

ASEAN Power Pathways to 2050: E3ME-FTT Model Projections

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Abstract

ASEAN's power sector faces the hard task of cutting fossil dependence. Using the macro-econometric E3ME-FTT model calibrated to the IEEJ 2023 Outlook, we project outcomes under four pathways. The Reference (REF) and Current Technology Trajectory (CTT) cases yield only modest renewable gains by 2050. By contrast, the Nationally Determined Contribution (NDC) and Ambitious (AMB) cases deliver large increases, with renewables supplying about 85% and 93% of electricity, respectively. NDC combines a domestic ETS with subsidies for CCS, wind, and solar, plus feed-in tariffs; AMB further tightens additions of new fossil capacity. Model results indicate that, although employment could fall in fossil-fuel industries, higher clean-energy investment can raise ASEAN-wide GDP. Given the peninsular and archipelagic geography of many member states, policies also attend to grid stability and access, not only climate mitigation. These findings underscore the importance of coherent policy packages and credible near-term power plans to steer the transition.

Keywords : ASEAN · Power sector · Renewable energy · Nationally Determined Contribution (NDC) · E3ME-FTT model

1. Introduction

1.1 Background

The Association of Southeast Asian Nations (ASEAN) is a regional economic union likely to experience rapid growth in the near future, accompanied by significant increases in energy consumption and associated carbon dioxide emissions (IEEJ, 2022). Although ASEAN's share of global greenhouse gas emissions was only 5% in 2022, absent mitigation efforts, future growth is expected to be environmentally significant.

In recent years, most ASEAN Member States (AMS) have announced carbon-neutrality targets to be achieved around the middle of this century (UNFCCC, 2024). Given these countries' reliance on fossil energy and their economic growth trajectories, the path to carbon neutrality is steep (IEA, 2022a; IEEJ, 2022; Lau, 2023). Beyond domestic efforts, cooperation and support from countries with carbon-free technologies and financing—such as Japan, China, and South Korea—will also be important.

Achieving carbon neutrality requires economy-wide decarbonization, with particular urgency in the power sector. This study therefore focuses on the power sector because (i) it offers large and immediate emissions reductions through generation and investment choices, (ii) low-carbon power technologies are already mature and increasingly cost-competitive, and (iii) power-sector decarbonization is a prerequisite for electrifying other sectors and reducing their emissions. Mature low-carbon alternatives in electricity are rapidly outcompeting incumbent carbon-intensive technologies in deployment and cost (IEA, 2024), and a decarbonized grid can accelerate electrification in other sectors.

Across ASEAN, net-zero pledges and updated NDCs are increasingly complemented by power-sector policies that prioritise rapid renewable deployment and grid enabling conditions, alongside a gradual shift away from unabated coal. At the regional level, the ASEAN Plan of Action for Energy Cooperation (APAEC) 2026–2030 sets an aspirational target of 45% renewables in installed power capacity by 2030 (ACE, 2025). Indonesia's Enhanced NDC raises its 2030 mitigation target to 31.89% (unconditional) and 43.20% (conditional) below BAU, and the JETP CIPP further articulates a conditional pathway with

power-sector emissions peaking by 2030 ($\leq 290 \text{ MtCO}_2$) and reaching net zero by 2050 (Government of Indonesia, 2022; JETP Secretariat and Working Groups, 2023). Malaysia's National Energy Transition Roadmap (NETR) outlines a "Responsible Transition" pathway targeting 70% renewables in installed capacity by 2050, providing policy context for the scenarios analysed in this paper (Ministry of Economy Malaysia, 2024).

However, under current policies, power-sector decarbonization is unlikely (IEA, 2022a; IEEJ, 2022). Policy support and enforcement—carbon pricing, subsidies, and, in some cases, regulations on fossil power generation (e.g., phase-outs)—are needed to spur power producers to invest in and adopt decarbonization technologies.

1.2 Literature review

According to the IPCC (2023), achieving carbon neutrality on a global scale requires significant reductions in fossil-fuel usage in the power sector, adoption of carbon capture and storage (CCS), carbon-free power systems, widespread electrification, and energy conservation and efficiency improvements. Furthermore, the cost of reducing CO_2 emissions by one ton is under \$20 for solar and wind energy, energy efficiency improvements, and methane emission reductions (from coal mining, oil and gas, and waste), contributing significantly to emission reductions. However, it is acknowledged that achieving net-zero CO_2 emissions from the industrial sector is challenging. Nevertheless, coordinated actions across the entire value chain, including demand management, energy and material efficiency, emission reductions, and transformations in production processes, can make this possible.

Regarding the decarbonization of the power sector in ASEAN, Lau (2023) argues that coal and natural gas have historically dominated ASEAN's power sector, accounting for 77% of the electricity generation in 2019. To achieve net zero by 2050, AMS need to decarbonize the power sector over the next 30 years.

Regarding the importance of climate change measures in AMS, the Asian Development Bank (ADB) estimates that if climate change is not mitigated, major industries such as agriculture, tourism, and fisheries, as well as human health and labor productivity in AMS, will be severely impacted (Raitzer et al., 2016). This could lead to an 11% reduction in GDP in the region by the end of the century, with AMS potentially suffering greater losses than most other regions worldwide.

Given the significance of climate change impacts in AMS, recent years have seen modelling analyses on decarbonization targeting these nations. The IEA (IEA, 2023) utilized the GEC (Global Energy and Climate) model, a bottom-up technology selection model, to simulate the pathway to decarbonization in ASEAN countries up to 2050. Assuming a GDP growth rate of 3.8% from 2020 to 2050, and analyzing the Announced Pledges Scenario (APS) from the World Energy Outlook 2022 (IEA, 2022a), it is estimated that the total energy supply will grow at an annual rate of 1.5%, with CO_2 emissions peaking around 2030 and subsequently decreasing at an average annual rate of -1.7% , achieving carbon neutrality by 2050. The importance of decarbonizing the power sector through an increased share of renewable energy is also highlighted. Similarly, Kimura et al. (2022) and IEEJ (2022) utilized the IEEJ-NE (Institute of Energy Economics, Japan-New Earth) model Otsuki et al. (2019, 2022), a bottom-up technology selection model, to conduct similar simulations, outlining the pathway to decarbonization in AMS centered on electrification and the transition to renewable energy sources. The former investigated the optimal configuration under the constraints of Net-Zero, while the latter produces energy system outlooks in a "Reference" and "Advanced technologies scenario". Phoumin et al. (2021) applied the bottom-up Low Emissions Analysis Platform (LEAP) software tool and adapted it to the case of the ASEAN power generation sector. They exposed the LEAP platform to various power generation configurations, though not per se with full decarbonization in mind. IRENA and ACE (2022) investigated various decarbonization scenarios focusing on renewable energy, using the REmap toolkit, which includes PLEXOS to estimate long-term power capacity planning. Lastly, the IEA (2022b) also published decarbonization pathways specific to the case of ASEAN, building on their inhouse developed scenarios using the GEC model (IEA, 2023).

