	O and M cost (1,000USD/MW)
Coal/Lignite	• Existing technology	• 1,050[1]	• 38–39[1]
	• Advanced technology	• 2,582–4,157[2]	• 40–66[2]
Coal/Lignite with CCS	• Advanced technology with CCS	• 3,400–4,500[1, 3]	• 109–121[1, 3]
Natural gas	• Existing technology	• 1,050[1]	• 10[1]
	• Advanced technology	• 648–861[2]	• 33–50[2]
Natural gas with CCS	• Advanced technology with CCS	• 1,200–2,600[1, 3]	• 19–41[1, 3]
Fuel oil	• Existing technology	• 1,050[1]	• 22[1]
Diesel	• Existing technology	• 430–687[1]	• 7–39[1]
Solar	• Existing technology	• 2,300[4]	• 33[4]
	• Advanced technology	• 1,254[5]	• 18[5]
Wind	• Existing technology	• 2,833[4]	• 66[4]
	• Advanced technology	• 2,004[5]	• 47[5]
Biogas	• Existing technology	• 2,560[4]	• 34[4]
	• Advanced technology	• 1,937[5]	• 19[5]
MSW	• Existing technology	• 3,000[4]	• 53[4]
	• Advanced technology	• 3,448[5]	• 61[5]
Biomass	• Existing technology	• 2,200[4]	• 21[4]
	• Advanced technology	• 964–5,601[5]	• 8–168[5]
Biomass with CCS	• Advanced technology with CCS (BECCS)	• 3,585[6]	• 187[6]

Remark: 1 Initial cost and O&M costs of electricity generation technology follow IEA [12]
2 Initial cost and O&M costs of electricity generation technology follow IEA [13]
3 Initial cost and O&M costs of electricity generation technology follow Rubin, John, and Howard [14]
4 Initial cost and O&M costs of electricity generation technology follow IRENA [15]
5 Initial cost and O&M costs of electricity generation technology follow IRENA [16]
6 Initial cost and O&M costs of electricity generation technology follow BES [17]

Table 2. Information on electricity generation technologies in Thailand.

Electricity generation technology	Lifetime (Year)	Plan factor[4] (%)
Coal/Lignite	40[1]	85
Coal/Lignite with CCS	40[1]	85
Natural gas	30[1]	85
Natural gas with CCS	30[1]	85
Fuel oil	25[1]	85
Diesel	25[1]	85
Solar	25[2]	15–18
Wind	25[2]	21–25
Biogas	20[2]	24–70
MSW	30[2]	44
Biomass	25[2]	52–70
Biomass with CCS	25[3]	70

Remark: 1 Lifetime and efficiency of electricity generation technology follow IEA [13]
2 Lifetime and efficiency of electricity generation technology follow IRENA [16]
3 Lifetime and efficiency of electricity generation technology follow BES [17]
4 Plan factor followed PDP 2018 [18]

Furthermore, the IPCC recommends that discount rates for climate-related projects be set lower than conventional rates —around 5 percent for short-term initiatives and 2 percent for long-term ones. Developing countries typically apply discount rates between 5 and 7 percent, whereas developed nations tend to use lower rates. Accordingly, this study examines three discount rates:

1. 3 percent – A rate lower than that commonly seen in developing countries and consistent with practices in developed countries.
2. 6 percent – Representing the average rate generally applied in developing nations.
3. 10 percent – Reflecting the rate currently observed in real-world applications.

3.2 The Social Cost of Carbon

Project costs can generally be separated into two main categories:

1. Private Costs: These are expenses directly related to production, such as wages, land, fuel, equipment, and interest rates. They are critical for evaluating the economic viability of the project.

2. External Costs: These costs represent the impacts on society or the environment resulting from the project's operations.

This categorization helps ensure that both the direct financial implications and the broader societal or environmental consequences are considered during project appraisal.