From the studies above, we selected the scenarios that are publicly available and somewhat similar to the AMB (Ambitious) scenario displayed in this study, but we note substantial differences in scenario design as well. Most of the aforementioned

studies investigated economy-wide decarbonization while in this study we limited ourselves to the power sector alone. This means that, depending on the scenario inputs, assumptions, and methodology, other studies show significant increases in electricity demand due to electrification of e.g. road transport. In this study, electricity demand is affected by electricity prices and sectoral output. Impacts on the latter only occur through indirect effects of the scenario inputs. The selected scenarios of the selected studies are displayed in **Table 1**.

In contrast, in a study performed by the ASEAN Centre for Energy (ACE) and Gesellschaft für Internationale Zusammenarbeit (GIZ) (2022) the LEAP model was used to simulate the decarbonization pathway for AMS up to 2050. The simulation results indicate that the total investment required for decarbonization from 2021 to 2050 amounts to \$726 billion under the APS, with 77% of this investment directed towards renewable energy.

Furthermore, analyses focusing on the power sector using the E3ME model, which is also utilized in this study, include

Table 1 Overview and description of the selected scenarios of selected studies for comparison

Source	Scenario	Model	Brief description
Kimura et al. (2022)	CN2050/2060 (Carbon neutral by 2050 or 2060, depending on national pledges)	IEEJ-NE	“CN2050/2060 reflects nationally declared carbon-neutral target years and considers natural carbon sinks in Indonesia, Malaysia, Myanmar, Thailand and Viet Nam based on discussions with each country.”
IEEJ (2022)	Advanced Technology Scenario	IEEJ-NE	“In the Advanced Technologies Scenario, measures to maximize the reduction of carbon dioxide (CO ₂) emissions and to ensure energy security will be enhanced with consideration given to their application opportunities and acceptability to society. Each country and region will actively implement aggressive energy efficiency and decarbonization policies that contribute to securing a stable energy supply, enhancing climate change measures, and accelerating the development and introduction of innovative technologies globally.”
Phoumin et al. (2021)	APS (Alternative policy scenario)	LEAP	“The APS refers to Alternative Policy Scenario and assumes that states will increase more efficient final energy consumption, more efficient power generation, a higher share of renewables, and the introduction of nuclear power plants, based on each AMS government policy. The assumptions used in the APS are described in the table below.”
IEA (2022b)	SDS (Sustainable development scenario)	GEC	“In the SDS, CO ₂ emissions drop to zero around 2070 and there are rapid reductions in non-CO ₂ emissions. The 1.5°C level is exceeded in the early 2030s and the rise in temperature peaks at just under 1.7°C around 2050. The SDS is in line with the Paris Agreement objective of ‘holding the increase in the global average temperature to well below 2°C’.”
IRENA and ACE (2022)	TES (Transforming Energy Scenario)	REmap and PLEXOS	“The TES describes an energy pathway based largely on currently available and competitive low and zero carbon technologies. It is characterized largely by renewable energy expansion and energy efficiency.”
	1.5-S 90% (consistent with achieving 1.5C global warming, with a 90% uptake of renewables in the power sector by 2050)		“The 1.5-S is a more ambitious energy pathway, and outlines options to further reduce CO ₂ emissions in the energy system in challenging sectors. It largely follows the WETO scenario aiming to reach net-zero emissions globally by 2050.”
	1.5-S 100% (consistent with achieving 1.5C global warming, with a 100% uptake of renewables in the power sector by 2050)		

Source: Author’s summary

those by Pollitt (2020) and Lee et al. (2022). Pollitt (2020) predicts that if China achieves carbon neutrality, cumulative CO₂ emissions will decrease by approximately 215 Gt, and China's GDP will increase by about 5% over the next decade. This is attributed to increased investments in the power sector, technological advancements related to coal phase-out, and the promotion of fuel substitution. Lee et al. (2022) estimate the macroeconomic impacts of Japan achieving carbon neutrality by 2050 and how Japan's energy mix will change. The results indicate that, assuming the decommissioning of nuclear power plants by 2040, about 90% of the energy mix in 2050 will consist of renewable energy. GDP is projected to increase by 4.0–4.5% compared to the baseline scenario, and employment is expected to increase by 1.5–2.0%, demonstrating the potential for simultaneous achievement of decarbonization and economic growth.

1.3 Purpose of this study

In this study, we will investigate announced policies using the Nationally Determined Contribution (NDC) documents (UNFCCC, 2024) and policy documents specific to the respective domestic power sectors (ACE, 2023). Using the E3ME-FTT model, we can enter the interpretation of the announced policies to investigate the impact on technology uptake, emissions, and macro-economic consequences. E3ME-FTT is a simulation model, which can yield substantially different results when compared to optimization models (Mercure et al., 2019). Simulation models have so far rarely been used to investigate decarbonization of the power sector in the ASEAN context, however, as mentioned in the previous section, various studies have been conducted using optimization models (e.g. (Phoumin et al., 2021; Kimura et al., 2022; Matsumoto and Phoumin, 2022; IEEJ, 2022)). Finally, Barbrook-Johnson et al. (2024) argue that energy models built on optimization and cost-benefit analysis, while useful, are not suitable for policy appraisal and they suggest a shift away from such models for policy appraisal purposes.

The E3ME-FTT model will be used to investigate whether the policies mentioned in NDC documents are sufficient to meet the renewable energy targets. In addition, we will expose the ASEAN power systems to a more stringent set of policies to investigate what the decarbonization potential is and how much investment is required to achieve such decarbonization. Though, the aim is not to seek economy-wide decarbonization. This study focusses on quantitative impacts on technology diffusion, CO₂ emissions, and upfront investment costs in the power sector, while also showing macroeconomic impacts. The main questions this study seeks to answer are:

- Are the NDC policies sufficient to achieve renewable energy and emission targets in the power sector?
- What are the economic impacts of an isolated transition in the ASEAN power sectors?
- What level of investments are required to achieve Net-Zero in the ASEAN power sectors?

2. Analysis Method

2.1 Brief description of E3ME-FTT

Here, we use the E3ME-FTT model to explore the impacts of various policy packages on the ASEAN economies. The E3ME-FTT framework combines macro-econometrics based on the post-Keynesian school of thought (E3ME) with technology diffusion models based on evolutionary economics theory (FTT). For a more detailed description of the econometric equations and the economic accounting framework within E3ME, we refer to the E3ME model manual (Cambridge Econometrics, 2022). In brief, E3ME is grounded in empirically derived relationships between macroeconomic indicators, based on long time series data. The model covers the whole globe divided into 71 regions and 70/43 sectors in European/non-European regions.