Economic analyses for general projects primarily focus on private costs; however, climate change projects require the inclusion of external costs, which encompass both positive and negative impacts on society. This is referred to as the "social cost." When evaluating the external cost specifically related to carbon dioxide (CO_2) emissions reduction, it is called the "social cost of carbon (SCC)." Similarly, when considering external costs tied solely to greenhouse gas (GHG) emissions reduction, it is called the "social cost of greenhouse gas."

A high SCC indicates that while climate change projects significantly reduce GHG emissions, the cost of achieving such reductions is substantial. Conversely, a low SCC reflects strict policies, and though GHG emissions are reduced under such conditions, these policies may hinder the progress of projects.

Figure 2 depicts the cost-benefit analysis of applying the social cost of carbon to climate change policies by contrasting Policy A and Policy B against a baseline scenario. With the SCC set at 50 USD per ton of CO_2, the analysis reveals the following outcomes:

- Policy A: No climate change mitigation measures are adopted, leading to heightened greenhouse gas emissions. Consequently, the mitigation cost escalates to 25,000,000 USD.

- Policy B: Climate policies are enforced, resulting in a reduction in greenhouse gas emissions. This generates a benefit of 25,000,000 USD from emission reductions.

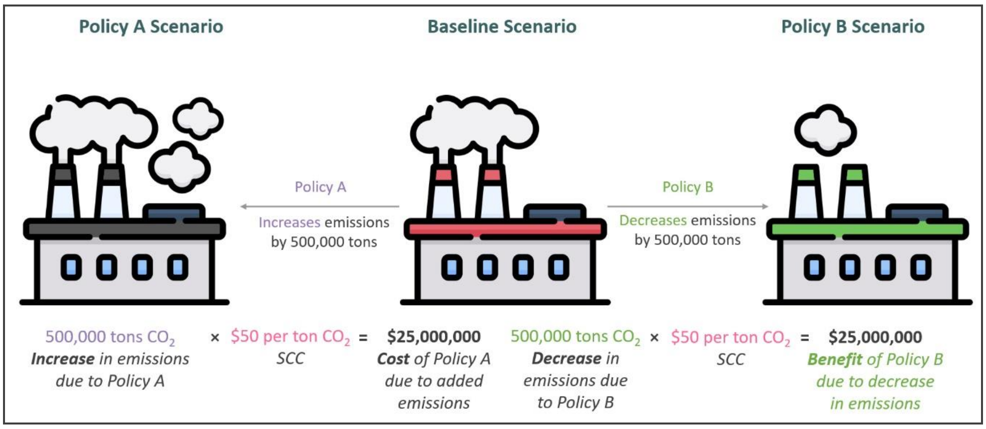

Fig. 2. Costs and benefits in climate policies [23].

The social cost of carbon is a key element in establishing carbon pricing that supports climate-related policies and regulations in several countries, including the North America [24]. The careful selection of the appropriate SCC for cost-benefit analyses is crucial, as it has a significant impact on policy decisions.

The approaches and models used to evaluate the SCC in developed countries vary widely. However, they are still grounded in two fundamental principles and share the same goal: estimating the societal impact of emitting one tonne of carbon. These principles can be summarized as follows:

1) The SCC is determined using a Future World Damage Function that quantifies potential losses in monetary terms—a measure commonly known as the "Future Worldwide Damage Cost." This method is grounded in cost-benefit analysis, which evaluates both the economic impacts of CO_2 emissions and the advantages of reducing them. [25, 26, 27].

2) The SCC is determined by applying a carbon price -implemented through incentives or taxes- to stimulate greenhouse gas (GHG) reduction efforts, thereby enabling a country to meet its emissions mitigation targets. These objectives are predominantly outlined in the Paris Agreement, which strives to limit global temperature increase this century to under 2°C, with an ambitious goal of capping it at 1.5°C. This method, rooted in cost-effectiveness analysis, is commonly expressed as the Marginal Abatement Cost (MAC), indicating the expense related to mitigating one additional unit of emissions [28, 29]. Accordingly, this study employs the second approach—estimating the Social Cost of Carbon via a carbon pricing mechanism—because it harmonizes with the second principle and integrates seamlessly with the structure of the AIM/Enduse model.