It utilizes a system of econometric equations to track economic activity undertaken by persons, households, firms and

other groups in society, and how it affects other agents. Through the economic structure, E3ME includes various feedback loops affecting effective demand: Interaction between sectors; an income loop; an investment loop; and a trade loop. This is illustrated in **Figure 1**.



Figure 1 Illustration of the economic structure as represented in E3ME
Source: Cambridge Econometrics

E3ME-FTT differs from most other macro-economic modelling (or Integrated Assessment Models (AIMs)) frameworks. Mercure, et al. (Mercure et al., 2019) reviewed the various economic and energy/technology modelling approaches and described why different approaches can lead due to the simulation approach, rather than applying optimization routines and restrictive assumptions as found in many other macro-economic models. Most other models start from the premise that economies operate in equilibrium, that prices and wages adjust to clear markets, and assume a fixed supply of money. In the E3ME-FTT framework, none of the aforementioned assumptions are included. Instead, under-utilized capacity can be activated through policy, prices and wages can be sticky, and money is created through lending.

The world is divided into 71 regions of which major economies and EU member states are represented individually. The ASEAN community of nations is subdivided into 3 regions; Indonesia and Malaysia are represented individually, while all other AMS are represented as a single aggregate region. The time horizon for this study runs from 2020 to 2050. Finally, FTT: Power includes 24 different power generation technologies. However, the model does not include hydrogen mixing as an option by default due to a lack of a hydrogen supply module.

We use E3ME-FTT because it directly matches our aims: E3ME quantifies economy-wide impacts of NDC policy packages (via demand, investment and trade feedbacks), while FTT: Power simulates policy-driven decarbonization of the electricity mix through technology diffusion and competition. Their integration allows us to link power-sector transitions to macroeconomic outcomes for ASEAN over 2020–2050 in a consistent framework.

2.2 Theoretical background of FTT: Power

FTT: Power is coupled bidirectionally with the macro-econometric model E3ME. E3ME endogenously determines electricity demand as the broader economy evolves—for example through changes in prices and sectoral activity—while FTT: Power determines the technological configuration of electricity supply consistent with that demand. The supply module represents technology diffusion as a path-dependent process: today's fleet composition influences tomorrow's choices, costs respond to the economic environment (notably energy and carbon prices), and learning-by-doing reduces costs as cumulative capacity grows, including spillovers across related technologies. The initial formulation of the FTT family is described in Mercure (2012), with a concise overview of recent developments in Nijssse et al. (2023), and the mathematical justification for the Lotka-Volterra diffusion framework provided in Mercure (2015).

Investment decisions are based on levelised cost of electricity (LCOE), which aggregates all relevant lifetime costs—upfront investment, operations and maintenance, fuel, and carbon costs—discounted over time. In FTT: Power these cost components are represented as distributions rather than single point values, allowing uncertainty to propagate into LCOE estimates. Policies act directly on these components: investment subsidies lower initial outlays; carbon prices increase running costs for carbon-intensive technologies; and movements in fuel and electricity prices alter operational economics. As deployment expands, cumulative capacity updates the model's learning relationships, so that future cost projections embody learning-by-doing and associated technology spillovers.

Pairwise comparisons of technology-specific LCOE then translate into probabilistic investor preferences via a binary-logit representation. Larger, more certain cost advantages yield stronger preferences; small or uncertain advantages yield weaker ones. These preferences feed a Lotka-Volterra-type substitution mechanism that shifts market shares gradually over time. Substitution depends on retirements of incumbent plant (age-based survival), feasible build rates and lead times of alternatives, and the degree of incumbency—capturing bottlenecks when new technologies and their supply chains are not yet fully established. In this way, market shares evolve incrementally rather than jumping discontinuously, reflecting observed frictions in technology transitions (Mercure, 2015).

System operation and variability are handled using a residual load-duration curve (RLDC) framework parameterized following Ueckerdt et al. (2017). This provides, for a given technology mix, indicative levels of curtailment of variable renewables, requirements for short- and long-term storage, and achievable load factors for dispatchable technologies. The dispatch process itself is mimicked as a matching problem between technologies and load bands. Technologies “bid” for suitable load ranges according to their marginal costs and technical suitability (e.g., base-load versus peak), while load bands “accept” bids depending on how full they already are, prioritizing system reliability rather than pure cost minimization. An iterative matching routine inspired by the Gale-Shapley algorithm (Gale and Shapley, 1962) allocates remaining capacity to unfilled load bands until the stack is satisfied.

In summary, E3ME determines how much electricity is demanded, while FTT: Power determines with which technologies it is supplied over time. Costs respond to policy and learning; investors choose probabilistically under uncertainty; fleets turn over gradually subject to retirements and build constraints; and operational feasibility is respected through RLDC-based flexibility and a reliability-oriented dispatch heuristic. **Figure 2** summarizes the resulting flow of information within FTT: Power.

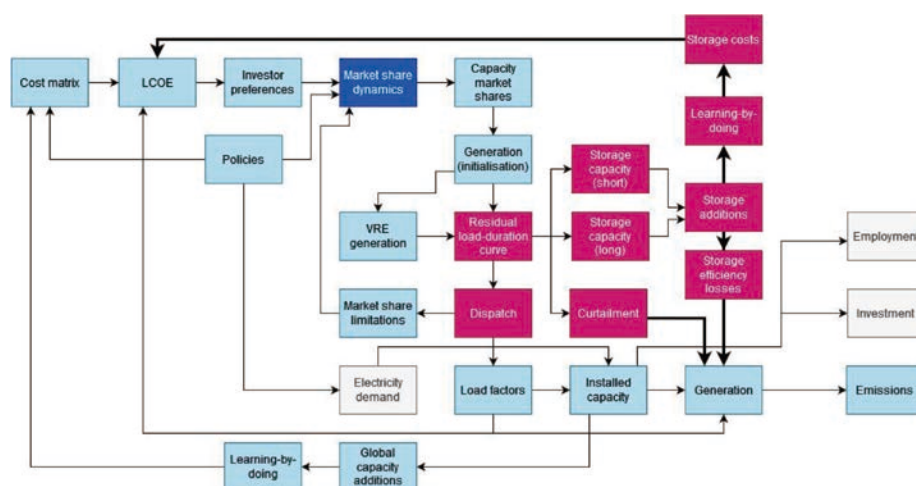


Figure 2 Illustration of the flow of information inside FTT: Power

Source: University of Exeter and Cambridge Econometrics

3. Scenario Design

In this study we seek to expose the ASEAN power sectors to various policy environments in order to investigate the impact of such policies on renewable technology diffusion. The reference scenario (REF) is calibrated to the reference scenario in the IEEJ 2023 Outlook (IEEJ, 2022). Calibration applies to macro-economic indicators and energy consumption projections. In the REF scenario, FTT: Power is not used to determine technology diffusion endogenously; instead it is fed to the model exogenously while keeping the accounting part enabled. We also investigate a scenario where FTT: Power simulates

Table 2 Overview of scenarios considered in this study

Scenario	Abbr.	Region	Policy context
Reference	REF	All	Fully calibrated to the IEEJ 2023 Outlook (macro-economic variables and power sector configuration). No further policies included.
Current technology trajectory scenario	CTT	All	Only macro-economic indicators are calibrated to the IEEJ 2023 Outlook. Nuclear power is based on IEEJ 2023 Outlook and entered as an exogenous input, where applicable. No further policies included.
Nationally determined contribution scenario	NDC	Indonesia	Includes policies based on NDC and domestic power sector policy documents. Implementation of a domestic ETS (see Figure 3). Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Charcoal co-firing in coal power plants (up to 20% on energy basis by 2030; constant after) Follow the Indonesia Electricity Supply Business Plan (RUPTL) in the short-term (2021–2030)
		Malaysia	Nuclear power is based on IEEJ 2023 Outlook and entered as an exogenous input. No ETS or carbon tax mentioned in NDC documents. Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Follow the Malaysia Renewable Energy Roadmap (MREP) in the short-term (2021–2039)
		Rest of ASEAN	Nuclear power is based on IEEJ 2023 Outlook and entered as an exogenous input. No ETS or carbon tax mentioned in NDC documents. Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Follow an aggregate version of the various roadmaps provided by individual countries
Ambitious scenario	AMB	Indonesia	Implementation of a domestic ETS (see Figure 3). Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Phase-out regulations on new fossil-fuel power plant capacities from 2025 onwards. Charcoal co-firing in coal power plants (up to 20% on energy basis by 2030; constant after)
		Malaysia	Nuclear power is based on IEEJ 2023 Outlook and entered as an exogenous input. Implementation of a domestic ETS (see Figure 3). Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Phase-out regulations on new fossil-fuel power plant capacities from 2025 onwards.
		Rest of ASEAN	Nuclear power is based on IEEJ 2023 Outlook and entered as an exogenous input. Implementation of a domestic ETS (see Figure 3). Subsidies on upfront investment for CCS applications (25%), wind power (50%), and solar PV (10%). Feed-in-Tariffs on wind power and solar PV. Phase-out regulations on new fossil-fuel power plant capacities from 2025 onwards.

Source: Authors' summary

technology diffusion endogenously in order to compare to the REF scenario. This is called the current technology trajectory (CTT) scenario. Comparing REF and CTT isolates the effect of endogenous technology diffusion on the evolution of the power mix and related economic outcomes. In this paper, “technology diffusion” refers to changes over time in the uptake of specific generation technologies (i.e., installed capacity and generation shares across coal, gas, oil, hydro, solar PV, wind, biomass, geothermal, and other technologies represented in FTT: Power).

Then, we made interpretations of the policy options mentioned in the NDC documents and built a detailed policy package. These scenarios also include capacity plans as published policy documents related to the power sector. Finally, a more ambitious policy package is developed to test how far decarbonization can reach (abbreviated AMB). **Table 2** provides an overview.

All policies are exclusively applied to the power sector, with the exception of carbon prices, for which it would likely apply wider. **Figure 3** displays the carbon prices used in this study. Only Indonesia has explicitly announced to implement an emission trading scheme and hence why it is the only country to apply an ETS in the NDC scenario. The more ambitious scenario includes higher carbon price projections for each of the AMS.

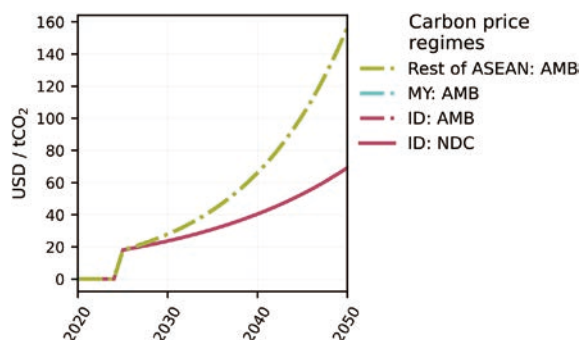


Figure 3 Exogenous carbon price projections (nominal) included in the scenarios

Note: The projections for each of the countries in the AMB scenario overlap. MY: AMB is overlapping with Rest of ASEAN: AMB, and ID: AMB is overlapping with ID: NDC. MY refers to Malaysia, and ID refers to Indonesia.

Source: Created by authors based on the E3ME model analysis results

ACE (2023) reviewed each country’s power generation outlook and renewable energy targets. The targets abide by various definitions: renewable energy share of total primary energy, total final energy, total installed capacity, or total electricity generation. Given that the countries within the “Rest of ASEAN” group did not formulate RE targets along a uniform metric, we cannot evaluate a weighted aggregate target. Indonesia has set its target in relation to the total capacity addition over the period from 2021 and 2022. Malaysia and the whole of ASEAN have targets in relation to the total installed capacity by a given year. This is summarized in **Table 3**.

Table 3 Renewable target pledges

Region	Year	RE target
Indonesia	2030	51.6% of capacity addition between 2021–2030
Malaysia	2025	31% of installed power capacity
	2035	40% of installed power capacity
ASEAN	2030	35% of installed power capacity

Source: Authors

4. Analysis Results

4.1 Estimation of power generation technologies

According to the IEEJ 2023 Outlook (REF scenario, see **Figure 4**), the ASEAN community of nations remains reliant on fossil-fuels for its power generation. Without additional policy support, Indonesia and Malaysia rely on domestic supply of coal and natural gas respectively. The share of renewables in the generation profile across all AMS hover between 23–27% over the whole time period. Under the current technology trajectory (CTT) scenario, similar diffusion trends are noted. Like the REF scenario, a 29% generation share is attributed to renewables in 2030. However, towards the end of the timeline (around 2040) uptake of renewables starts to take off, indicating the existence of a positive tipping point. By 2050, this yields a 40% share of renewables in the generation profile. In both the REF and CTT scenarios, Malaysia remains behind with a renewable share of 18% and 11% by 2030 and a 19% and 22% share by 2050 respectively. Indonesia also performs slightly worse than the ASEAN average, with a renewable share of 23% and 21% by 2030 and a 27% and 26% share by 2050 in the REF and CTT scenarios respectively.