4. SCENARIO DESCRIPTIONS TO ESTIMATE THE SOCIAL COST OF CARBON AND GREENHOUSE GAS

The AIM/Enduse model is utilized to determine the suitable discount rate and calculate the SCC as a carbon pricing mechanism for electricity generation. Its primary goal is to encourage the integration of CCUS and BECCS technologies, thereby aiding Thailand in reaching its target of carbon neutrality by 2050. The research is organized into two distinct scenarios.

1) The PDP2018 scenario: This scenario represents the baseline case, characterized by a "low challenge for mitigation," where mitigation policies primarily rely on fossil fuels. Under this scenario, renewable energy accounts for 19 percent of Thailand's total electricity generation, in alignment with the PDP2018 Rev. 1 [30]. Consequently, using a 10% discount rate and excluding the implementation of SCC, the estimated CO_2 emissions in 2050 are projected to reach 471.62 $MtCO_2$. Achieving carbon neutrality by 2050 will require the energy sector to balance CO_2 emissions by offsetting them with an equivalent reduction.

2) The RE50 scenario: This scenario represents a "high challenge for mitigation," aiming for significant advancements in renewable energy integration. Under this scenario, the contribution of new renewable energy power plants is projected to rise, accounting for 50 percent of Thailand's total electricity generation. Consequently, renewable energy is projected to account for 69 percent of total electricity production in the target year.

Electricity demand is a major driver of changes in greenhouse gas emissions. Historical consumption data is extracted from annual energy reports, and the 2037 demand forecast is derived from the PDP2018 Rev.1. Projections for electricity demand in 2050 are then calculated using a linear regression method (see Fig. 3).

This study establishes a target year and outlines a pathway to carbon neutrality for Thailand, aligning with the nation's long-term climate change objectives. Within the scenario framework illustrated in Fig. 4, the case study examines how variations in three key factors: 1) the discount rate, 2) the fuel mix or electricity generation technologies, and 3) the social cost of carbon impacts GHG emissions and the potential for reductions through the adoption of CCUS and BECCS in the power generation sector.

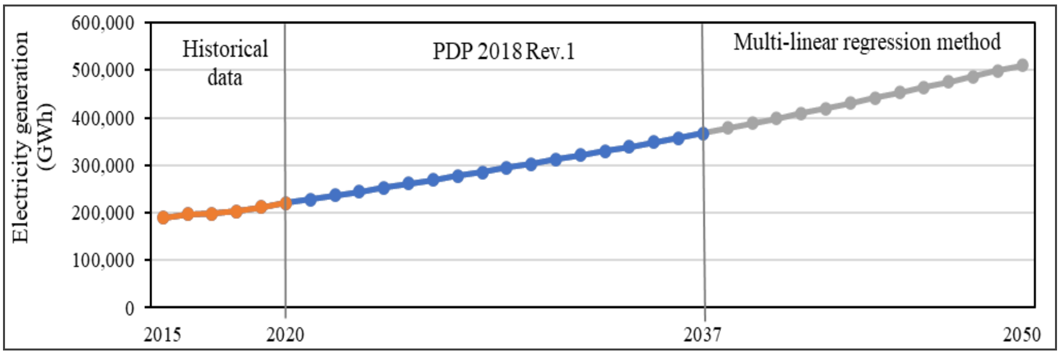

Fig. 3. Forecasting Thailand's electricity demand (2020–2050).