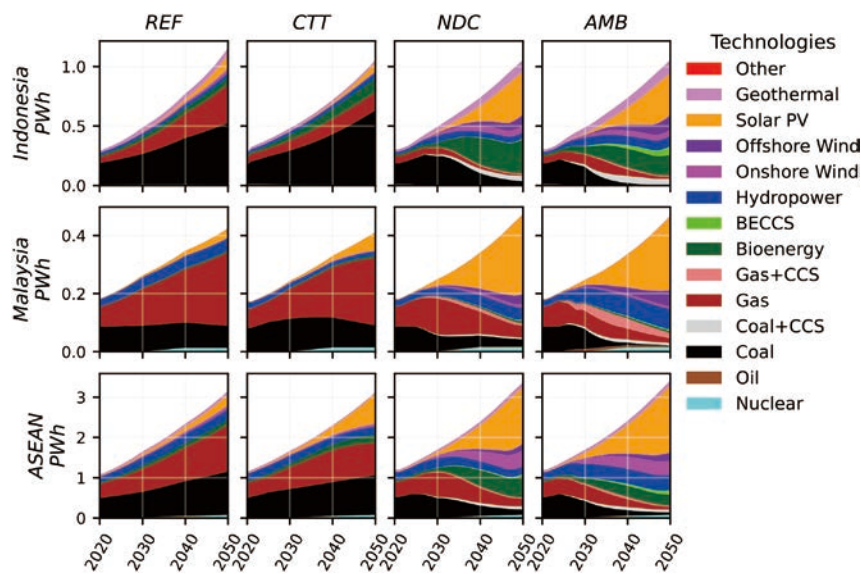


Figure 4 Generation by technology in PWh. Shown individually for Indonesia and Malaysia and for ASEAN as a whole

Note: In REF, Gas and Coal remain dominant, while in AMB, Solar PV and Hydropower expand significantly. These results do not explicitly show the impact of charcoal blending in coal power plants.

Source: Created by authors based on the E3ME model analysis results

Policies in the NDC and AMB scenarios can bring the tipping point forward in time. The NDC scenario indeed shows increased uptake of solar PV in all regions, biobased technologies in Indonesia and the Rest of ASEAN, and wind power in the Rest of ASEAN. The stronger renewable uptake in the NDC scenario is mainly driven by the combined effect of (i) carbon pricing/ETS-type measures that penalise fossil generation and shift investment and dispatch toward low-carbon options, and (ii) renewable support such as feed-in tariffs (FITs) that improve project economics—especially for solar PV, resulting in higher PV broadly, more bio-based generation in Indonesia and the Rest of ASEAN, and stronger wind uptake in the Rest of ASEAN. This results in a renewable generation share of 33% (including charcoal co-firing; not shown in **Figure 4**) by 2030, and a share of 85% by 2050 across all AMS. Indonesia is outperforming over other AMS in the NDC scenario (39% renewable share by 2030 and 93% renewable share by 2050), whilst Malaysia remains behind (24% by 2030 and 79% by 2050). This can be attributed to some degree to the Malaysia Renewable Energy Roadmap, which describes a continued reliance on coal

power.

Under the AMB scenario, the short- to medium-term outlook as presented in the power sector roadmap documents is forfeited. Gas-based power can therefore be phased out at a greater rate in Malaysia. The phase-out regulations on new capacity additions of fossil-fueled power plants also help to create space for renewable technologies to diffuse into, which is evident across the whole ASEAN. Renewable generation shares increase from 54% in 2030 to 92% in 2050.

Furthermore, it is noteworthy to state that Malaysia sees some uptake of offshore wind power despite the country's limited access to offshore areas with high wind speeds. In E3ME-FTT, offshore wind is represented at the national level and the model does not resolve detailed geographic siting constraints. The offshore wind uptake in Malaysia should therefore be read as an indicative substitution when solar PV approaches its technical limit and fossil additions are constrained in the NDC/AMB scenarios. If real-world site constraints are binding, offshore wind would be lower and the modelled generation would be met by other low-carbon options instead.

Both the NDC and AMB scenarios show substantial changes to the total electricity generated compared to the REF scenario. This is driven by two parts: responses in electricity demand, and additional generation needs due to storage losses (when conventional storage is insufficient) and curtailment. Indonesia shows an overall decrease in both the NDC and AMB scenarios, a carbon price is implemented in Indonesia which increases energy prices depending on their emission intensity. The dominant response is to lower energy demand rather than energy substitution. This will be discussed in more detail in section 4.5. Malaysia, and ASEAN overall show increased generation levels due to storage losses and curtailment.

Table 4 displays the RE targets and the outcome in each of the scenarios. In the REF and CTT scenarios, none of the RE targets are met as the power systems remain to be dominated by fossil-fueled technologies. However, all targets are met under the NDC and AMB scenarios, with the exception of the 2025 target in Malaysia. The 2025 target is missed because there is simply not enough time for the policies to adequately change investment decisions. Between the NDC and AMB scenarios, the latter typically overshoots the target by some margin (at least 5% greater than the target).

Table 4 Overview of renewable generation targets and the renewable energy levels attained in the respective scenarios

Region	Year	RE target	RE% achieved			
			REF	CTT	NDC	AMB
Indonesia	2030	51.60% of capacity addition between 2021–2030	35.4%	29.1%	56.5%	63.5%
Malaysia	2025	31% of installed power capacity	20.6%	21.4%	22.5%	24.4%
	2035	40% of installed power capacity	20.3%	21.1%	42.8%	47.7%
ASEAN	2030	35% of installed power capacity	26.9%	30.1%	45.8%	57.4%

Source: Created by authors based on the E3ME model analysis results

4.2 Estimation of primary energy demand in power sector

Primary energy demand for electricity generation responds to the diffusion of technologies (see **Figure 5**). A continued reliance on fossil-fuels is noted in the REF and CTT scenarios. Using primary energy conversion factors in accordance with the IEA, the share of renewable primary energy demand follows an increasing trend in line with uptake of e.g. solar PV and wind power, however, the shares are smaller than in the generation profile due to the primary energy conversion factors. For example, using coal to generate electricity converts only 33% of the primary energy potential to electricity.

In the NDC and AMB scenarios a strong shift to renewables in the primary energy demand profile is noted. Total primary energy demand in Indonesia is reduced by a third and by a half by 2050 in the respective scenarios, while the remainder primary energy demand is predominantly biomass. Malaysia still relies to a moderate degree on fossil-fuels, however, a large

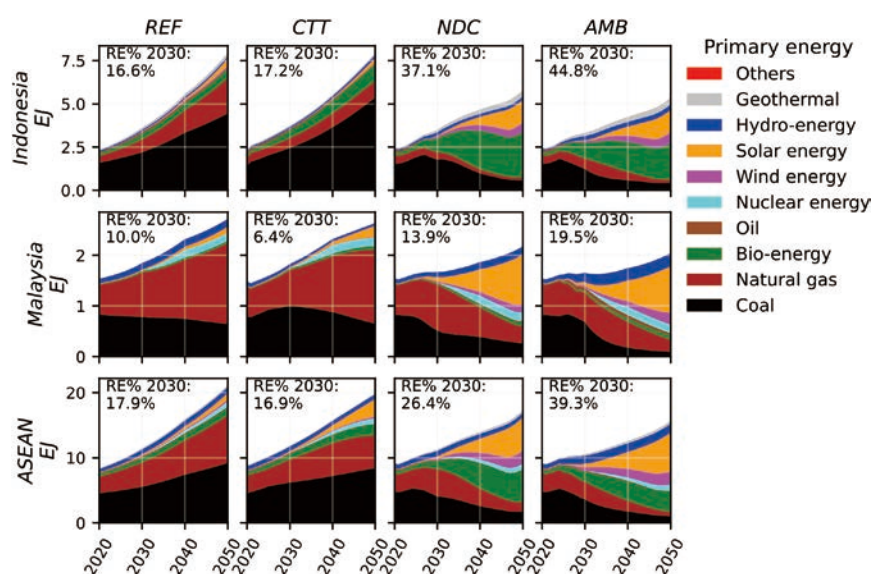


Figure 5 Primary energy demand by energy type in EJ. Shown individually for Indonesia and Malaysia and for ASEAN as a whole

Note: In REF, natural gas and coal are the dominant sources, whereas in AMB, solar power and bioenergy expand, while natural gas declines. These results do not explicitly show abated fossil-fuel demand.

Source: Created by authors based on the E3ME model analysis results

portion feeds into fossil-fueled power plants with CCS applications.

4.3 Estimation of CO₂ emissions in power sector

Direct CO₂ emissions in the REF and CTT scenarios continue to rise sharply in line with increased electricity demand and continued dominance of fossil-fueled power plants (see **Figure 6**). The endogenous FTT scenario (CTT) displays a slightly greater reliance on coal power and therefore shows higher emissions compared to the REF in 2030. However, by 2050, the push towards renewables starts to take off everywhere except in Indonesia. This leads to 25.6% lower emissions between the two scenarios. See **Figure 6** and **Table 5**.

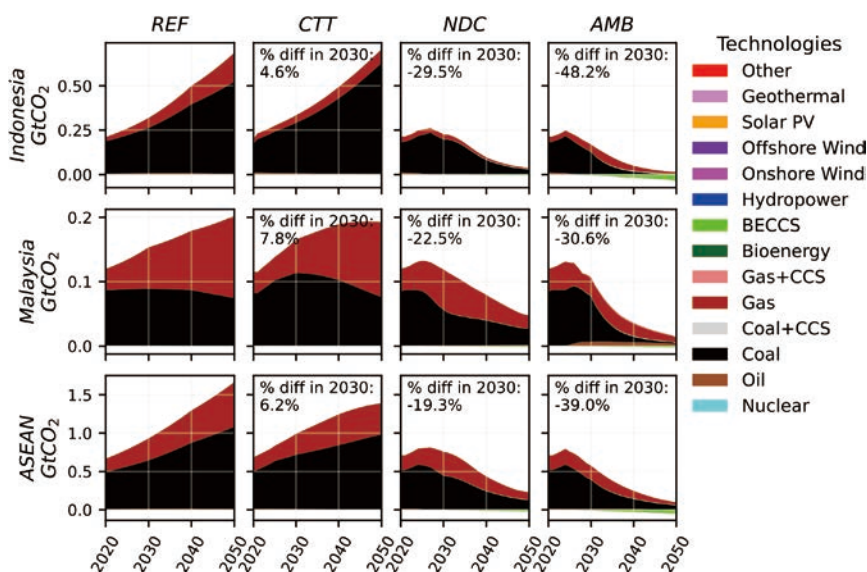


Figure 6 Direct CO₂ emissions by technology in GtCO₂. Shown individually for Indonesia and Malaysia and for ASEAN as a whole.

Note: In all scenarios, coal and natural gas account for the largest shares.

Source: Created by authors based on the E3ME model analysis results

Table 5 Direct CO₂ emissions in scenario in 2030 and 2050 relative to the REF scenario in the same year.

Direct CO ₂ emission difference to REF (%)	CTT	NDC	AMB	CTT	NDC	AMB
	2030			2050		
Indonesia	+ 4.6	− 29.5	− 48.2	+ 2.9	− 95	− 103.2
Malaysia	+ 7.8	− 22.5	− 30.6	− 4.9	− 76.9	− 94.2
All of ASEAN	+ 6.2	− 19.3	− 39	− 25.6	− 89	− 97.8

Source: Created by authors based on the E3ME model analysis results

The uptake of renewables is pushed forwards via policies in the NDC and AMB scenarios. Additional uptake of renewable technologies replaces fossil-fuels and therefore also affect direct CO₂ emissions. By 2030, the NDC policies reduce emissions by 19.3% across all of ASEAN compared to the REF scenario. Emissions are reduced by 39% in the AMB scenario. Indonesia shows the greatest decline in emissions (95% and 103.2% reduction in the NDC and AMB scenarios resp. compared to the REF scenario in 2050) as it has sufficient potential for renewable alternatives. Malaysia has less potential for biobased energy sources and wind power and therefore needs to rely more on CCS applications to reduce emissions (76.9% and 94.2% reduction in the NDC and AMB scenarios resp compared to the REF scenario in 2050). The combined emission reduction across all ASEAN power sectors by 2050 is 89% in the NDC scenario and 97.8% in the AMB scenario.

4.4 Estimation of upfront investment requirements

Expanding power generation capacity requires investments, which is displayed in **Figure 7**. The investment portfolio in the REF and CTT scenarios remains focused on thermal power generation, more so in the latter scenario than the former. Nuclear power investments occur in Malaysia, and in the Rest of ASEAN group (Thailand and Viet Nam), which follows IEEJ projections across all scenarios (IEEJ, 2022). Overall, both scenarios show a lot of overlap. The portfolios start to diverge heavily in the NDC and AMB scenarios as investment decisions start to gravitate towards various forms of renewables. Renewables are typically more CAPEX heavy rather than OPEX heavy, increasing the investment needs. By 2050, investments into unabated fossil-fueled power plants in the AMB scenarios are practically removed.