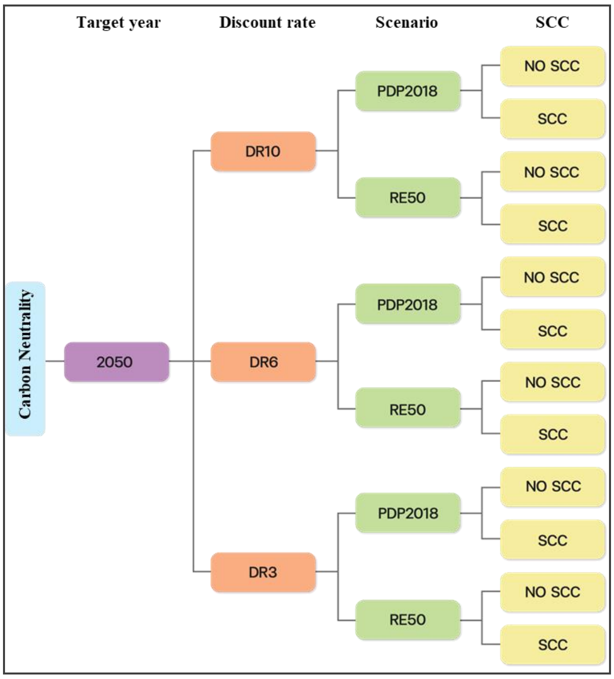

Fig. 4. Development of case studies to assess the appropriate discount rate and estimate the SCC.

5. RESULTS AND DISCUSSION

The model incorporates the discount rate and the SCC to guide selection of CCUS and BECCS technologies. These factors are crucial in shaping strategies to help Thailand's power generation sector achieve net zero CO_2 by 2050. The explanation is detailed as follows.

5.1 The Constant Discount Rate

Under the PDP2018 scenario, the power generation sector is projected to emit 472 $MtCO_2$ by 2050. By introducing the social cost of carbon (SCC) as a carbon pricing mechanism, it serves as an incentive or policy tool to support greenhouse gas mitigation efforts, aligning with Thailand's climate targets. The study reveals that carbon neutrality by 2050 can be achieved if the price of carbon at least USD 153 per t-CO_2 is implemented. Additionally, lowering the discount rate from 10% to 6% and 3% decreases the required SCC to 103 and 71 USD per ton of CO_2, respectively.

In the RE50 scenario, which incorporates a higher share of RE in electricity generation, CO_2 emissions are projected to reach 458 $MtCO_2$ by 2050 if no carbon pricing policy is implemented. However, when the SCC is applied as a carbon tax to drive progress toward carbon neutrality by 2050, the required SCC is estimated at 129 USD per ton of CO_2 under a 10% discount rate. Reducing the discount rate to 6% and 3% lowers the required SCC to 88 USD per ton of CO_2 and 63 USD per ton of CO_2, respectively.

Figure 5 illustrates the comparison of SCC values across varying discount rates, demonstrating that lower discount rates result in reduced SCC values. Notably, under the PDP2018 scenario, the SCC is higher compared to the RE50 due to the difficulty in achieving the CO_2 emission reduction target necessary for carbon neutrality by 2050. This reflects the intensified challenge faced in the PDP2018 scenario.

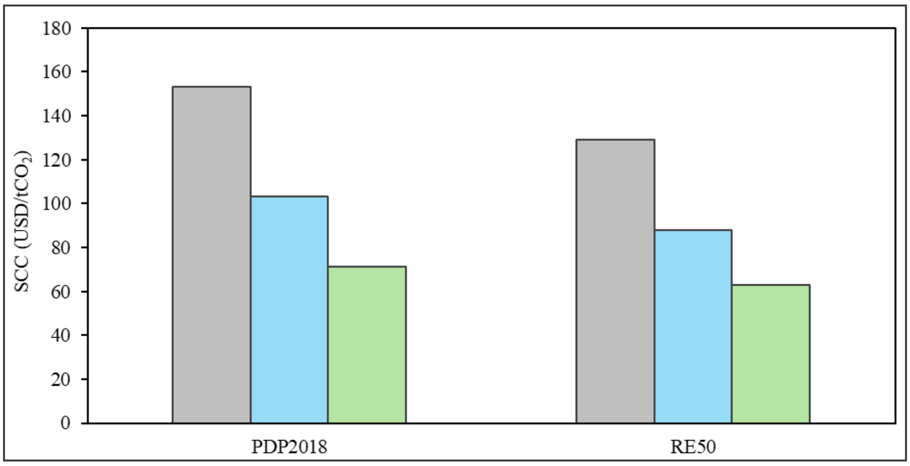

Fig. 5. Comparison of SCC values under different discount rates.