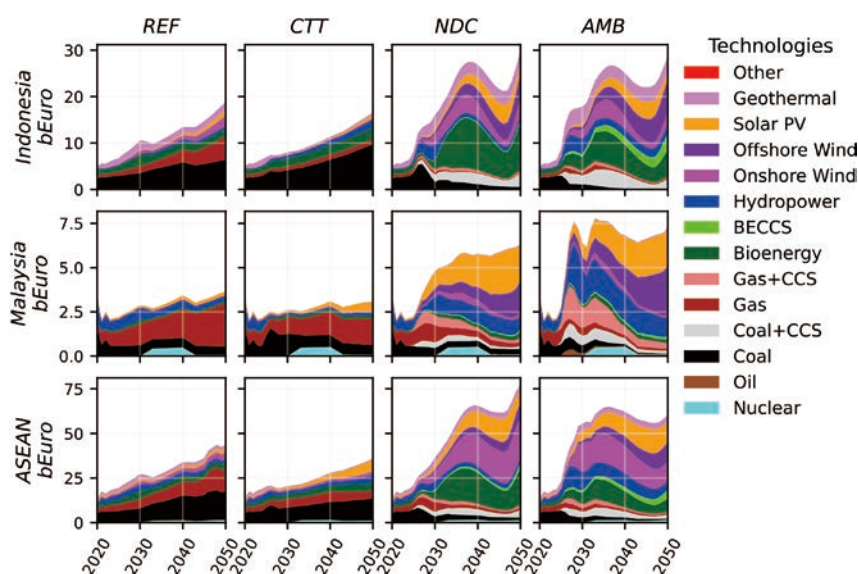


Figure 7 Upfront investment requirements by technology in billion 2010 Euro. Shown individually for Indonesia and Malaysia and for ASEAN as a whole.

Note: In AMB, the shares of solar PV, onshore wind, offshore wind, and hydropower are relatively large.

Source: Created by authors based on the E3ME model analysis results

Overall, decarbonizing the ASEAN power sector would require substantial investments between 2025 and 2050 (see **Table 6**). The NDC and AMB scenarios require a cumulative investment of 1388 and 1458 billion 2010 Euro. This is mostly driven by investments in additional renewable technologies. This is 70% and 79% higher than the investment needs in the REF scenario, which sits at 815 billion 2010 Euro. In the CTT scenario, we find that the ASEAN region requires 680 billion 2010 Euro investment for the same period to maintain current diffusion trajectories. The difference is largely due to lower geothermal and wind uptake (both capital intensive technologies) relative to the REF scenario. In relative terms, Malaysia sees the largest increase; investment more than double in the AMB scenario compared to the REF scenario.

Table 6 Total cumulative investment needs in power generation technologies between 2025 and 2050.

Cumulative investment in billion (2010 price of Euro)	REF	CTT	NDC	AMB
Indonesia	319	282	559	577
Malaysia	78	72	136	176
All of ASEAN	815	680	1388	1458

Source: Created by authors based on the E3ME model analysis results

4.5 Estimation of electricity prices

Up to 2040, electricity prices in the CTT scenario move approximately in line with the REF scenario in Indonesia and Malaysia (see **Figure 8**). Only towards the end of the time horizon deviations are observed. Malaysia and the Rest of ASEAN see a decline in electricity prices due to additional uptake of cheap solar PV (and wind power in the case of Rest of ASEAN). Indonesia sees an increase in electricity prices due to a slightly increased reliance on bio-based technologies compared to the REF scenario, which do not benefit from the same level of learning potential as other renewable alternatives. In addition, bio-based technologies suffer a slight efficiency penalty relative to fossil-fuel alternatives. Across all AMS, electricity prices decline towards the end of the time horizon.

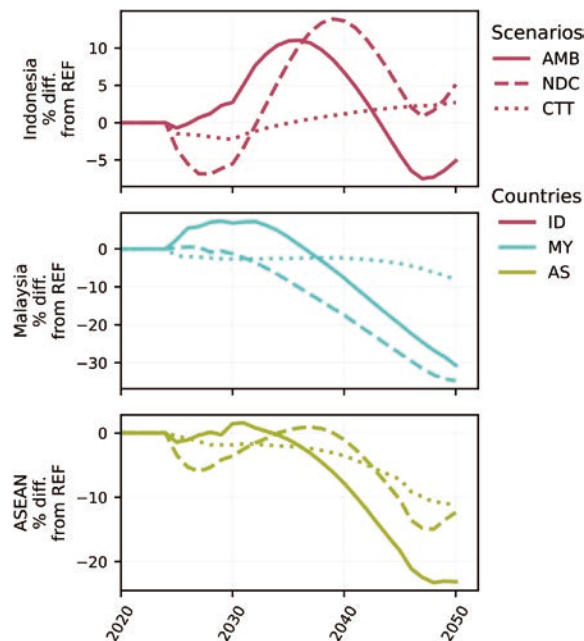


Figure 8 Electricity prices as a% difference from the reference scenario. Shown individually for Indonesia and Malaysia and for ASEAN as a whole.

Source: Created by authors based on the E3ME model analysis results

The NDC scenario equally shows varied impacts across the countries. Initially, electricity prices in Indonesia decrease to a minimum around 2030, followed by an increase which peaks around 2042. By 2050, electricity prices come down to levels slightly above the REF scenario. This behavior can be attributed to the relative contribution of more expensive bio-based energy technologies versus cheap solar PV. Malaysia sees a gradual reduction of electricity prices over the whole timeline, which reaches a limit as solar PV uptake encroaches on its potential deployment. Overall, across all AMS, electricity prices were simulated to decline considerably. This effect is reinforced in the AMB scenario. The largest driver is increased uptake of solar PV in Indonesia. Malaysia sees slightly higher electricity prices in the AMB scenario due to a greater reliance on CCS applications and wind power to further reduce emissions. The limited wind energy potential is represented by quickly declining capacity factors (Mercure and Salas, 2013), which negatively impacts the electricity price.

Electricity prices in E3ME-FTT reflect the evolving generation mix simulated with FTT: Power (24 generation technologies) and are shaped by scenario-specific policies together with common techno-economic constraints, including technology-specific deployment limits (e.g., solar PV saturation) and resource-related capacity-factor assumptions (e.g., declining wind capacity factors at higher penetration). Across scenarios, the technology set and constraint structure are held constant; the main differences are whether the power mix is imposed exogenously (REF) or evolves endogenously through diffusion and policy incentives (CTT, NDC, AMB). The price trajectories below should therefore be interpreted as changes in the marginal mix—most notably increased low-cost solar PV versus greater reliance on higher-cost options such as bio-based generation and CCS—under these stated assumptions.