5.2 The Declining Discount Rate

The study presents the SCC under a declining discount rate approach over time. The timeline for the discount rate adjustment is divided into two distinct periods: (1) from the present year to 2037, and (2) from 2037 to 2050. The findings of the study under this framework are detailed as follows.

5.2.1 The PDP2018 scenario

A gradual reduction in the discount rate is proposed across three cases. First, when the discount rate decreases from 10% to 6%, the SCC is 36 USD/tCO_2 during the initial period (2020–2037). For the subsequent period (2038–2050), the SCC rises to 103 USD/tCO_2 (see Fig. 6).

In the second case, a reduction from 10 percent to 3 percent is analyzed. The SCC remains at 36 USD/tCO_2 for the first period (2020–2037) but lowers to 71 USD/tCO_2 during the second period (2038–2050).

Finally, under the third case, a decline from 6 percent to 3 percent is considered. The SCC starts at 21 USD/tCO_2 in the first period (2020–2037) and increases to 71 USD/tCO_2 in the second period (2038–2050).

5.2.2 The RE50 scenario

A declining discount rate is analyzed across three scenarios. First, when the discount rate decreases from 10% to 6%, SCC is 36 USD/tCO_2 during the first period (2020–2037) and rises to 88 USD/tCO_2 in the second period (2038–2050).

Second, under a declining discount rate of 10% to 3%, SCC remains at 36 USD/tCO_2 for the initial period (2020–2037) but lowers to 63 USD/tCO_2 for the subsequent period (2038–2050).

Lastly, when the discount rate shifts from 6% to 3%, SCC starts at 21 USD/tCO_2 during the first period (2020–2037) and increases to 63 USD/tCO_2 in the 2nd timeframe (2038–2050).

This study highlights that the SCC in the PDP2018 scenario is higher compared to the RE50 scenario, owing to the greater difficulty in meeting the CO_2 emission reduction target under PDP2018 to achieve carbon neutrality by 2050. During the short-term period from the current year to 2037, SCC values remain consistent across all discount rates for both scenarios, as the duration is insufficient for the discount rate to meaningfully influence the present worth of greenhouse gas mitigation costs. However, in the long-term period from 2037 to 2050, SCC values begin to diverge for each scenario, even under identical discount rates.

In this study, the estimated SCC was evaluated to confirm whether it was appropriately calculated or subjected to over- or under-estimation. This validation involved comparing the study's findings against global carbon pricing data provided by the World Bank Group [30] and the International Monetary Fund [31]. The results demonstrated that the SCC values derived from the study align closely with existing carbon pricing practices worldwide.

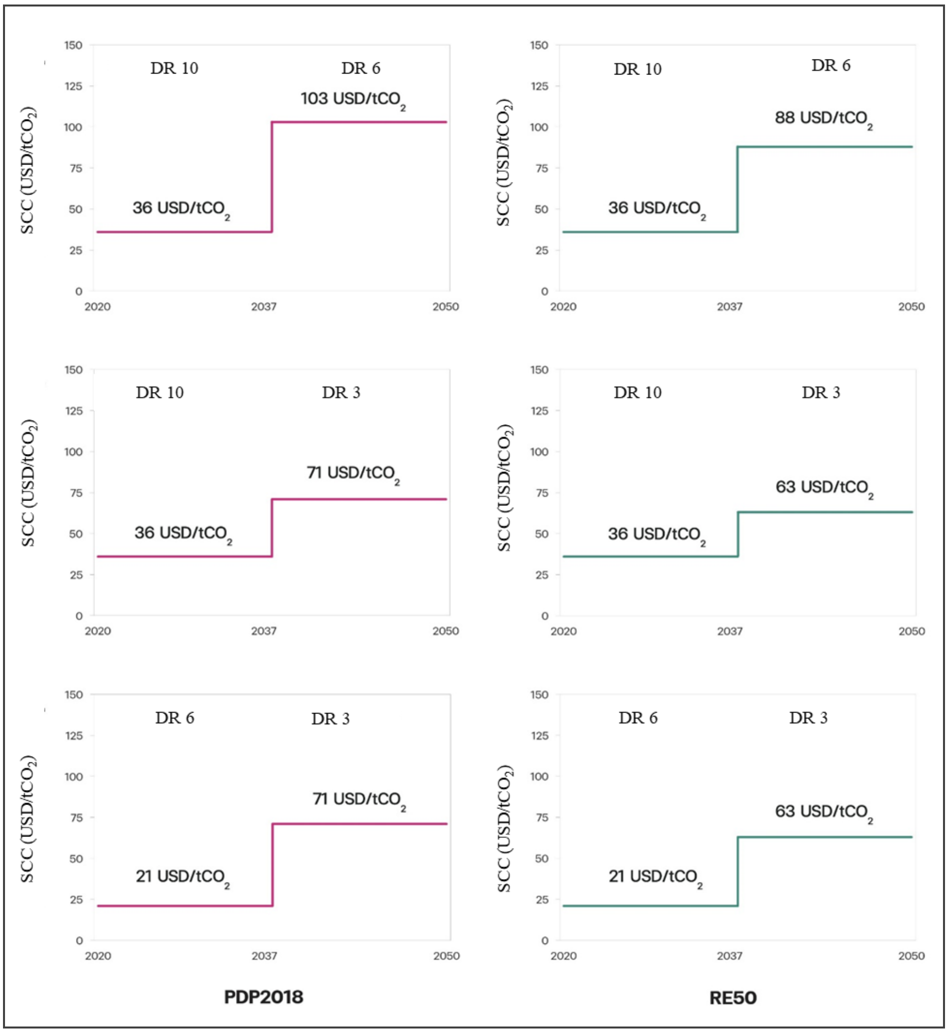

Fig. 6. SCCs for achievement of carbon neutrality target with declining discount rate in the PDP2018 and RE50 scenarios.

6. CONCLUSIONS

The strategy of using suitable discount rates and SCC is designed to support the power generation sector in the achievement of carbon neutrality goal by 2050. The methodology for establishing the discount rate at the measure level for CCUS and BECCS technologies is detailed below.

When evaluating projects or measures involving CCUS and BECCS technologies, a constant discount rate of 3% should be applied. Under this discount rate, the SCC begins at 71 USD per ton of CO_2 for the PDP2018 scenario and 63 USD per ton of CO_2 for the RE50.

When applying a declining discount rate, a 6% should be used for the assessment period from 2020 to 2037, coinciding with the conclusion of Thailand's PDP2018 Rev.1. Following this, the discount rate is reduced to 3% for the period from 2038 to 2050, leading to the achievement of carbon neutrality. The analysis reveals that SCC begins at 21 USD/tCO_2 during 2020–2037 under a 6% discount rate and increases to 63 USD/tCO_2 during 2038–2050 when the 3% discount rate is used.

The adoption of a 6% discount rate during the initial phase, transitioning to a 3% rate in the later period, is strategically chosen to ensure alignment with current practices while enabling a smooth adjustment for the market and stakeholders. This approach is practical as it yields a lower SCC compared to maintaining a consistently low discount rate throughout the entire timeline. The practicality of this strategy is particularly relevant because implementing SCC mechanisms, such as carbon pricing or taxation, could directly affect electricity costs, especially given the current dependency on fossil fuels in Thailand's power generation sector. By leveraging appropriate discount rates and social cost of carbon, CCUS and BECCS technologies can effectively contribute to Thailand's goal of achieving carbon neutrality by 2050.

The SCC estimates presented in this study are subject to uncertainty, as the costs associated with CCUS and BECCS technologies may evolve over time. As a result, further analysis is essential to ensure that these SCC and discount rate values are effectively aligned with the evolving cost structures of the technologies before practical implementation.

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