4.6 Estimation of macroeconomic impacts

Macro-economic effects of the policy scenarios have many facets to them. Invoking a transition in the power sector through policies leads to additional investments as shown in section 4.4, which propagate through the economic channels within the system of national accounts in the ASEAN economies. Additional investments can lead to additional job creation and can, through increased disposable income, lead to increased consumer spending. However, consumer spending is also affected by price levels. In turn, price levels are affected by electricity price developments which also invokes changes

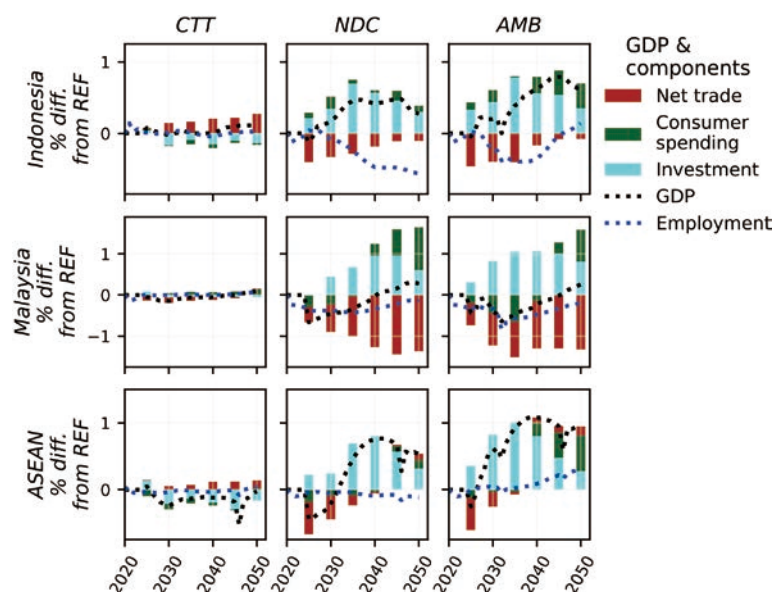


Figure 9 GDP and employment impacts by components for each scenario relative to the REF scenario

Note: The bars represent the weight of each GDP component relative to the overall GDP impact. Results are shown individually for Indonesia and Malaysia, and for ASEAN as a whole. GDP tends to increase more than employment compared with REF.

Source: Created by authors based on the E3ME model analysis results

to other industry prices depending on the degree of each sector's electrification. Carbon prices can lead to an increase in industrial prices depending on each sector's emission intensity and ETS coverage.

The net GDP impacts, and the contribution of its components are illustrated in **Figure 9**. In line with expectations, the CTT scenario does not show large deviations from the REF scenario. However, impacts become more diverse when considering the NDC scenario. In each region an increase in investment is noted, positively contributing to GDP. However, fossil-fuel producing countries such as Indonesia and Malaysia are negatively impacted due to decreased position of their net trade balance. As an aggregate country group, the Rest of ASEAN is a mix of countries which on average are reliant on energy imports and therefore stand to gain from a transition in the power sector, hence why overall ASEAN results on net trade towards the end of the time horizon are positive while negative impacts in Indonesia and Malaysia dominate initially.

Jobs related to the fossil-fuel industry are also negatively impacted by a transition which is visible in Indonesia and Malaysia in both the NDC and AMB scenarios. Indonesia in the AMB scenario also shows the impact of reduced electricity prices on job creation and consumer spending, especially when compared to the NDC scenario, where Indonesia is exposed to higher electricity prices by 2050.

Overall and across all AMS, GDP impacts are positive by 2050, but some negative impacts may occur in the initial phase of the transition. Malaysia is the main exception as positive effects are almost completely negated by negative effects.

5. Conclusion

Here, we simulate multiple scenarios of ASEAN power-sector decarbonization and their economic consequences using the E3ME-FTT model. If the REF scenario—aligned with IEEJ (2022) projections—materializes, grid emission intensity in ASEAN will not decline, hindering decarbonization via electrification. In the CTT scenario, reliance on fossil-fuels remains similar to REF; however, signs of a positive tipping point toward (variable) renewables emerge around 2040 in most ASEAN countries. Policies can target such tipping points to accelerate technology uptake (e.g., solar PV) (Nijssse et al., 2023).

Indeed, the NDC and AMB scenarios show that policies advance the tipping point toward solar PV and other renewables across all AMS. In both scenarios, RE targets beyond 2025 are achieved; in fact, the AMB scenario over-achieves. Malaysia is the only country missing its 2025 target, reflecting the short window for policies to affect investment decisions and continued short-term reliance on coal. With additional renewables, power-sector emissions fall by 89.0% in NDC vs. REF in 2050 and by 97.8% in AMB.

We find that large-scale transitions in NDC and AMB are feasible and can yield positive GDP effects overall, though regional differences exist. Gains are driven mainly by investment stimuli in low-carbon technologies and along their value chains, typically creating jobs; these gains can be offset by lower export volumes and inflationary effects. In both scenarios, Malaysia and Indonesia lose trade volumes, predominantly linked to fossil-fuel trade.

The required investment stimulus for large-scale decarbonization is substantial. Achieving it could require €1,458 billion (2010 prices) between 2025 and 2050—an additional €643 billion relative to REF. This estimate excludes storage investments (which are represented in the model) and grid reinforcement (not represented); needs would rise with further end-use electrification.

The investment numbers indicate the scale of capital required for the power transition. E3ME-FTT estimates macroeconomic impacts assuming this investment can be mobilised; it does not model country-specific fiscal and financial constraints. In practice, implementation requires credible financing and risk-reduction mechanisms (e.g., stable auctions/PPAs (Power Purchase Agreement), concessional or blended finance, guarantees, and public funding for grids and other enabling infrastructure).

Models have limits. FTT: Power excludes hydrogen-based technologies and co-firing of hydrogen/ammonia (biomass

co-firing is included), largely because the E3ME model lacks a hydrogen supply module. Hence, hydrogen/ammonia-consuming technologies are outside scope. Moreover, E3ME-FTT does not model each AMS individually. Although Indonesia and Malaysia account for roughly half of electricity generation, aggregation error remains possible.

Comparing Indonesia's GDP impacts in NDC vs. AMB highlights the importance of electricity prices. In FTT: Power, prices are a generation-share-weighted average of LCOE. While LCOE for variable renewables includes curtailment and storage costs, grid infrastructure costs—potentially material in these scenarios—are not included. For example, in AMB we diverge from the Malaysia Renewable Energy Roadmap's limited plant-deployment outlook; the roadmap's emphasis on reliable supply in remote areas would entail significant grid-strengthening investments. FTT: Power is also constrained by the RLDC framework, which uses coarse geographic regions that effectively assume a “copper-plate” system (i.e., free power flows).

Unlike many macroeconomic models, E3ME does not adopt the loanable-funds approach (Pollitt and Mercure, 2018). Credit creation via lending is possible in both the model and reality (McLeay et al., 2014), yet the model remains agnostic about the financial consequences of stimulus and technology decisions. Access to finance is approximated via interest rates, which influence choices depending on the ratio of upfront capital to operating costs. In the ASEAN context, finance access is a known constraint (ASEAN Secretariat, 2015). Future work will improve this aspect of the FTT framework.

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